OCEANOGRAPHY AND ACOUSTICS

MSC THESIS

ENVIRONMENTAL GUIDE FOR ASW IN EASTERN CANADIAN SHALLOW WATERS

Part II - Environmental Data

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Environmental Guide for ASW in Eastern Canadian Shallow Waters

Part II - Environmental Data

By

Capt Daniel Normand

Authors Note

This thesis consists of the following three parts:

Part I - An Assessment of the State of Knowledge
Part II - Environmental Data
Part III - Classified Data

A Table of Contents for all three parts is included at the end of each volume.

ENVIRONMENTAL GUIDE FOR ASW IN EASTERN CANADIAN SHALLOW WATERS

By

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B.Sc.A. Université Laval, 1980

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Chapter 1

Introduction

// This environmental guide identifies and presents information on oceanic parameters which affect ASW systems. ~~The information must be as complete as possible in order to be useful for planning purposes, yet it cannot, without becoming cumbersome to use, contain all the detailed data necessary for acoustic-performance prediction in a specific situation.~~ ~~These~~ Information is presented in a summary format such that their areal distribution and temporal variability can be readily accessed and extracted by non-specialist planners. The present guide limits itself to the continental shelf area off the east coast of Canada from the CANLANT western boundary (66°W) to the Strait of Belle Isle, including the Gulf of St. Lawrence.

Two basic groups of information are presented. The first group consists of general environmental aspects which provide a climatological and oceanographic perspective of the area of interest. These provide users who are not already familiar with the area with a good description of the basic features. The second group consists of specific ASW considerations and includes data of a more direct application to ASW operations. All portions of this guide taken together should help mission planners to take better advantage of the specific conditions found in the area of interest, and to adjust tactics accordingly. //

The information on these parameters has been regrouped into two parts:

- **Part I:** - contains an assessment of the state of knowledge on each of the parameters covered. It should be consulted whenever a question arises regarding the source or exact nature of the data. The information is generally organized as follows:

- description of the parameter
- its impact on ASW
- its variability (spatial and/or temporal)
- the resolution required for ASW
- existing data set:
  * source of data (agencies, data sets)
  * techniques or methodology used to collect the data
  * resolution and accuracy of the data
  * coverage provided.

- **Part II:** - contains the actual environmental information for each of the parameters. The information is presented as follows:
  - description by region
  - significant anomalies and special features
  - data products.

Chapter 2

Bottom Features

2.1 Bathymetry

The geographical boundaries of the area are the North Shore of Québec to the north and the St. Lawrence Estuary to 70° W longitude, the Gaspé Peninsula, New Brunswick, Nova Scotia and 66°W (CANLANT limits) to the west (Figure 2.1). The offshore limit to the south and to the east is determined by the 200 m isobath. The area includes as the most easterly point the Flemish Cap (~ 47°00'W). Several islands are found within this area: Newfoundland, Prince Edward Island, Anticosti Island, the Magdalen Archipelago, Sable Island, St. Pierre and Miquelon, to name the most important.

2.1.1 Regional Description

Gulf of St. Lawrence

The Gulf of St. Lawrence has an area of 214 x 10^3 km^2. The St. Lawrence River and other smaller rivers of the gulf receive the drainage from an area of approximately 13 x 10^6 km^2. The gulf connects with the open ocean through the Cabot Strait (104 km wide) and to a much lesser extent the Strait of Belle Isle (16 km wide).

The main feature of the bathymetry is the Laurentian Channel which cuts the St. Lawrence Estuary from the mouth of the Saguenay River and extends

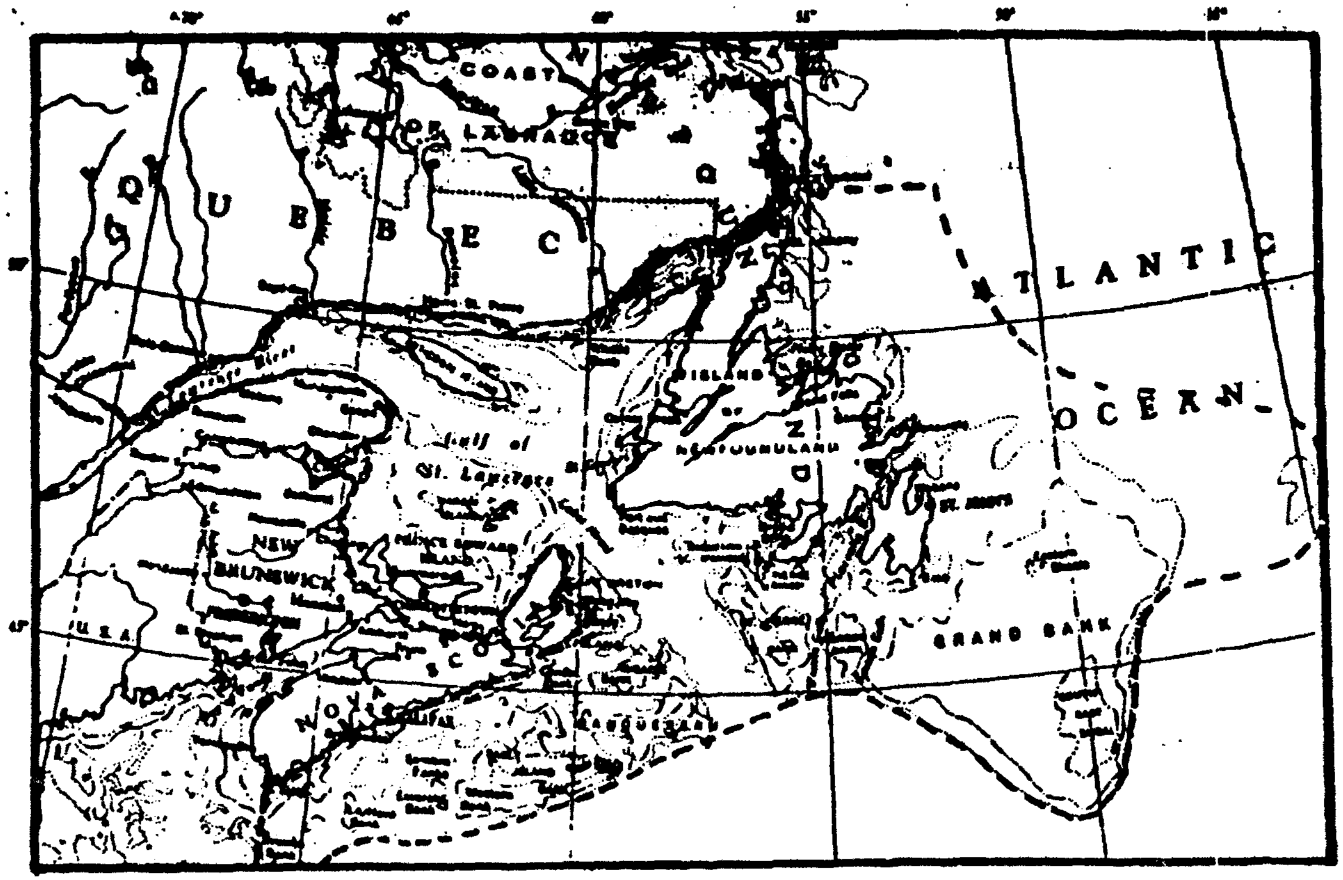


Figure 2.1: Area under study.

across the gulf with depths of 250 to 400 m. From Cabot Strait, the channel extends to the continental shelf south of Newfoundland with the depth increasing from 400 to 660 m while the width remains approximately 100 km. Another important feature is the Esquiman Channel which branches off from the Laurentian Channel and extends from the centre of the gulf northeastwards towards the Strait of Belle Isle. Its depth gradually decreases from 300 m to 60 m at the Strait of Belle Isle. The eastern portion of the gulf is occupied by the Magdalen Shallows which covers one-quarter of the gulf area and has an average depth of only 50 m.

Scotian Shelf

The Scotian Shelf is characterized by a rather complex bathymetry dominated by several notable features. The nearshore zone to a depth of 100 m is characterized by a rough topography. The central portion of the shelf has an average depth of 150 m and gradually deepens to form basins such as the Emerald Basin (~ 280 m) and the LaHave Basin (240 m) or rises to less than 100 m to form several small banks (Roseway, Mckenzie Spot, Canso, etc.). The outer shelf is occupied by a series of shallow banks with depths less than 100 m, gradually shoaling to the surface at Sable Island. It is cut by several channels such as the Fundian Channel (~ 250 m) and The Gully (~ 150 m). Several submarine canyons can also be found along the slope.

Grand Banks

The Grand Banks area consists of five main banks (St. Pierre, Green, Whale, Woolfall and Grand Bank) separated from each other and from the shore by four main channels (St. Pierre, Halibut, Haddock, and Avalon). The Banks are flat with a generally smooth surface, rising to within 100 m of the surface. Grand Bank itself forms a major continental shelf plateau extending approximately 500 km offshore, covering an area of some 270,000 km^2. It has an average depth of 60 m except over the Southeast Shoal, a large plateau where the depth decreases to 40 m. One important consideration for safety of navigation is the presence of some rock outcrops between Woolfall Bank and the northern portion of the Grand Bank: Virgin Rock located at 46°27'N, 50°44'W rises to a depth of only 4 m and Eastern Shoals located some 20 km east of Virgin Rocks rises to 14 m.

The northwest portion of the area is an area of irregular bathymetry with localised basins and shoals. Downing Basin contains numerous depressions 1 to 4 km wide and 5 to 15 km long with water depths of 100 to 250 m.

Further to the north and to the east, the depth increases rapidly to more than 1000 m. To the east, Flemish Pass separates the Grand Banks from Flemish Cap which rises to a depth of 140 m. Finally, the presence of several submarine canyons gouged in the slope along the edge of the Banks, particularly on the east side of the Tail of the Bank, is noted.

2.1.2 Bathymetric Charts

Detailed bathymetry is provided on the charts which have been produced by the Canadian Hydrographic Service (CHS) of the Department of Fisheries and Oceans:

- Map 801-A Bay of Fundy to Gulf of St. Lawrence (Bathymetry);
- Map 802-A Newfoundland Shelf (Bathymetry);
- Map NM-19 Lower St. Lawrence Estuary (Bathynetry);
- Map MN-21 Strait of Belle-Isle (Bathymetry).

These 1:1,000,000 charts provide bathymetric information with a depth resolution of 10 m.

2.1.3 GIS Bathymetry

A limited set of isobaths (50, 100, 150, 200, 300, 400, 500, and 1000 m) have been included in the initial GIS version. The complete set of depth contours (10 m interval) could however be included. Each isobath can be individually selected, deselected, or highlighted by assigning a different colour. Bathymetric information can thus be displayed in the most convenient way to meet the user's needs, from large area general features to detailed bathymetry of subareas of any size.

2.2 Sediment Types

2.2.1 Sediment Formations

King [1970] identifies five types of formations on the Scotian Shelf and the Western Grand Banks area. Some physical properties of the sediments constituting these formations are listed in Table 2.1. Loring and Nota [1972] in their study of the geology of the Gulf of St. Lawrence used a different sediment classification. Their sediment classification and its equivalence in terms of sediment classes used by King [1970] are shown in Table 2.2.

2.2.2 Sediment Properties

As mentioned in Part I, the geoacoustic profile is generally accepted as the most flexible and useful means of characterizing the interaction of sound with the seafloor. Given the complete geoacoustic profile (density, speed, and attenuation structure of the seafloor), it is theoretically possible to accurately predict bottom effects on acoustic propagation.

It is felt that the propagation in shallow water of bottom interacting signals will depend most strongly on the sound speed ratio at the water-sediment interface. The second most important consideration is the sediment thickness, followed by the combination of sediment attenuation and sound speed gradi-

Sediment Type	Lithography	Median Size	Thickness	Bottom roughness
Scotian Shelf Drift	-Cohesive and poorly, sorted dominantly sandy with abundant silt and clay, containing angular fragments of pebble to boulder size.	.01mm to m	0 - 90 m	Rough, hummocky surface
Sable Island sand and gravel	-Medium to coarse grained well sorted sand grading laterally to coarse gravel	[illegible]	0 - 15 m	Rough, but can be hummocky, flat or jagged, depending on the bedrock underneath
Sambro Sand	-Medium to fine grain, moderately to well sorted grading to sandy gravel or modified till	.06-.4 mm	thin veneer (0-5 m)	Flat and smooth
Emerald Silt	-Poorly sorted clayey and sandy silt mixed with some gravel. It mainly underlies the LaHave clay in depressions.	.01-.19 mm	0 - 200 m	Always flat and smooth
LaHave Clay	-Loosely compacted silty clay grading locally to clayey silt	.008-.04 mm .002-.018 mm *(Laurentian Channel)*	0-40 m 75 m *(center channel)*	Always flat

Table 2.1: Sediment formation characteristics (Scotian Shelf and western Grand Banks). (After King, 1970)

Sediment Type	Median Size	Scotian Shelf Equivalent
Glacial Drift	- Clay to boulder (0.01mm to m)	Scotian Shelf Drift
Gravel	- Pebble, cobble, boulder.	Sable Island Sand
Coarse Sand	0.25 - 2.0 mm	Sable Island Sand
Fine Sand	0.05 - 0.25 mm	Sambro Sand
Pelite	0 .002 - 0.05 mm	LaHave Clay Emerald Silt

Table 2.2: Sediment formation characteristics for the Gulf of St. Lawrence and the equivalent formations on the Scotian Shelf.

ent [Spofford et al., 1984]. Finally, shear wave sound propagation can play a significant role in some cases. Therefore shear wave speed and attenuation are required.

Estimates of some of the these acoustical properties of the sediments for the Scotian Shelf and the Grand Banks are listed in Table 2.3. These values were obtained from S.J. Hughes and D.D. Ellis [DREA, informal communication] and are based on their low frequency propagation modelling experience, and values from the existing literature [Hamilton, 1980].

2.2.3 Sediment Type Charts

Data are contained in a series of charts covering the following areas:

- Gulf of St. Lawrence (Figure 2.2)
- Western Scotian Shelf (Figure 2.3)
- Eastern Scotian Shelf (Figure 2.4)

Sediment Type	Specific Gravity	Compressional		Shear	
		Speed (m/s)	Attenuation (dB/m-kHz)	Speed (m/s)	Attenuation (dB/m-kHz)
LaHave Clay	1.5	1480	0.02	-	-
Emerald Silt	1.6	1580	0.60	100	10
Sambro Sand	1.8	1650	0.40	150	10
Sable Island					
Sand:(first 2 m)	1.9	1700	0.60	150	10
Sand: deeper	2.0	1800	0.30	200	10
Gravel	2.0	1900	0.25	300	10
Scotian Shelf Drift	2.1	2000	0.5	800	2.0

Table 2.3: Physical properties of the Scotian Shelf and Grand Banks sediments. Specific gravity refers to density relative to water. (From Hughes and Ellis, informal communication)

- Western Grand Banks (Figure 2.5)

2.2.4 GIS Sediment Type

Surficial geology information from the source documents listed in Part I has been digitized and incorporated into the GIS.

2.3 Sediment Thickness

The information available on sediment thickness consists of a series of charts [King et al., 1985] which show the present state of knowledge on the thickness of the sediment layers covering the Grand Banks and the Scotian Shelf. These maps have not been included in this document due to their large number and high resolution, and because it was beyond our resources to convert this information into a chart format more adequate for the present need. Some short descriptions taken from King's study [1985] on the main characteristics of the sediment layers are included in Subsection 2.3.1. (All sediment thickness charts have however been digitised and included in the GIS.)

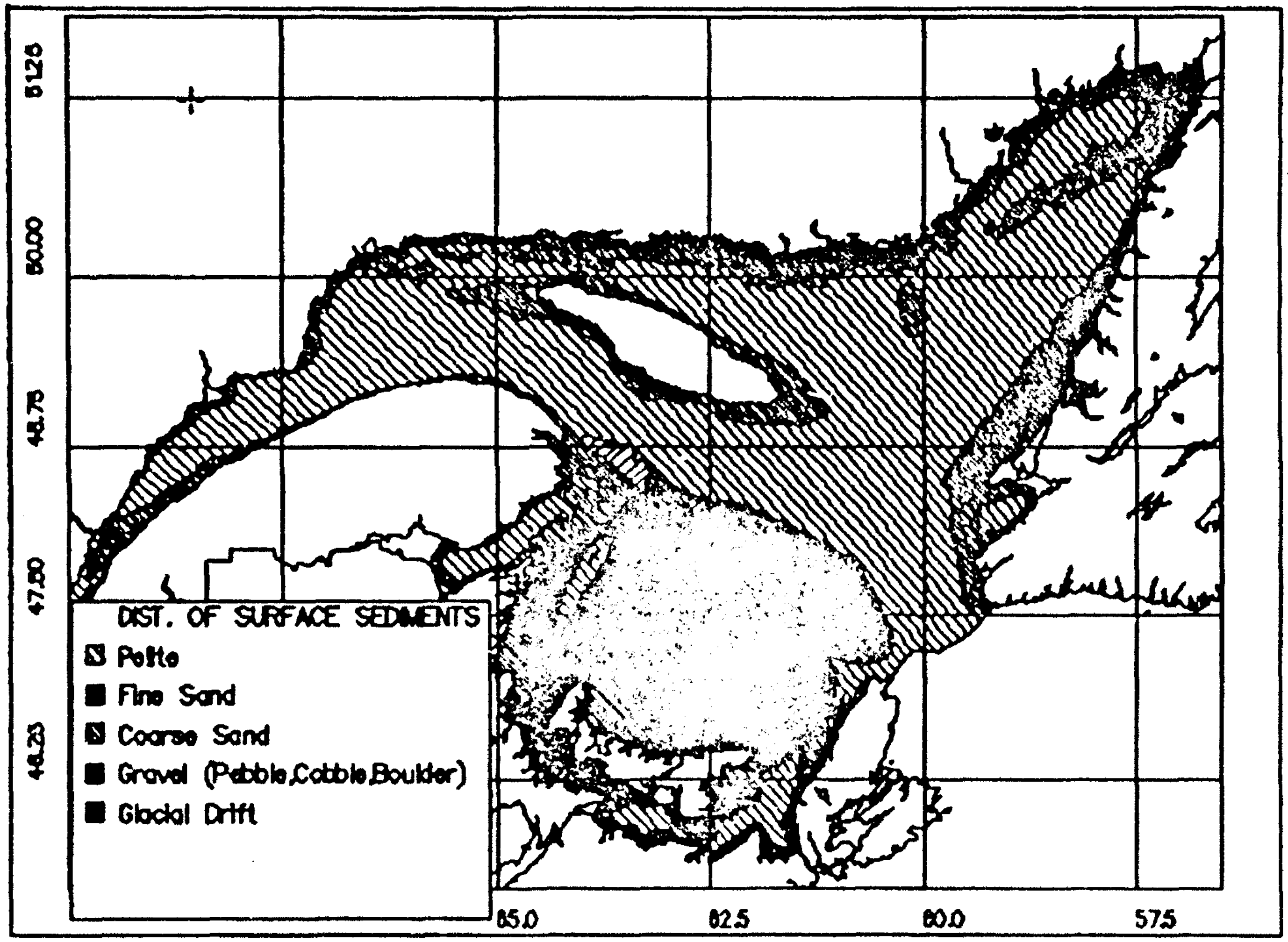


Figure 2.2: Distribution of surface sediments in the Gulf of St. Lawrence. (After Loring and Nota, 1972).

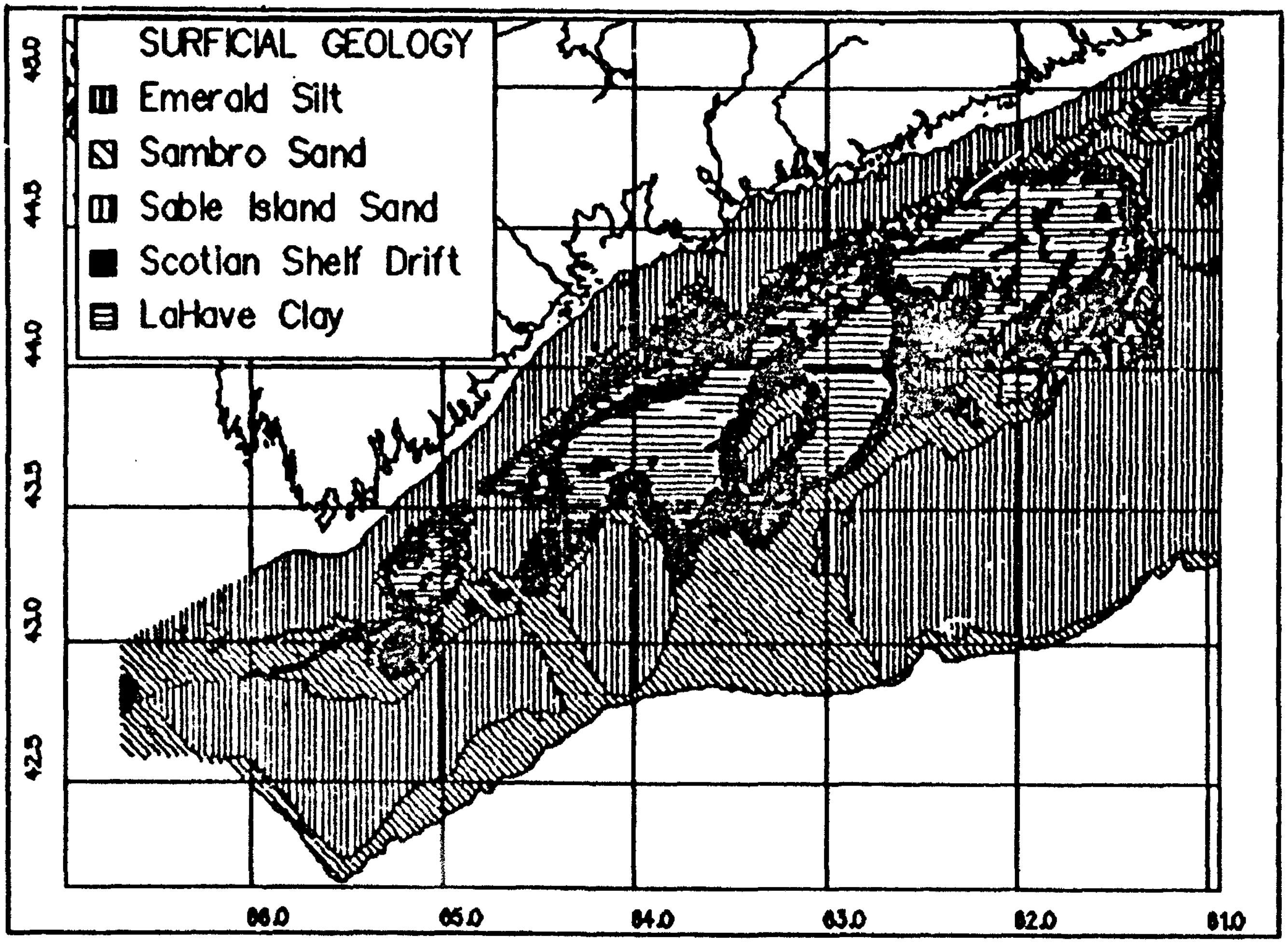


Figure 2.3: Distribution of surface sediments in the western portion of the Scotian Shelf. (After King, 1970 and Drapeau and King, 1972).

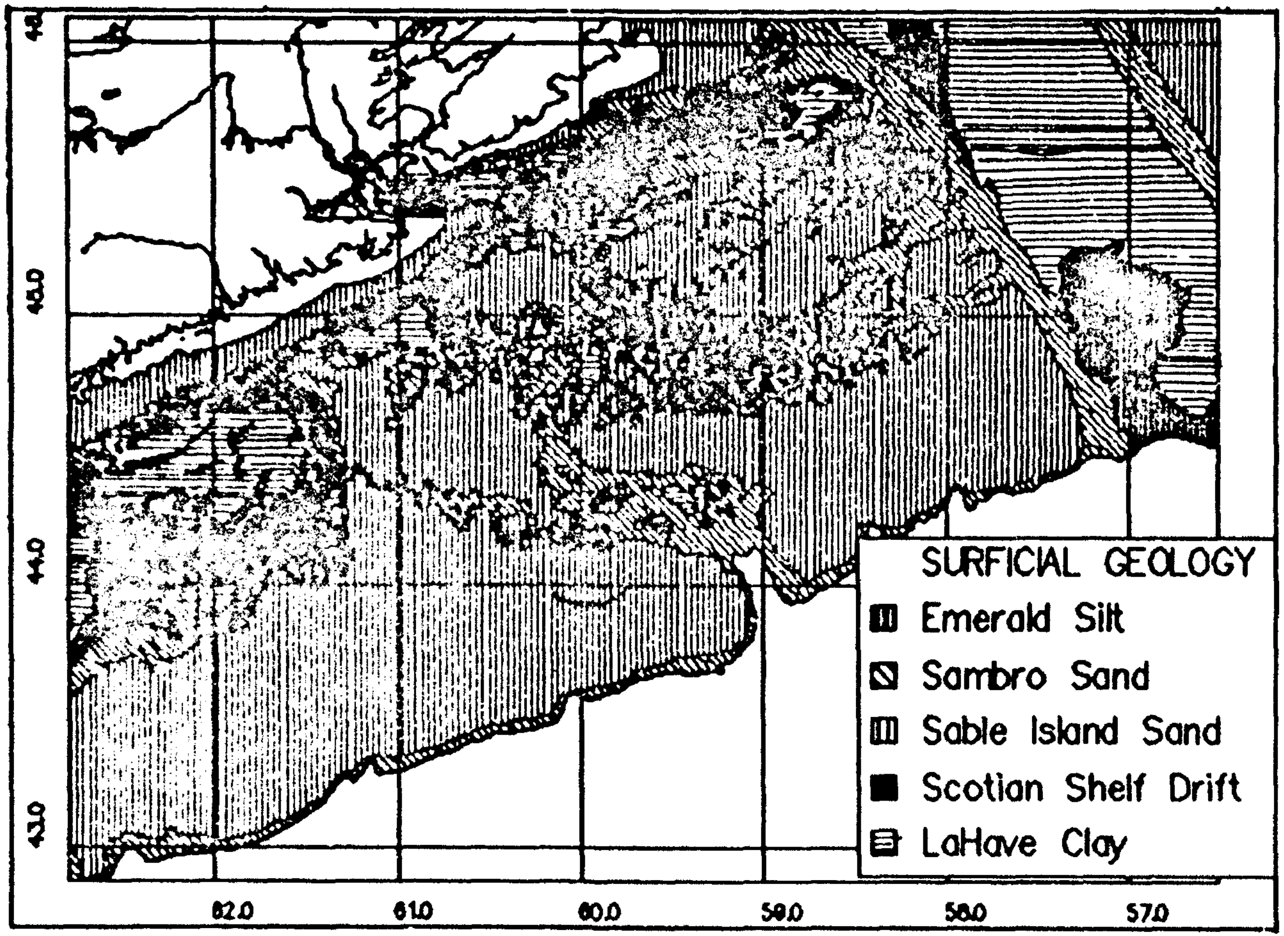


Figure 2.4: Distribution of surface sediments in the eastern portion of the Scotian Shelf. (After King, 1970, McLean and King, 1971 and McLean et al., 1977).

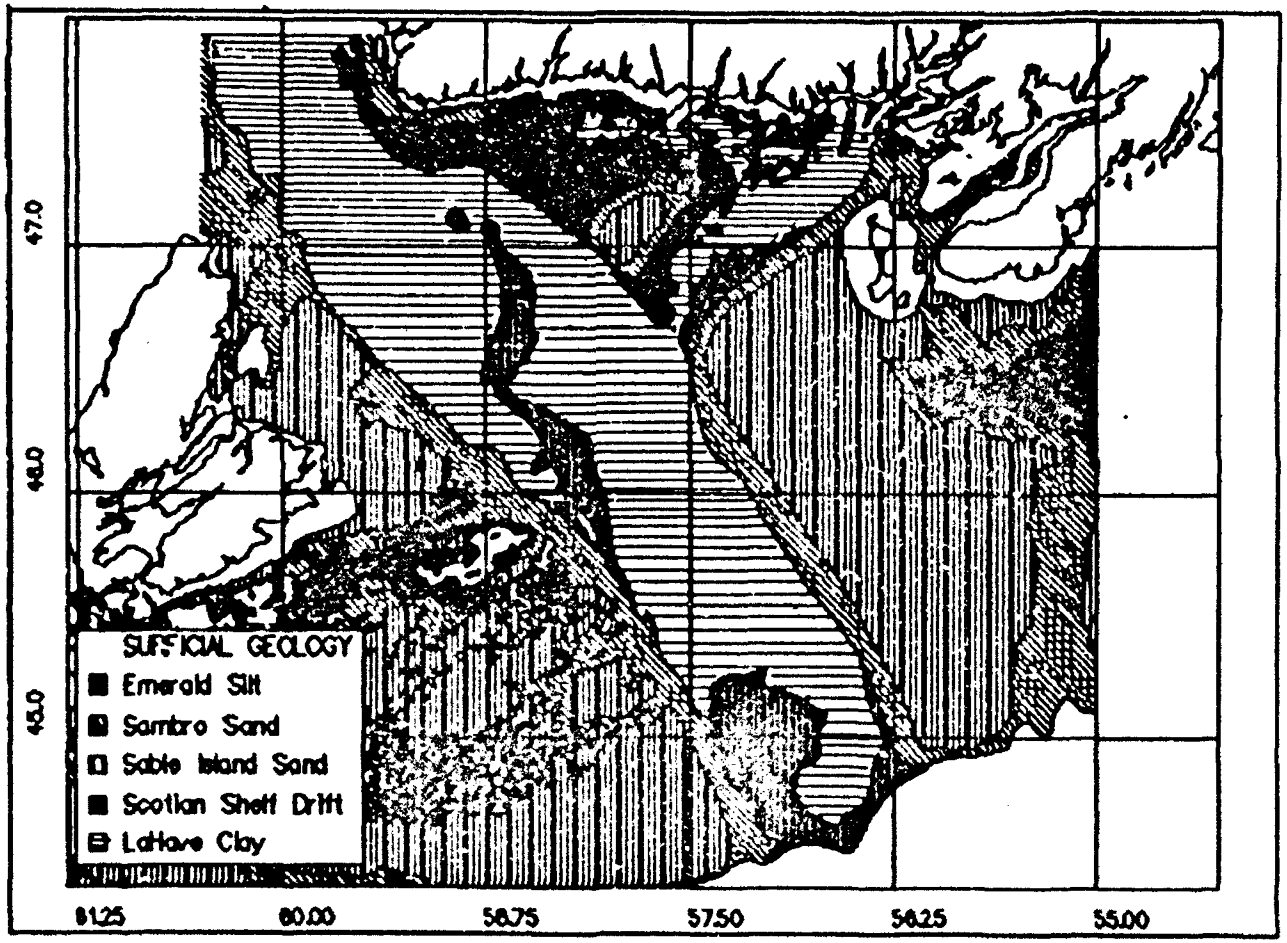


Figure 2.5: Distribution of surface sediments in the eastern portion of the Laurentian Channel and western Grand Banks. (After Fader et al., 1977).

2.3.1 Regional Description

The dominant features of the sediment thickness and their degree of variability have been identified from the study by King et al. [1985]. Where the data were too sparse to allow contour drawing, only qualitative assessment is given by the code letters A, B, and C which correspond to the following categories respectively:

- A. Significant sediment thickness.
- B. Region of highly variable sediment thickness.
- C. Sediment veneer to several metre thickness.

<u>Scotian Shelf</u>

- **Georges Bank:** The northeastern part of Georges Bank is covered by a thin and patchy (< 1 m) layer of sand over a thin gravel deposit. The sand patches are mainly low amplitude, long wavelength sand ridges. The eastern portion of the bank has a similar bedform occurring over a thicker layer of sand (2 to 10 m).

- **Fundian Channel:** The northeastern portion of the Fundian Channel develops seaward into several submarine canyons that are filled mostly by glacial till covered by sand (1 to 5 m thickness).

- **Browns Bank:** The sediment cover in the southwest portion is variable and ranges from less than 5 m to greater than 50 m in thickness. The poor quality of the data over the remainder of the area does not allow a clear description.

- **Baccaro Bank, LaHave Bank, Roseway Bank:** The poor quality of the data only permits the identification of a sediment veneer (Category C).

- **LaHave Basin, Roseway Basin and Emerald Basin:** LaHave Basin is covered by 30 to 70 m of sediments whereas Roseway Basin's sediments are usually limited to 30-45 m. The thickest accumulation in these basins infills the deepest erosion scars in the bedrock surface. In Emerald Basin, these infills can reach a thickness of more than 100 m.

- **Inner Shelf:** The high variability of the sediment thickness in this area prevents contouring. Average thickness is approximately 10 to 15 m, thinning towards land. The thickness varies depending upon the variability of the underlying bedrock and ranges from zero on the bedrock topographic heights to a maximum of 30 m in isolated pockets.

- **Canso Bank Area:** On the bank itself, a veneer of sand is found (< 10 m). Between the bank and the inner shelf zone, the sediment cover is variable and rather unpredictable. This complexity is due to the presence of several, very small basins related to the Glooscap fault system [King et al., 1985].

- **Misaine and Artimon Banks:** Sediment thickness is quite variable and dependent upon the geometry of the underlying bedrock surface which is heavily incised. The thickness is generally less than 10 to 15 m between bedrock channels, but can be as thick as 100 m within the channels. Channelling tends to be more intense near the edge of the banks.

- **Sable Island Bank Area:** The thickness is believed to average at least 100 m on Sable Island Bank. It often exceeds 150 m and tends to thin towards the Western Bank. The variability could be much higher than indicated, but the data coverage is not sufficient to ascertain the exact structure. Only the margins of Middle Bank have data coverage and extrapolation of results found in adjacent banks suggest a highly variable section (20-200 m thick). Much of the bank has not been surveyed, therefore contouring is not possible [King et al., 1985].

- **The Gully and Adjoining Channels:** This section includes the Gully and the irregular topography surrounding Misaine and Artimon Bank. Sediment thickness is highly variable, ranging from less than 20 m to more than 200 m in the deepest bedrock channels. In the Gully itself, the thickness can exceed 250 m. Except in the Gully, contouring is however not possible due to low data coverage.

- Banquereau: Sediment thickness averages well in excess of 100 m with thicker spots reaching 200 m. As on Sable Island Bank, the layer appears to thin towards the northern margin. Measurements are too sparse for regional contouring of this bank.

- Southeastern Laurentian Channel: The data for this region is both extensive and of good quality. The sediment surface is a relatively horizontal surface, except near the channel edges. Since the underlying bedrock is relatively smooth and has been eroded mostly in the centre of the channel, maximum sediment thickness is found in the centre of the channel (100 to 140 m). In the region of St. Pierre Bank and Misaine Bank however, the thickness increases to 250 m.

Grand Banks

The basins on the Grand Banks, are characterized by a highly variable sediment thickness. Over the southern and eastern Grand Banks, it is usually less than 10 m. On the northern Grand Banks, in water depths less than 110 m, the deposits are less than 3 m thick. Thickness increases in the Downing Basin and southern part of the Avalon Channel where up to 40 m of till has been mapped [Mobil Oil, 1984]. For the most part however, the Grand Banks is characterized by large expanses with thin to highly variable sediment cover.

- Halibut Channel: Features are similar to that of the Laurentian Channel. Sediment thickness ranges from less than 20 m on the adjacent bank tops to more than 100 m in the deepest, central part of the channel. Thinning takes place gradually towards the north, and more abruptly to the south.

- St. Pierre Channel, Green Bank, Haddock Channel, and Whale Bank: This whole area is, characterized by sediments that infill and cover an irregular, channelled, bedrock surface. The layer thins and becomes less variable towards the south, in the outer continental shelf areas. The variability is very high, and contouring is therefore impossible.

- **Inner Shelf:** This area has features similar to that of the Scotian Shelf nearshore area. The thickness is generally less than 10 m except near northeastern St. Pierre Bank.

- **Tail of the Bank and Grand Bank:** Most of this region is characterized by thin sediment cover with a random distribution of small, low amplitude sand ridges whose shape and orientation are unknown. Beyond the 80-90 m isobath, the sediments form a wedge down to 30 m along the shelf break. Virgin Rocks and Eastern Shoals are characterized by a very thin layer or the total absence of sediment.

- **Virgin Rocks to Whale Basin Area:** Whale Deep consists of a cluster of troughs with sediment infill of up to 185 m thick separated by sediment cover as low as 2 to 10 m. Between Whale Deep and Virgin Rocks, areas of thin sediment cover (0.5 to 7 m) are cut by numerous channels typically filled by 30 to 60 m of sediments (maximum 120 m).

- **Downing Basin, Conception Bay Area:** This region contains thick glacial infill reaching a thickness of over 85 to 130 m in the basins. The region between Downing Basin and the Avalon Channel is characterized by thin sand cover with low amplitude ridges. The northwest portion of this area is occupied by a basin which is blanketed by abundant glacial till with thicknesses ranging from 20 m near the flanks to over 160 m towards the centre. The flanks are also marked by heavy iceberg scouring of the surface which results in irregular sediment thickness.

- **Hibernia:** This region is characterized by a continuous sheet of sand which thickens in a northeast direction from 2 to 3.5 m. Some ridges with thicknesses of 2 to 5 m and sediment pockets infilling small depressions cause some variability in this pattern.

Flemish Cap

Measurements available over the Flemish Cap do not allow the identification of the sediment types or thickness. However, an indication on the roughness has been derived from the echo sounder data available. Based on the measurements of the amplitude and wavelengths, the relief features have been regrouped into the following roughness provinces:

- *Province A*: Dominant features are greater than 8 m in amplitude and wavelengths are roughly 200 to 500 m. This relief is attributed mostly to bedrock outcrop or strong bedrock control.
- *Province B*: Relief features vary from 1 to 8 m and their wavelength between 50 m to 1 km. This type of relief is believed to be also associated with bedrock outcrop and bedrock covered by a thin sediment veneer.
- *Province C*: Relatively flat surfaces with frequent isolated occurrences of low amplitude (1 to 3 m) relief features.
- *Province D*: Essentially a flat (±0.5 m to ±2 m) smooth surface.

The map in Figure 2.6 shows that the roughest areas of the Flemish Cap are caused by numerous isolated occurrences with relief of up to 20 m. The smoothest areas exhibit relief of less than 2 m, occur among the rougher patches, and are associated with some sediment cover over bedrock. The flanks of Flemish Cap exhibit an intermediate roughness, often with terraces, and are also associated with sediment cover [King et al., 1985].

2.3.2 GIS Sediment Thickness

All the information on sediment thickness obtained from King et al. [1985] has been digitized and is included in the GIS for easy access at the required scale.

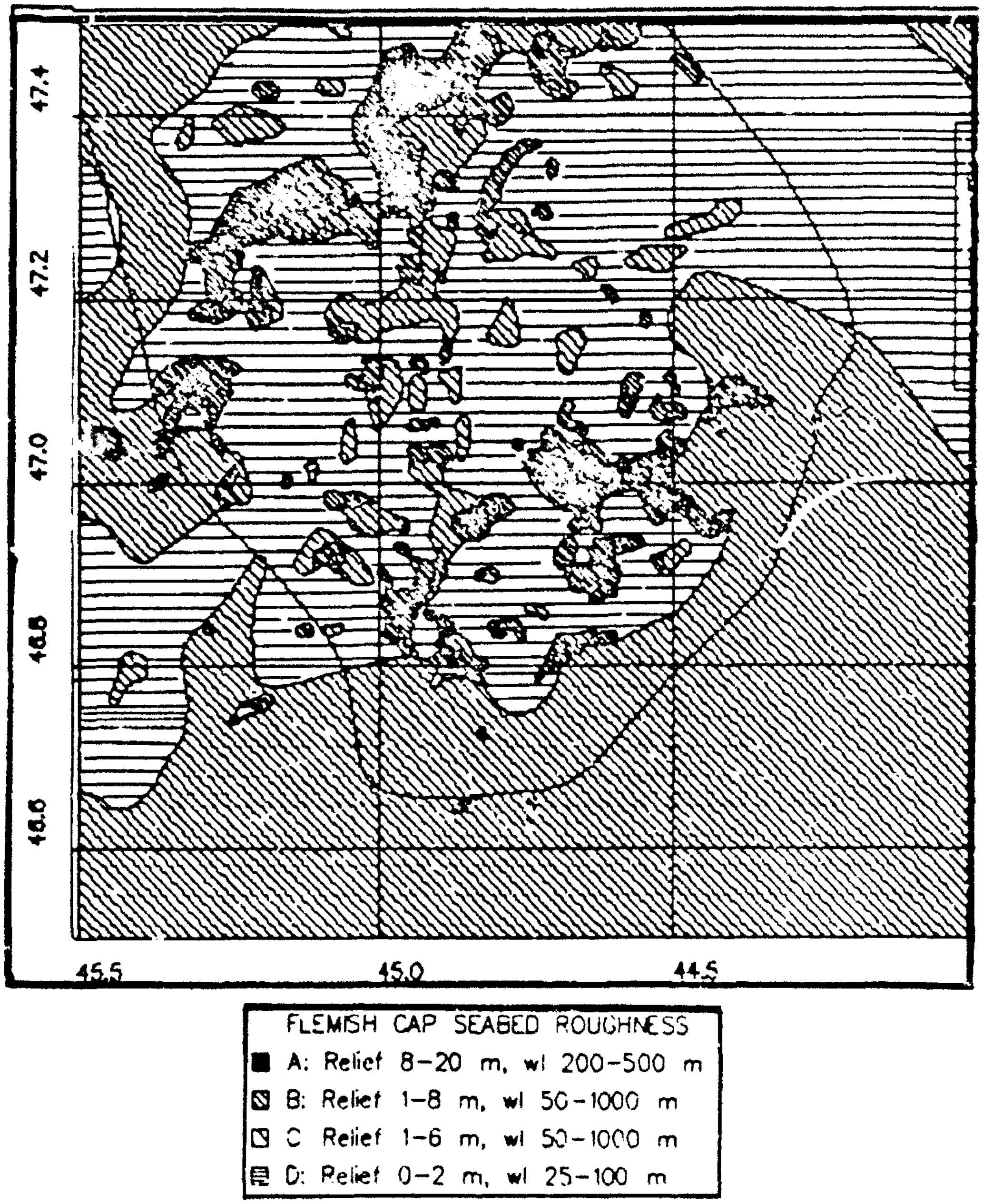


Figure 2.6: Bottom roughness map of the Flemish Cap (After King et al., 1985)

2.4 Physiographic Provinces

2.4.1 Physiographic Provinces Chart

Physiographic provinces represent areas of similar topographic, structural and morphological characteristics that are likely to show a similar acoustic response. These are shown on the chart in Figure 2.7. Furthermore, a description of these provinces is given in the following section.

2.4.2 Physiographic Provinces Description

Inner Shelf

This province includes the areas from the shore to a depth of 100 m along the coast of the Québec North Shore, along most of the Newfoundland coast and along the coast of Nova Scotia . This region has a relatively constant width of approximately 30 km along Nova Scotia and Québec, but is very irregular along the coast of Newfoundland, in particular the east and south coasts. It is characterized by a rough bathymetry, since it is an extension of the adjacent land into the ocean thus having the same bedrock formation and a similar geological history [Drapeau and King, 1972]. It is mostly covered by a thin layer of sand and gravel.

Sound propagation is expected to be very poor at low frequencies due to the shallow depth and the presence of a thin and irregular layer of sediment. At higher frequencies, high bottom scattering can be expected due to bottom roughness.

Laurentian Channel

This a broad trough-like depression that extends from an area near the mouth of the Saguenay River in the St. Lawrence Estuary, through the Gulf of St. Lawrence and continues across the continental shelf to the shelf edge. From the Pointe-des-Monts area, it is on average 100 km wide and forms a relatively

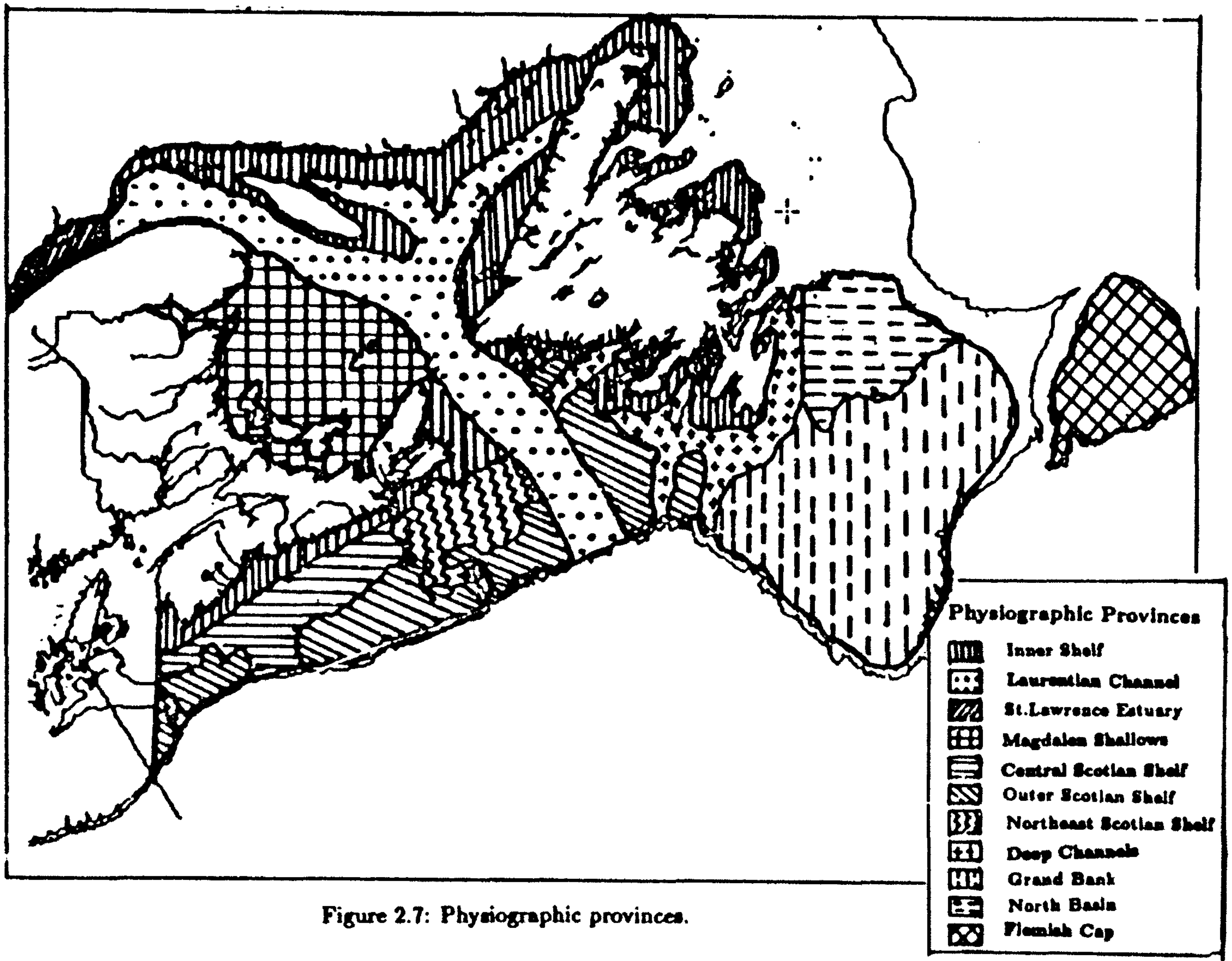


Figure 2.7: Physiographic provinces.

straight trough with steep sides. The floor of this channel contains several large elongated depressions presumably formed by glacial overdeepening. Tributary channels join the main channel (er. Esquiman Channel). Its floor generally has a smooth surface except for those areas in which the presence of glacial till produces an undulating surface [MacLean and King, 1971].

Sound propagation should be better, or at least more predictable, than in most of the area under study wher both the receiver and the target are inside the Channel, due to the greater depth and the homogeneity of the sediment's composition, thickness and structure.

Lower St. Lawrence Estuary

The Laurentian Trough extends upstream into the St. Lawrence Estuary to Tadoussac, seaward of the Saguenay Fjord entrance. The width of the channel decreases from 40 km to less than 10 km while the depth remains relatively constant at 300 m. This area is basically a fjord and the problem of side boundaries is therefore more predominant.

Magdalen Shallows

Very shallow (50 m) and flat area that covers one-quarter of the Gulf of St. Lawrence. The bottom is covered mostly by sand and gravel. Sound propagation characteristics should be relatively constant over the whole area.

Central Scotian Shelf

The southwest and middle portion of the central shelf forms a broad trough which lies parallel to the coastline. The trough is 40 to 50 km wide and extends more or less continuously along this portion of the Scotian Shelf to 61°N. It comprises two main basins which form large transverse depressions branching from the longitudinal trough: Emerald and LaHave Basins. They reach a depth of up to 275 m. A third smaller and shallower basin, Roseway Basin, lies to the southwest, separated from the others by Roseway Bank. The basins and troughs have smooth, gently sloping surfaces and are partly filled and mantled by unconsolidated sediments with the top layer of these sediments consisting of a very fine nature, such as La Have Clay and Emerald Silt [King, 1970].

Outer Scotian Shelf

The outer shelf is a broad zone, 50 to 65 km wide and comprised of a chain of shallow banks which extend along the continental margin. It is an area of high relief which runs parallel to the shelf edge. Several broad, more or less flat-topped banks separated by shallow depressions form a saddle shape. They are covered by a layer of material which is coarser than that found in the basins. This material is mostly Sable Island sand and gravel [King, 1970].

Northeast Scotian Shelf

This portion of the central shelf between 61°W and the Laurentian Channel is more highly dissected and bathymetrically more complex than the portion of the shelf to the west. The seabed across the area is irregular and in places, very rough. The roughness arises from an uneven surface of underlying bedrock as well as from the presence of glacial debris which may have been partly modified [McLean and King, 1971]. In addition, some of the depressions have been filled by sediments of various types which results in large fluctuations in sediment thickness over a small area. Sound propagation characteristics, when bottom interaction is important, can be expected to be highly variable and unpredictable.

Deep Channels

Several narrow channels of 10 to 30 km width, can be found mostly east of the Grand Banks. They represent discontinuities in the relatively shallow and flat bathymetry of the surrounding banks. The bottom is generally covered by a thin layer of Sambro sand and glacial till.

Grand Bank

This is a vast shallow area with a very smooth bottom, especially in its centre and northeast portion (Great North). It also includes the very shallow areas of the Southeast Shoal and Woolfall Bank. The thickness of the sediment layers is variable, but they form mostly a thin veneer over the bedrock. Sound propagation should be poor for low frequencies due to the shallow depth and the sediment structure. Use of high frequencies should be hampered by high bottom reverberation levels.

North Basin

This is the area north of Grand Bank, between the Avalon Channel and Great North Basin. It is characterized by an increased depth (100-200 m) and a rougher bathymetry. The sediment distribution is also less homogeneous. Glaciomarine sediments and till commonly fill channels and depressions in the bedrock surface. The sediments consist of sand and gravel in the shallow portions (less than 100 m), and glacial deposit and fine grained marine sediments predominantly in deep channels and basins [Fader and King, 1981].

Flemish Cap

The Flemish Cap is a bank that rises in a gentle slope from depths of approximately 350 m to 120 m on the west and north side. On the east side, the slope is steeper, whereas on the south side it drops abruptly into the Newfoundland Basin (3500 m).

2.5 False Targets

See the classified appendix of this document.

2.6 Magnetic Anomaly

The available information may unfortunately be of little value for tactical purposes for the reason given in Part I. Some information is nevertheless included and the areas that are potentially more noisy for MAD systems due to the strong spatial gradients in the magnetic field are identified.

2.6.1 Magnetic Anomaly Chart

Verhoef and Macnab [1987] have compiled all the existing geomagnetic data to produce an updated 1: 5,000,000 chart covering most of the continental margin of eastern Canada. Part of this chart is included in Figure 2.8. It shows the locations where strong shear gradients in the geomagnetic field exist as the transition between dark and light areas on the map. These zones may be associated with higher noise. As well, areas of sharp topographic features are also potentially noisy areas for MAD systems.

2.6.2 Other Data Sets

Additional information is contained in the classified appendix of this document.

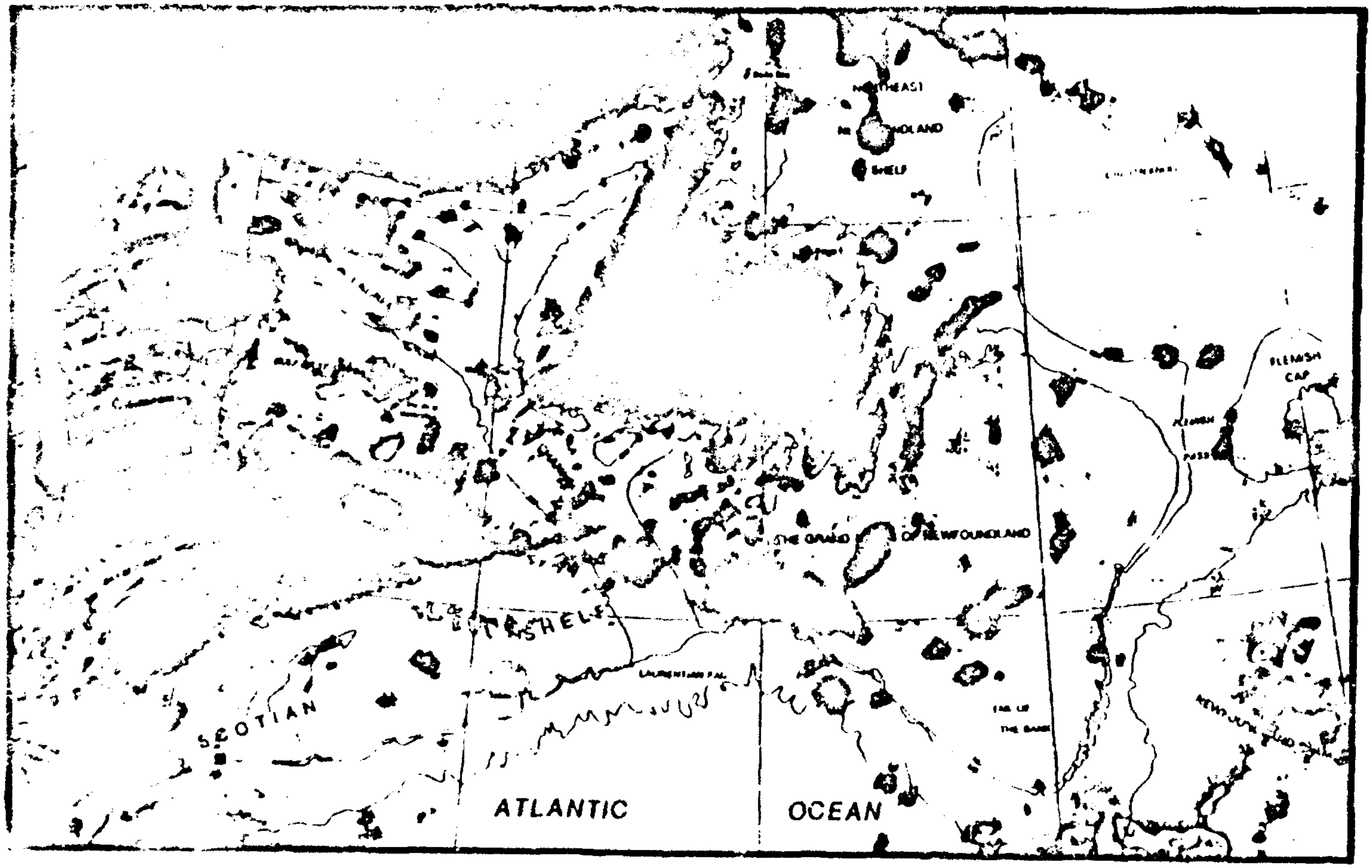


Figure 2.8: Magnetic anomaly chart (After Verhoef and MacNab, 1987).

Chapter 3

Climatology

3.1 Canadian East Coast Climatology

3.1.1 Storm Frequency Statistics

The low pressure systems that bring cloudiness and precipitation tend to move northeastwardly across the area. The storm frequency is highest during the cold months (December through May) as shown in Figure 3.1.

Tropical cyclones that drift westward across the Atlantic and then recurve to the north and northeast often reach the Canadian east coast area as tropical storms. Their peak months of occurrence are September and October as seen in Figure 3.2.

3.2 Wind Data Products

3.2.1 Mean Winds

Under the influence of the dominant large-scale atmospheric pressure field (eg., Icelandic low, Azores high), surface winds are generally northwesterly during autumn and winter, and southwesterly during spring and summer.

Maps depicting monthly mean wind speed and direction are included in

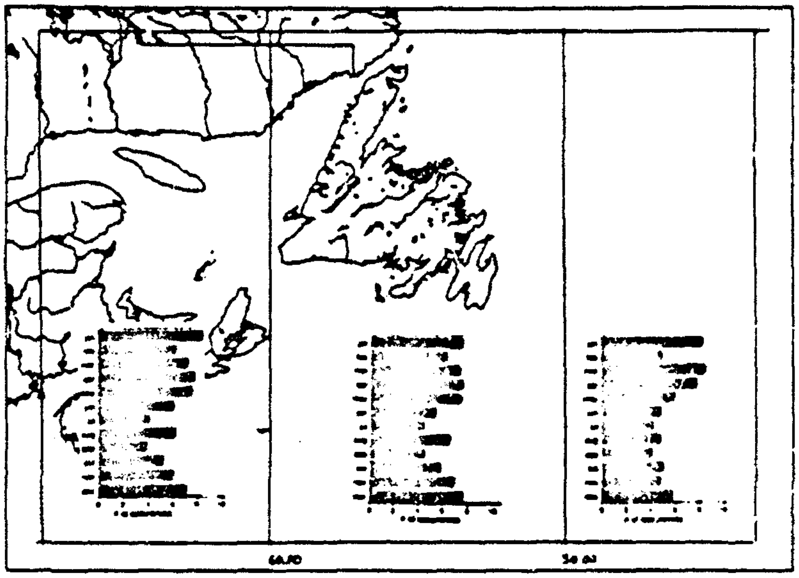


Figure 3.1: Mean number of low pressure storms per month on Canadian east coast regions. (After Crutcher and Quayle, 1974)

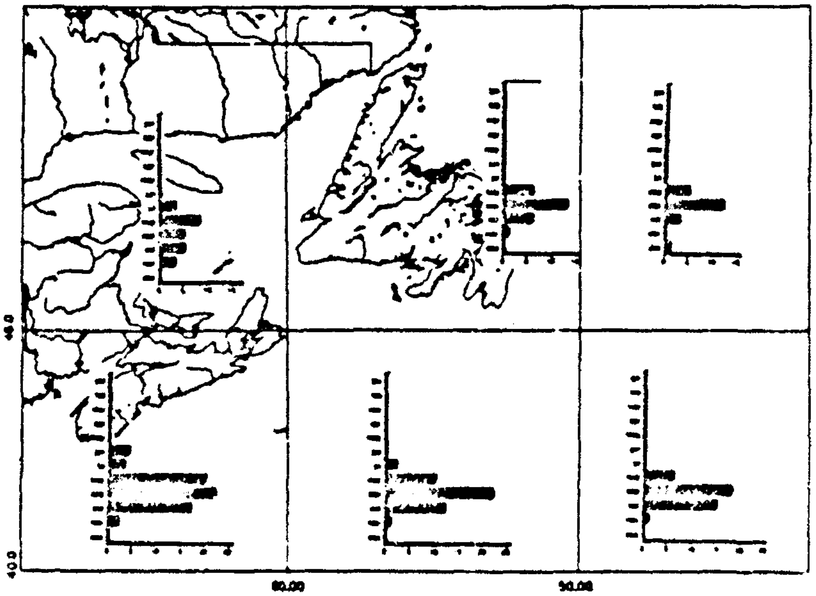


Figure 3.2: Monthly percent probability of tropical storms on Canadian east coast regions. (After Naval Weather Service Command, 1974)

Figures 3.3 and 3.4 . The winds are computed from the ships' observation database.

3.2.2 Wind Roses

A more complete description of the wind variability is provided by monthly 8-point wind roses which indicate the joint frequency distribution of the wind from a particular direction against wind speed in five knot classes as described in Figure 3.5. The roses are included for 3 locations situated roughly at the centre of the Gulf of St. Lawrence (Figure 3.6), the Scotian Shelf (Figure 3.7), and the Newfoundland and Grand Banks areas (Figure 3.8).

3.2.3 Storm and Gale Force Wind Frequency Maps

These data show the frequency of occurrence of wind speeds greater than predetermined wind speed thresholds for selected months of the year (Figure 3.9). The thresholds are 34 knots for gale force winds, and 48 knots for storm force winds.

3.2.4 Storm Force Wind Duration Contour Maps

The maps in Figure 3.10 show contours of estimates of the maximum duration of the storms (wind speed greater than or equal to 48 knots) over the area at different times of the year. The Geostrophic Wind Climatology data set was used for the duration analysis.

3.2.5 GIS Data

The monthly contour maps of mean wind speed and direction shown in Subsection 3.2.1, storm and gale force wind frequency shown in Subsection 3.2.3, and storm duration shown in Subsection 3.2.4 are included in the GIS database.

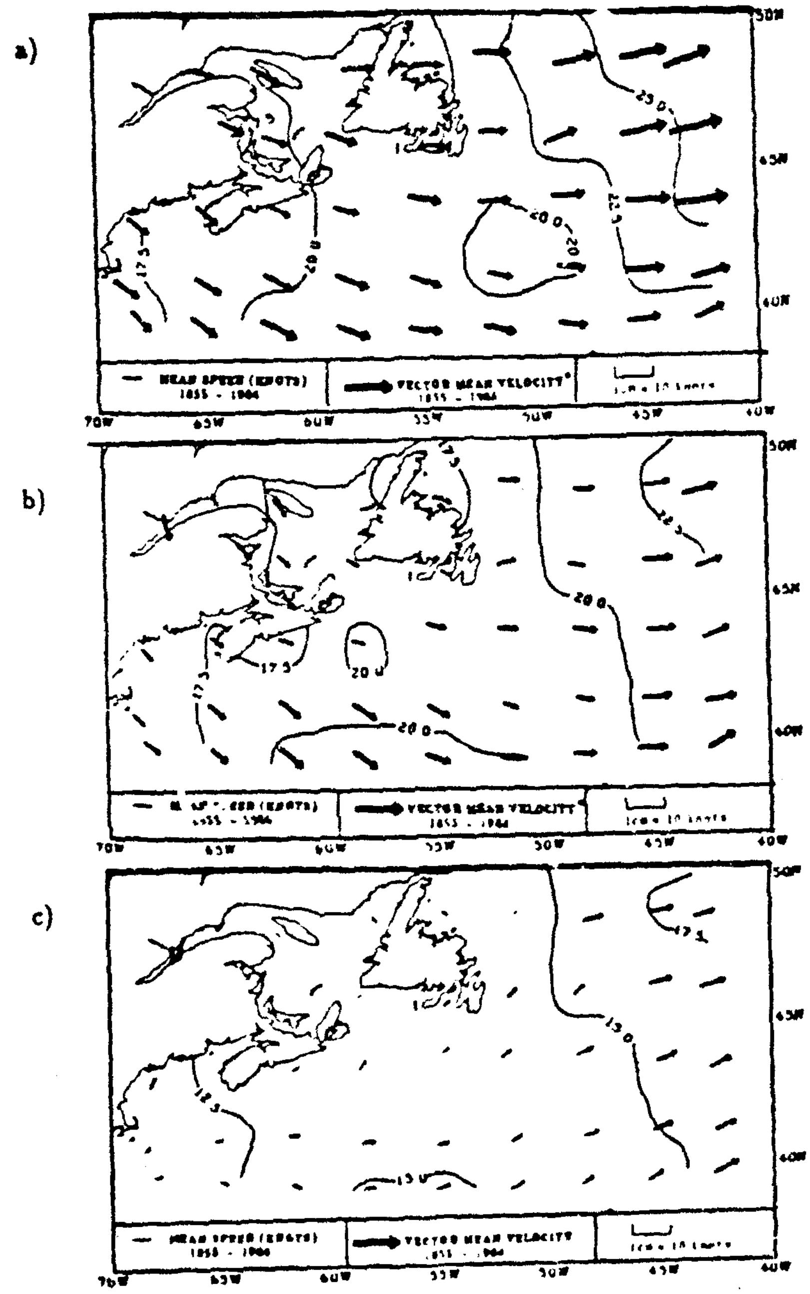


Figure 3.3: Monthly mean wind direction and speed maps for the months of a) January, b) March, and c) May. (From Mortsch et al., 1985)

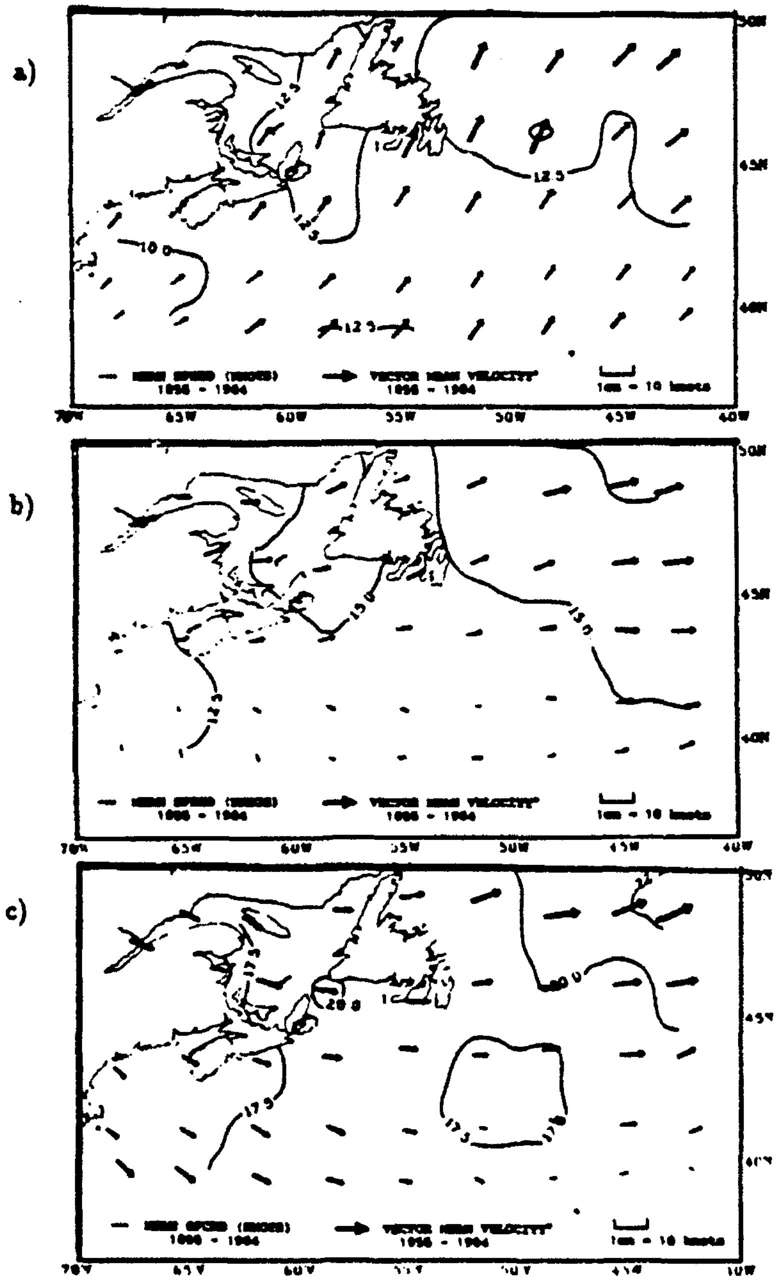


Figure 3.4: Monthly mean wind direction and speed maps for the months of a) July, b) September, and c) November. (From Mortsch et al., 1985)

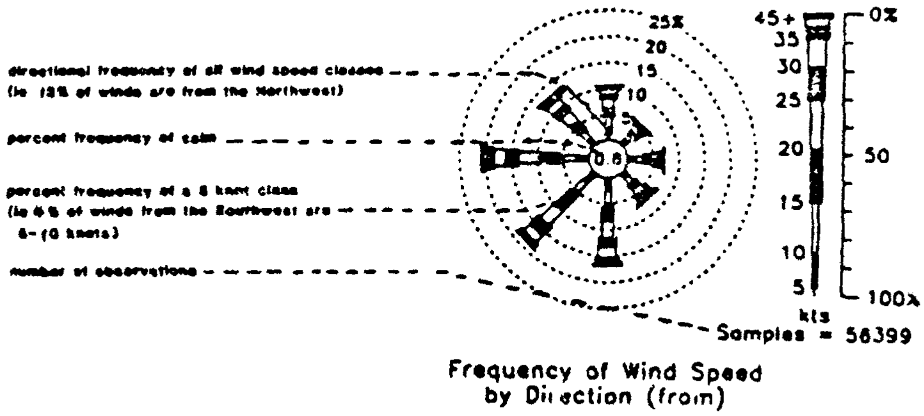


Figure 3.5: Wind rose key. (From Mortsch et al., 1985)

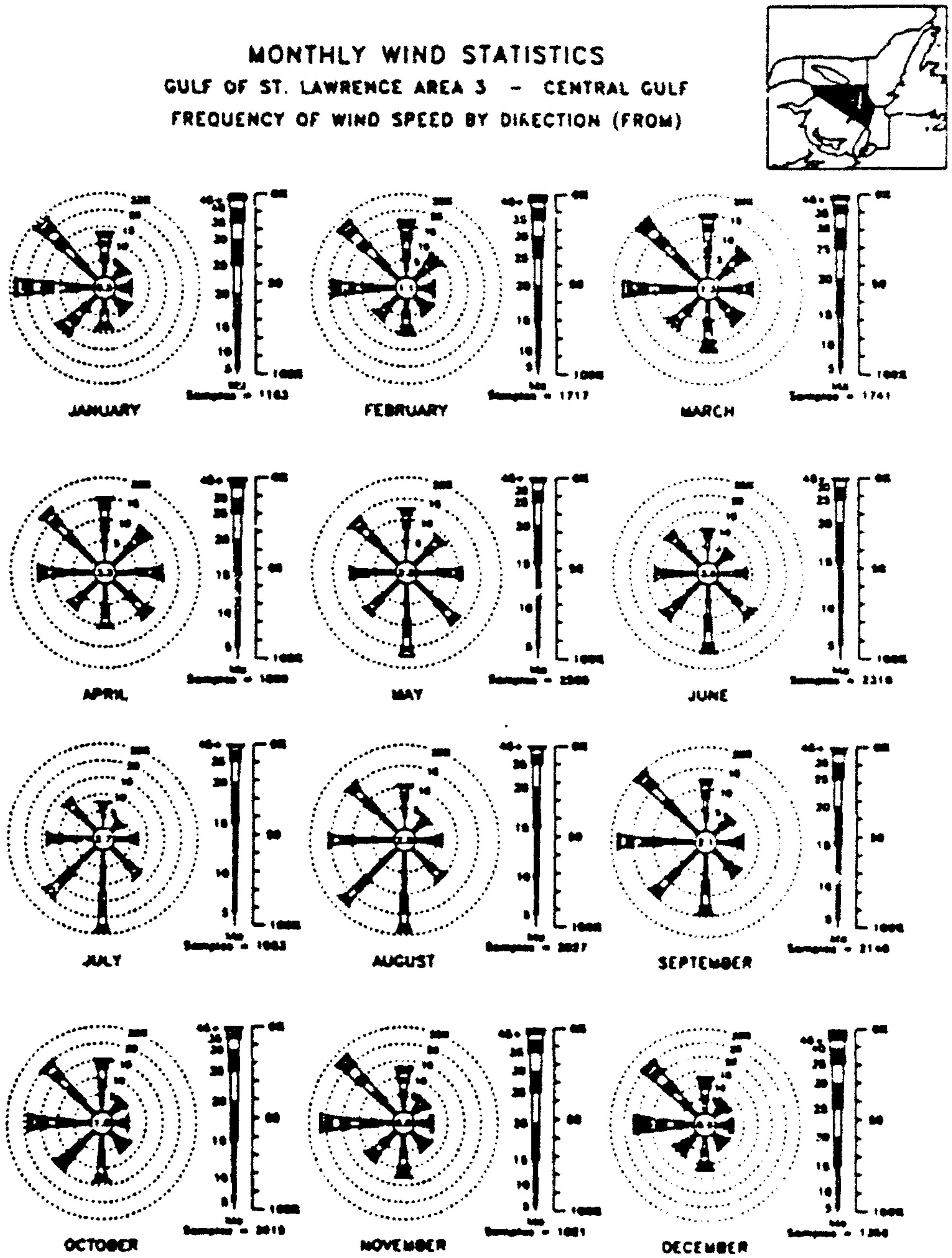


Figure 3.6: Monthly wind roses for the Gulf of St. Lawrence - Central area. (After Swail, 1990)

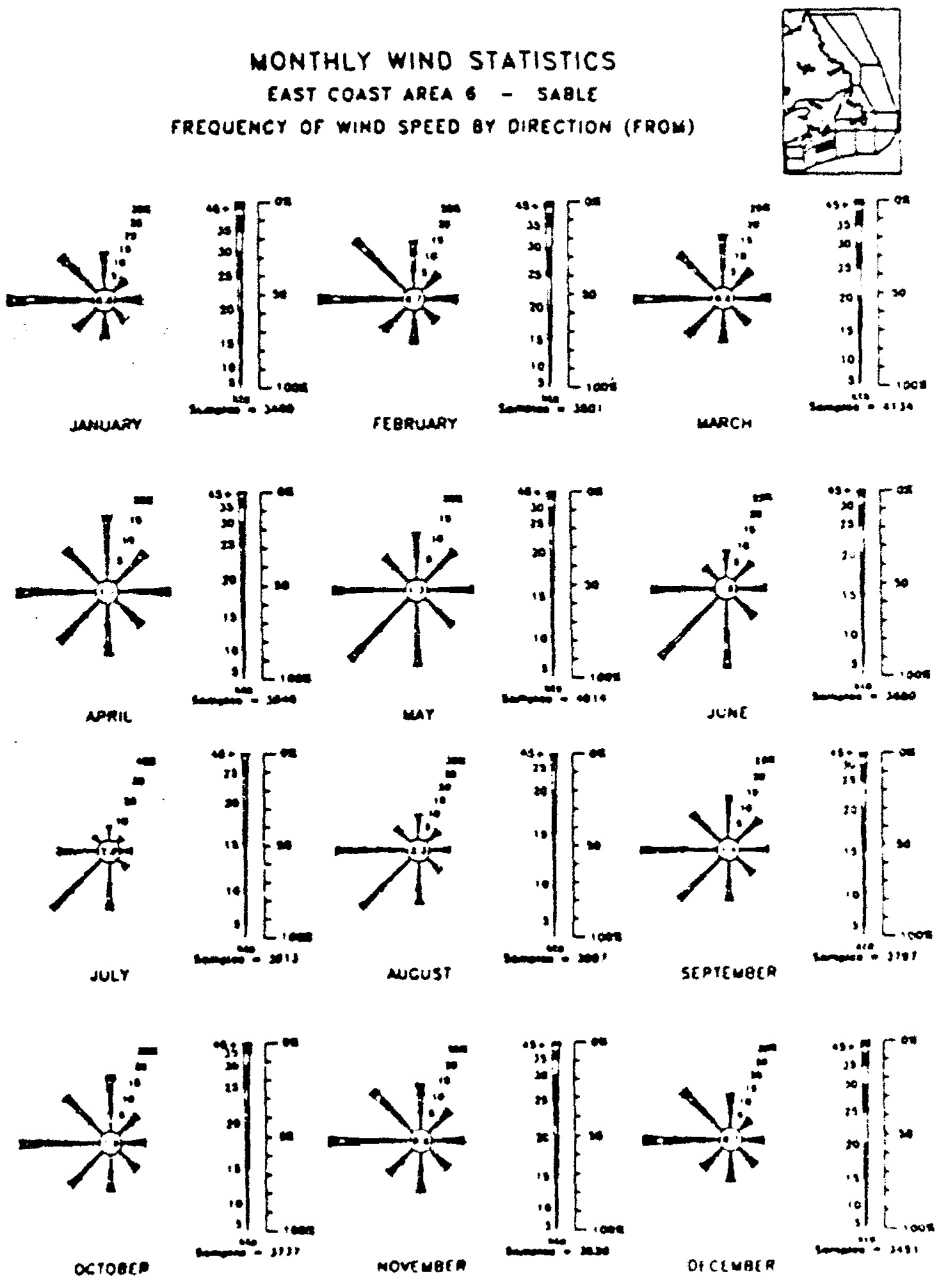


Figure 3.7: Monthly wind roses for the Scotian Shelf - Sable area. (After Swail, 1990)

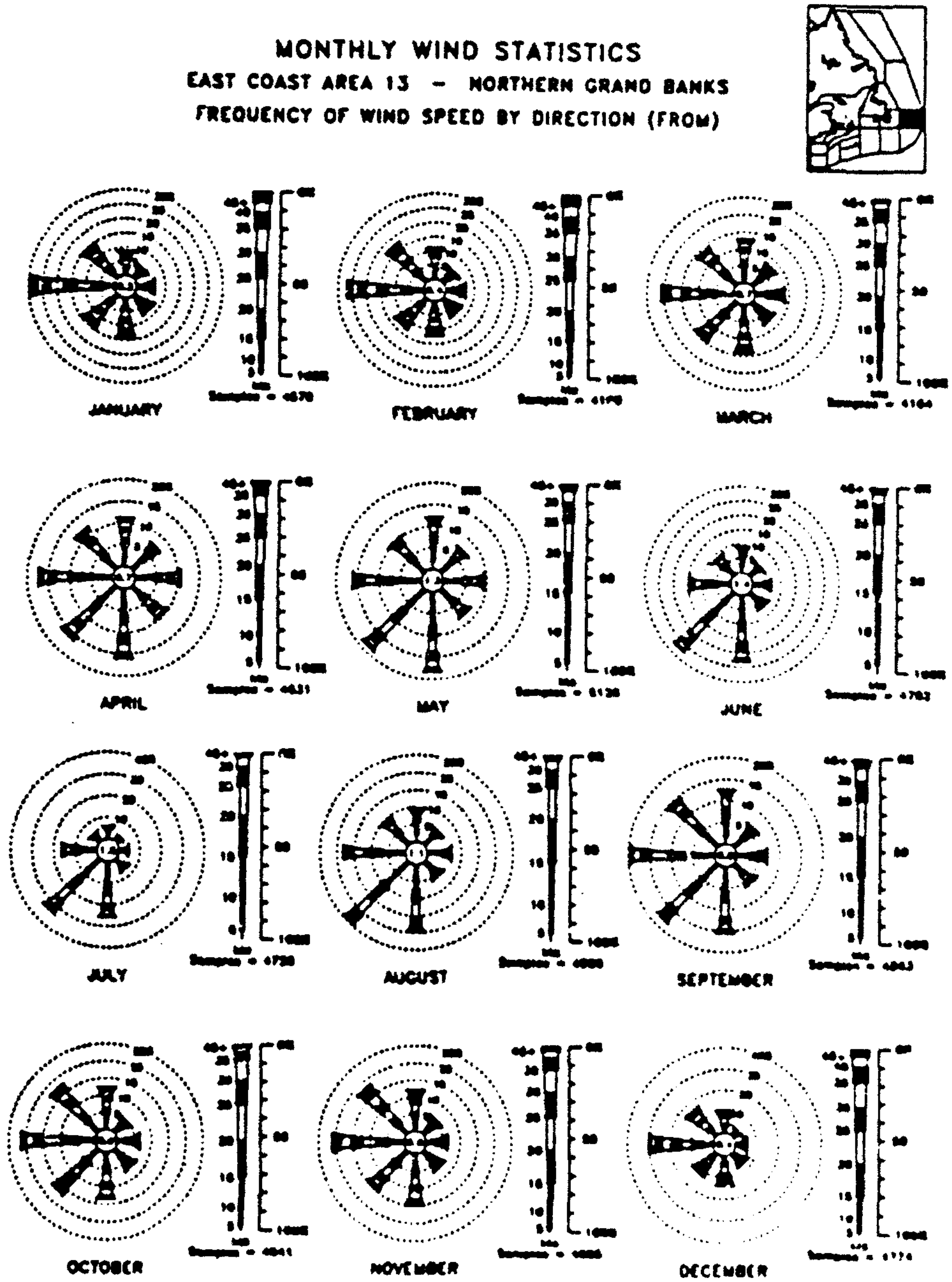


Figure 3.8: Monthly wind roses for the Grand Banks - Northern Grand Banks area. (After Swail, 1990)

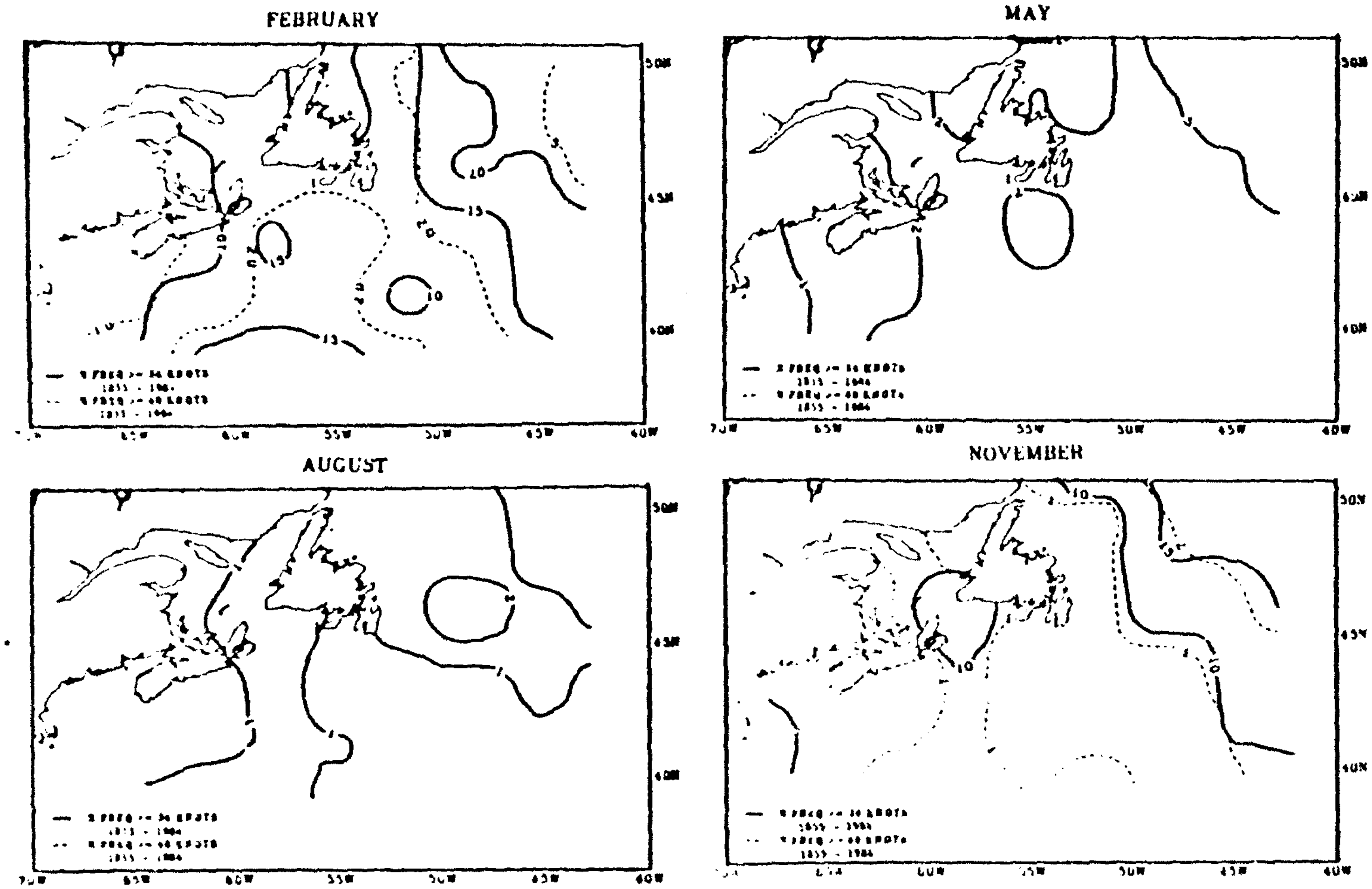


Figure 3.9: Storm force and gale force wind frequency maps for each mid-seasonal month: February, May, August and November (From Mortsch et al., 1985).

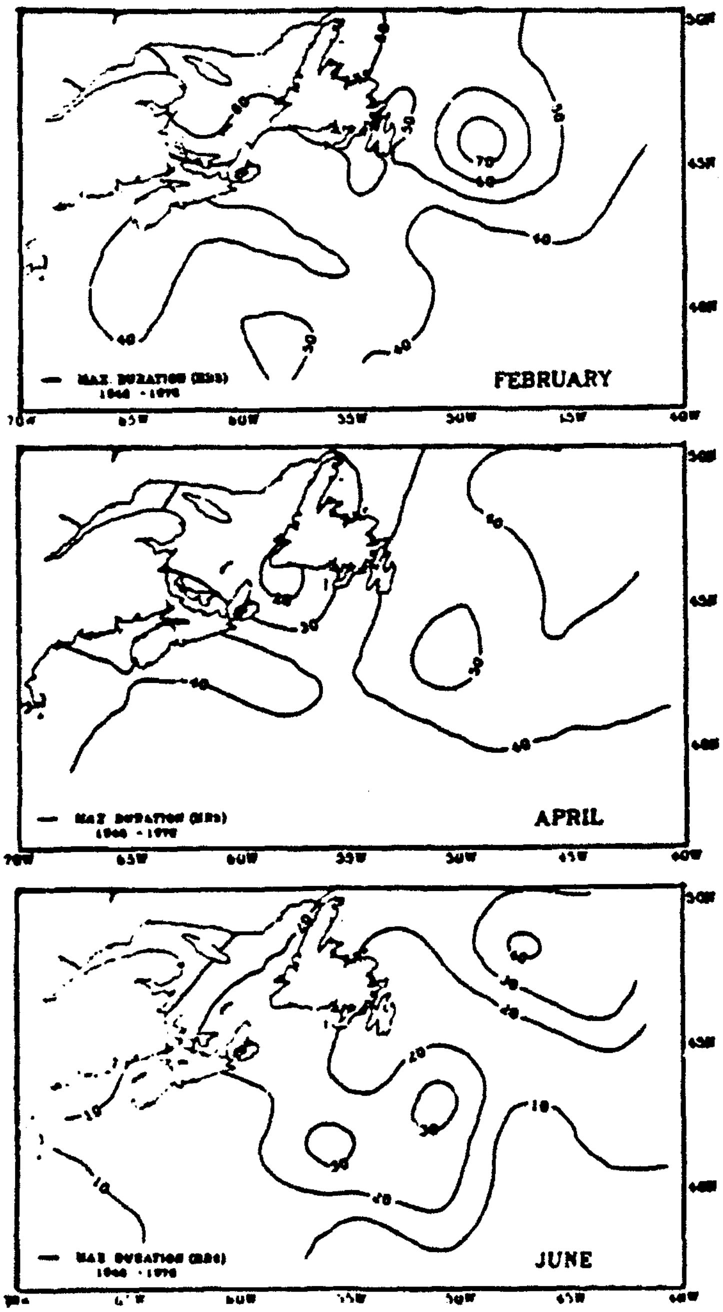


Figure 3.10: Contour map of the average duration of storm force wind ($\geq$ 48 knots) for February, April and June. (From Mortsch et al., 1985)

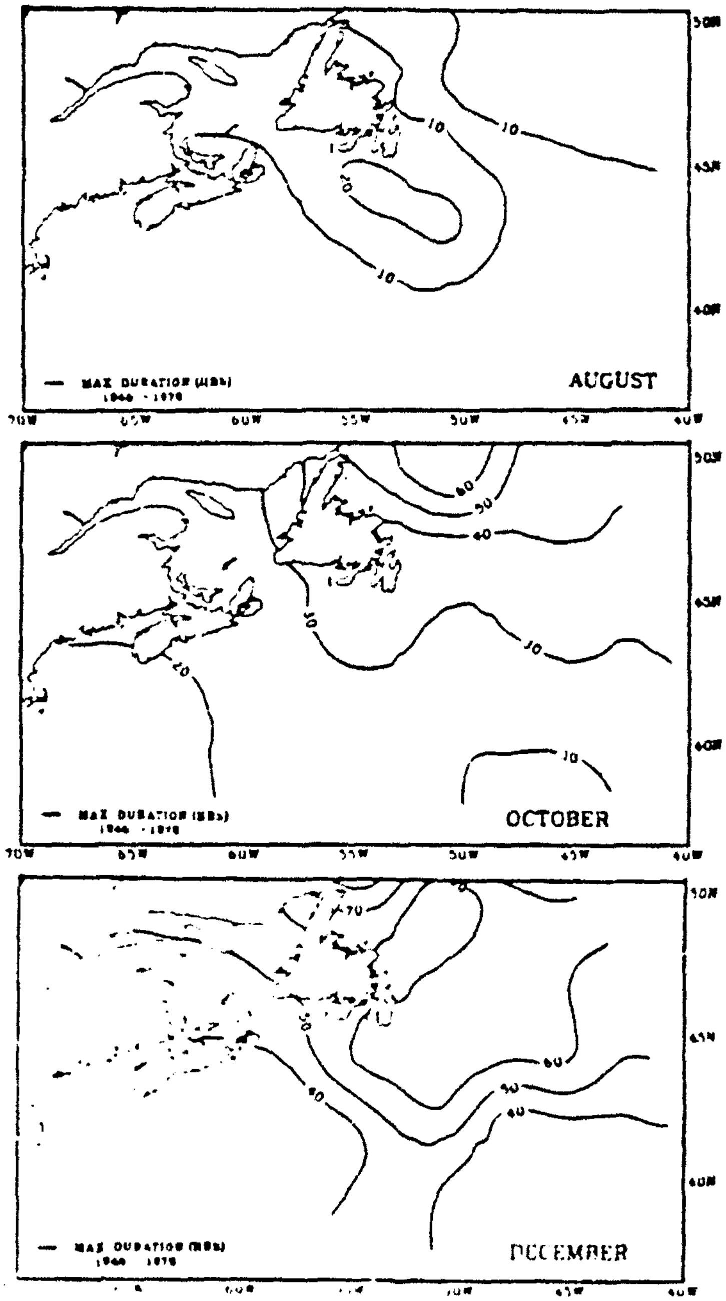


Figure 3.11: Contour map of the average duration of storm force wind ($\geq$ 48 knots) for August, October and December (From Mortsch et al., 1985).

3.3 Flying Weather

Weather conditions affecting low level flying (cloud ceiling and visibility) have been summarized and categorized into three types commonly used in aviation:

Flight Rule Category	Minimum Weather Requirements		
	Visibility		*Ceiling*
Visual Flight Rule (VFR):	$\geq$ 2.5 mi	AND	$\geq$ 1000 ft.
Instrument Flight Rule(IFR):	$\geq$ 0.6 mi	AND	$\geq$ 300 ft.
AND	< 2.5 mi	OR	< 1000 ft
below IFR:	< 0.6 mi	OR	< 300 ft

3.3.1 Flying Weather Statistics

A graphical summary of flying weather conditions for central locations in each of the three main subareas has been included in Figure 3.12

3.3.2 Flying Weather Maps

The contour maps for selected months shown in Figures 3.13 and 3.14 depict the percent frequency of below IFR conditions and the percent frequency of IFR conditions. It follows that the percent frequency of VFR conditions can be derived from these two contour lines by using the formula:

VFR conditions = 100% -[(% freq. < IFR + % freq. IFR)]

3.3.3 GIS Data

Monthly contour maps of flying weather conditions as described in Subsection 3.3.2 have been included in the GIS.

a) Sable Island b) Gulf- Magdalen Island c) Northern Grand Banks

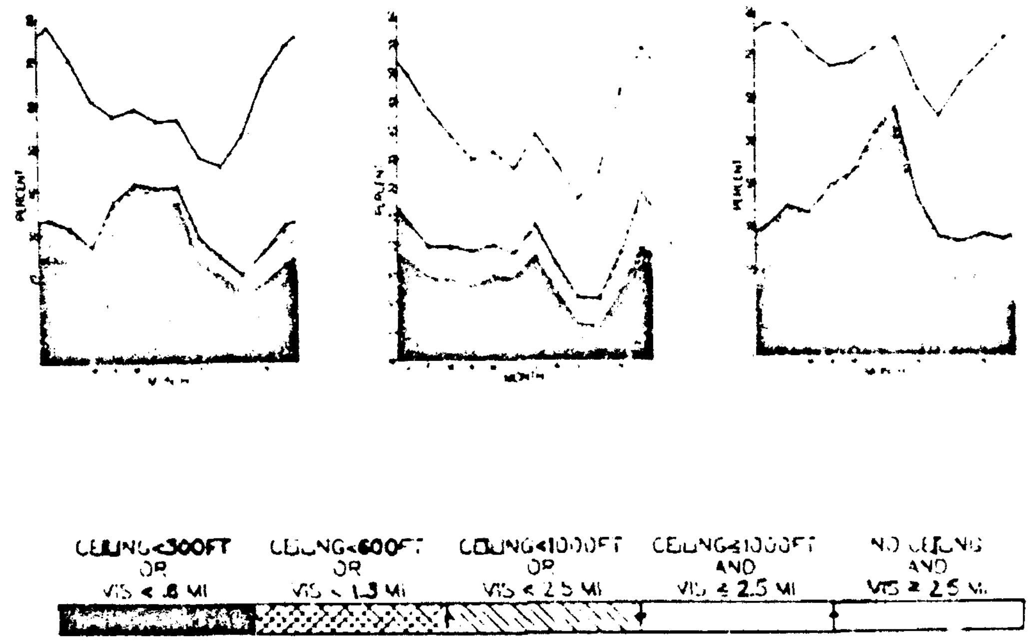


Figure 3.12: Flying weather statistics for: a) Sable Island region, b) Gulf-Magdalen Island region, and c) Northern Grand Banks. (From Mortsch et al., 1985)

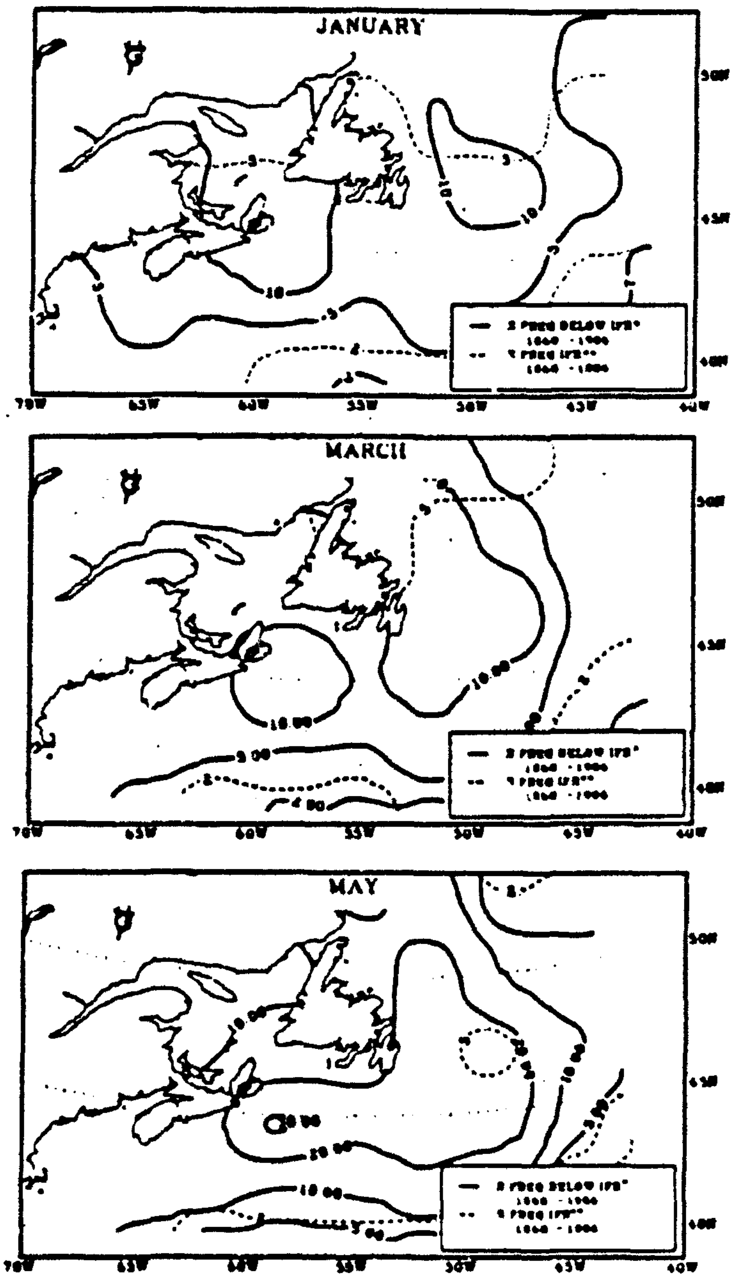


Figure 3.13: Contour map of flying weather conditions for January, March and May. (From Mortsch et al., 1985)

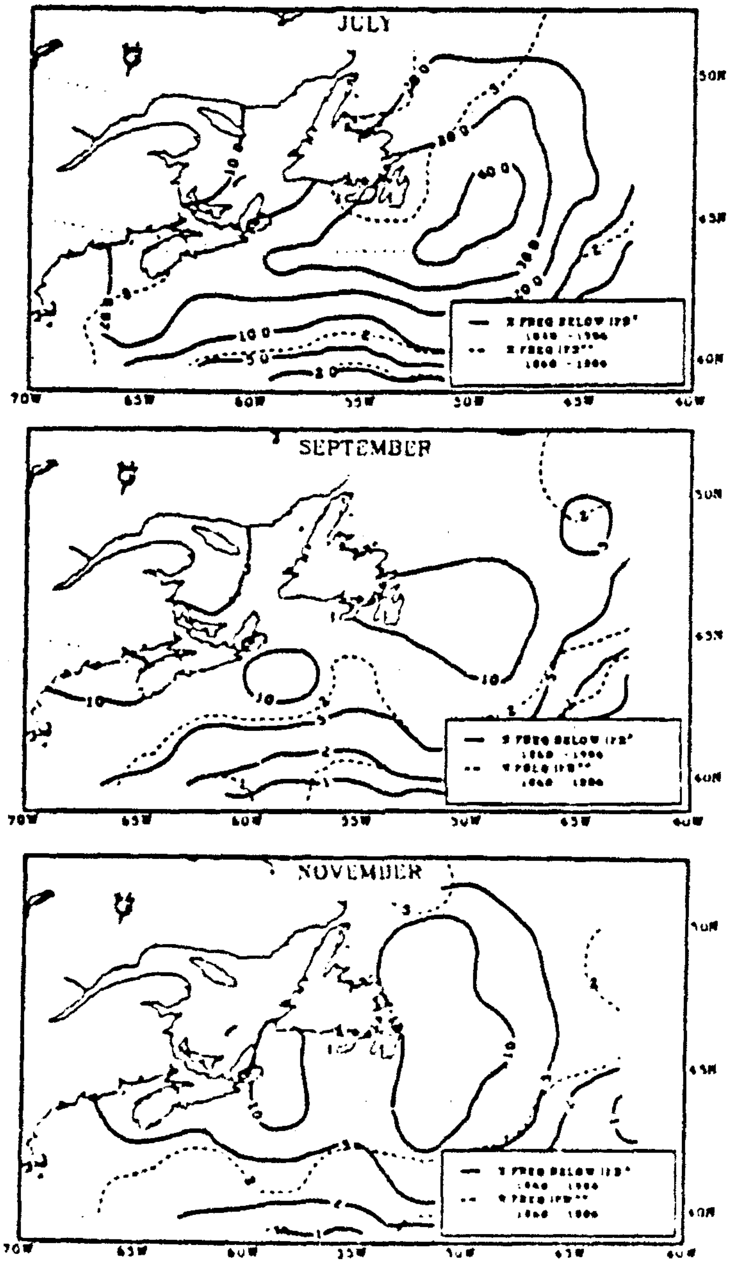


Figure 3.14: Contour map of flying weather conditions for July, September and November. (From Mortsch et al., 1985)

3.4 Visibility

3.4.1 Visibility Statistics

Statistics on visibility conditions for the Sable region on the Scotian Shelf, for the Gulf-Magdalen region, and for the Northern Grand Banks are summarized in Figure 3.15. Visibility ranges are regrouped into five categories outlined as follows:

Category 1	< 0.5 nmi	
Category 2	≥ 0.5 nmi	to < 1.1 nmi
Category 3	≥ 1.1 nmi	to < 2.2 nmi
Category 4	≥ 2.2 nmi	to < 5.4 nmi
Category 5	≥ 5.4 nmi	

3.4.2 Shipping Visibility Contour Maps

The contour maps in Figures 3.16 and 3.17 show the percent frequency of visibility less than 0.5 nautical mile, and the percent frequency of occurrence of visibility greater than 2.2 nautical miles combined with wind speed less than 25 knots, which is defined as "good shipping" conditions [Mortsch et al., 1985].

3.4.3 GIS Data

The monthly contour maps of shipping visibility conditions (as shown in Subsection 3.4.2) have been included in the GIS database.

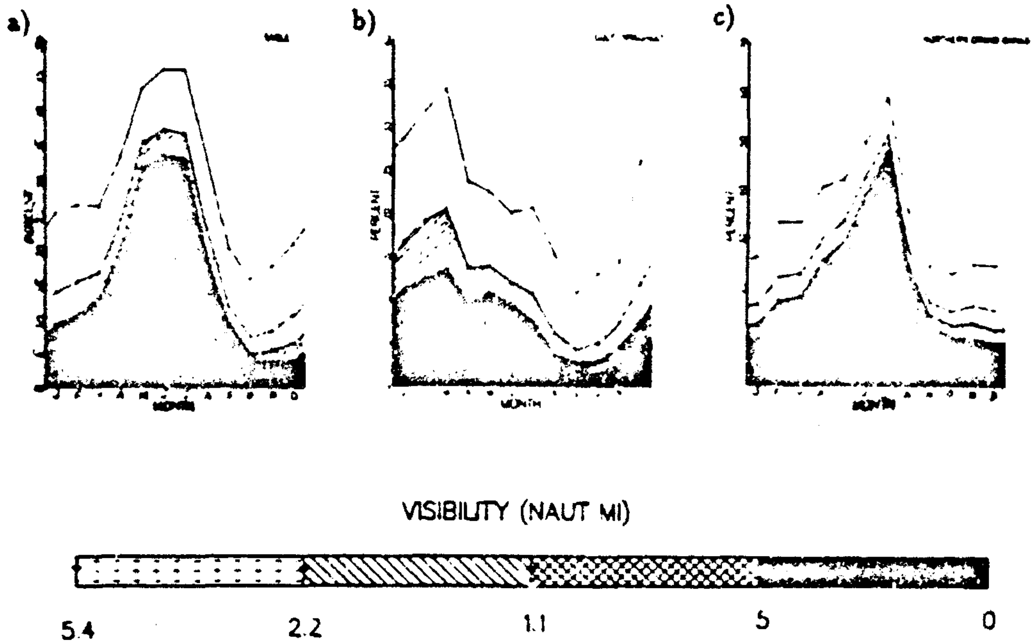


Figure 3.15: Visibility statistics for: a) Sable Island region, b) Gulf-Magdalen Island region, and c) Northern Grand Banks region. (From Mortsch et al., 1985)

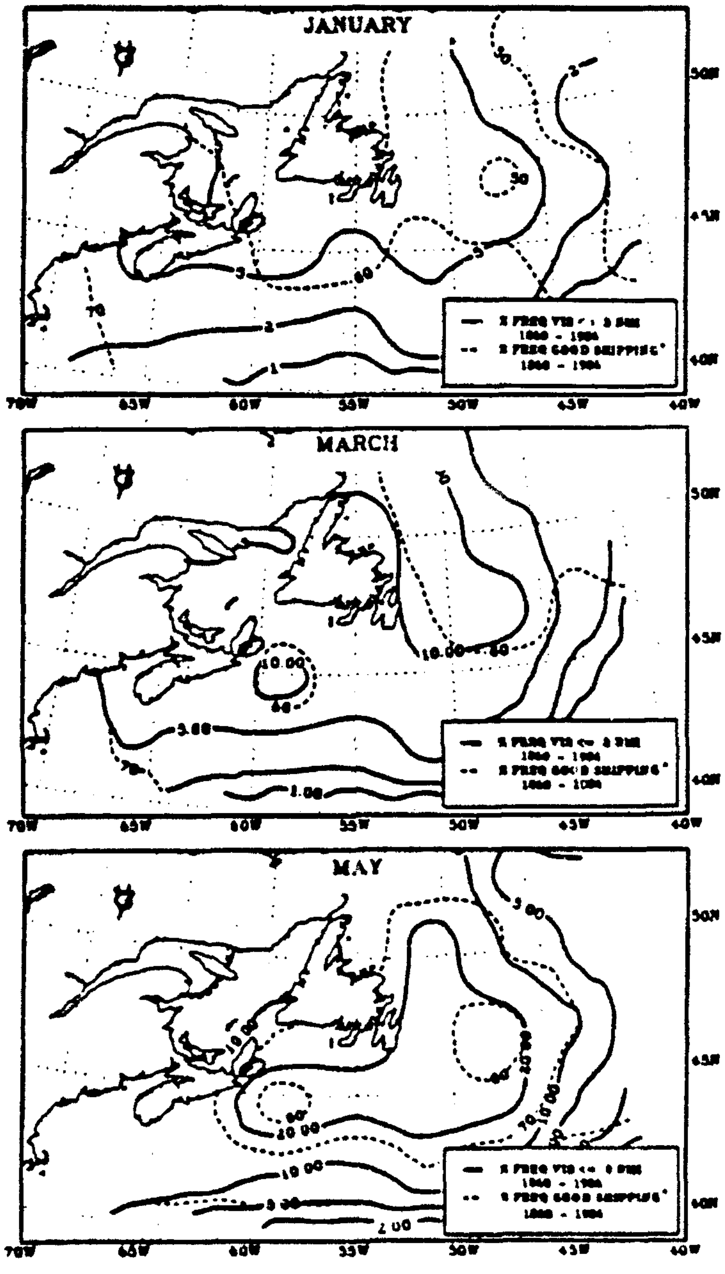


Figure 3.16: Contour map of shipping weather conditions for January, March and May. (From Mortsch et al., 1985)

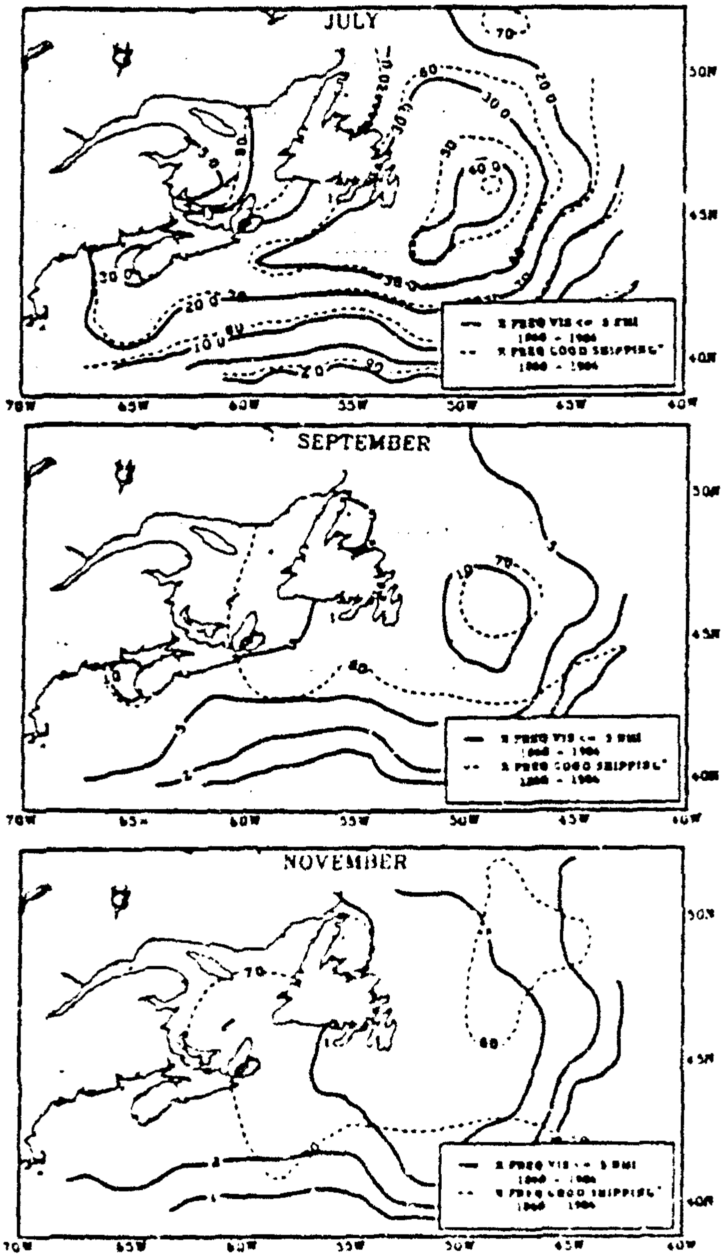


Figure 3.17: Contour map of shipping weather conditions for July, September and November. (From Mortsch et al., 1985)

3.5 Air Temperature

3.5.1 Air Temperature Statistics

Statistics on the air temperature for the Sable region, the Gulf- Magdalen region and the Northern Grand Banks region are given in Figure 3.18.

3.5.2 Air Temperature Contour Maps

The mean air temperature and the standard deviation in degrees Celsius are presented for the four mid-seasonal months in Figure 3.19.

3.5.3 GIS Data

Monthly contour maps of mean air temperature and its standard deviation as shown in Figure 3.19 have been included in the GIS.

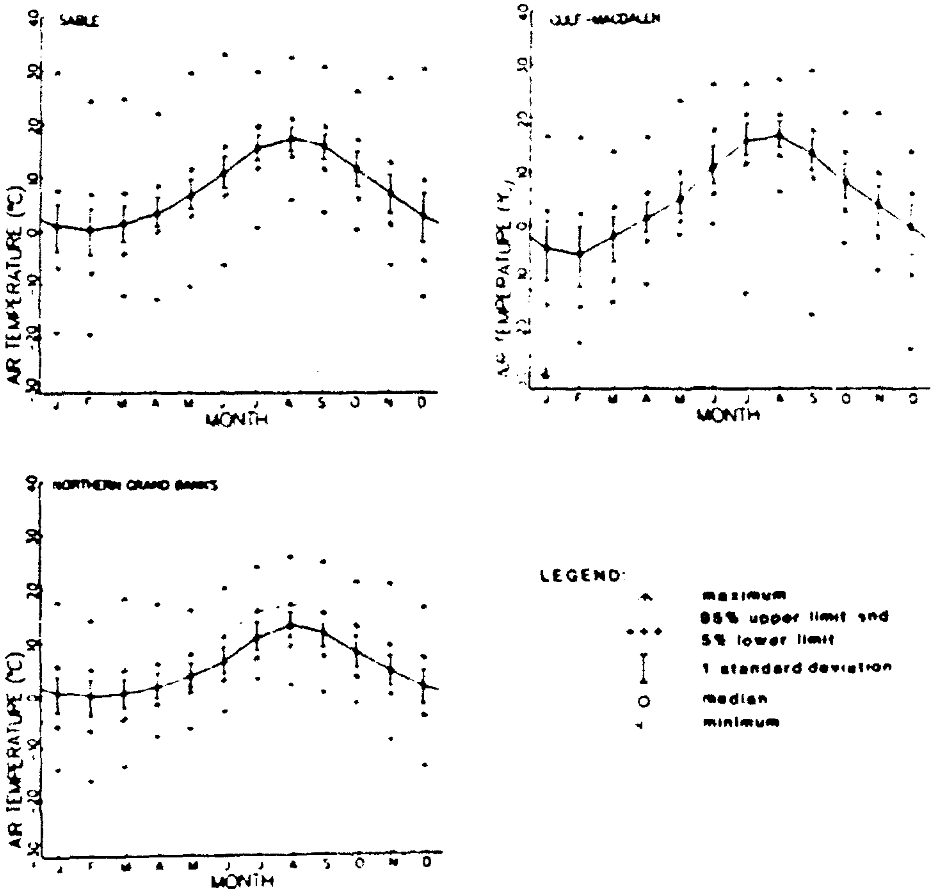


Figure 3.18: Air temperature statistics for: a) Sable Island region, b) Gulf-Magdalen Island region, and c) Northern Grand Banks region. (From Mort:ch et al., 1985)

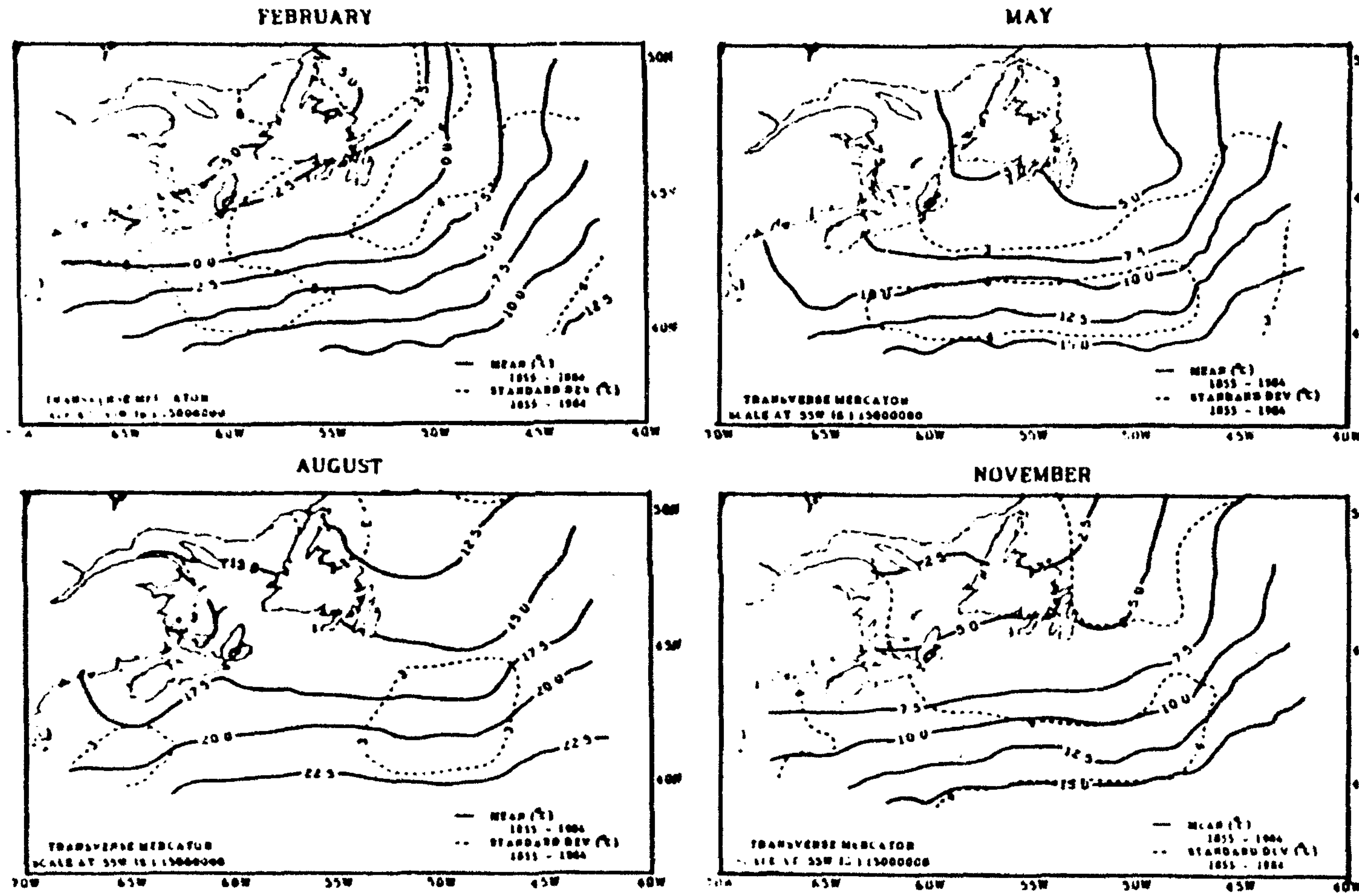


Figure 3.19: Contour map of surface air temperature for February, May, August and November. (From Mortsch et al., 1985)

3.6 Precipitation

3.6.1 Precipitation Statistics

Precipitation statistics for the Sable Island region, the Gulf-Magdalen region and the Northern Grand Banks region are shown in Figure 3.20. The total percent frequency of precipitation is broken down into four categories: light rain, heavy rain, light snow, and heavy snow.

3.6.2 Precipitation Contour Maps

The percent frequency of precipitation reported and the percent frequency of snow reported are presented for the four mid-seasonal months in Figure 3.21. The percent frequency of precipitation combines the observations of all forms of precipitation. Furthermore, a third contour that delineates the furthest extent of snow in each of the selected months is included.

3.6.3 GIS Data

Monthly contour maps showing the percent frequency of precipitation and percent frequency of snow as presented in Subsection 3.6.2 have been included in the GIS.

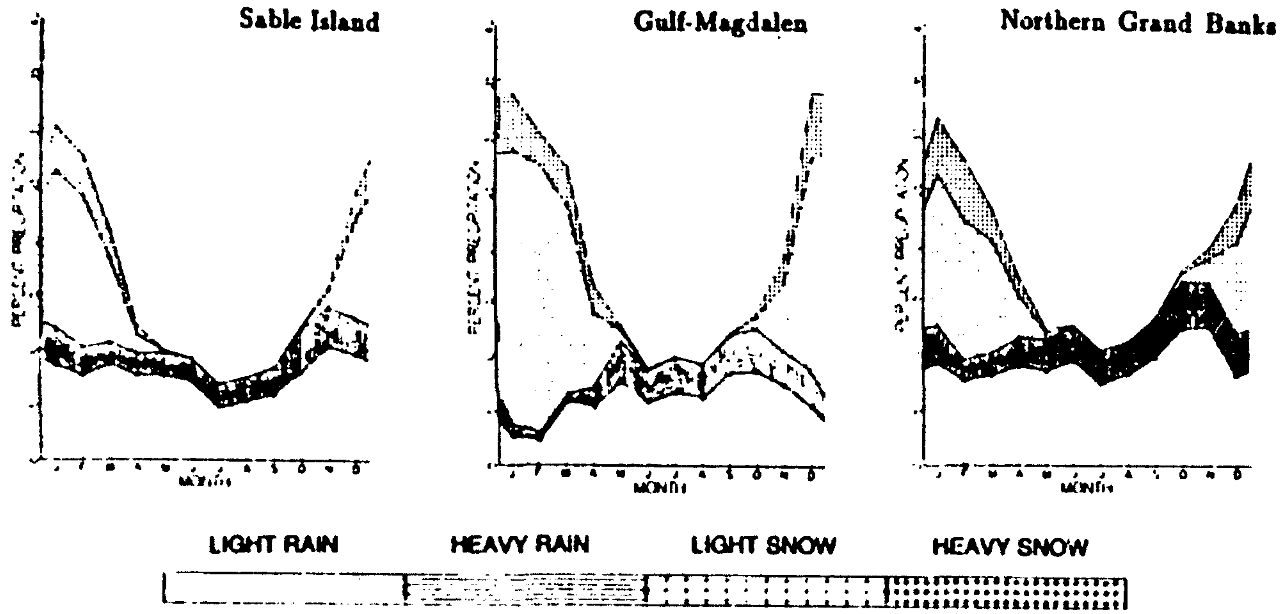


Figure 3.20: Precipitation statistics for the Sable Island region, the Gulf-Magdalen Island region and c) the Northern Grand Banks region. (From Mortsch et al., 1985)

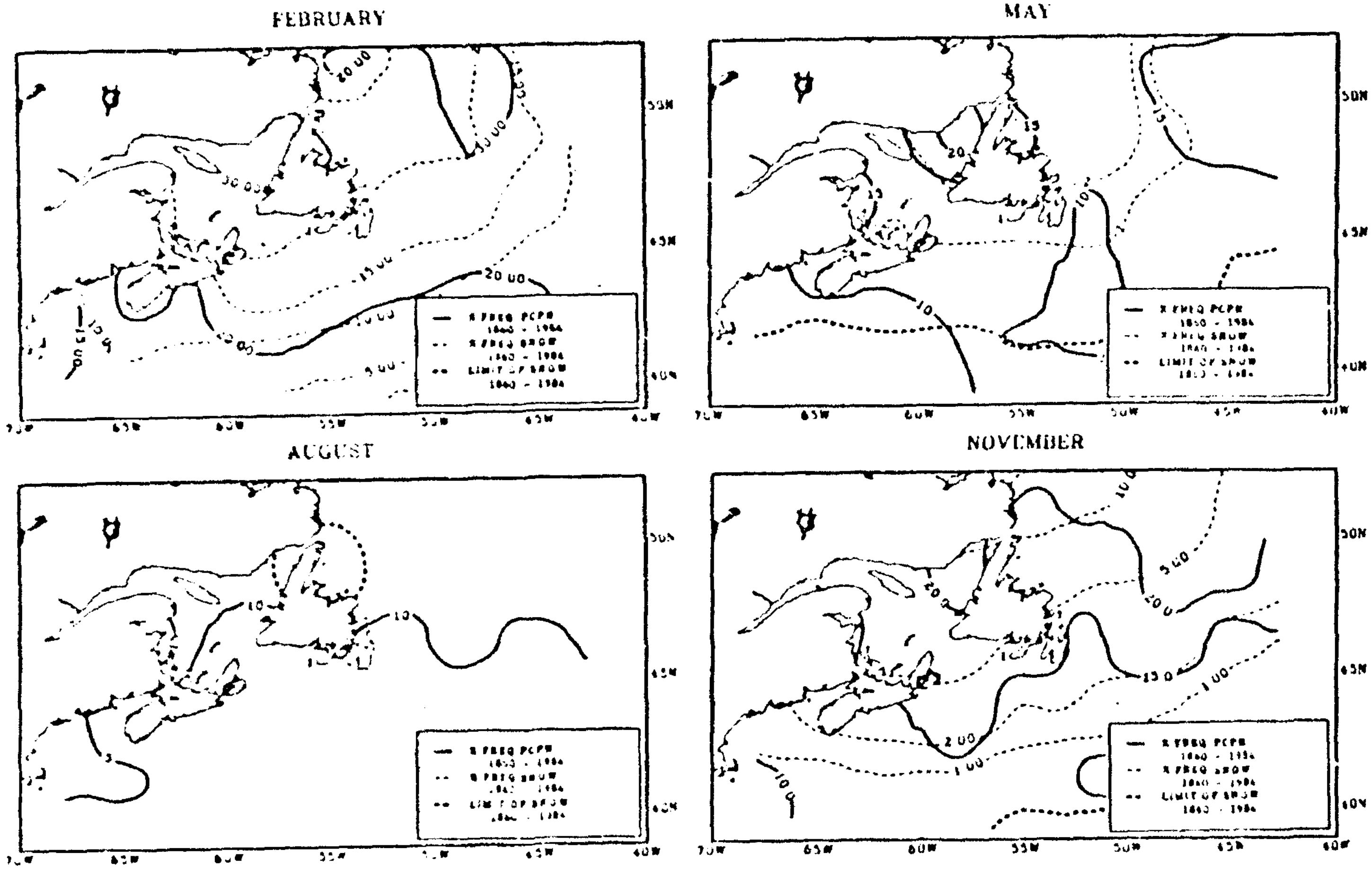


Figure 3.21: Contour map of the percent frequency of precipitation and snow for February, May, August and November. (From Mortsch et al., 1985)

3.7 Sea Ice

3.7.1 Ice Climatology

Ice Cover

Gulf of St. Lawrence. Initial ice formation occurs in December in the St. Lawrence River due to the low salinity of the water, and on the coastal shallows of New Brunswick. It then usually forms along the North Shore and in the Strait of Belle Isle. The growth and spread of ice then proceeds across the Gulf of St. Lawrence during January and February, progressing southward and eastward to gradually occupy the western half of the gulf from the north tip of Cape Breton Island to the southeastern end of Anticosti Island, and from this point to the west coast of Newfoundland near Daniels Harbour. The ice cover continues to grow through February and the beginning of March until it occupies the entire gulf. The break-up tends to begin in the middle of March in the eastern part of the gulf (leeward areas) and in thinner ice areas. It proceeds southward and southeastward until the last sea ice area in the southern portion between Prince Edward Island and Cape Breton Island has melted, usually in the middle of May [AES, 1985].

This pattern can vary greatly. There have been mild winters with very little ice when shipping routes were open through the winter while on the other hand, the gulf can be totally covered by the end of January and ice can persist in some areas until the middle of June.

Grand Banks and East Newfoundland Waters. Sea ice usually begins to form along the coast of southern Labrador and into the Strait of Belle Isle at the end of December. It then continues to spread southward and reaches Notre-Dame Bay at the end of January and Cape Bonavista by the end of February. It also expands seaward to a distance of approximately 300 km. The ice cover extends to near 48°N 50°W by March. The retreat of ice is slow, and reaches the north end of the Strait of Belle Isle by the end of May [AES, 1989].

The variations in this pattern can be very large. There are records of the presence of ice extending to the Avalon Peninsula by the end of January and extending south to 45°N by the end of March, thus covering the whole northern half of the Grand Banks. During mild winters, very little ice can be found south of Notre-Dame Bay and the Strait of Belle Isle may be open most of the winter.

Type of Ice Cover

In the Gulf of St. Lawrence, with the exception of some small areas near shore, the ice does not form a continuous sheet, but ice floes will aggregate and form a sheet of close pack ice. This ice usually grows to a thickness of 45 to 60 cm. Where ridging occurs, the thickness may reach more than one metre [AES, 1984].

The pack ice of the East Newfoundland area is characterized by the presence of 10 to 20% of multi-year ice which originates in the Arctic and is carried south by the Labrador Current. The thickness of the ice grows to between 90 to 120 cm thick. Ridging seldom occurs except along the coastline, but when it does occur in the offshore pack, it may increase the thickness to two metres [AES, 1984].

3.7.2 Ice Cover Maps

The maps in Figures 3.22 and 3.23 show the maximum ice limit to which sea ice has been reported at least once at the time of the year indicated during the database period of 25 years. The minimum ice limit indicates where sea ice has always been observed for the date of the chart. The median ice limit is also presented for the 25 year observation period.

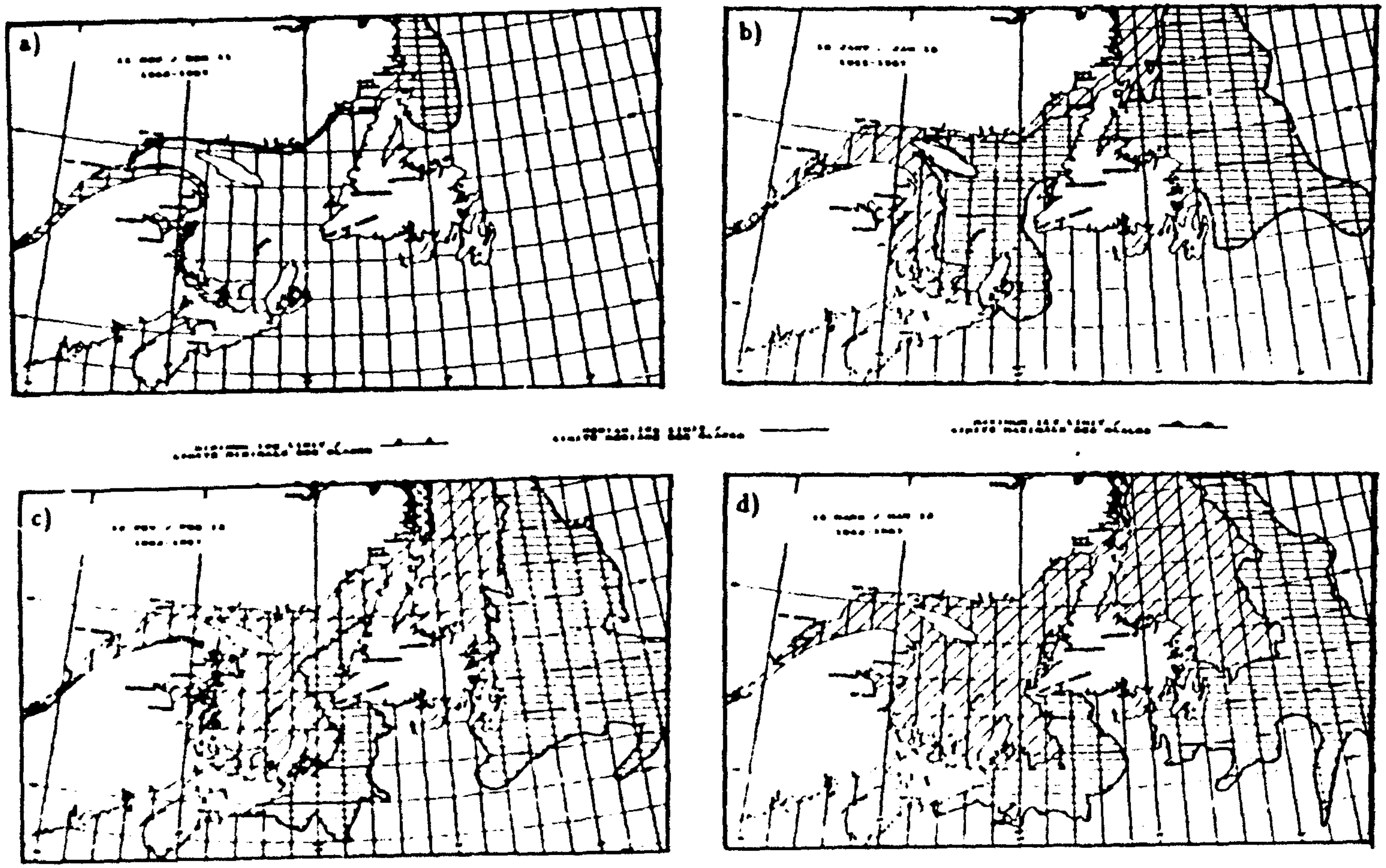


Figure 3.22: Contour map of ice cover for: a) December, b) January, c) February, and d) March. (From AES, 1989)

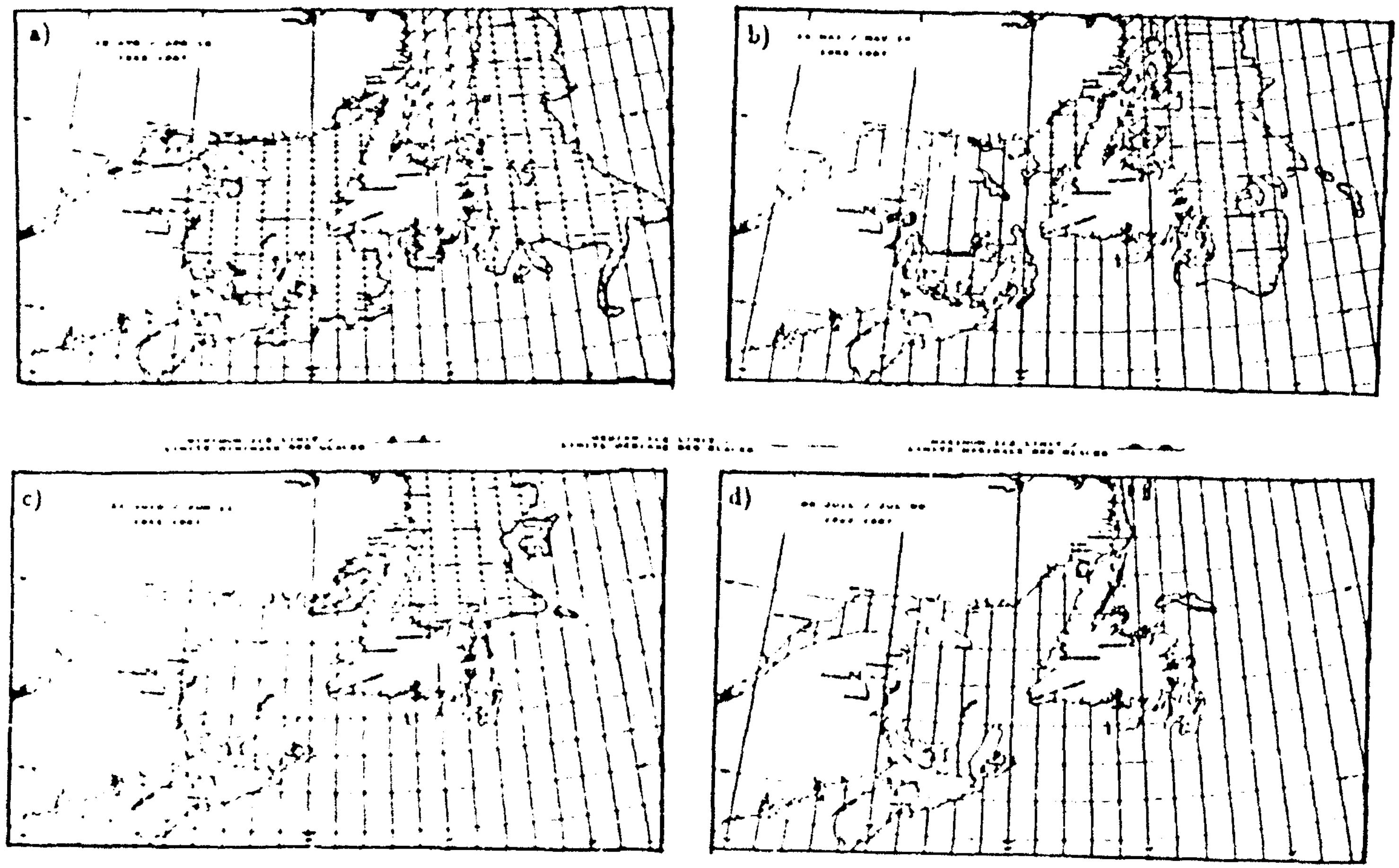


Figure 3.23: Contour map of ice cover for: a) April, b) May, c) June, and d) July. (From AES, 1959)

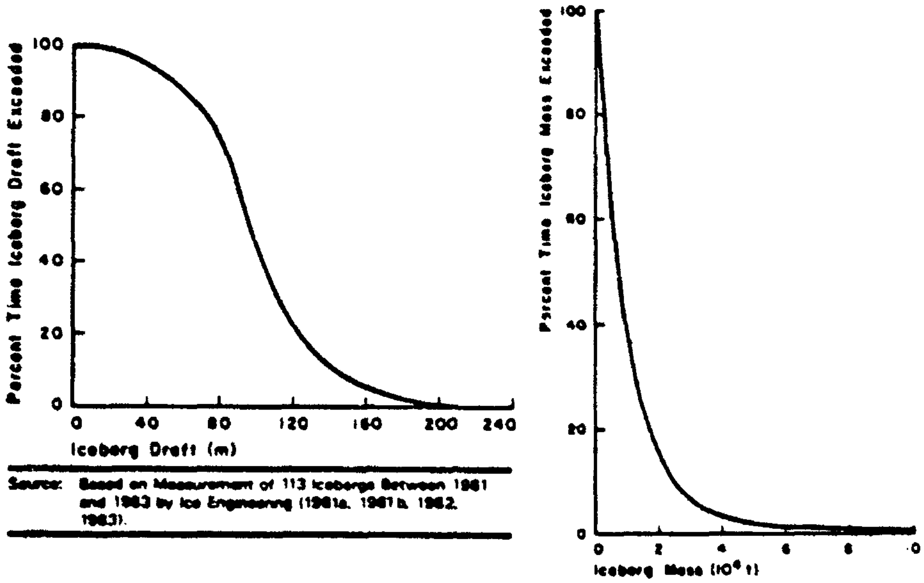


Figure 3.24: Percent exceedance of a) iceberg draft and b) iceberg mass on the northern Grand Banks. (From Mobil Oil, 1984)

3.8 Icebergs

3.8.1 Iceberg Number Statistics

Table 3.1 shows the estimated number of icebergs reported south of 48°N on a monthly basis by the International Ice Patrol. Data from 1979-80 to 1985-86 are included. Additional estimates from selected seasons from as far back as 1945-46 are included to show the range of variability that can be observed. Finally, the monthly average of the estimates from 1945-46 to 1985-86 has been computed.

3.8.2 Iceberg Size Statistics

Figure 3.24 shows some statistics on iceberg mass and iceberg draft.

Season	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1945-46	0	0	0	0	7	67	98	168	88	7	0	0	430
1950-51	1	2	0	0	3	2	0	0	0	0	0	0	9
1951-52	0	0	1	0	0	0	12	2	0	0	0	0	15
1956-57	0	0	0	3	43	41	172	265	288	113	6	0	931
1957-58	0	0	0	0	0	0	0	0	0	1	0	0	1
1965-66	0	0	0	0	0	0	0	0	0	0	0	0	0
1966-67	0	0	0	0	0	25	134	209	35	8	0	0	441
1970-71	0	0	0	0	0	31	4	20	7	11	0	0	73
1971-72	0	0	0	0	40	185	501	559	225	48	26	0	1,584
1975-76	0	0	0	0	0	33	13	67	35	3	0	0	151
1976-77	0	0	0	0	3	7	12	0	0	0	0	0	22
1979-80	2	7	0	9	4	0	0	0	0	0	0	0	23
1980-81	0	0	0	0	0	48	10	5	0	0	0	1	63
1981-82	0	0	0	0	0	17	61	13	94	3	0	0	188
1982-83	0	0	2	9	165	124	339	405	168	76	4	0	1,352
1983-84	0	0	0	0	0	101	953	484	227	335	93	9	2,202
1984-85	3	11	7	2	57	129	208	205	247	123	39	32	1,063
1985-86	0	0	0	0	3	40	60	59	24	18	0	0	204
Average (1945-86)	0	1	0	2	12	39	117	100	61	25	6	1	364

Table 3.1: Estimated number of icebergs south of latitude 48° N (AES, 1985).

3.9 Icing

3.9.1 Freezing Spray Statistics

The potential for the accumulation of ice due to freezing spray is calculated from the observed conditions of sea surface temperature, air temperature, wind speed, wave height and salinity. An empirical relationship involving these factors is used to determine a rate of ice accumulation. The actual freezing spray ice accretion on a vessel however varies considerably depending upon factors such as the vessel structure, its course or orientation to the wind and its speed. The potential freezing spray ice accretion rates are reported in five broad categories:

CATEGORY	ACCRETION RATE
no icing	< 0.5 mm/hr
light	≥ 0.5 mm/hr to < 1.25 mm/hr
moderate	≥ 1.25 mm/hr to < 2.5 mm/hr
heavy	≥ 2.5 mm/hr to < 6.25 mm/hr
severe	≥ 6.25 mm/hr

Detailed statistics on all ice accretion classes for the Sable Island region, the Gulf-Magdalen region and the Northern Grand Banks region are included in Figure 3.25.

3.9.2 Ice Accretion Maps

The maps in Figures 3.26 and 3.27 show contours of the percent frequency of moderate or greater (≥ 1.25 mm/hr) ice accretion potential. In addition, percent frequency of moderate to heavy freezing rain was contoured.

3.9.3 GIS Data

Monthly contour maps of ice accretion potential and frequency of moderate to heavy freezing rain as described in Subsection 3.9.2 have been included in the GIS.

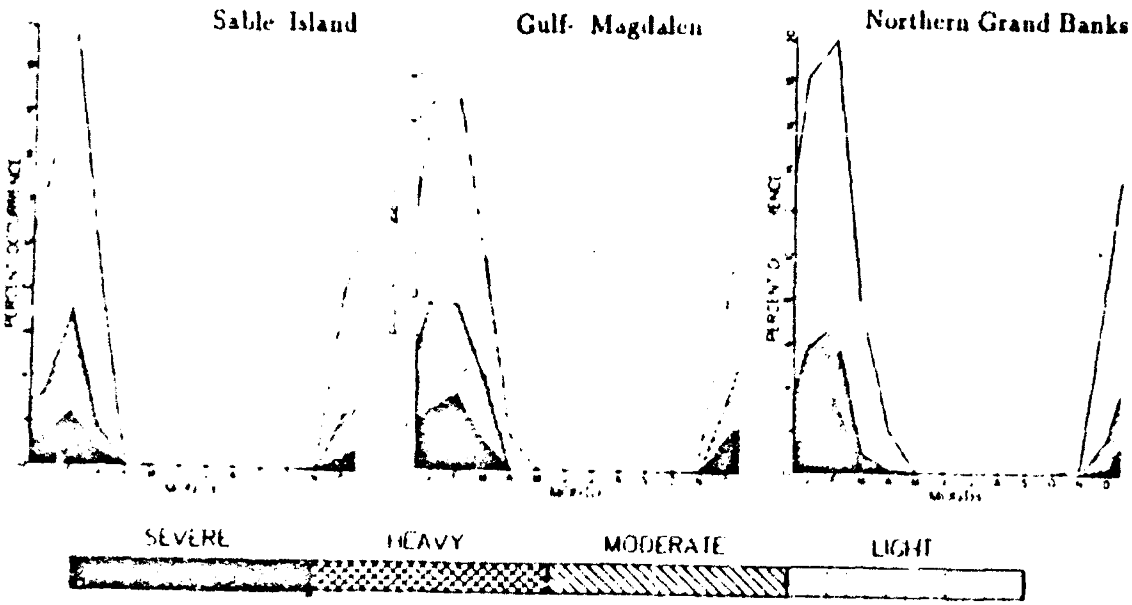


Figure 3.25: Ice accretion statistics for the Sable Island region, the Gulf-Magdalen Island region and c) the Northern Grand Banks region. (From Mortsch et al., 1985)

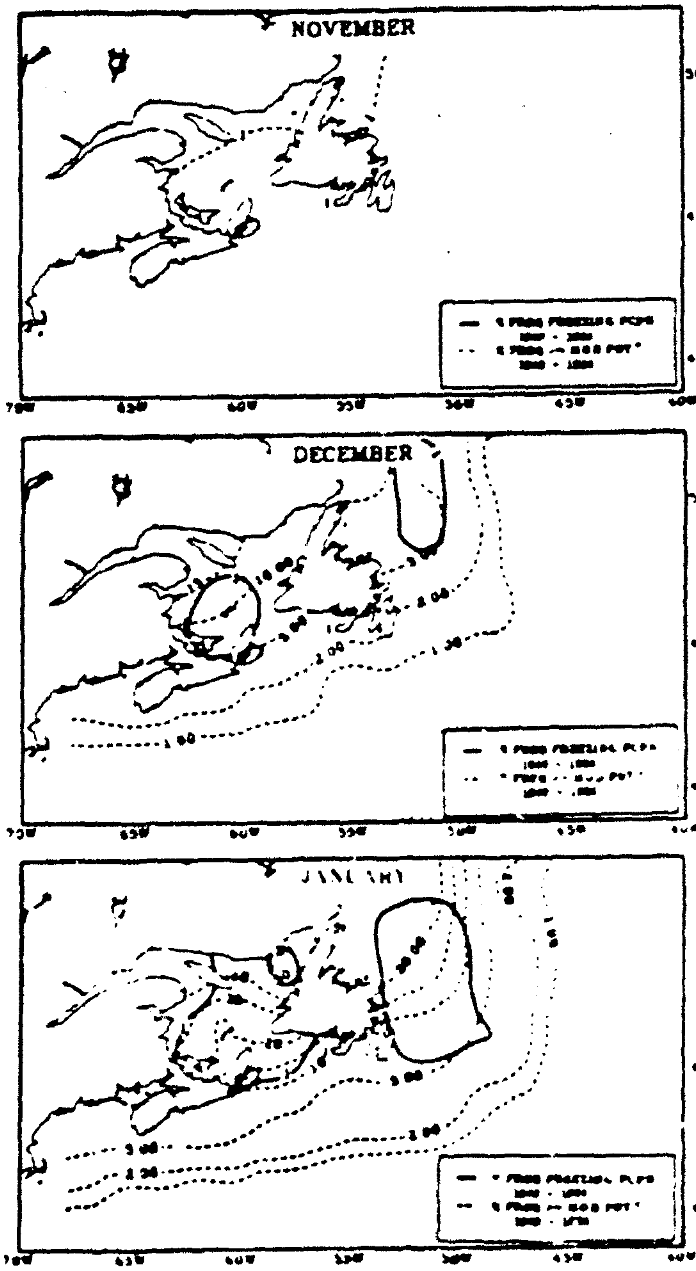


Figure 3.26: Contour map of ice accretion potential and frequency of moderate-heavy freezing rain for November, December and January. (From Mortsch et al., 1985)

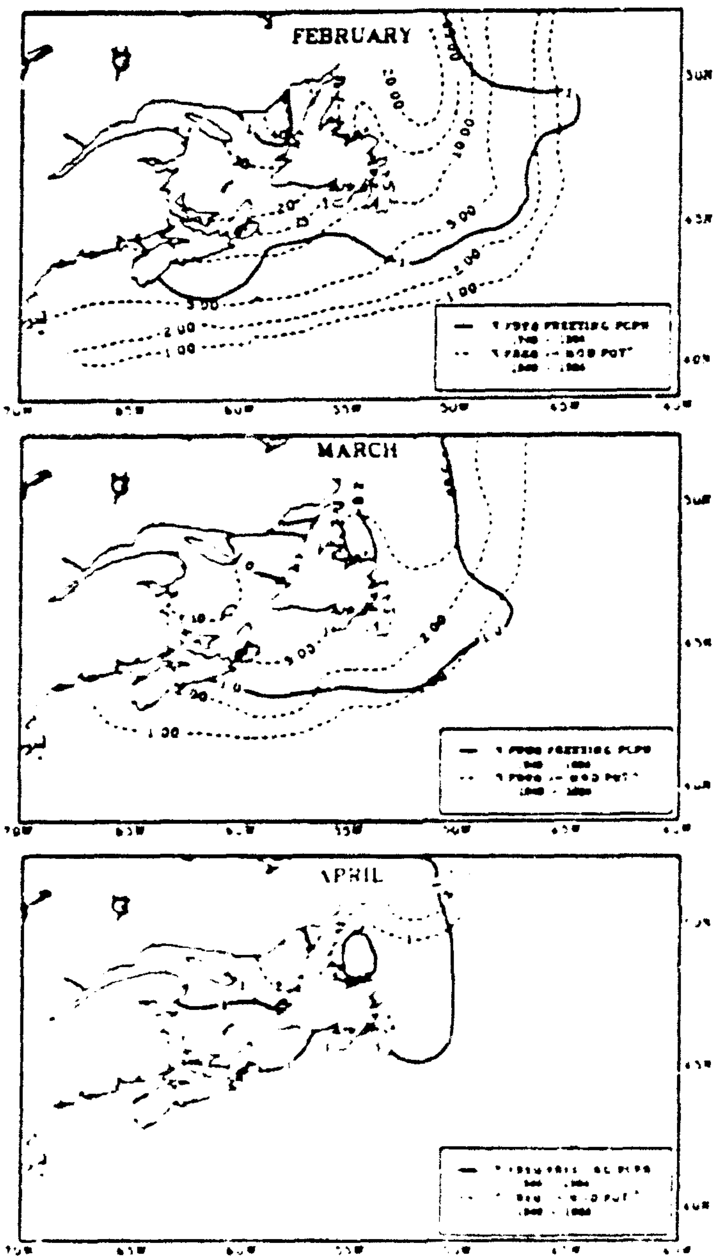


Figure 3.27 Contour map of ice accretion potential and frequency of moderate heavy freezing rain for February, March and April (From Mortsch et al., 1985)

Chapter 4

Oceanography

4.1 Waves

4.1.1 Wave Climatology by Region

Gulf of St. Lawrence: Although the gulf is relatively easy to access, the data are still insufficient to obtain a complete picture of its wave climatology. It however appears that waves are less severe than in the other more exposed areas such as the Grand Banks. Special problems for wave prediction in the gulf include shallow water effects, currents, and ice [Ouellet and Llamas, 1979].

Scotian Shelf. Long waves propagating over this shallow region experience shoaling. The modification of the waves will be particularly significant in nearshore regions where the decreasing depth affects almost the entire ocean wave spectrum. Sheltering due to Sable Island, and possibly wave-current interactions will also impact on wave characteristics. Finally, wave refraction, which causes the energy to converge in some areas resulting in increased wave height, is also possible on the Scotian Shelf [Neu, 1976].

Grand Banks. The highest sea states are generated in winter during northwesterly outbreaks of cold air. The lower levels of the atmosphere become very unstable with their passage over open water and this causes strong surface winds. In these situations the wave field is fetch limited by the shore or ice edge, and hence builds to the southwest [Neu, 1976].

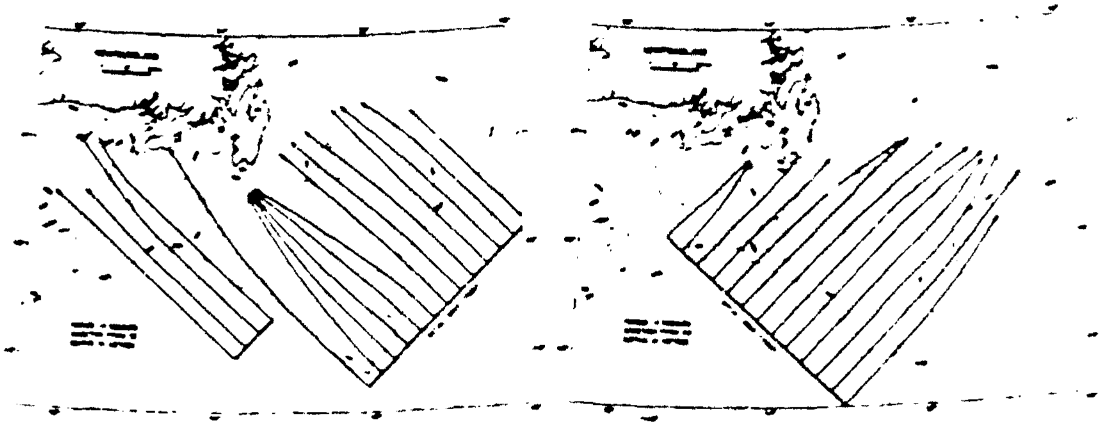


Figure 4.1: Wave refraction over the Grand Banks of Newfoundland. (From Neu, 1970)

Since the Grand Banks are relatively shallow, long period swell that frequently propagates onto the Banks from the south has wavelengths long enough to experience bottom refractive effects that tend to concentrate the energy and increase the wave heights in some locations as shown in Figure 4.1 [Neu 1976].

4.1.2 Wave Roses

Monthly wave roses representing the directional frequency of 1 m wave height classes are included for selected subareas in Figure 4.2. These are taken as fairly representative of each of the three main areas the Gulf of St. Lawrence (Fig. 4.3), the Scotian Shelf (Fig. 4.4) and the Grand Banks (Fig. 4.5).

A key to the wave rose interpretation is given in Figure 4.2.

4.1.3 Wave Period Statistics

A graphical summary of the percent frequency of the combined wave period has been included in Figures 4.6 to 4.8. The combined wave period is the period of the higher of wave or swell height. If they are the same height, the longer

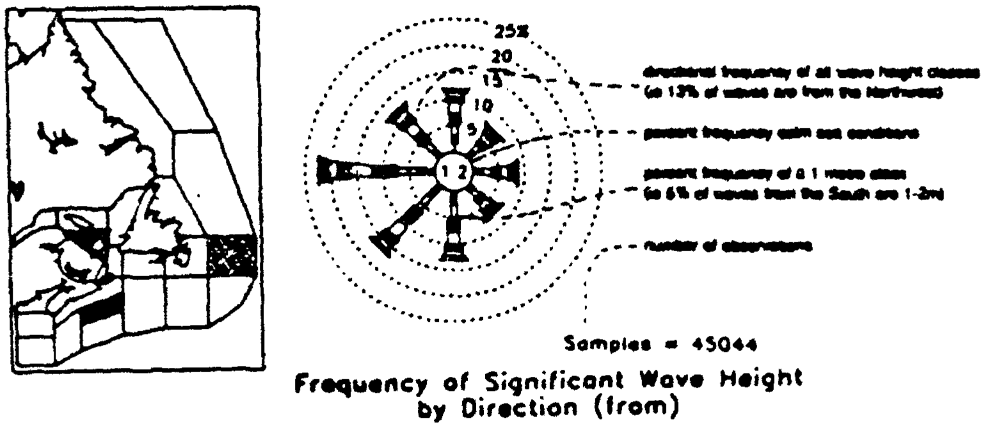


Figure 4.2: a) Wave rose source subareas. b) Wave rose key.

period has been chosen. Therefore, although they provide useful complementary information to the wave roses regarding the shape of the dominant waves, they can be misleading as far as giving a representation of the sea surface roughness.

4.1.4 Combined Wave Height and Frequency Contour Maps

Combined wave height is a representation of the sea surface motion that includes the interaction of the swell which are waves generated by a storm or winds at a large distance from the observation point, and the wave generated at the site due to the local winds.

The combined wave height (H_c) is calculated using the formula:

$$H_c = ((H_s)^2 + (H_{sw})^2)^{1/2}$$

where H_s is the sea wave height and H_{sw} is the swell height [Mortsch et al., 1985]. These values are usually estimated visually from a ship.

The monthly charts in Figures 4.9 to 4.12 show contours of the percent frequency of occurrence of combined wave height less than or equal to 2 me-

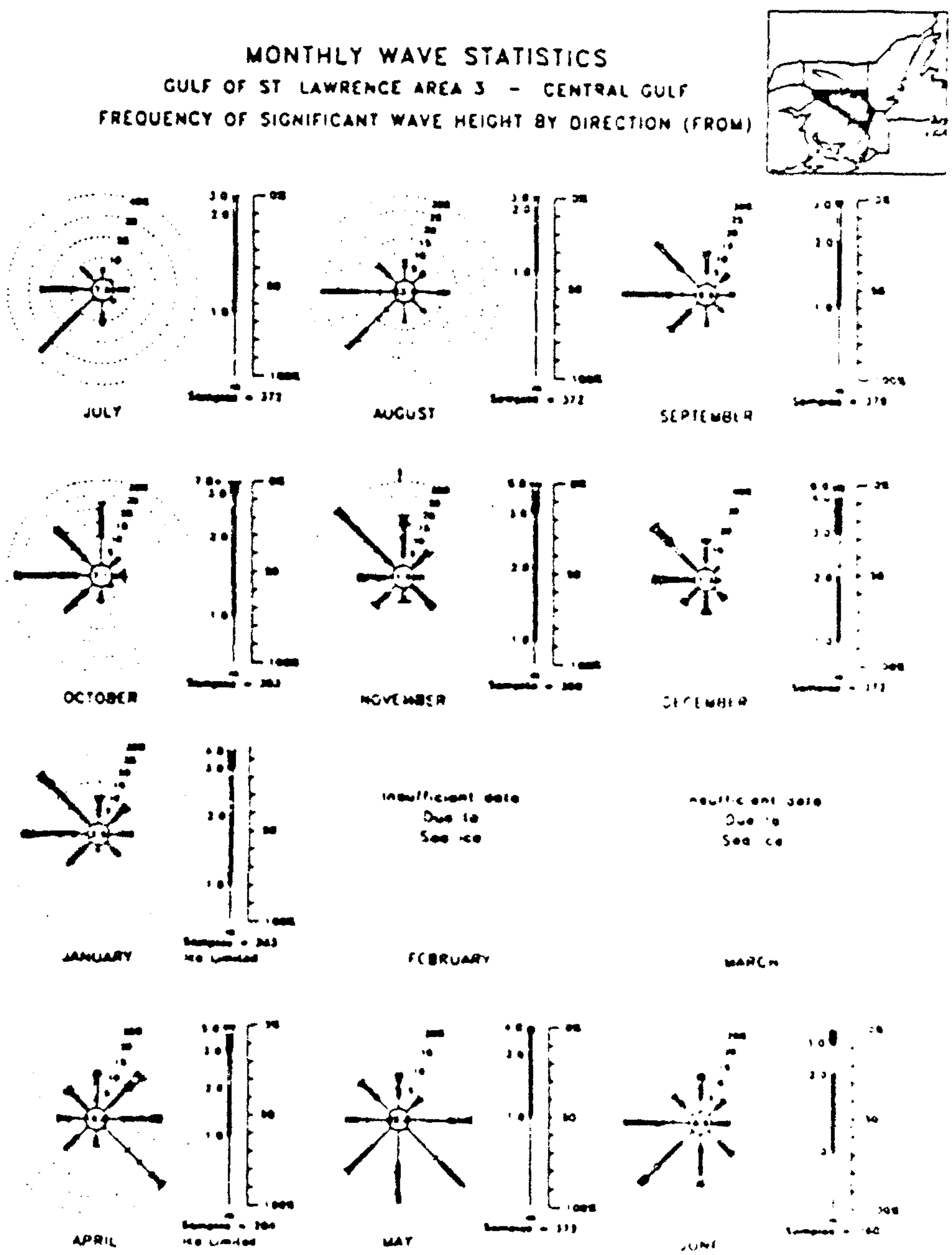


Figure 4.3: Monthly wave roses - Gulf of St. Lawrence (From Swail, 1991)

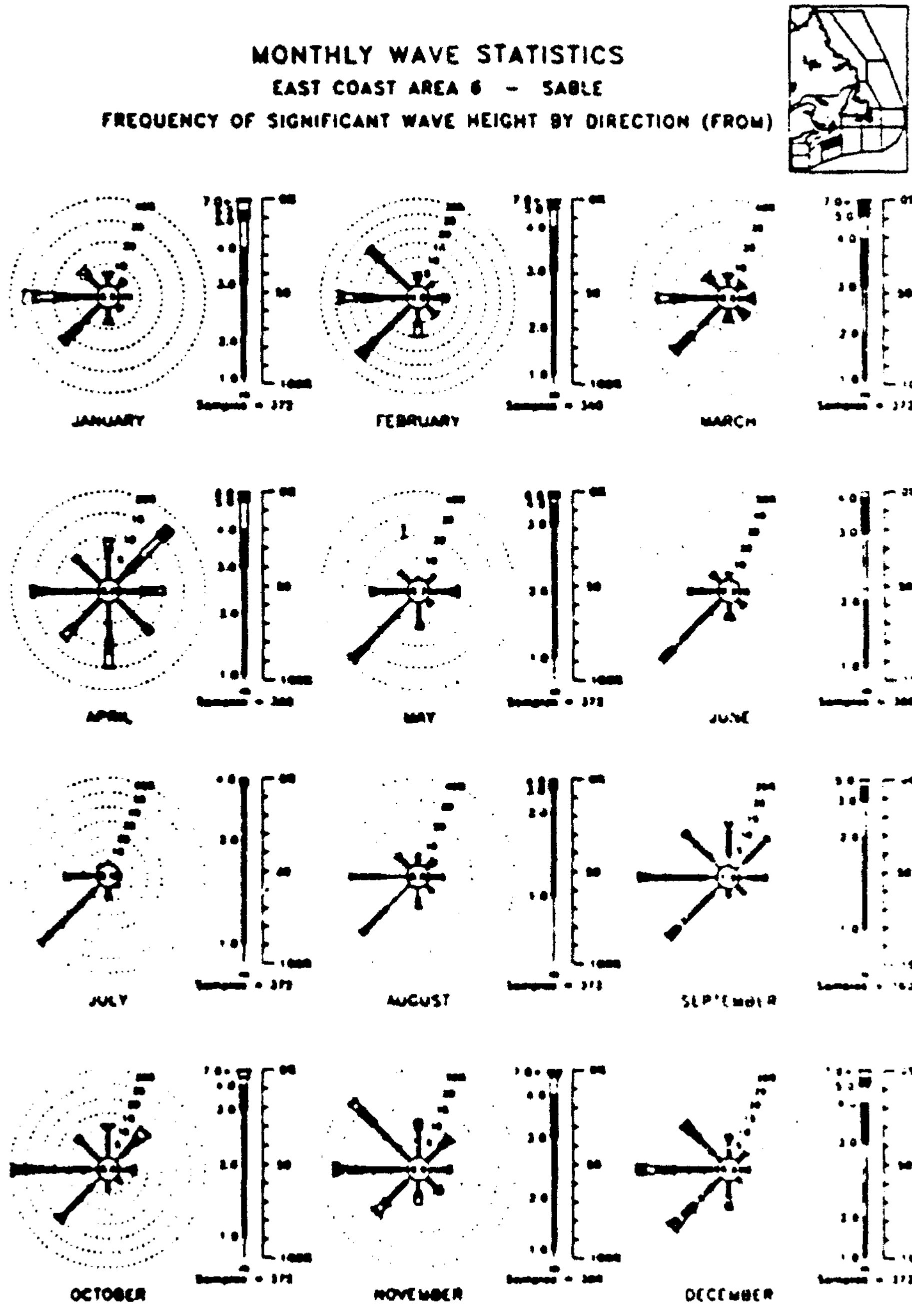


Figure 4.4: Monthly wave roses - Scotian Shelf. (From Swail, 1991)

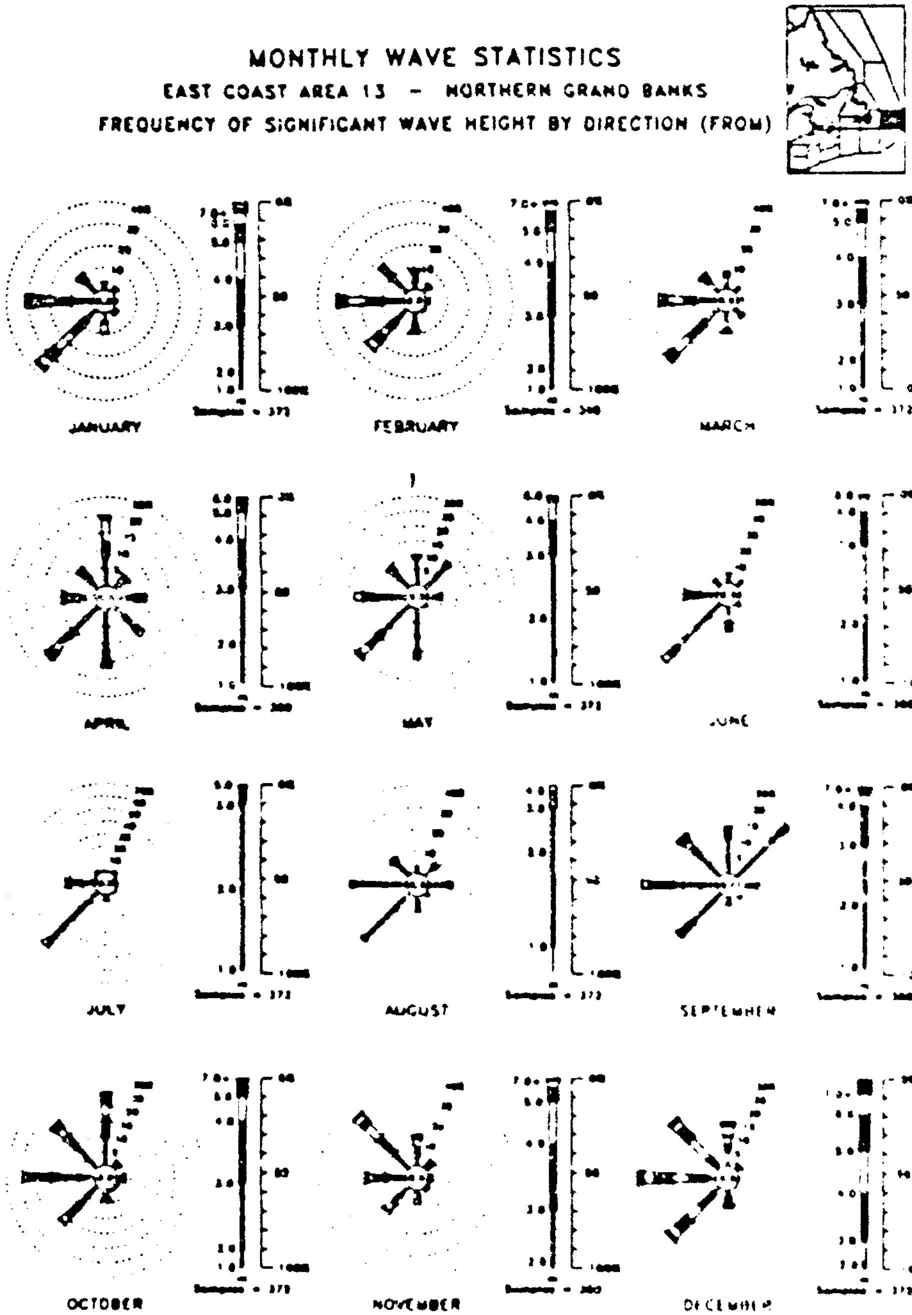


Figure 4.5: Monthly wave roses - Grand Banks. (From Swail, 1991)

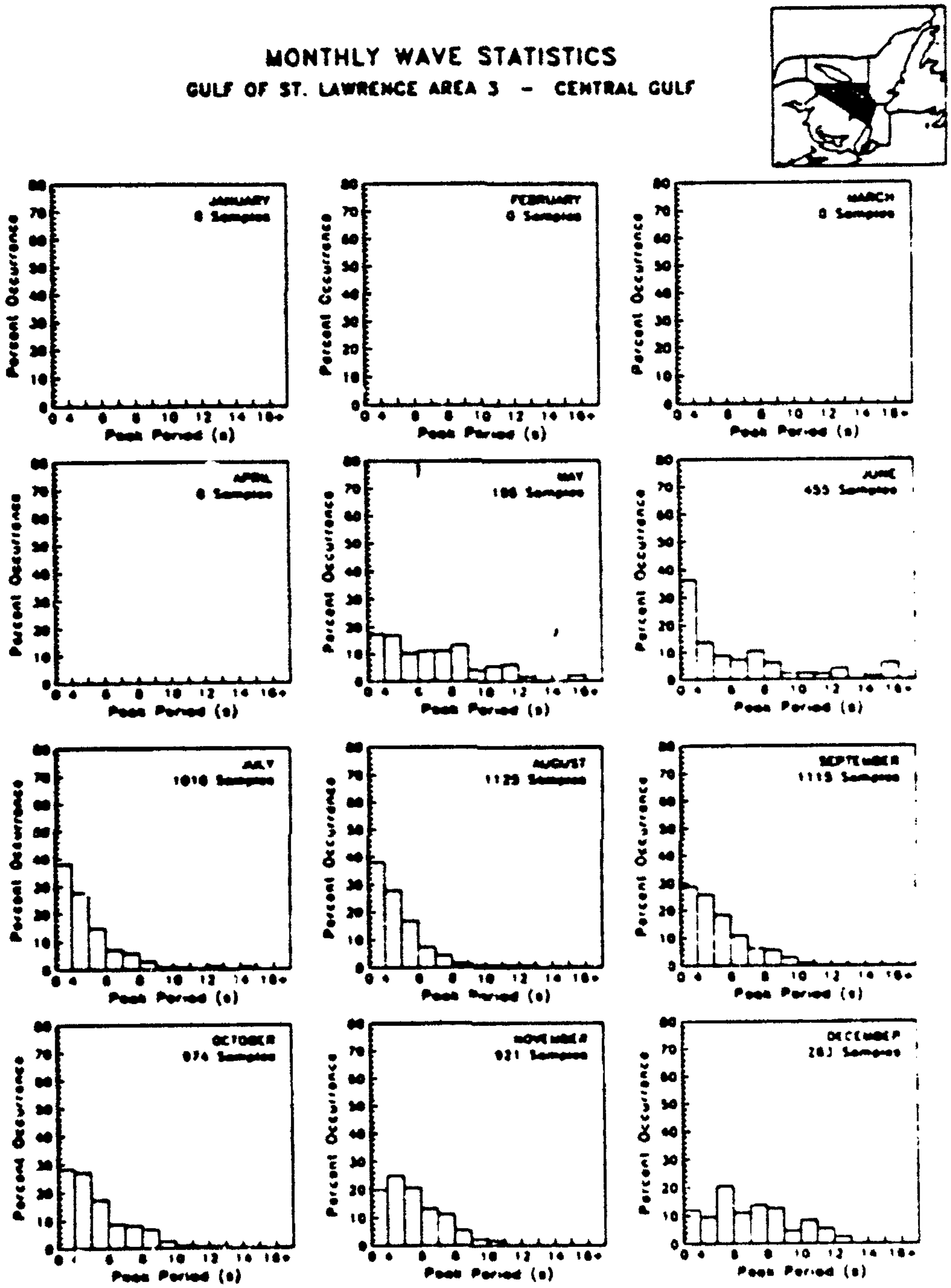


Figure 4.6: Monthly wave period percent frequency - Gulf of St. Lawrence. (From Swail, 1991)

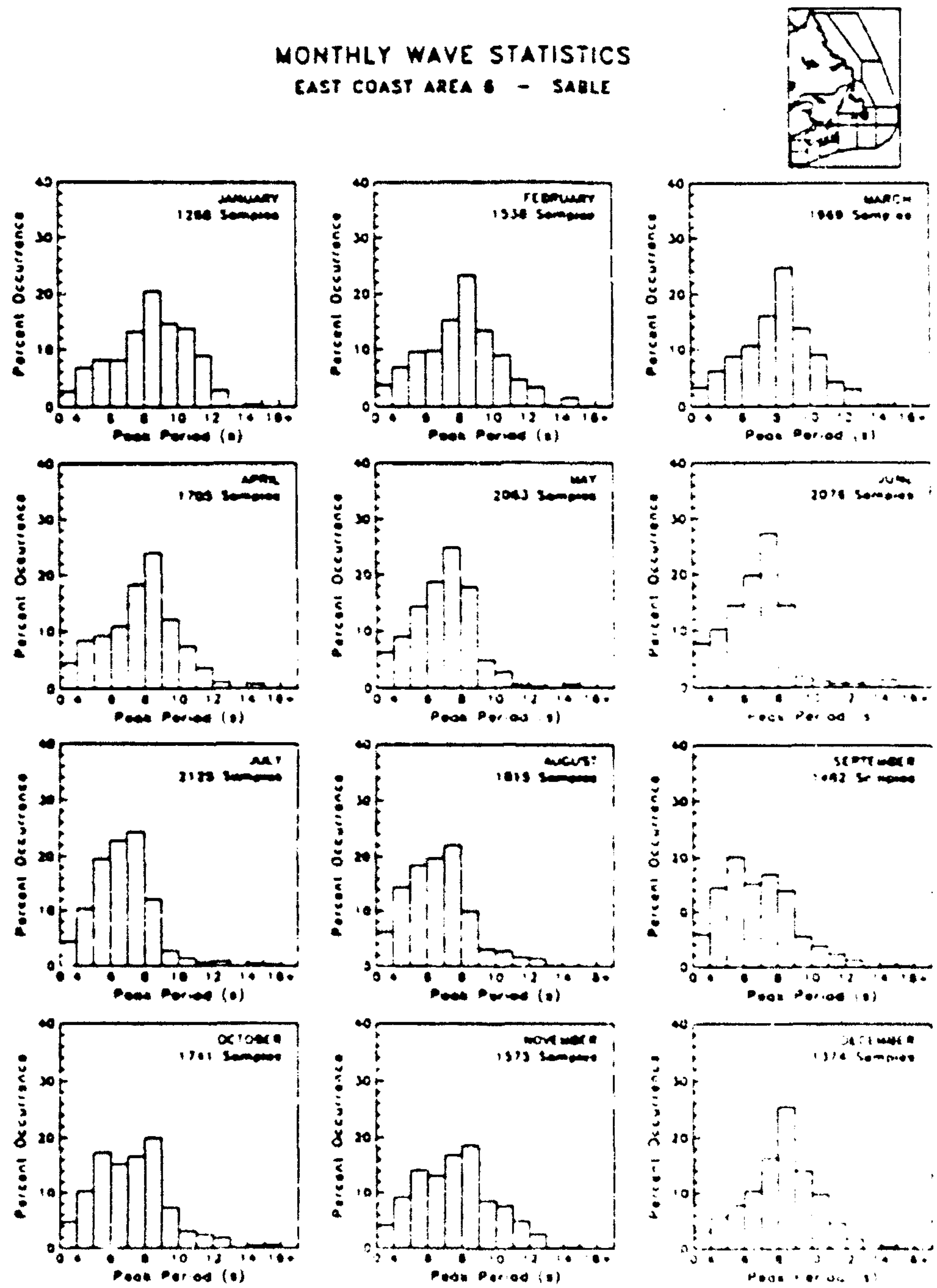


Figure 4.7: Monthly wave period percent frequency - Scotian Shelf. (From Swail, 1991)

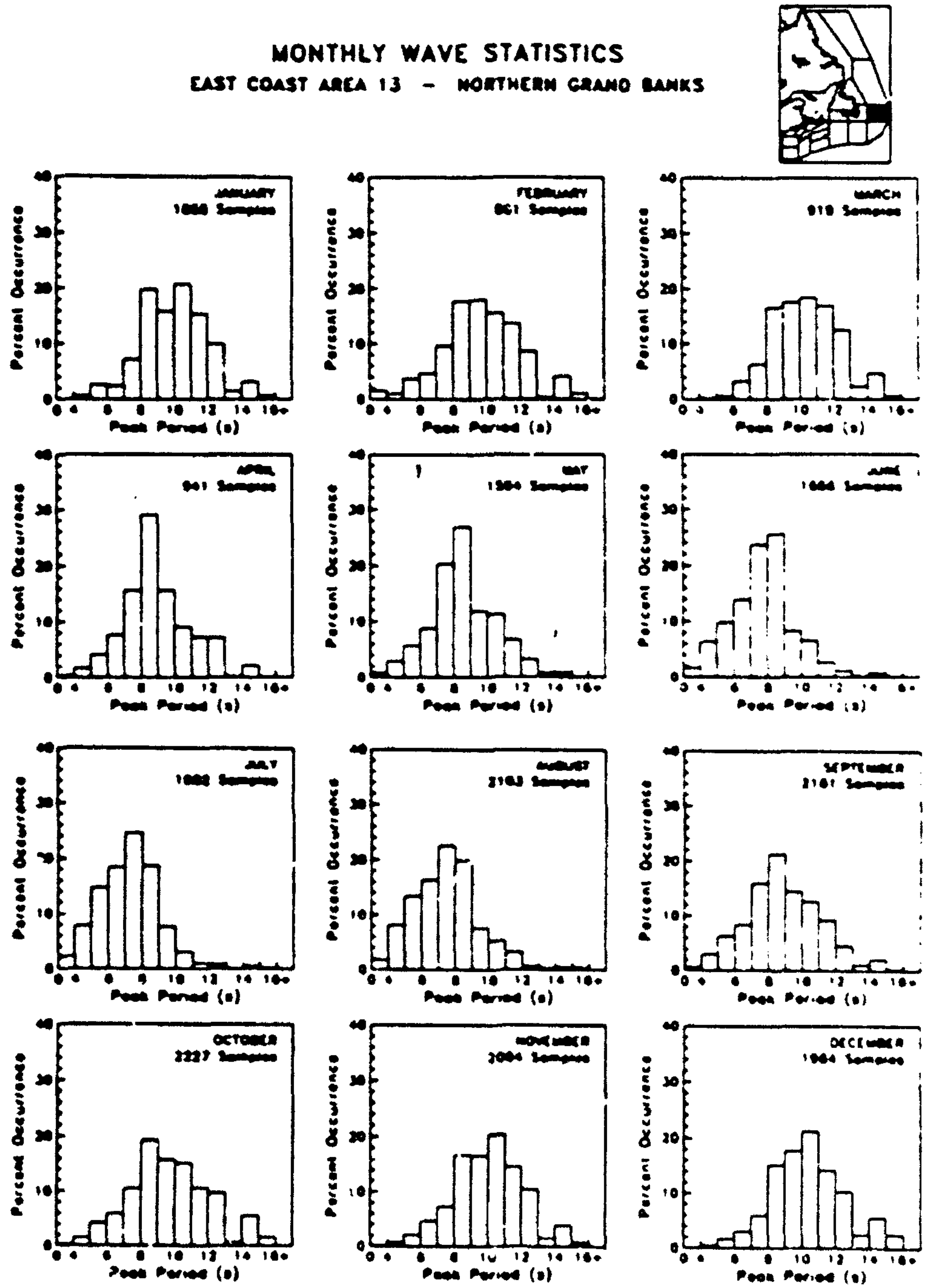


Figure 4.8: Monthly wave period percent frequency - Grand Banks. (From Swail, 1991)

tres (relatively calm sea) and of the percent frequency of occurrence of severe conditions (combined wave height greater than or equal to 6 metres).

4.1.5 GIS Data

Monthly contour charts of combined wave height such as those defined in Subsection 4.1.4 have been included in the GIS database.

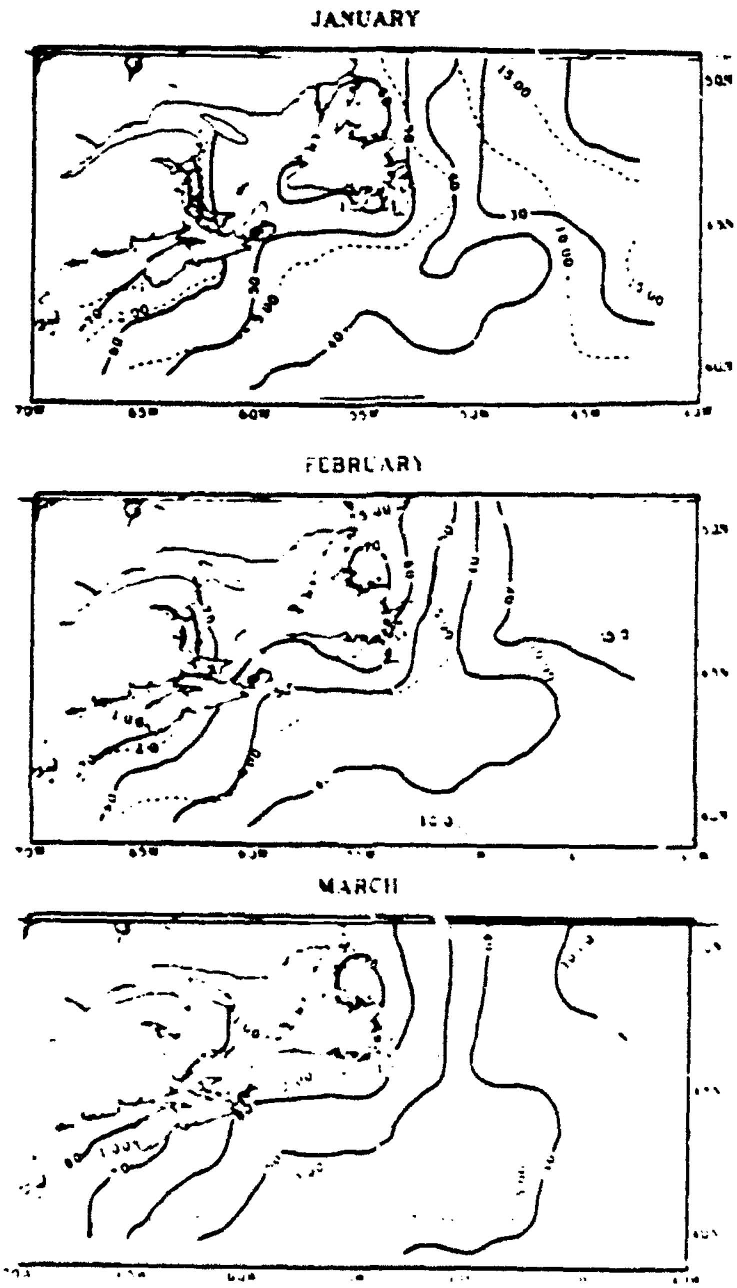


Figure 4.9: Combined wave height frequency - Winter.(Solid line contours indicate percent frequency ≤ 2 m. Dashed line contours indicate percent frequency ≥ 6 m. (After Mortsch et al., 1985)

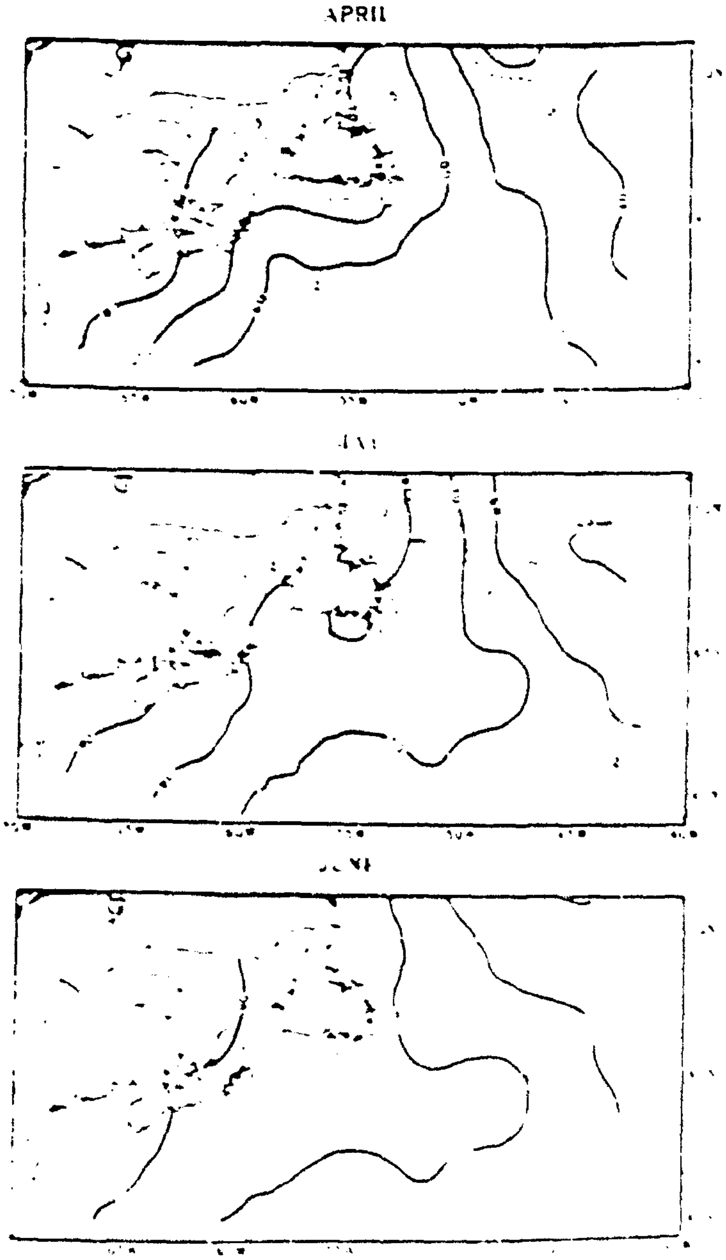


Figure 4.10. Combined wave height frequency - Spring (Solid line contours indicate percent frequency ≤ 2 m. Dashed line contours indicate percent frequency ≥ 6 m. (After Mortsch et al., 1985)

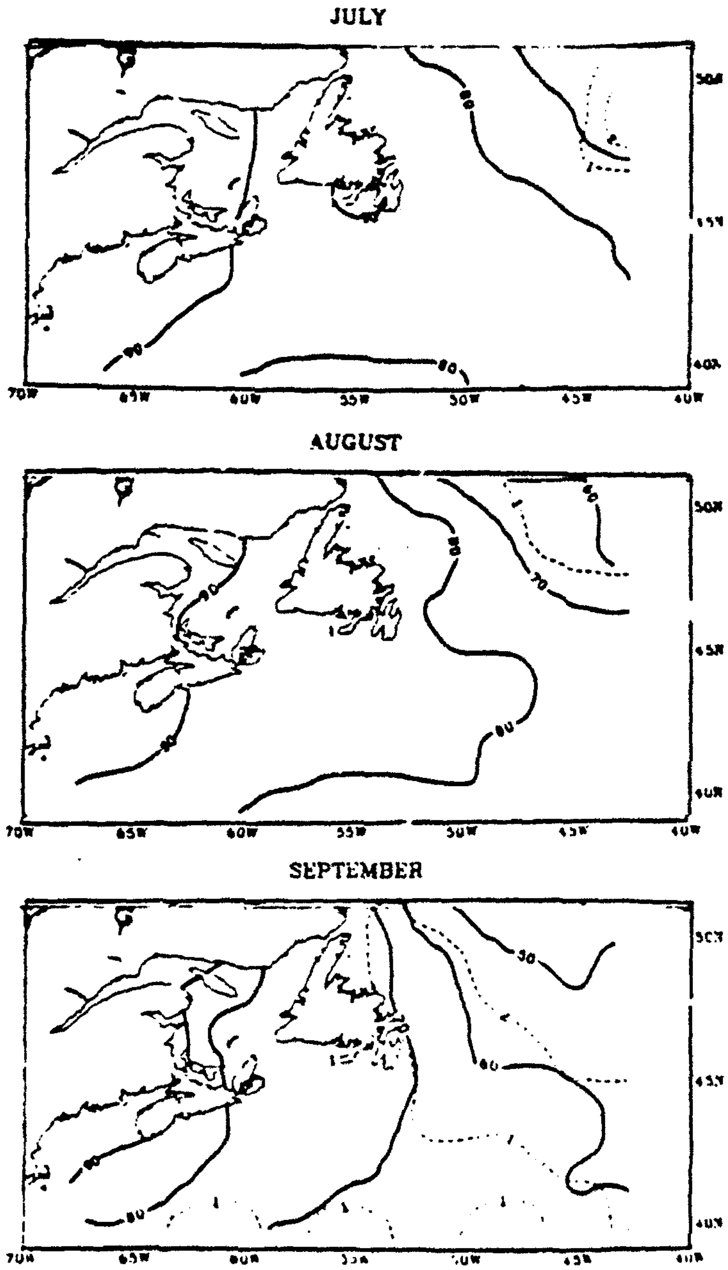


Figure 4.11: Combined wave height frequency - Summer.(Solid line contours indicate percent frequency ≤ 2 m. Dashed line contours indicate percent frequency ≥ 6 m. (After Mortsch et al., 1985)

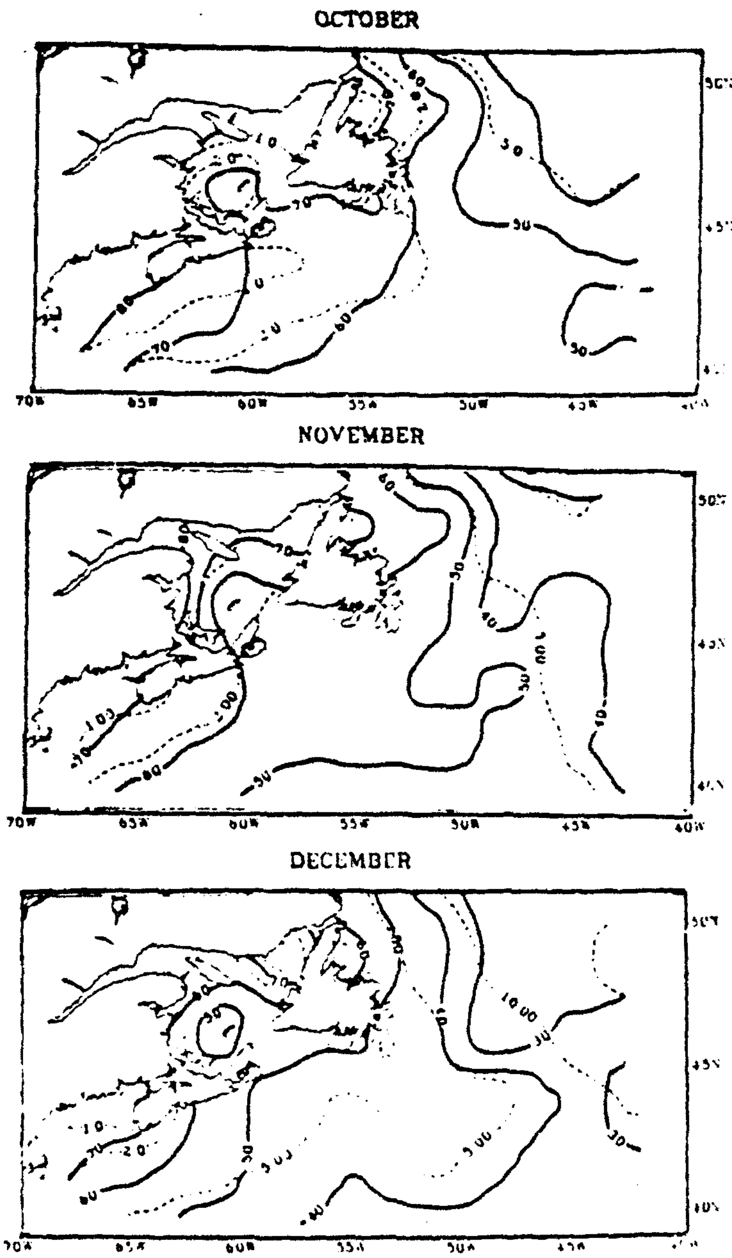


Figure 4.12: Combined wave height frequency - Fall. (Solid line contours indicate percent frequency ≤ 2 m. Dashed line contours indicate percent frequency ≥ 6 m. (After Mortsch et al., 1985)

4.2 Currents Description

4.2.1 Mean Surface Currents

Figure 4.13 shows the main features of the surface circulation in the area of interest. Seasonal variations in the main flow are well documented for the Gulf of St. Lawrence only (Figure 4.14). Further descriptive comments on the main currents are included in the following subsections.

Gulf of St. Lawrence

The Gulf of St. Lawrence has been subject to numerous surveys, but direct current measurements still exist only for a small proportion of its surface [El-Sabh, 1976]. In addition, most of these surveys were conducted during the ice-free months; as a result, a complete picture of surface circulation in the Gulf of St. Lawrence is not available from observations. The surface circulation has therefore been deduced using the geostrophic method and a network of averaged stations for different periods of the year. The circulation pattern thus obtained agrees with the results of synoptic observations [El-Sabh, 1976].

- **St. Lawrence Estuary:** The main feature of the surface circulation in the estuary is the presence of a strong outflow of surface water confined to the upper 25-50 m along both shores, although the south shore outflow is much stronger in most places (50-70 cm s^{-1} versus 30-50 cm s^{-1} in summer). The St. Lawrence Estuary is also characterized by the existence of strong transverse currents. Their most obvious manifestation is the "Rimouski eddy" (Figure 4.15, a clockwise gyre located between Rimouski and Pointe-des-Monts, and a northerly transverse current in the Ile du Bic region [El-Sabh, 1979].

The variability of these currents is high since they are related to the volume of outflowing freshwater which is at a maximum in May and a minimum in winter [El-Sabh, 1979]. There is also a relationship with the lunar cycle. The

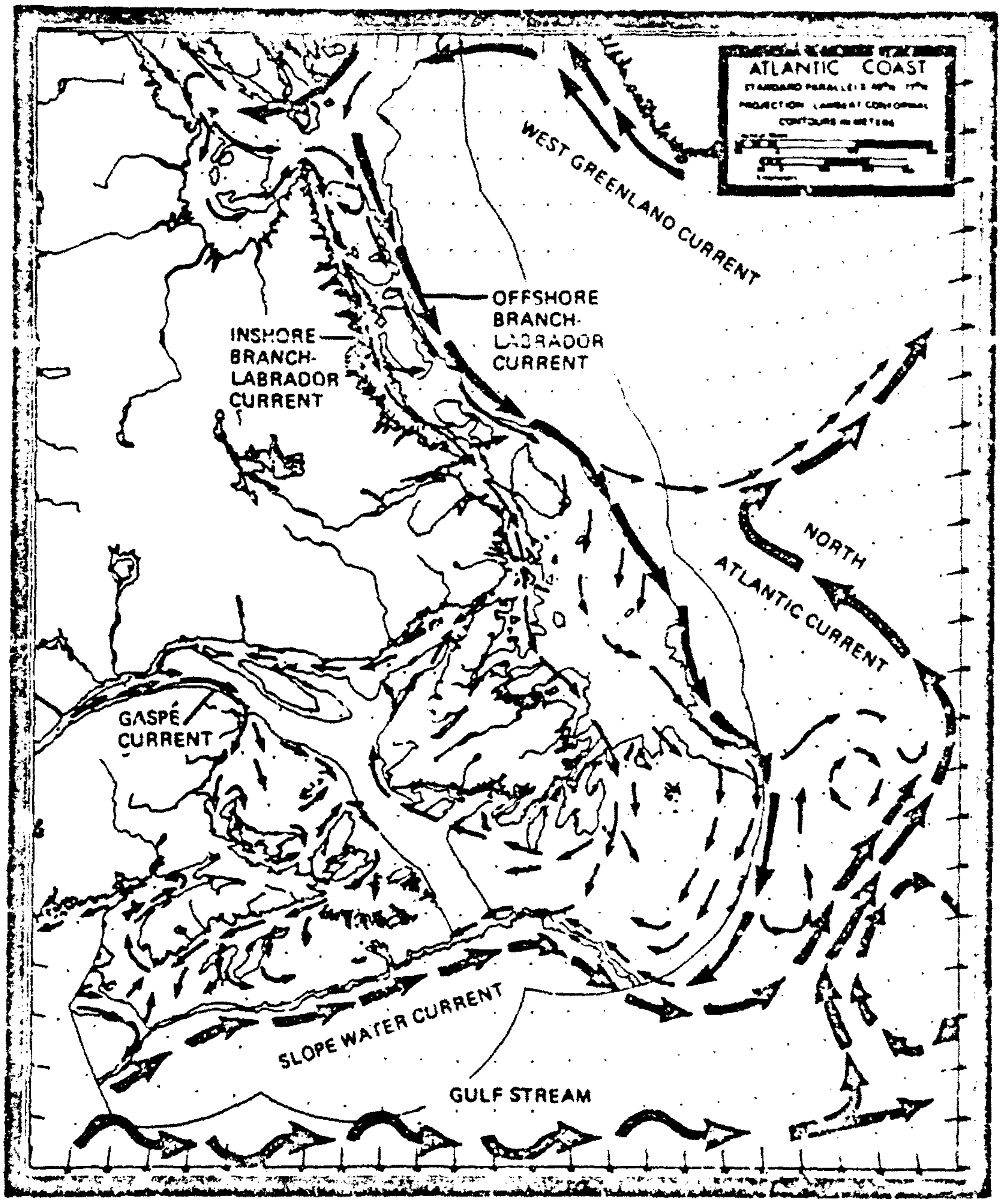
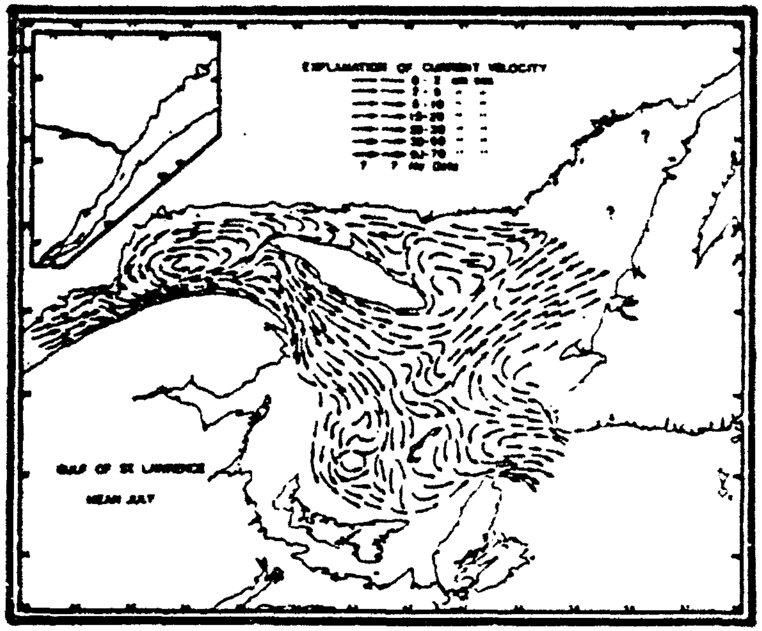


Figure 4.13: General surface circulation. (From Scarratt, 1982)

a)



b)

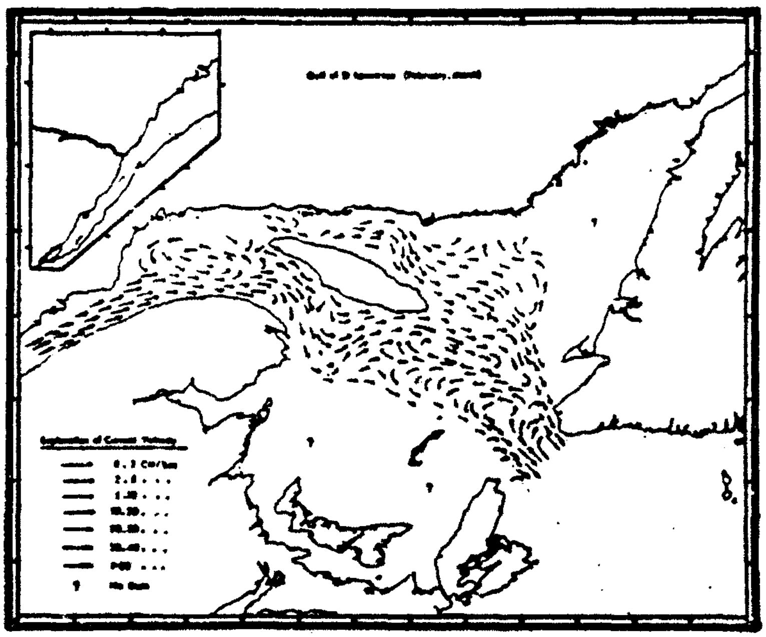


Figure 4.14: Mean surface circulation in the Gulf of St. Lawrence: a) summer and b) winter. (From El-Sabh, 1975)

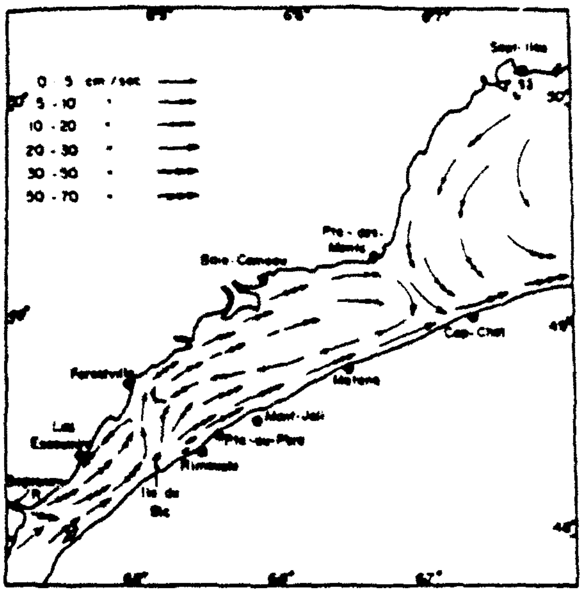


Figure 4.15: Mean surface circulation in the lower St. Lawrence Estuary. (From El-Sabh, 1979)

Gaspé Current reaches its maximum velocity three or four days before the moon's quarters when the estuary is emptying [Koutitonsky, 1979].

- **Gaspé Current:** The outflow of fresh water from the St. Lawrence River has a strong influence on the circulation in the gulf. *Its most striking feature is* the Gaspé Current which flows along the Gaspé Peninsula from the Rimouski-Pointe-des-Monts area to Cape Gaspé. This current is subject to wide seasonal variation in strength corresponding to the variations of the volume of freshwater outflow. The maximum velocities (greater than 75 cm s^{-1}) therefore occur in May . In summer, the velocity decreases from 66 cm s^{-1} in July to 30 cm s^{-1} in August. During the fall, it reaches speeds of 38 cm s^{-1} and its lowest values (5 to 10 cm s^{-1}) are observed in the winter. Most of the year, the Gaspé Current is also coupled with an inflow on the Anticosti Island side. On average, it has a width of 15 km, a thickness of 30 m and its direction is relatively constant [Tang, 1980]. It is a relatively stable current geographically speaking, however its magnitude is subject to large seasonal variations (the current may actually vanish on occasion [Farquharson, 1966]).

- **Magdalen Shallows:** As it enters into the gulf, the Gaspé Current spreads out in a general southeasterly direction, with velocities decreasing to between 1 and 5 cm s^{-1}. Between the Magdalen Islands, Prince Edward Island, and the western part of Cape Breton Island there is an eastward flow towards Cabot Strait.

- **Cabot Strait Circulation:** The surface flow out of the gulf has its maximum strength on the Cape Breton side of the strait and forms the Cape Breton Current. Its velocity is on the order of 20 cm s^{-1} on average, with a maximum of 30 cm s^{-1} in August and in the winter, and a minimum of less than 15 cm s^{-1} in July [El-Sabh, 1976]. On the Newfoundland side of the strait, there is a weak flow into the gulf from the Atlantic Ocean. This inflow divides into two branches: the first moves northeastward along the coast of Newfoundland, the second turns west shortly after entering the gulf and joins the Cape Breton Current. This pattern is modified in winter when the circulation becomes outward on both sides of the strait with an inflow in the middle of the strait which then turns west, probably under the influence of the prevailing northwest winds and drifting ice, and eventually rejoins the outflowing current on both sides [El-Sabh and Johannessen, 1972].

- **Eastern Gulf Circulation:** The water entering through Cabot Strait tends to follow the west coast of Newfoundland with some of it continuing towards the Strait of Belle Isle and the remainder flowing north. Southwest of Anticosti Island the circulation is characterised by a large permanent anticlockwise eddy during the ice-free months of the year. This eddy is highly variable in dimension and position. Furthermore, in winter, it is replaced by a smaller clockwise gyre [El-Sabh, 1976].

- **Strait of Belle Isle Circulation:** The Strait of Belle Isle circulation is highly variable since its most probable driving mechanism is the sea level difference between the opposing ends of the strait produced by large-scale meteorological forcing [Garrett and Petrie, 1981]. Garrett and Petrie also noted that both inflow and outflow are stronger on the south side of the strait. Finally, there is evidence for substantial inflows into the gulf through the strait during winter.

- **North Shore circulation:** Labrador water entering through the Strait of Belle Isle and the northwest flow in the Esquiman Channel join and are deflected to form a westward drift that flows along the north shore beyond Anticosti Island during the ice-free months of the year. In winter, this flow tends to reverse, and form an eastward drift.

- **Anticosti Eddy:** Along the north shore of the gulf, between Anticosti Island and the St. Lawrence Estuary, the surface water sets westward then swings across the estuary towards the south shore where it reinforces the Gaspé Current, which in turn sheds a branch that closes the loop. This anticlockwise eddy is a permanent feature of the gulf circulation [El-Sabh, 1976].

Scotian Shelf

- **Nova Scotia Current:** Winter time circulation over the Scotian Shelf consists of southwestward flow along the coast and a northeastward flow on the outer portion of the shelf. The coastal current is called the Nova Scotian Current and it carries the Gulf of St. Lawrence water from Cabot Strait along the shore of Nova Scotia. It is bounded on its offshore side by the Scotian Front, which is the surface expression of the transition from the Nova Scotia Current water to the mixed water offshore [Anderson and Smith, 1989]. The mean surface speed of this current is estimated to be 9 cm s^{-1} [Sutcliffe et al., 1976]. Near surface current up to 29 cm s^{-1} can be found in the core of the current usually located at approximately 45 km off the coast.

Some of the flow occurs across the shelf, in a general southerly direction, particularly over the troughs between the LaHave Bank, Emerald Bank and Browns Bank [Gregory and Smith, 1988]. The current tends to be strongest in winter (10-30 cm s^{-1}), while during the fall it is approximately 10 cm s^{-1}.

- **Southwest Nova Scotia Circulation:** The features of interest for the southwest Nova Scotia circulation are the presence of a westward longshore coastal current (4-10 cm s^{-1}) and an anticyclonic gyre around Browns Bank (5-15 cm s^{-1})

Grand Banks

Over the banks themselves the currents are generally weak and highly variable, while the circulation around the banks is an important current, the Labrador Current (Figure 4.16). The Labrador Current contains relatively cold and low salinity water compared to the surrounding waters and flows south along the Labrador Coast and the east coast of Newfoundland, roughly following the 200 m isobath. Velocities between 20 to 60 cm s^{-1} are recorded on that portion of the current [Lazier, 1982]. Along the way, some exchange occurs between the Labrador Current and the Gulf of St. Lawrence through the Strait of Belle Isle [Garrett and Petrie, 1981]. As the seafloor rises onto the banks area, the flow is steered into the two deeper channels, the Avalon Channel and the Flemish Pass, thus forming two branches of the current. Data are too limited to determine seasonal variations in the current pattern. Note that wind-driven currents can be significant in this area. They naturally tend to be strongest near the ocean surface and diminish with depth. These currents are subject to inertial motion, which has a period of approximately 16.5 hours at these latitudes. Although the winds are stronger in winter, wind-driven currents and inertial currents tend to be stronger in summer due to the water stratification which results in a thin mixed layer ($\sim$ 30 m). For example, maximum near surface current velocities at Hibernia range from 60 to 80 cm s^{-1} during late summer and early autumn and from 45 to 60 cm s^{-1} in winter [Mobil Oil, 1984].

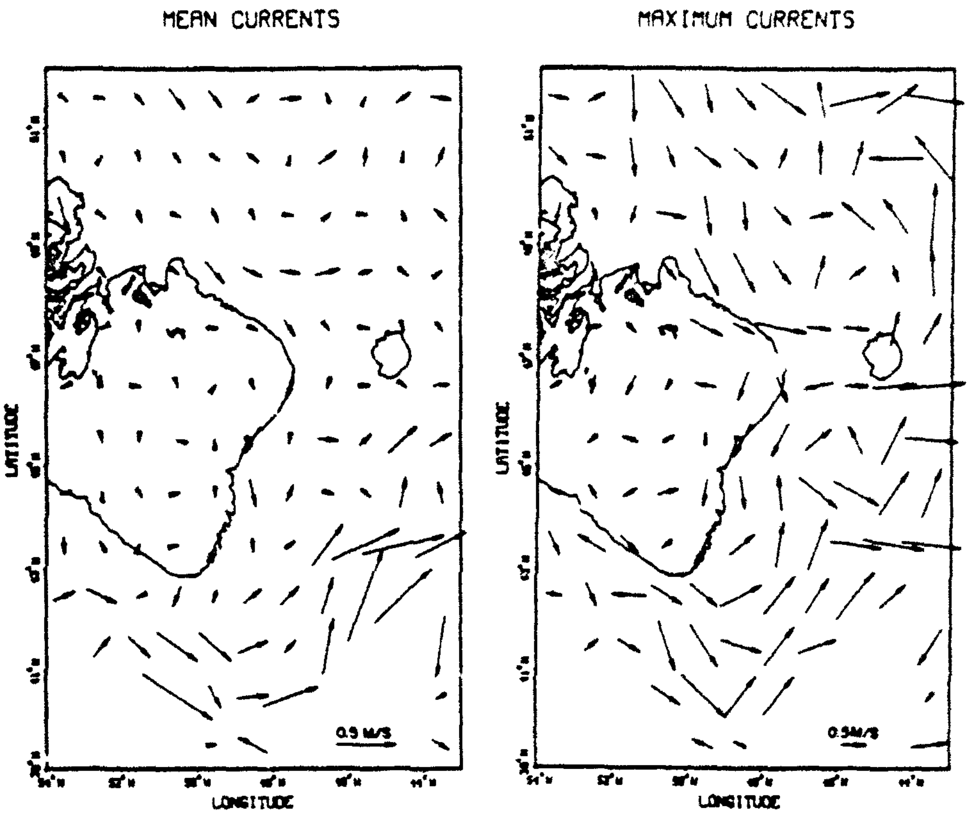


Figure 4.16: Mean current vectors and maximum daily currents observed in each 1° × 1° square in the Grand Banks area. An open (solid) arrow head signifies a current between 0 and 0.05 m s^{-1} (0.05 and 1.10 m s^{-1}). (From Petrie and Warnell, 1988.)

- **Labrador Current (Inshore):** The west branch of the Labrador Current, the less intense of the two (Petrie and Anderson [1983] estimate that it contains 10% of the transport), flows south through Avalon Channel. It is probable that most of the flow is then diverted offshore where it joins the eastward slope current. The remainder (about 20%), turns westwards towards Cabot Strait [Petrie and Anderson, 1983]. The flow then tends to move into the Gulf of St. Lawrence and northeast along the west coast of Newfoundland. In the area of St. Pierre, Green and Whale Banks, there is evidence of an onshore flow northward. Current speeds in that section range between 10 to 20 cm s^{-1}.

- **Labrador Current (Offshore):** The east branch of the Labrador Current flows along the northern slope of the Grand Banks before turning south through Flemish Pass. In the Pass, the Labrador Current follows the 200 m isobath and flows from north of the Banks to the Tail of the Banks with an average speed of about 30 cm s^{-1} [Petrie and Isenor, 1983]. A portion of the current is then directed eastward and joins the North Atlantic Current; another portion flows around the Tail of the Bank and sinks under the slope water. The current is estimated to be about 50 km wide with excursions normal to the 200-m isobath of at least 60 km [Petrie and Isenor, 1983].

- **Grand Banks Circulation:** The currents over the banks themselves are weak and variable; velocities are generally less than 10 cm s^{-1} [Petrie and Isenor, 1985]. There is also indication of the presence of a weak anticyclonic gyre in the southeastern part [Petrie and Anderson, 1983].

- **Flemish Cap:** Over the Flemish Cap, the flow forms a clockwise gyre.

4.2.2 Deep Currents

Some of the features of the circulation at depth that may impact on ASW operations are described in this section.

Gulf of St. Lawrence:

With the exception of the Gaspé Current, the Strait of Belle Isle Current and the Cabot Strait Current, the flow at depth between 30 and 100 m is weak and variable over most of the gulf. Below 100 m, there is no indication of currents that could be significant for ASW operations. Areas of upwelling exist along the north shore, the St. Lawrence estuary, the New Brunswick shore and possibly, southwest of the Magdalen Islands [Sutcliffe et al, 1976].

- **St. Lawrence Estuary:** The outflow of surface water is mostly confined to the upper 25-50 m along the south shore. An upstream current lies immediately below the seaward current, with its core at 100 m depth. Information is rather sparse on deep circulation.

- **Gaspé Current:** Current meters have recorded velocities of up to 25 cm s^{-1} at depths between 30 and 100 m [Gregory et al., 1989].

- **Strait of Belle Isle:** The deep flow follows the same pattern as the surface flow and is driven mostly by sea level differences resulting from meteorological forcing. The bottom currents are constant across the strait, but are significantly weaker and less variable than the surface currents [Garrett and Petrie, 1981]. Currents meter records indicate a flow predominantly into the gulf at depths greater than 35 m [Petrie and Warnell, 1988].

Scotian Shelf

The deep circulation over most of the Scotian Shelf is weak and variable. There is an upwelling circulation off Cape Sable with a mean onshore current of 2 cm s^{-1} [Smith, 1983].

- **Nova Scotia Current:** The Nova Scotia Current maintains a constant direction with depth and can reach a maximum speed of 20 cm s^{-1}. In general, the longshore currents tend to decrease with depth, but they have also been observed to be nearly uniform through the water column [Anderson and Smith, 1988].

- **Southwest circulation:** There is a deep inflow of slope water through the Northwest Channel which is at a maximum in late summer. The speed of this inflow is about 10 cm s^{-1} at 100 m decreasing to about 3 cm s^{-1} toward the bottom. An outflow current has also been recorded at depths of 100 and 150 m on the southwest side of the channel with magnitudes of 7 and 2 cm s^{-1} respectively [Smith, 1983].

<u>Grand Banks</u>

- **Labrador Current (Inshore):** The Labrador Current has been measured at up to 50 cm s^{-1} in the Flemish Pass and along the east slope of the Grand Banks at depths greater than 50 m [Petrie and Warnell, 1988]. A current parallel to the isobaths with speeds of 46 cm s^{-1} and 18 cm s^{-1} at 110 m and 380 m respectively, is also present. Part of this current flows around the Tail of the Banks, where it sinks below 50 m, under the eastward Slope Current. It then flows along the slope and into the Laurentian Channel penetrating into the Gulf of St. Lawrence at a speed of 15 to 25 cm s^{-1} [Petrie and Anderson, 1983].

- **Labrador Current (Offshore):** Bottom circulation inferred from sea-bed drifter data indicates a south-southwest motion through Avalon Channel and to the southeast. Once through the Avalon Channel, the flow is either along the coast reaching into Fortune Bay or through Haddock Channel and then westward along the shelf break [Petrie and Anderson, 1983].

- **Grand Banks:** Over the broad expanses of the Grand Banks, near-bottom currents tend to be greatly influenced by the topographic variation of the shelf.

... of Partial Tide	Symbol	Period (Solar hours)
S... nal Component:		
...ipal lunar	M_2	12.42
...cipal solar	S_2	12.00
...rger lunar elliptic	N_2	12.66
Diurnal components:		
Lunisolar diurnal	K_1	23.93
Principal lunar diurnal	O_1	25.82

Table 4.1: Principal tidal harmonic components (From Knauss, 1978).

The flow is relatively weak (2 to 10 cm s^{-1}) and highly variable, although generally towards the south. Over shallow areas, currents show an essentially consistent circulation pattern with depth. Bottom currents are usually less than 4 cm s^{-1} [Mobil Oil, 1984].

4.2.3 Tidal Currents

The tidal circulation can be quite significant. For example, in the vicinity of Cape Sable, the M_2 tidal circulation is roughly five to ten times larger than the mean circulation [Smith, 1983]. Table 4.1 lists the tidal harmonic components that have a noticeable effect on the circulation in the study area. Figure 4.17 shows the progression of the main tidal component (lunar semi-diurnal M_2) in the study area. A description of the main circulation features associated with the tidal forcing follows.

Gulf of St. Lawrence

In the Gulf of St. Lawrence, the tide propagates as a Kelvin wave, i.e. as a very low frequency wave rotating about a nodal point (amphidrome) like the spokes of a wheel. The amphidrome is a location of zero rise and fall with cotidal lines (points of equal phase at any instant) radiating from it and rotating in anti-clockwise direction [Pond and Pickard, 1983]. The tidal waves found in the gulf are a combination of the tidal waves found in the adjacent open ocean

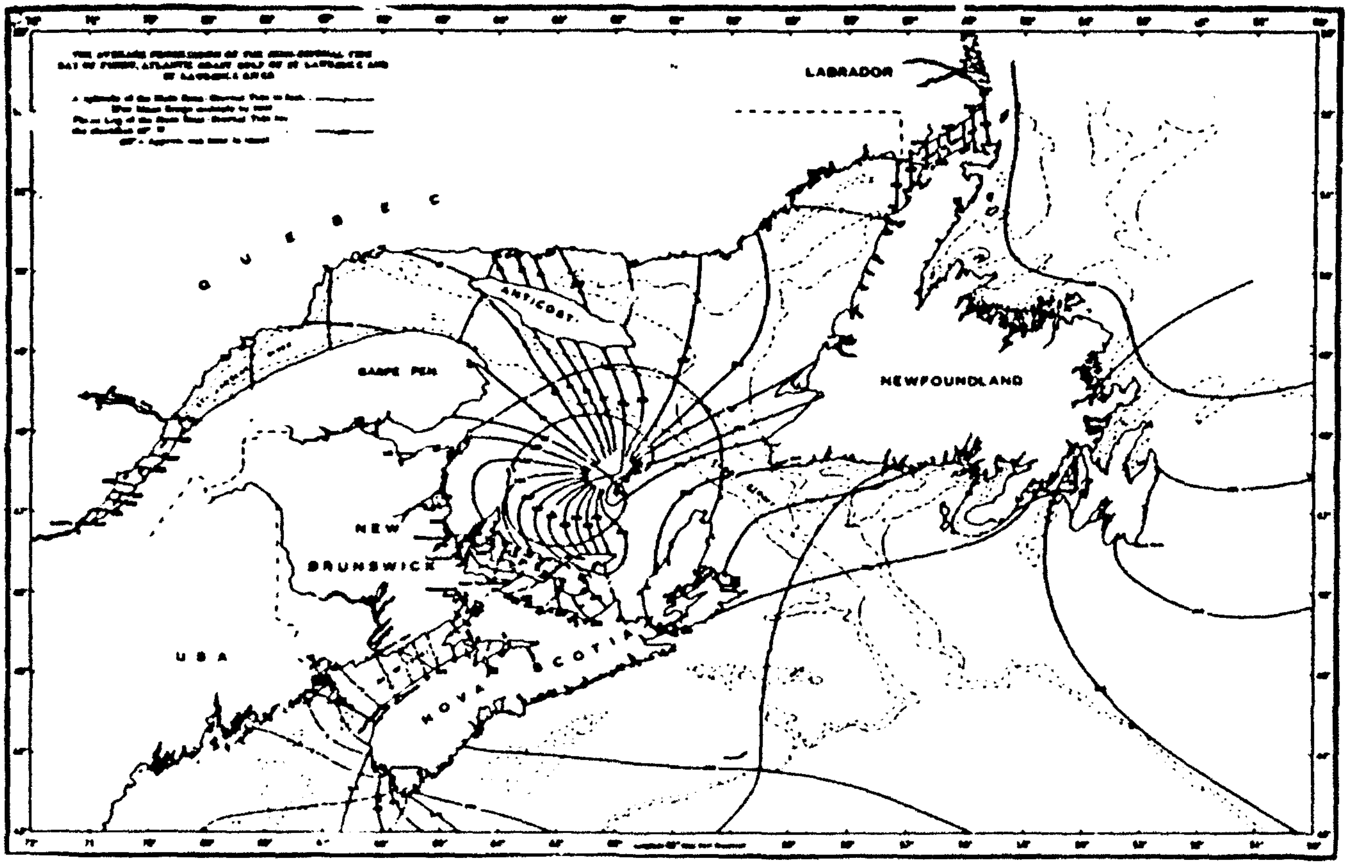


Figure 4.17: Average progression of the semi-diurnal tides (From Dohler, 1966).

and the waves induced by friction between the tides and freshwater output. The most important constituent, the semi-diurnal lunar (M_2) dominates the other semi-diurnal components by a factor of 3 to 1 and the diurnal components by factors of 7 to 1 or more. Using M_2 to obtain a rough picture of the effect of tides in the gulf, it is noted that an amphidromic point is located just west of Magdalen Island [Godin, 1979]. The amplitude of the M_2 component is small over the Magdalen Shallows and increases radially east and north. The largest amplitudes are found in the St. Lawrence Estuary. Due to the decreasing cross-section, the range of the semi-diurnal tide progressively increases from 2.5 m at Sept-Iles to a value of 4.0 m at Tadoussac [El-Sabh, 1979]. As a result, surface tidal currents near the mouth of the Saguenay are very strong with peak speeds reaching 300 cm s^{-1} during large tides [El-Sabh, 1979].

In the estuary, the currents induced by M_2 are mostly in the longitudinal sense, with the exception of a transverse current that reaches 70 cm s^{-1} at the mouth of the Saguenay River. The tidal currents are on the order of 100 cm s^{-1} on the north shore west of the Saquenay, and reduce to 50 cm s^{-1} on the south side. East of the Saguenay mouth, the longitudinal tidal current is on the order of 25 cm s^{-1} [El-Sabh et al., 1979].

Scotian Shelf

Figure 4.18 shows the tidal current variability based on a model simulation. The model results are in good agreement with the observations made on the Scotian Shelf. The main axes of the tidal ellipse are depicted. It can be seen that strong tidal currents exist off southwest Nova Scotia with a peak magnitude of almost 200 cm s^{-1} in the east-west direction off Cape Sable and gradually shifts to an almost north-south direction over Georges Bank. Tidal currents of about 25 cm s^{-1} with no dominant axis are found over Sable Island Bank and Banquereau [Gregory, 1988].

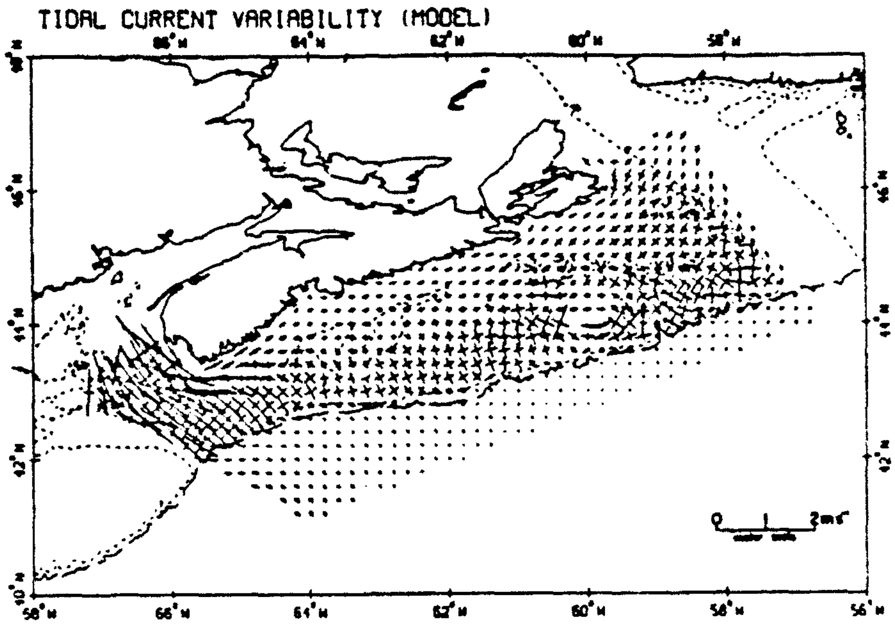


Figure 4.18: Tidal Current Variability on the Scotian Shelf from a numerical model simulation (From Gregory, 1988)

Grand Banks

Petrie [1982] has shown that the tides are an important part of the circulation in the Grand Banks area, since they account for 51% of the kinetic energy for periods longer than 12 h. The principal constituents, M_2, S_2, N_2, K_1 and O_1, accounted for 93% of the variance in sea-level elevation. The tide appears to propagate from north to south. The largest constituent, M_2 has amplitudes of about 0.30 m and tends to increase at locations near the shore. S_2 and N_2 behave similarly but have smaller amplitudes of about 0.10 and 0.07 m respectively [Petrie et al.,1987]. Currents resulting from the tides have been estimated to have a maximum speed of 28 cm s^{-1} at a depth of 25 m, 18 cm s^{-1} at 50 m and 15 cm s^{-1} at 80 m in the Hibernia area [Mobil Oil, 1984].

4.3 Sea Surface Temperature

4.3.1 Regional Description

The sea surface temperature regime of the east coast of Canada is dominated by the cold inflow from the Labrador Current. The other major factors influencing sea surface temperature are the seasonal variation of solar radiation and the immense heat capacity of water. The resulting slow heating and cooling are responsible for the late occurrence of the summer maximum and the winter minimum of sea surface temperature. The southern area is also affected by the Gulf Stream which flows along the periphery of the Scotian Shelf and Grand Banks. Meanders in the Gulf Stream and the warm eddies that are shed, occasionally bring much warmer water onto the Scotian Shelf and southern Grand Banks. The presence of sea ice also has an effect since the surrounding water remains at the freezing point of sea water: −1.8°C. When the ice melts, it introduces a continuous supply of cold water which delays the warming of the waters until the ice is gone.

4.3.2 Data Products

Statistics

Statistics for the sea surface temperature are shown in Figure 4.19. The data are from subareas representative of the three main areas under study

Contour charts

Mean sea surface temperature and its standard deviation in degrees Celsius are displayed on the contour charts shown in Figures 4.20 and 4.21.

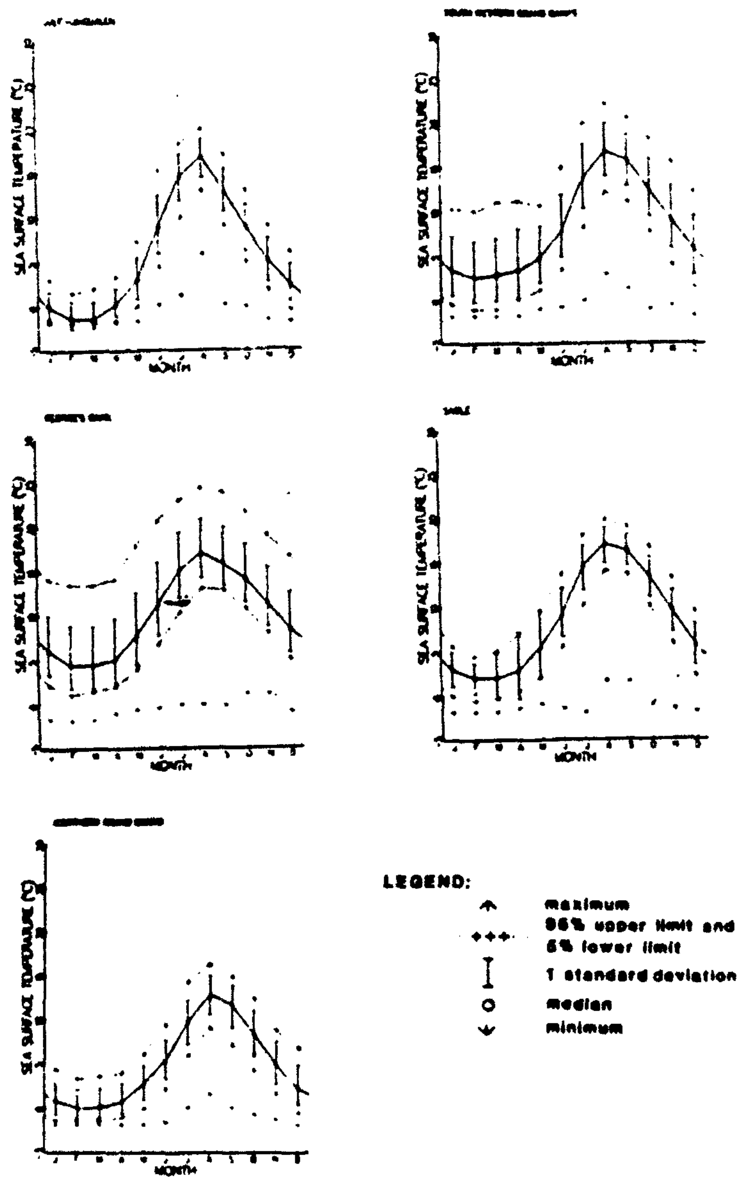


Figure 4.19: Sea surface temperature statistics. (After Mortsch et al, 1985)

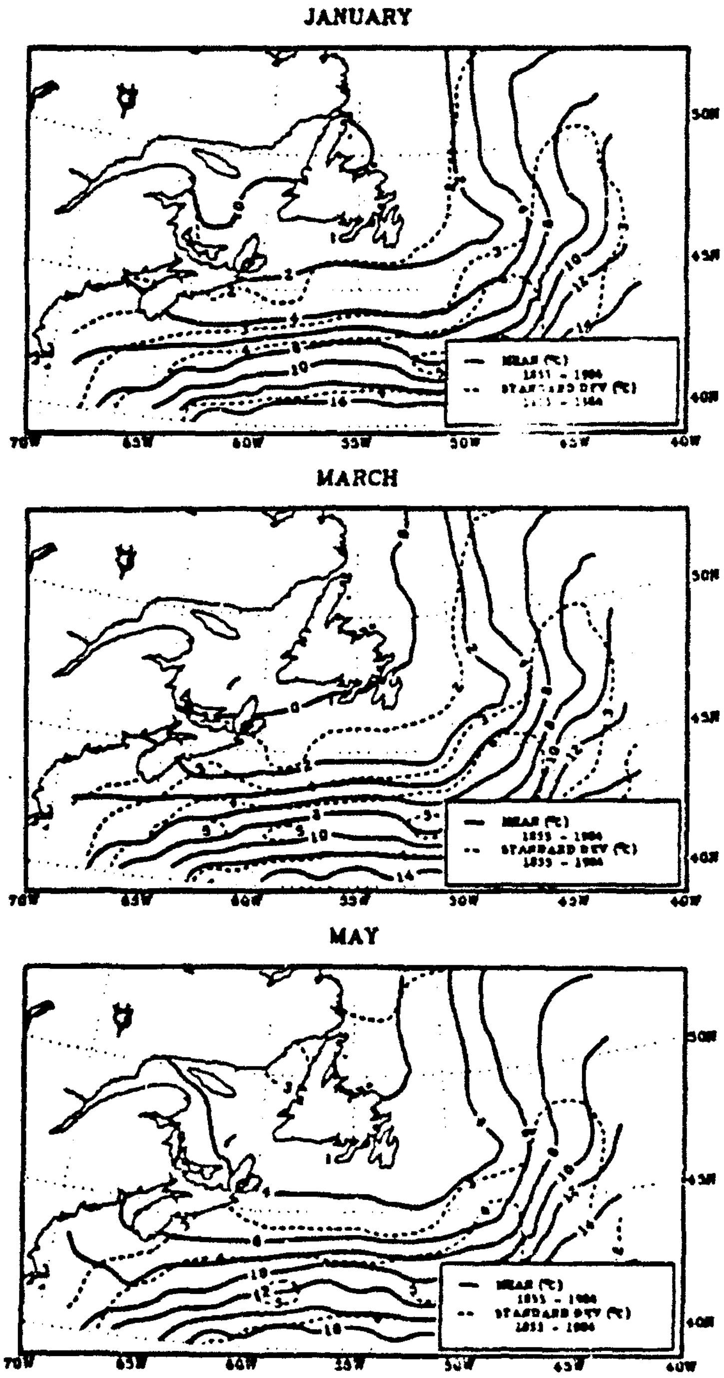


Figure 4.20: Sea surface temperature for January, March and May. Contours show mean temperature and standard deviation. (After Mortsch et al., 1985)

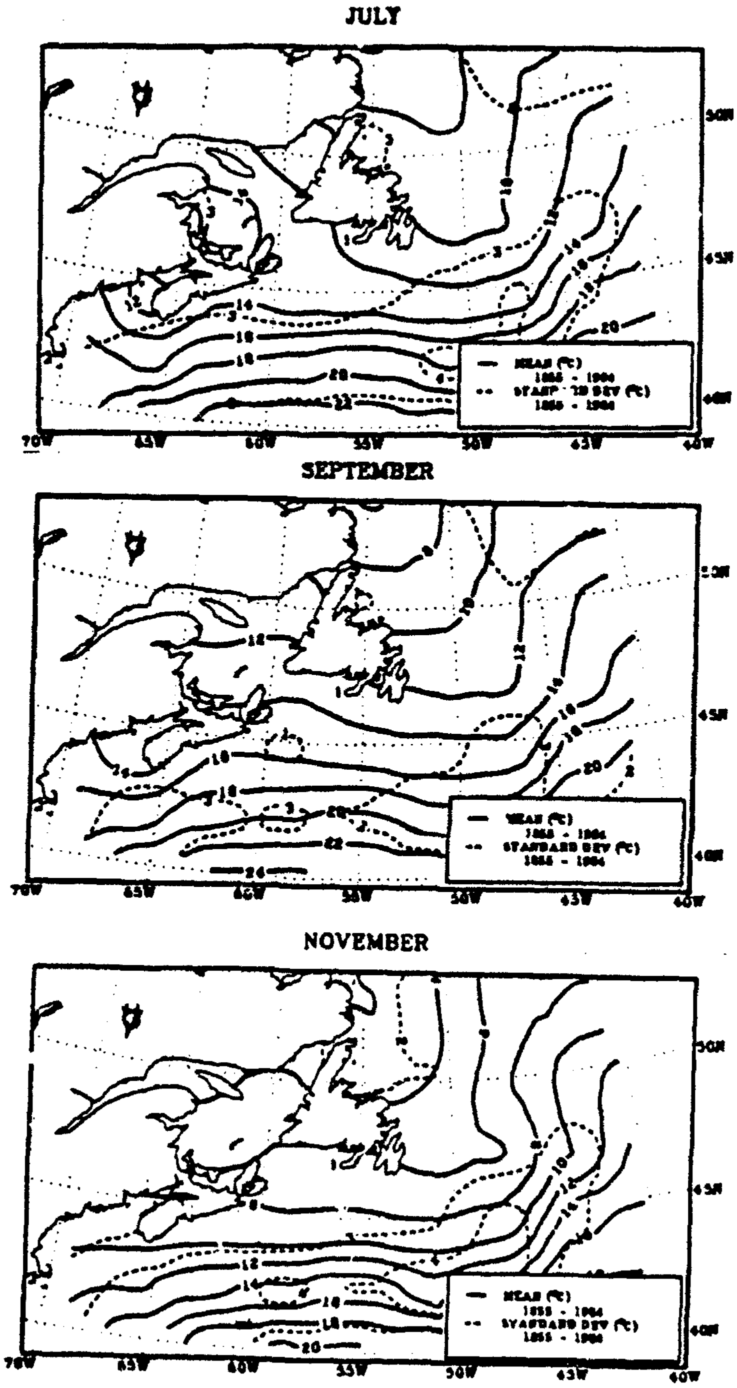


Figure 4.21: Sea surface temperature for July, September and November. Contours show mean temperature and standard deviation. (After Mortsch et al., 1985).

4.4 Water Masses and Fronts

4.4.1 Water Mass Distributions

Water masses are parcels of water that can be recognized by characteristic values of some of their physical properties, in particular temperature and salinity. Ocean Feature Analysis (OFA) is used here to illustrate the distribution of these water masses and their seasonal migrations.

Water masses are labelled using the ICAPS water mass classification. Under this designation system, the water masses found in the area under study are the following: (from the coldest to the warmest)

- Labrador Current (LC)
- Cold Shelf (CSH)
- Labrador Sea (LS)
- Shelf (SH)
- Slope (SL)
- Transition (TRS) (Between Labrador Sea and Gulf Stream water)
- Warm Eddy (WE)

The water mass distribution identified by OFA reveals the following pattern:

Gulf of St. Lawrence: Cold Shelf Water entirely occupies the gulf most of the year, except at the end of the summer when it recedes gradually northwards as the Shelf Water moves in. A tongue of Labrador Current Water which enters through the Strait of Belle Isle and extends into the Esquiman Channel is also a common feature throughout the year.

In the Gulf of St. Lawrence, there is good evidence to suggest that increases in temperature are associated with decreases in salinity and decreases in temperature with increases in salinity. This follows from a correlation showing that high runoff years are associated with high temperature years and that minimum salinity on the Magdalen Shallows varies inversely with the estimated April to June runoff from the St. Lawrence watershed.

The fresh water from the St. Lawrence moves seaward and mixes with sea water to form a low salinity surface layer in the southwestern portion of the Gulf of St. Lawrence, stretching from the St. Lawrence Estuary to Cabot Strait [Sutcliffe et al., 1976]. This layer eventually flows out through Cabot Strait and is the major contributor to the total outflow. The magnitude of the outflow is sufficient to replace most of the volume of water on the Continental Shelf between the Laurentian Channel and Cape Cod each year.

Scotian Shelf: The Scotian Shelf is completely covered by Cold Shelf Water during the winter. During spring, warmer Shelf Water gradually encroaches onto the continental shelf and at times, tongues of Slope Water and Warm Eddies reach the edge of the shelf. Shelf Water eventually covers the entire shelf area by the end of the summer. During the fall, the reverse process takes place. Cold Shelf Water gradually extends from the coast towards the shelf and the Shelf Water may be reduced to a narrow band that allows Slope and Warm Eddy Waters to reach the shelf. Occasionally (mostly during spring and summer) these Gulf Stream rings which impinge on the shelf edge cause anomalously warm, salty water to be present at the surface [Anderson and Smith, 1988].

Water properties: The water which overlies the shelf is comprised of mixtures of water of various sources:

- surface water flowing from the Gulf of St. Lawrence through the western side of Cabot Strait;
- surface Slope Water;
- intermediate Slope Water (100 - 150 m);
- subsurface water (100-150 m) in the Cabot Strait, possibly of Labrador Current origin;
- deeper slope water (200-300 m).

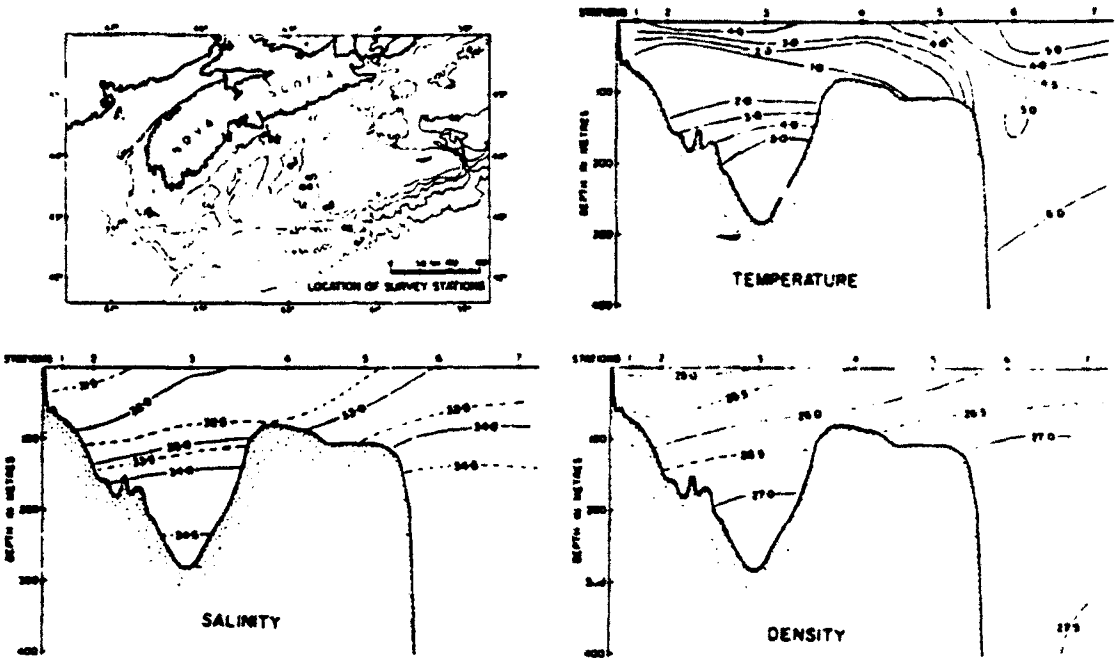


Figure 4.22: Water properties across the Scotian Shelf (May): a) location, b) temperature, c) salinity and d) density (After de la Ronde, 1972).

As a rule, the proportion of Gulf of St. Lawrence Water is higher near the shore, and the proportion of Slope Water increases with offshore distance [Anderson and Smith, 1988].

The coldest, fresher water is found adjacent to the coast. Warmer water lies below and offshore, but its higher salinity gives it a greater density than the coastal surface water. Thus, isopycnal surfaces generally shoal in the offshore direction over the entire section as seen in Figure 4.22, which is dynamically consistent with a southwestward, geostrophic, surface-intensified coastal current. Lower salinities are observed in winter (December) in the inshore zone as compared to the spring (April) conditions which reflect the recent passage of low salinity water from the gulf.

The main oceanic features affecting the water masses of the Scotian Shelf are the Nova Scotia Current, the Cape Breton Current, and the Slope Water. These are for their part directly affected by the Labrador Current, the Gulf

Stream, and the freshwater discharge from the St. Lawrence River. In addition, on-site meteorological factors, such as solar heating, wind patterns, cloud cover, precipitation, and evaporation further modify these waters [Sutcliffe et al., 1976]. Labrador Current Water is found on Banquereau occasionally, but there is no evidence that it reaches farther south.

Grand Banks: Labrador Current Water can be found throughout the year along the east coast of Newfoundland and as a tongue of water that extends along the east edge of the Grand Banks. The Flemish Cap is covered with Labrador Sea Water during the entire year. In winter, Labrador Current Water gradually covers most of the Grand Banks and extends all the way to the Laurentian Channel. At the end of spring, the reverse process takes place. Cold Shelf Water gradually moves north and east until it occupies the entire Grand Banks in the fall. Occasionally, Transition Water and Warm Eddies reach the edge of the southeast portion of the Grand Banks.

4.4.2 Front Location Chart

The main front in the area is associated with the cold Labrador Current which is bounded to the west by the warmer Shelf Water and to the east by the warm North Atlantic Current. The current itself is ~ 50 km wide [Isenor, 1988] and its position can shift up to 60 km, as seen in Figure 4.23 which was constructed from satellite imagery.

4.4.3 OFA Charts

OFAs for each month of 1989 are shown in Figures 4.24 to 4.27. These charts do not show average conditions, but the overall pattern of the water mass distribution and migration is fairly representative of what can be expected any year.

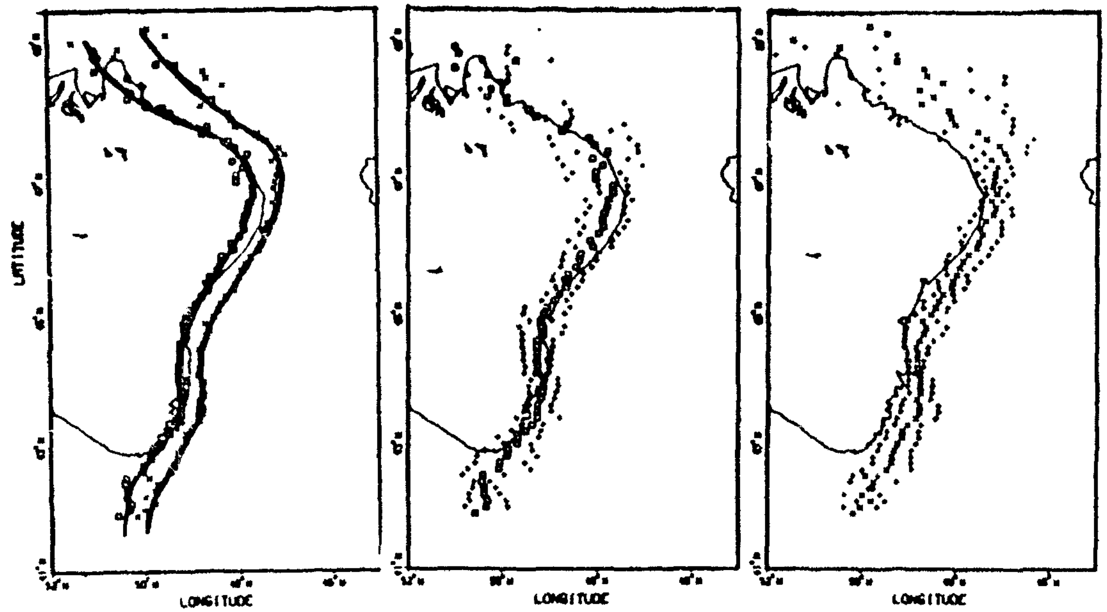


Figure 4.23: Labrador Current location: a) mean position, b) western boundary mean position denoted by "□" and one standard deviation either side, denoted by "+", c) eastern boundary mean position, denoted by "×", and one standard deviation either side, denoted by "+ ". (After Isenor, 1988)

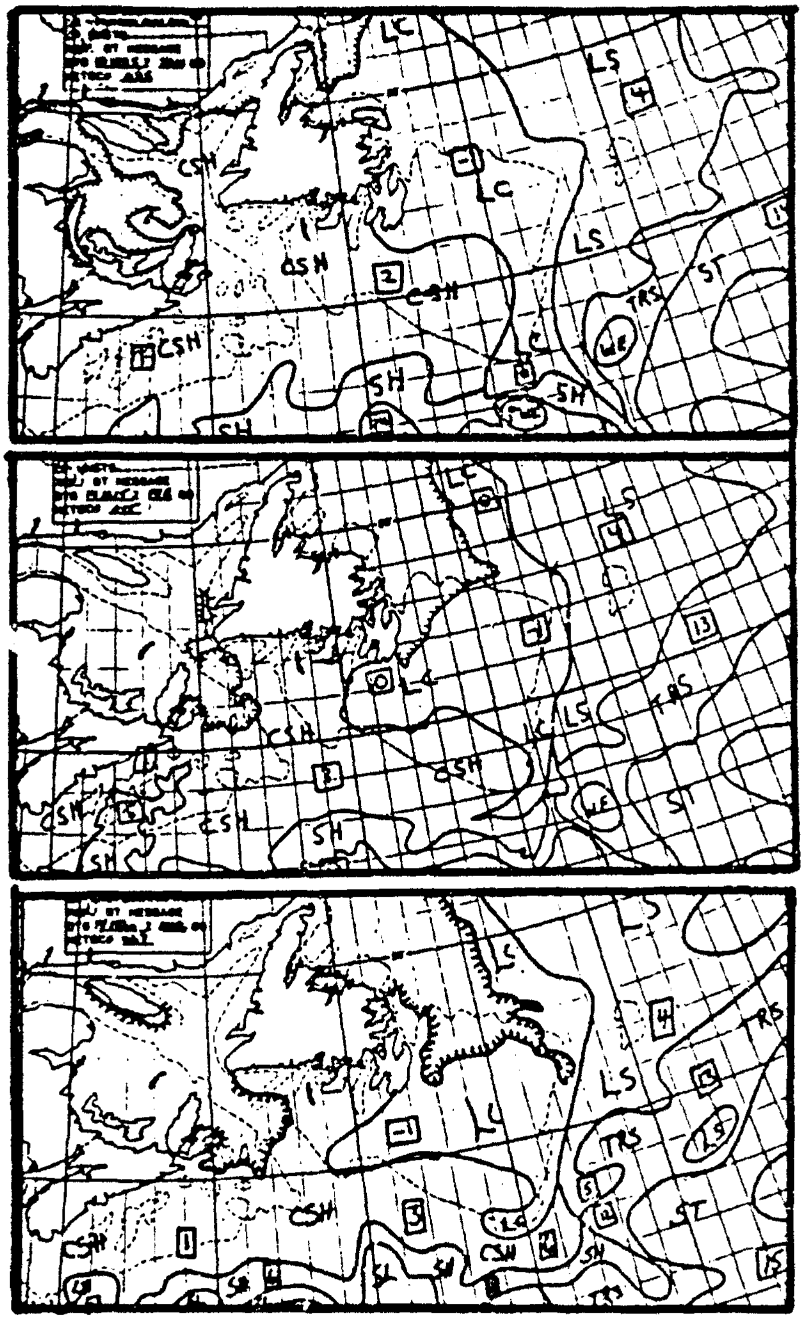


Figure 4.24: Ocean Feature Analysis for a) January, b) February and c) March. Contours show boundaries of the water masses and digits in squares indicate average sea surface ter perature (From CF METOC Centre).

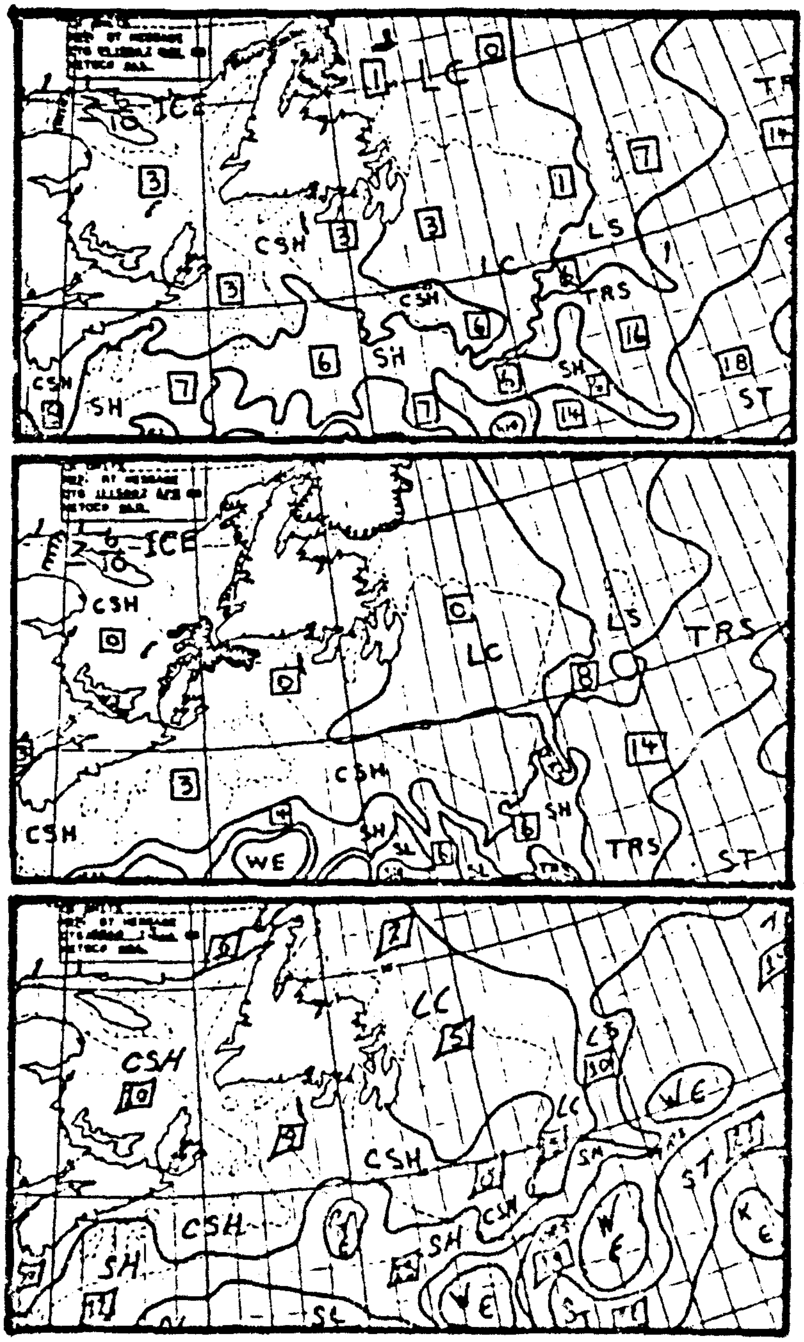


Figure 4.25: Ocean Feature Analysis for a) April, b) May and c) June. Contours show boundaries of the water masses and digits in squares indicate average sea surface temperature (From CF METOC Centre).

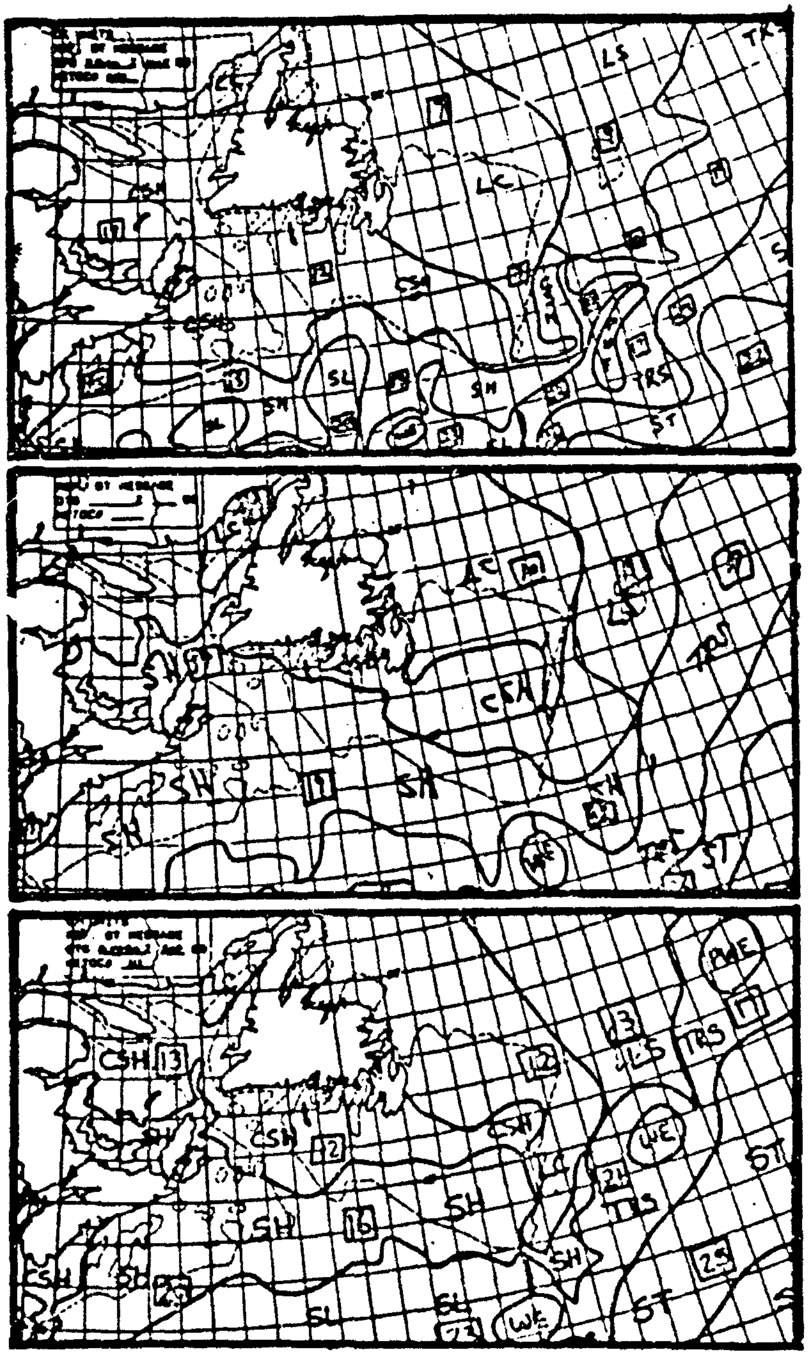


Figure 4.26: Ocean Feature Analysis for a) July, b) August and c) September. Contours show boundaries of the water masses and digits in squares indicate average sea surface temperature (From CF METOC Centre).

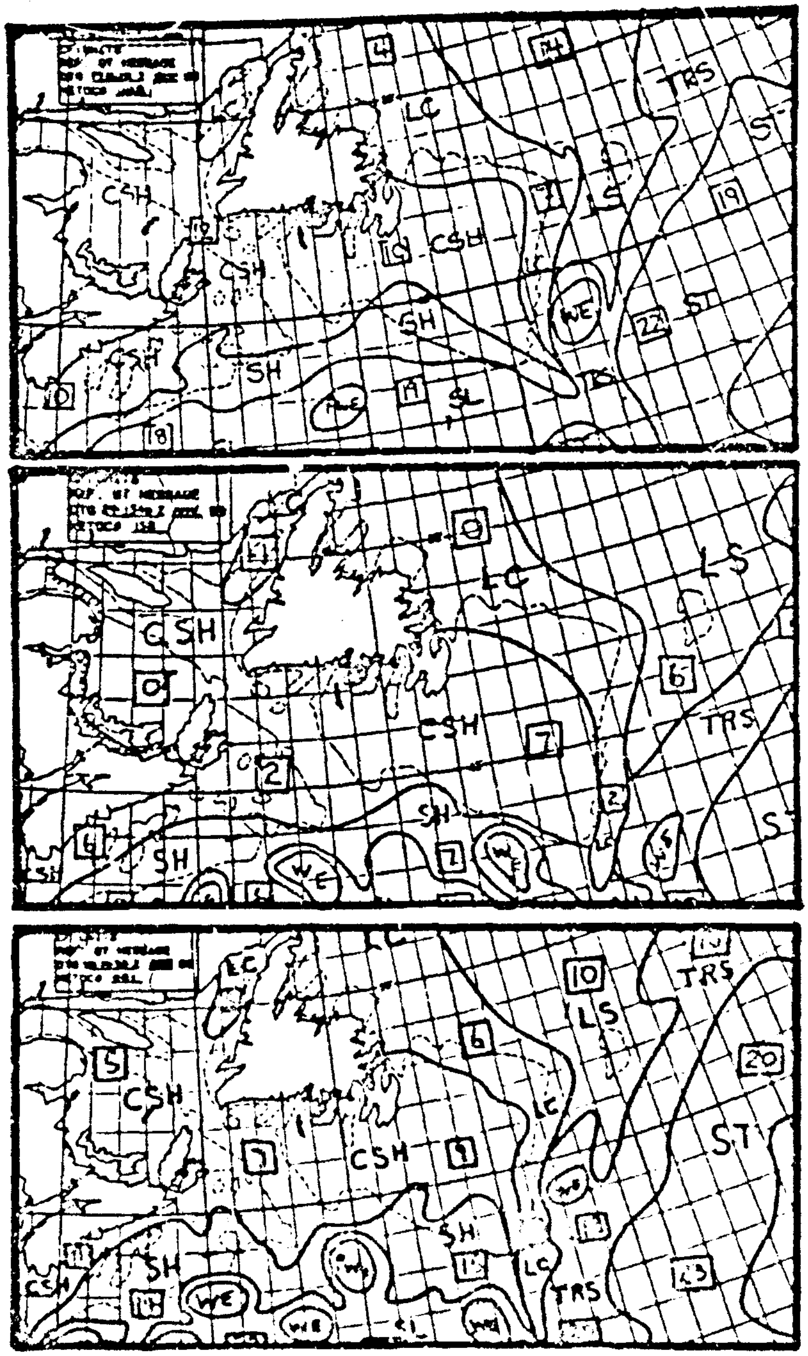


Figure 4.27: Ocean Feature Analysis for a) October, b) November c) December. Contours show boundaries of the water masses and digits in squares indicate average sea surface temperature (From CF METOC Centre).

4.5 Temperature and Salinity Distributions

The area is characterized by a surface layer which has salinities that are lower than the water beneath and lower than the surface layer waters further offshore. This low salinity (24 to 32 psu) varies between locations depending upon the source of fresh water present. The inputs of less saline water tend to vary seasonally as well as for a given location. Salinity reaches about 34 psu below 200 m and is relatively constant throughout the area throughout the year.

Surface temperature fluctuations are typical for areas at this latitude. Maximum surface temperature occurs at the end of the summer (September) and minimum at the end of the winter (March).

Gulf of St. Lawrence

In the Gulf of St. Lawrence, the development of a shallow warm layer is observed in the summer with the lowest average temperature occurring in the estuary and the highest in the Magdalen Shallows. Freshening of the near-surface waters due to the freshwater runoff of the St. Lawrence River is also evident, particularly during the spring in the estuary where the salinity decreases to less than 24 psu (Figures 4.28 and 4.29). The freshening process generally occurs later in the seaward direction. For example, it occurs in late August or September in Cabot Strait (Fig 4.30). The coldest surface water in the estuary is due to enhanced upwelling and vertical mixing of cooler, deeper waters [Petrie, 1990]. At 50 m, the temperatures are generally less than 2°C most of the year. Below 50 m, the temperature rises to 2 – 3°C at 150 m due to the influence of Slope Water from the Atlantic Ocean which enters the gulf through Cabot Strait. It can be recognized by the higher salinities which exhibit more "oceanic" characteristics (≈ 34 psu) below 150 m. Salinity as well as temperature, show small changes either spatially or temporally at greater depths. The characteristic flow pattern through Cabot Strait is also apparent from the

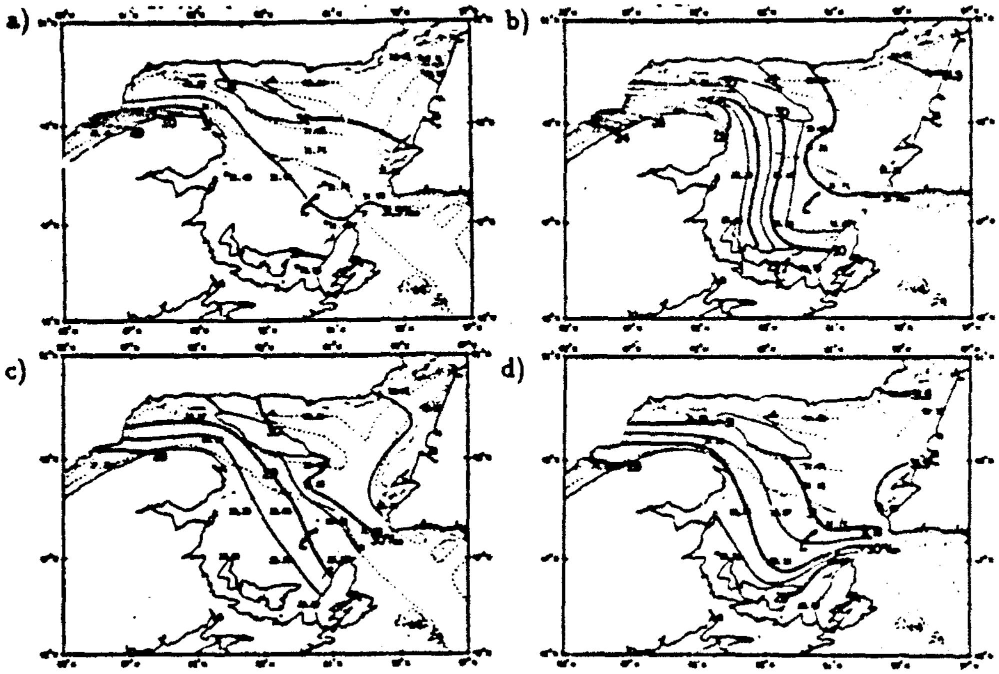


Figure 4.28: Mean surface salinity for the Gulf of St. Lawrence in a)February, b) May, c) August and d) November (From Petrie, 1990).

lower salinity of the water above 75 m on the west side (outflow) compared to the east side (inflow into the gulf). Similarly the circulation at the entrance of the estuary is marked by lower salinity on the south shore associated with the Gaspé Current (Figure 4.31).

Scotian Shelf

Traces of the freshwater outflow from the St. Lawrence can be observed in the surface layer of the Scotian Shelf Water in the form of a pulse of minimum salinity (~ 30.5 psu) in the fall as seen on Figures 4.33 and 4.34. The positive salinity gradient with depth is therefore not as strong as it is in the gulf and it occurs while the seasonal thermocline is well developed. Therefore its effect on the sound speed profile and the propagation path is not as significant. The low salinity surface layer generally extends approximately to the 2000 m isobath on the slope where a sinuous front separates the coastal waters from the warmer

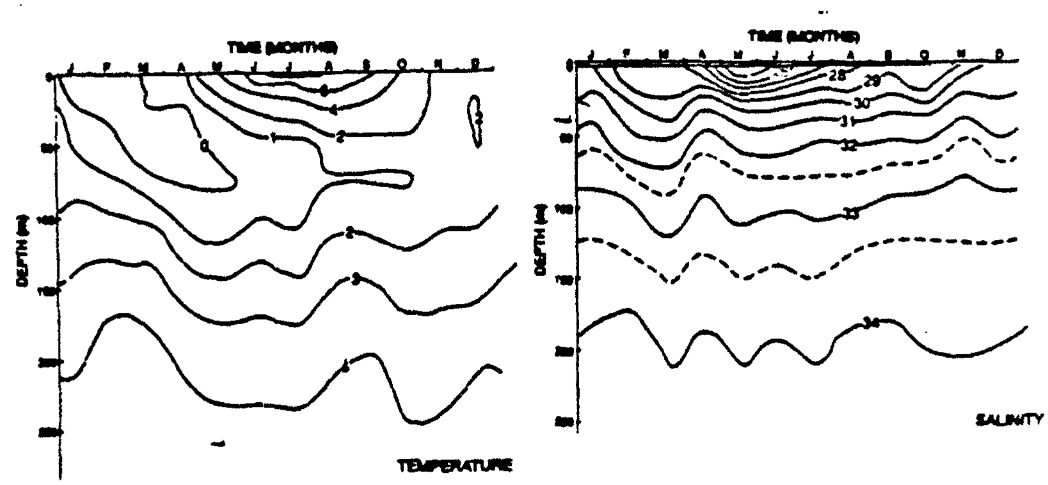


Figure 4.29: Time-depth distribution of the monthly mean temperature and salinity for the St. Lawrence Estuary (From Petrie, 1990).

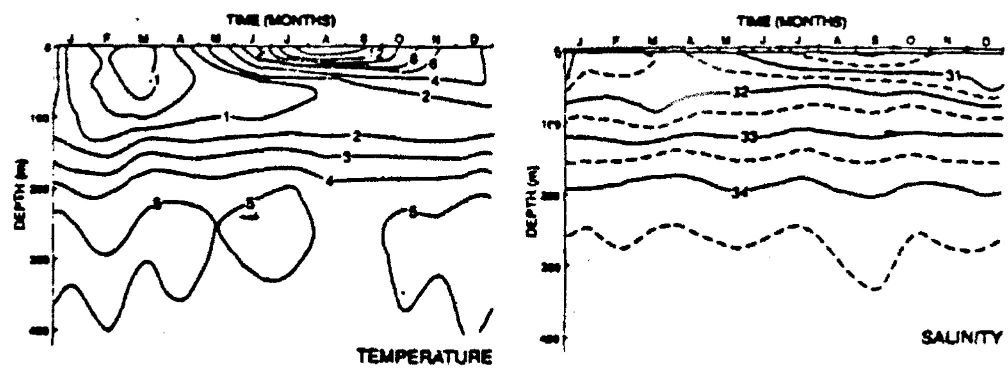


Figure 4.30: Time-depth distribution of the monthly mean temperature and salinity for the west side of Cabot Strait (From Petrie, 1990).

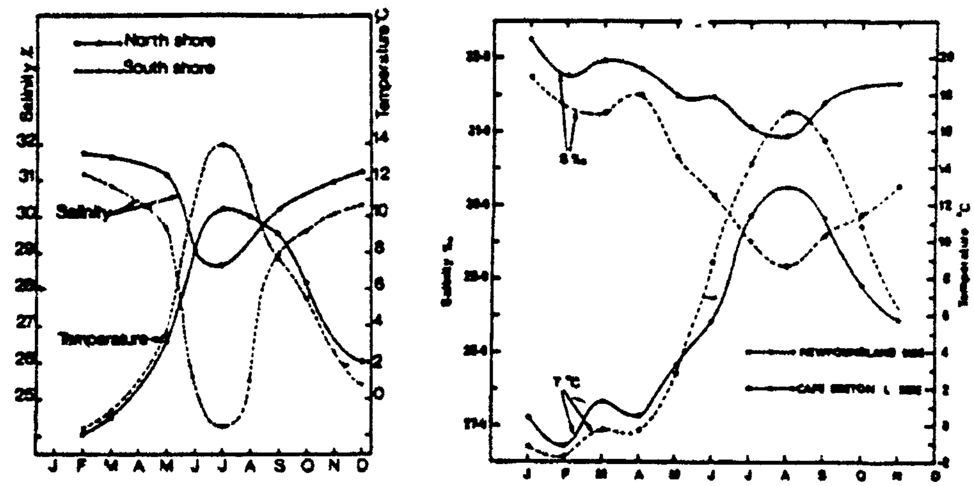


Figure 4.31: Monthly variation of the surface salinity and temperature in the a) St. Lawrence Estuary and b) Cabot Strait (From El-Sabh, 1975).

and more saline (> 34 psu) oceanic water offshore (Fig. 4.32).

The maximum temperature of the surface layer is reached in late summer. The highest temperatures occur over the slope area in July. The high temperatures gradually extend to the middle section of the shelf (Sable Island area) and finally reach the northeast portion of the shore by September. The cold middle layer found in the gulf is not present on the shelf. In the basins, the deep water remains at approximately 8°C.

Grand Banks

. The waters over the Grand Banks are similar to those found to the north on the Labrador Shelf where these waters mostly originate. The salinity usually reaches a low of ~ 31.5 - 32 psu in early fall coincident with a pulse of low salinity water associated with the spring runoff from Hudson Bay which moves gradually down the Labrador coast (Figure 4.35). While lower than in the open ocean, the salinity over the Grand Banks areas is however higher than that on the Scotian Shelf and in the gulf. Salinity gradually increases in an offshore direction. Temperatures range from the freezing point in winter (- 1.8° C) to

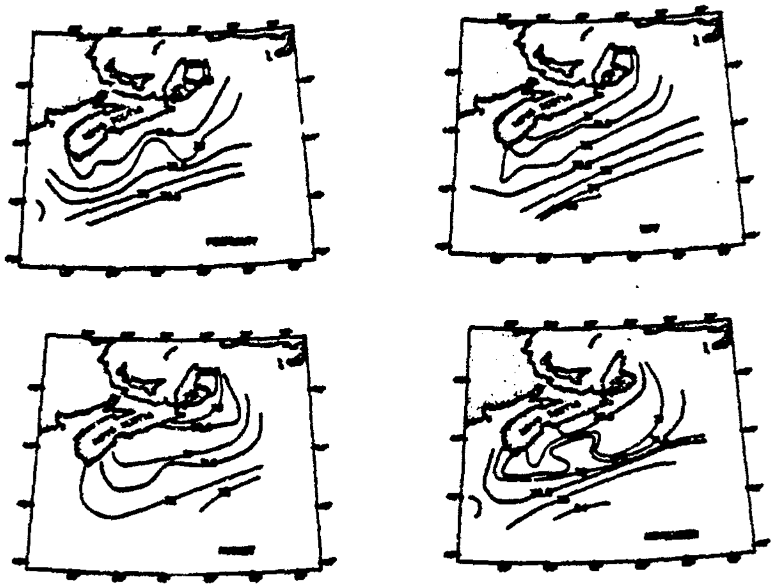


Figure 4.32: Mean surface salinity for the Scotian Shelf in February, May, August and November (From Drinkwater and Trites, 1987).

a)

b)

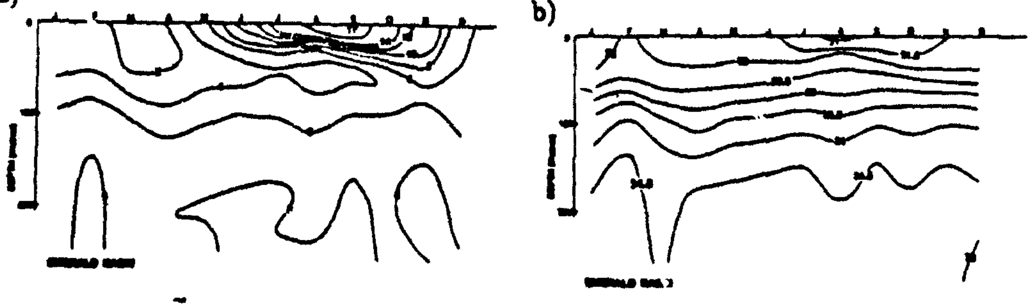


Figure 4.33: Time-depth distribution of the monthly mean a) temperature and b) salinity for Emerald Basin (From Drinkwater and Trites, 1987).

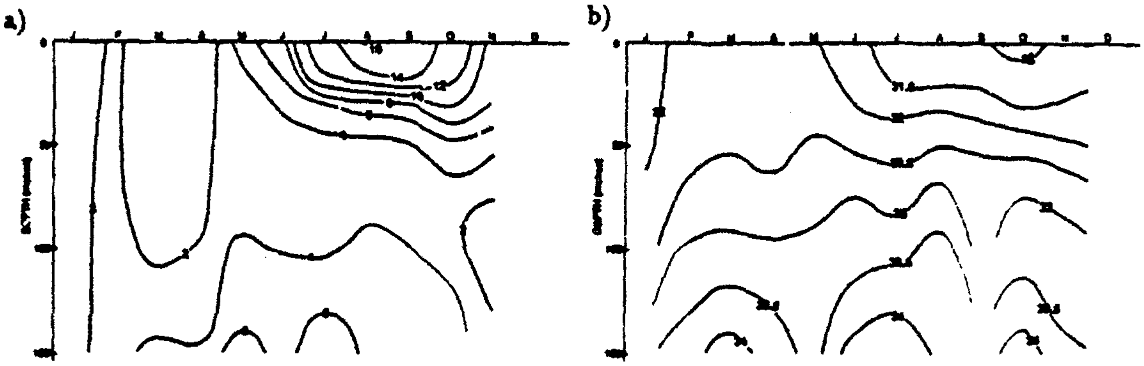


Figure 4.34: Time-depth distribution of the monthly mean a) temperature and b) salinity for the Banquereau Bank (From Drinkwater and Trites, 1987).

highs of 12° C in summer. A seasonal thermocline builds up in the summer with the strongest gradients of temperature found over the southern part of the Grand Banks and St. Pierre Bank.

The bottom water is a higher salinity water which has moved onto the shelf from offshore. It has an average salinity of about 33 psu and temperatures around 3° C with the occasional intrusion of warmer and more saline water over the southern Grand Banks (8° C and 34.5 psu) from the North Atlantic Current.

4.5.1 Temperature Profiles

Typical temperature profiles for six months of the year for the most representative subareas of the region under study (Figure 4.36) are included in Figures 4.37 to 4.87. The graphs contain profiles of the mean values and the values at plus or minus one standard deviation from the mean.

4.5.2 Salinity Profiles

Salinity profiles for typical winter and summer conditions for the subareas of the region under study are included in Figures 4.37 to 4.87. The profiles

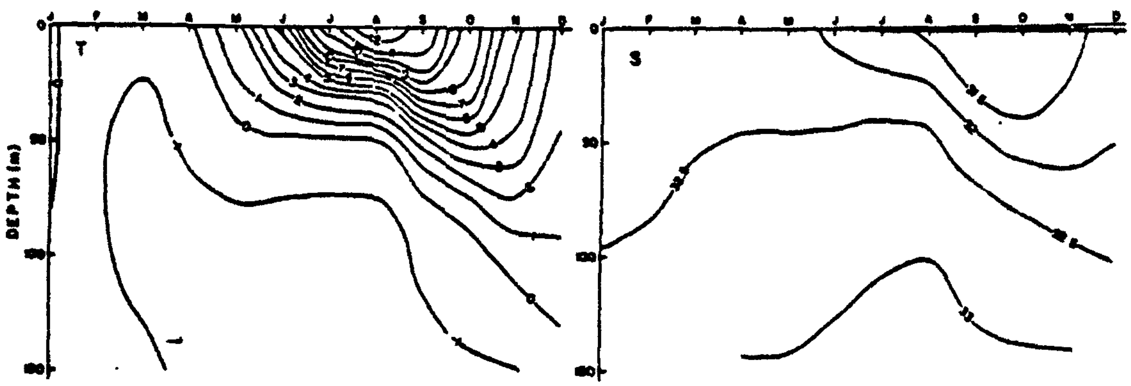


Figure 4.35: Time-depth distribution of the monthly mean temperature and salinity for the Avalon Channel (From Drinkwater and Trites, 1986).

include a plot of the mean values and the values at one standard deviation from the mean.

4.5.3 GIS Data

The complete temperature and salinity data set for all areas shown in Figure 4.36 for the 12 months of the year has been included in the GIS data base. Any profiles can thus be viewed or printed as required.

4.6 Sound Speed Profiles

The sound speed profiles at all locations show large changes between seasons. This is due to the formation in summer of a strong thermocline at a depth of 25-50 m which results in the formation of a surface duct that practically isolates the bottom layer from the surface. In the winter, a strong positive speed gradient exists in most areas which results from the surface cooling and the erosion of the thermocline.

Sound speed profiles are computed using Leroy's equation [1969] for each area using the available temperature and salinity. Figures 4.37 to 4.87 show

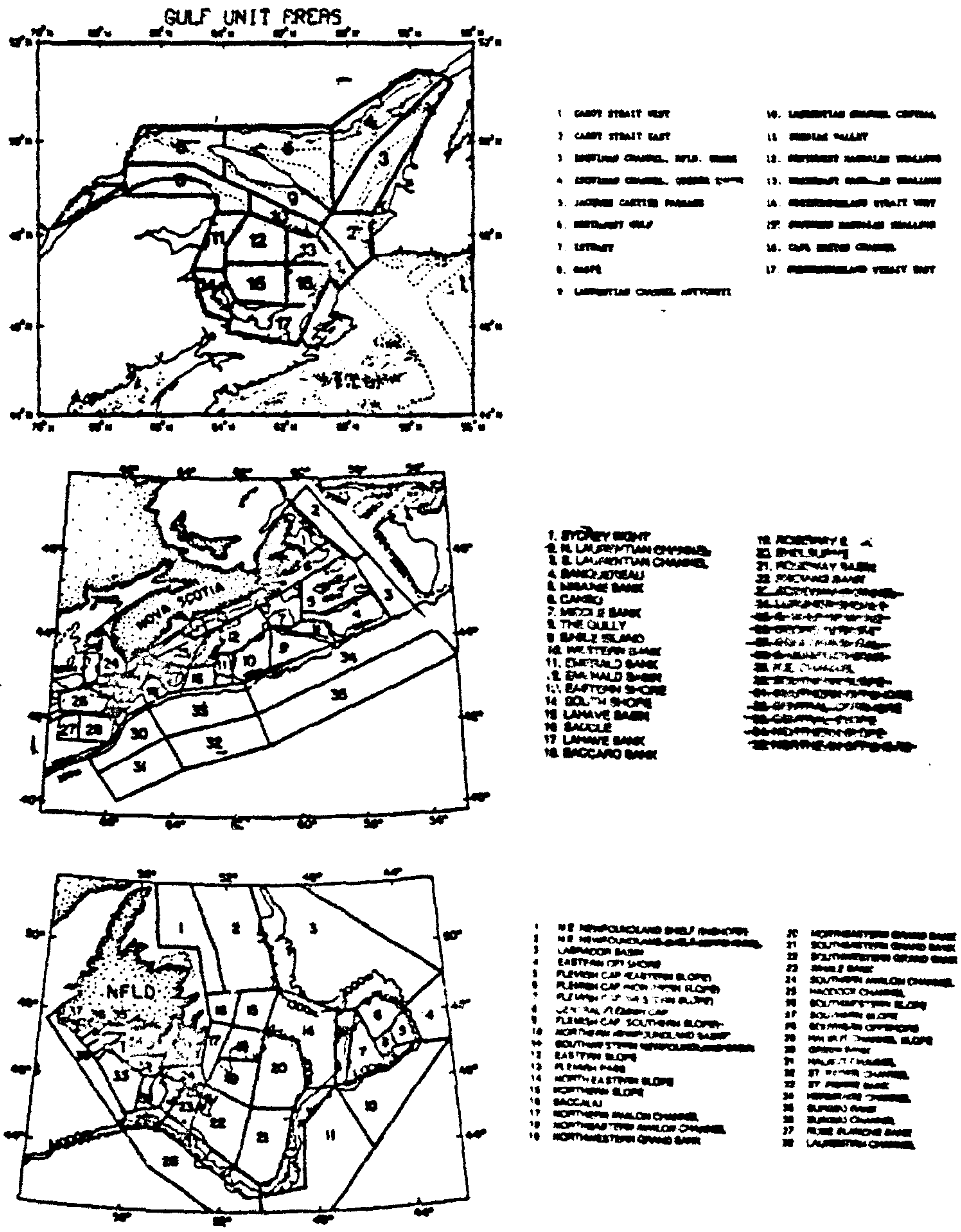


Figure 4.36: Subareas for mean temperature and salinity calculation.

the resulting profiles for six months of the year for the most representative areas.

It should be noted that the spread about the mean shown is not a valid statistical quantity, since it is computed from values of temperature and salinity at plus or minus one standard deviation. However, the lowest salinity will not necessarily occur when the lowest temperature is observed and vice versa. Nevertheless, since the fluctuations of the temperature about the mean are by far the dominant factor which causes fluctuations in the sound speed about its mean and since in most cases, the variations in salinity are small, the curves obtained are judged acceptable to give an indication of the spread in sound speed values that could be observed.

4.6.1 GIS Data

The complete sound speed data set for all areas shown in Figure 4.36 for the 12 months of the year has been included in the GIS database. Any profiles can thus be viewed or printed as required.

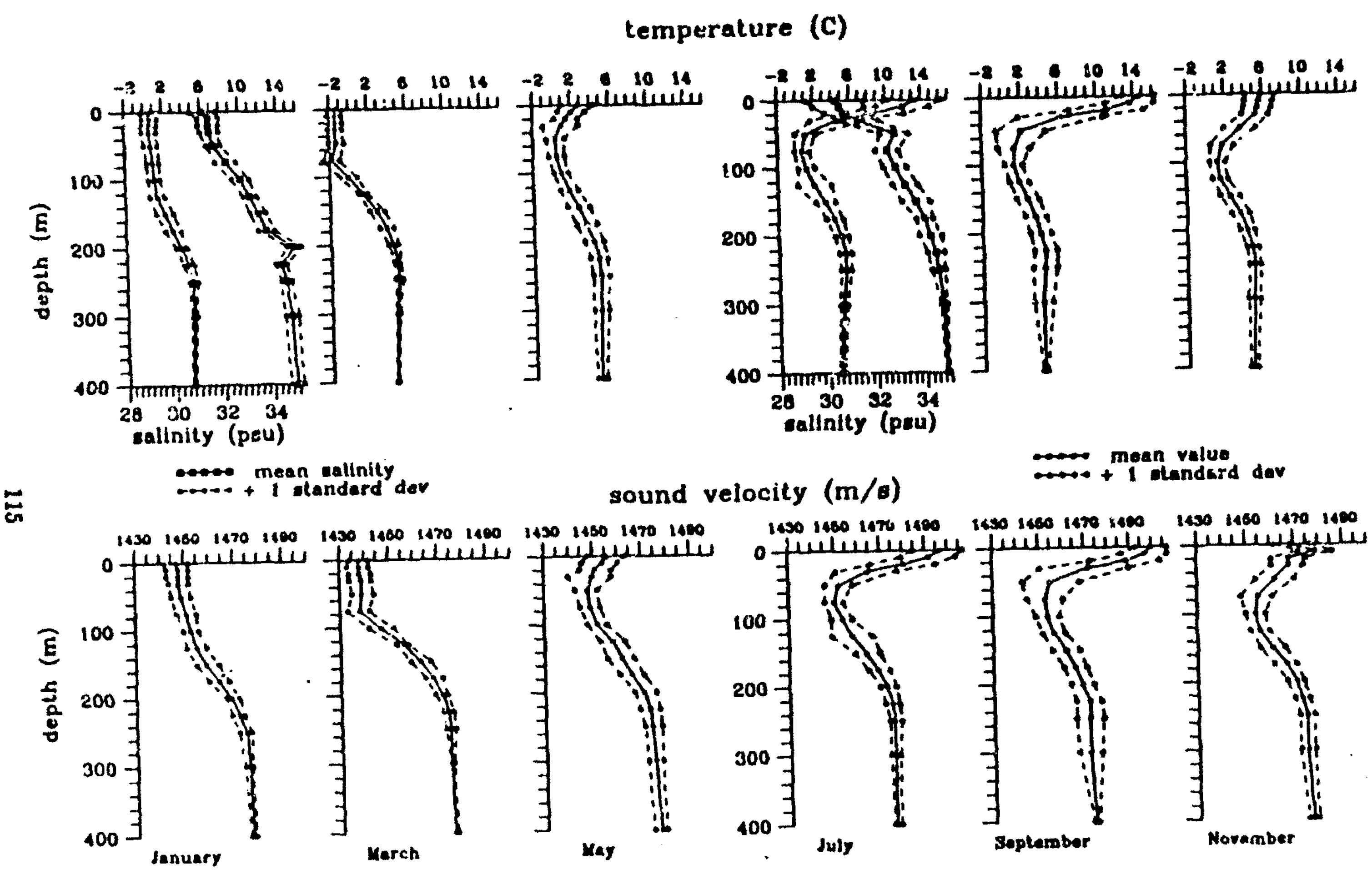


Figure 4.37: Temperature, salinity and sound speed profiles for the Gulf area # 1: Cabot Strait West.

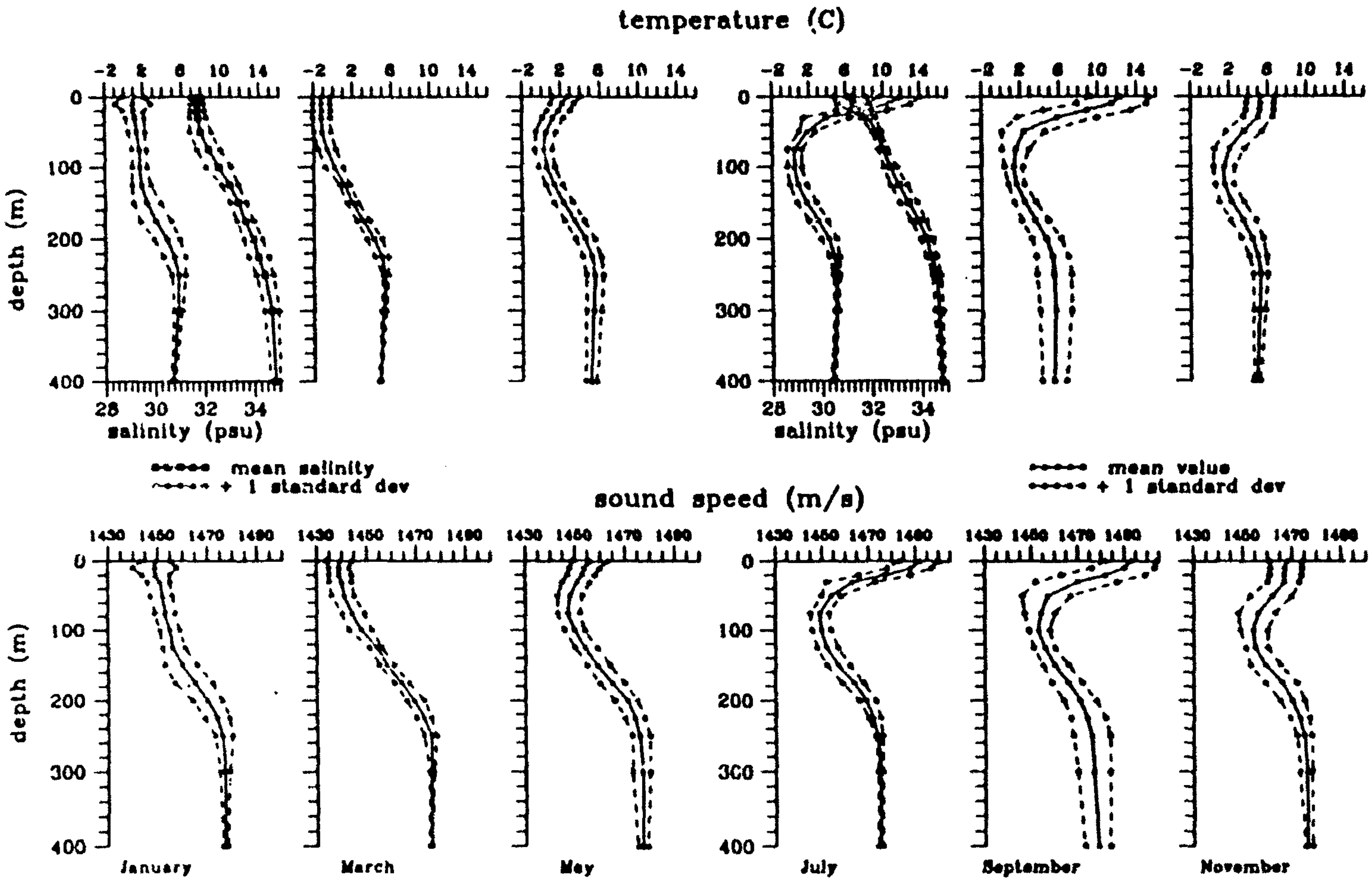


Figure 4.38: Temperature, salinity and sound speed profiles for the Gulf area # 2: Cabot Strait East.

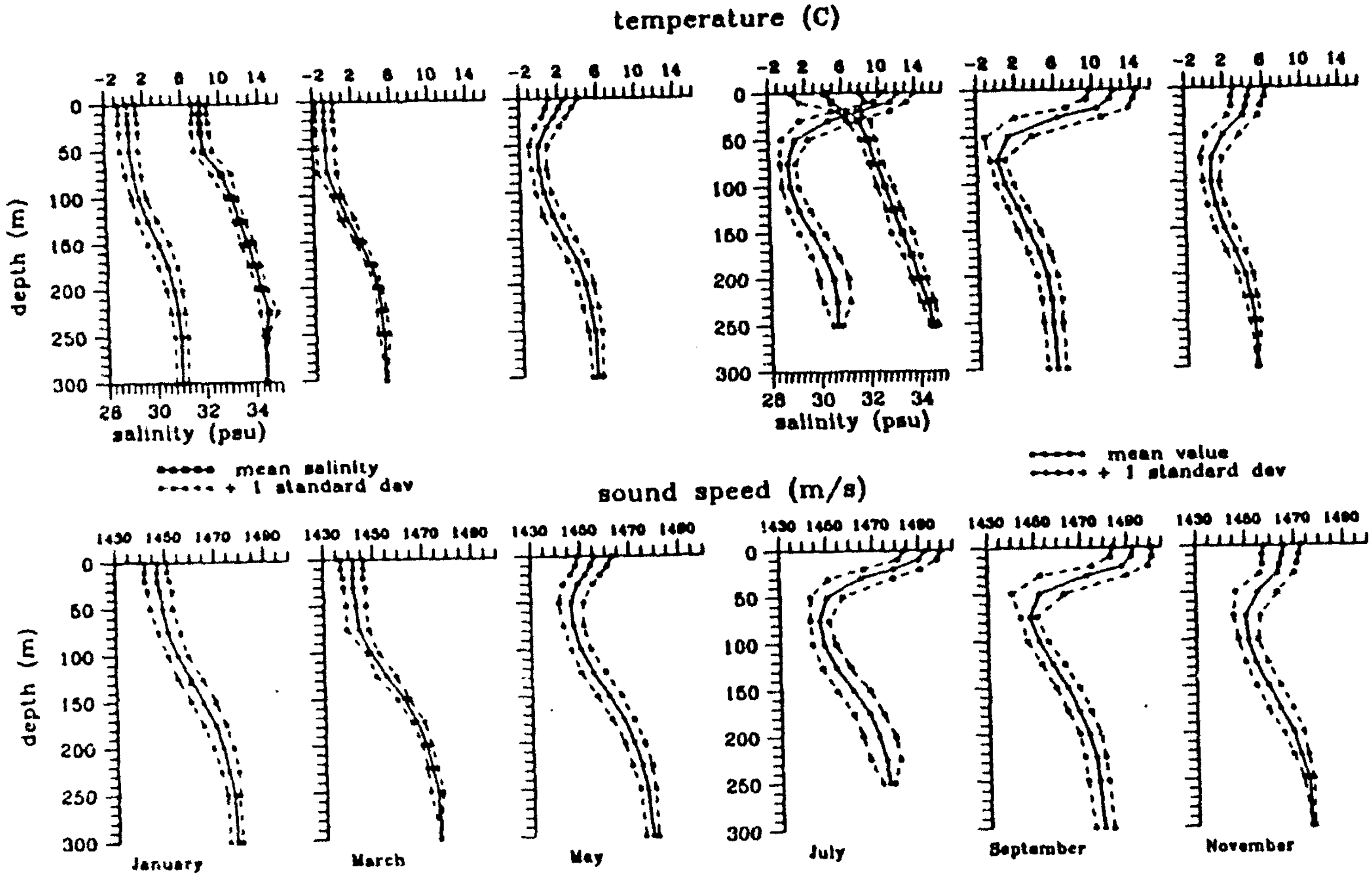


Figure 4.39: Temperature, salinity and sound speed profiles for the Gulf area # 3: Esquiman Channel, Nfdl Shore.

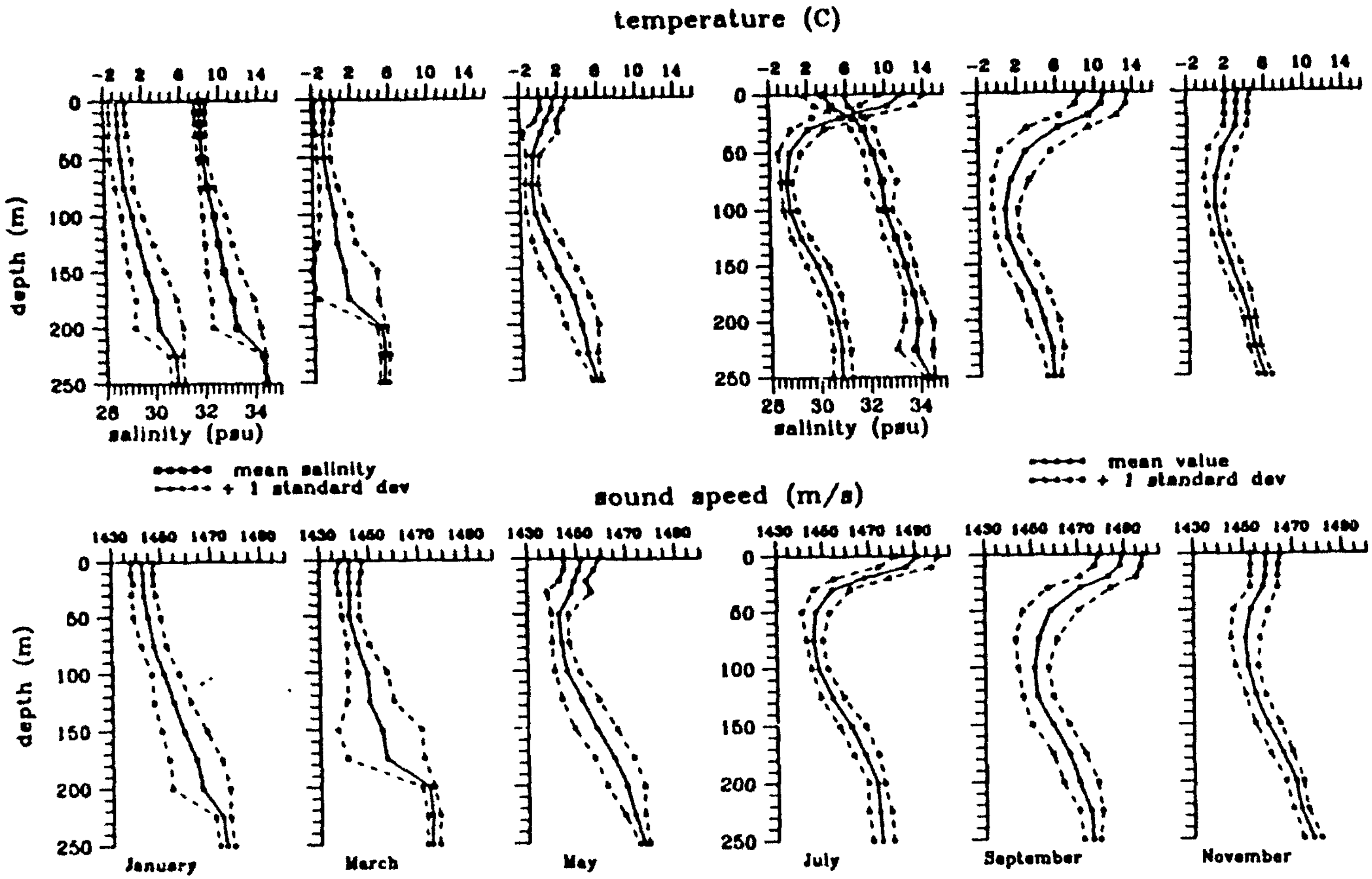


Figure 4.40: Temperature, salinity and sound speed profiles for the Gulf area # 4: Esquiman Channel, Québec Shore.

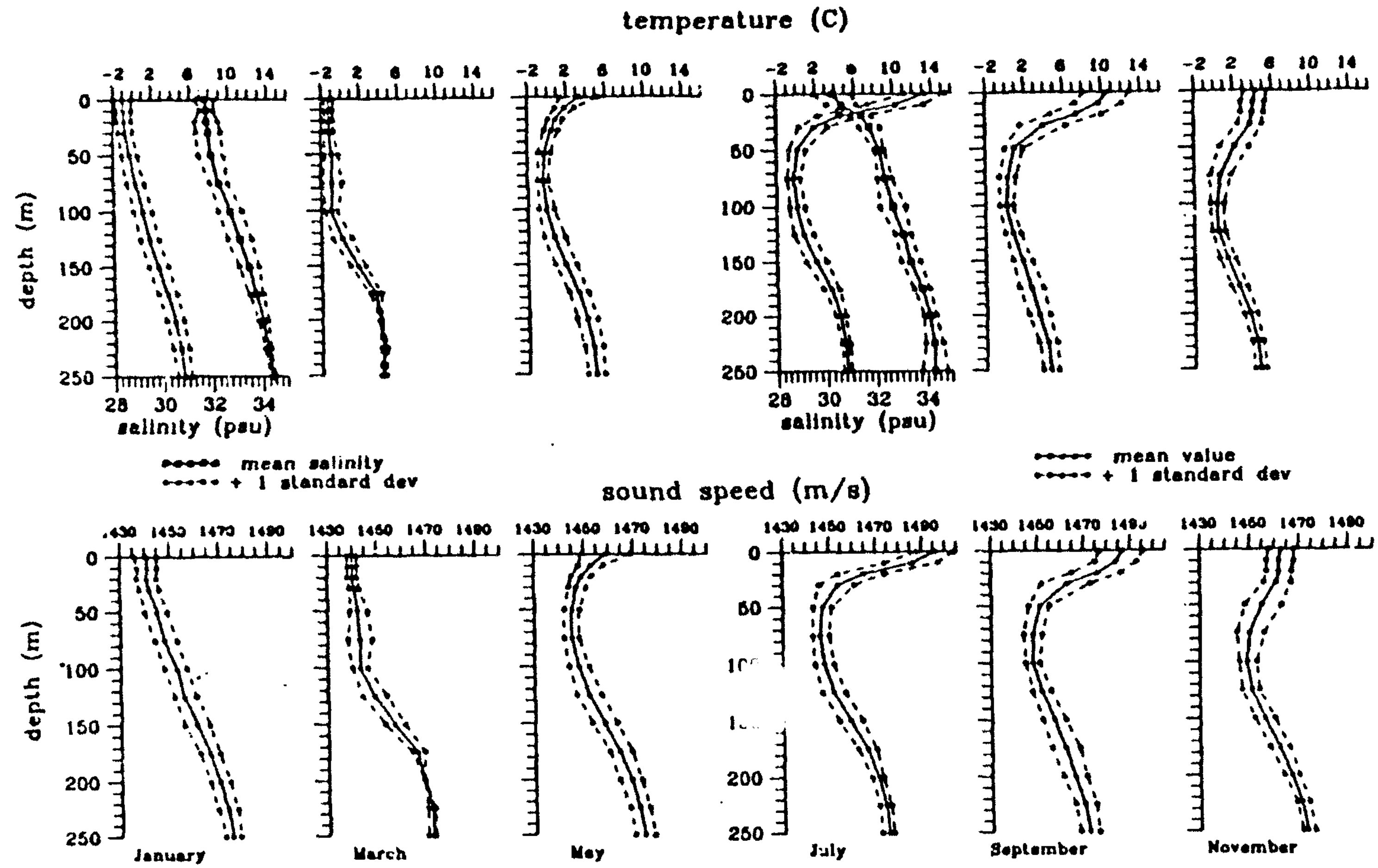


Figure 4.41: Temperature, salinity and sound speed profiles for the Gulf area # 5: Jacques Cartier Passage.

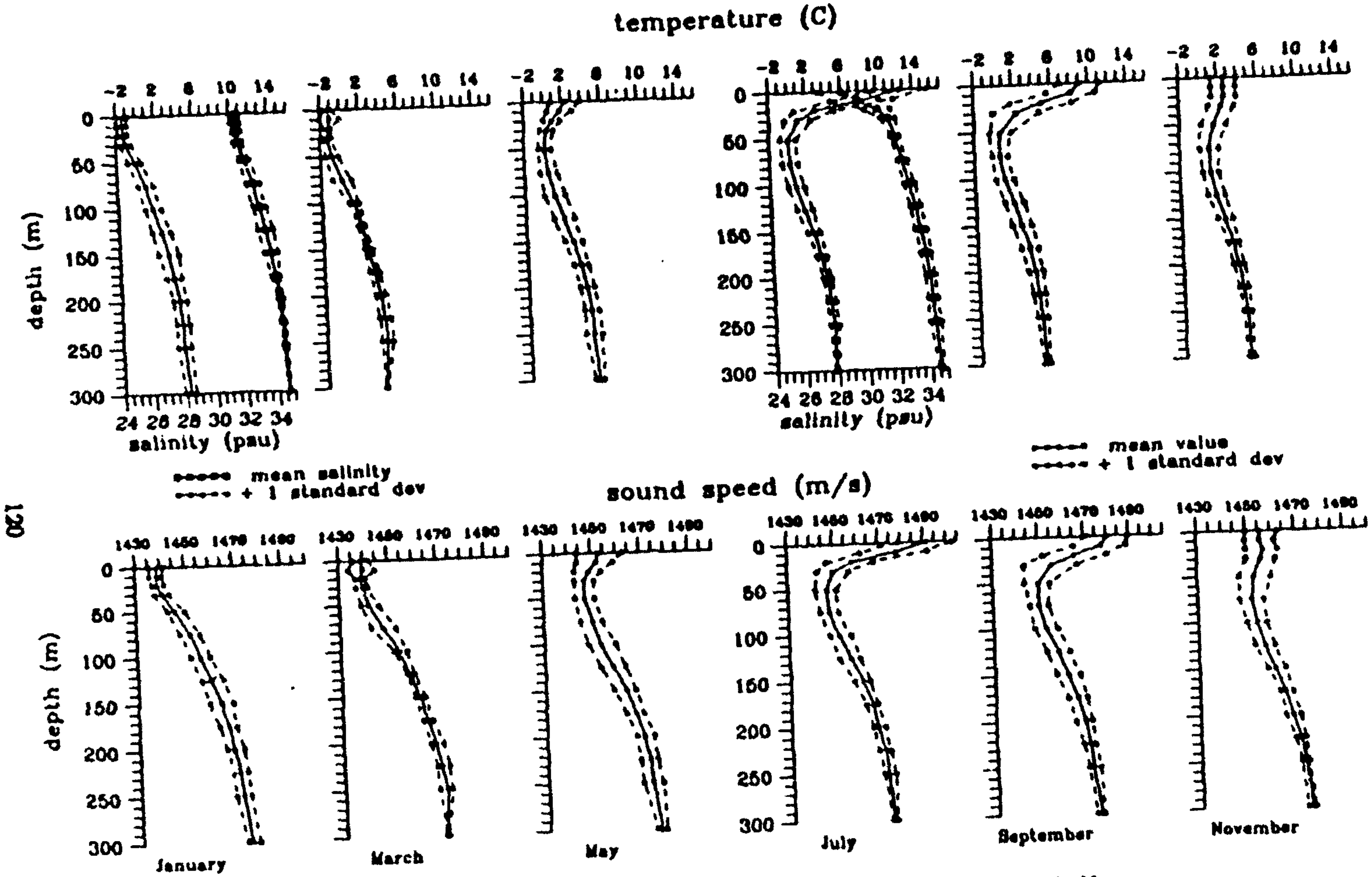


Figure 4.42: Temperature, salinity and sound speed profiles for the Gulf area # 6: Northwest Gulf.

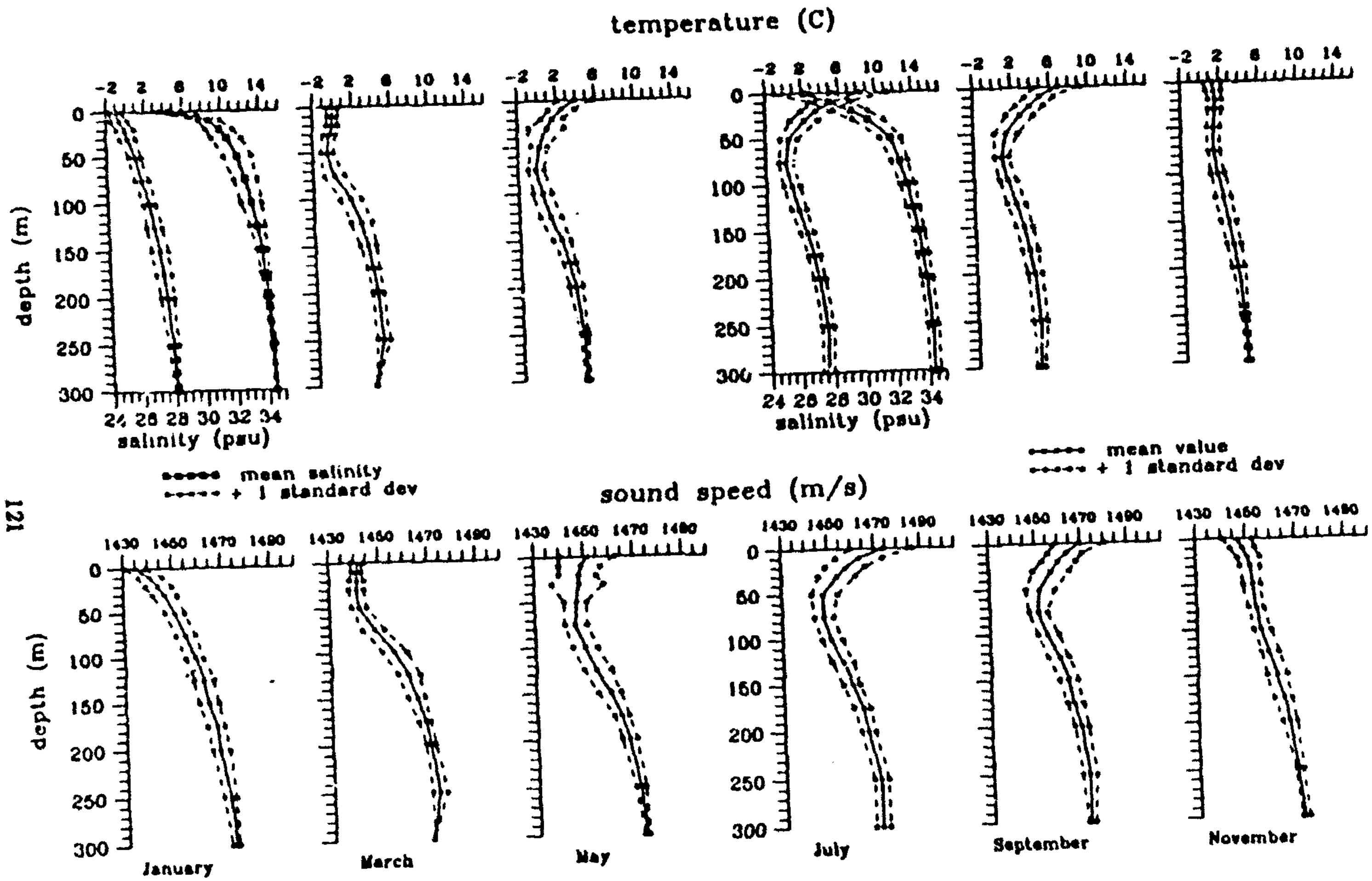


Figure 4.43: Temperature, salinity and sound speed profiles for the Gulf area # 7: Estuary.

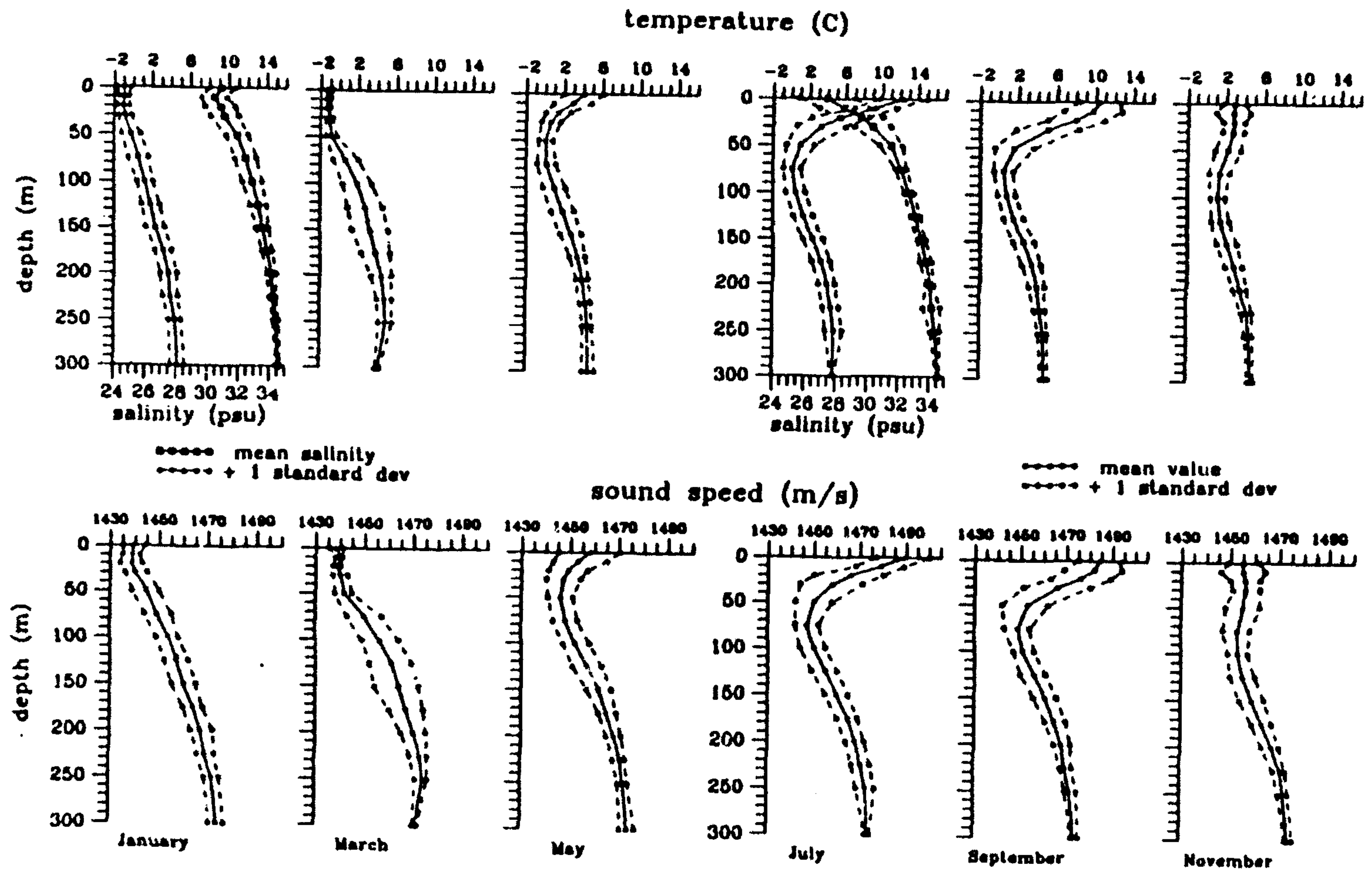


Figure 4.44: Temperature, salinity and sound speed profiles for the Gulf area # 8: Gaspé.

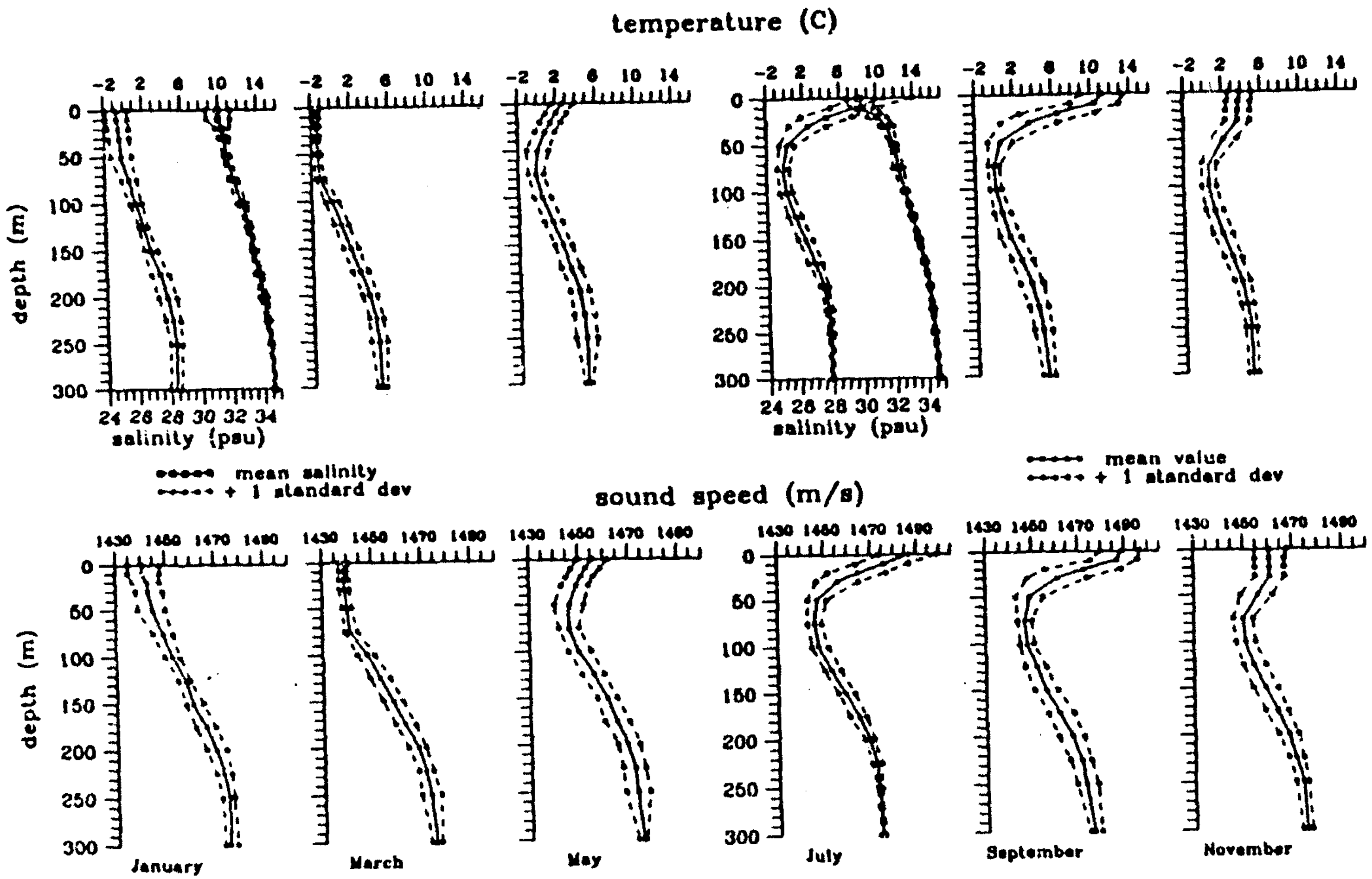


Figure 4.45: Temperature, salinity and sound speed profiles for the Gulf area # 9: Laurentian Channel, Anticosti.

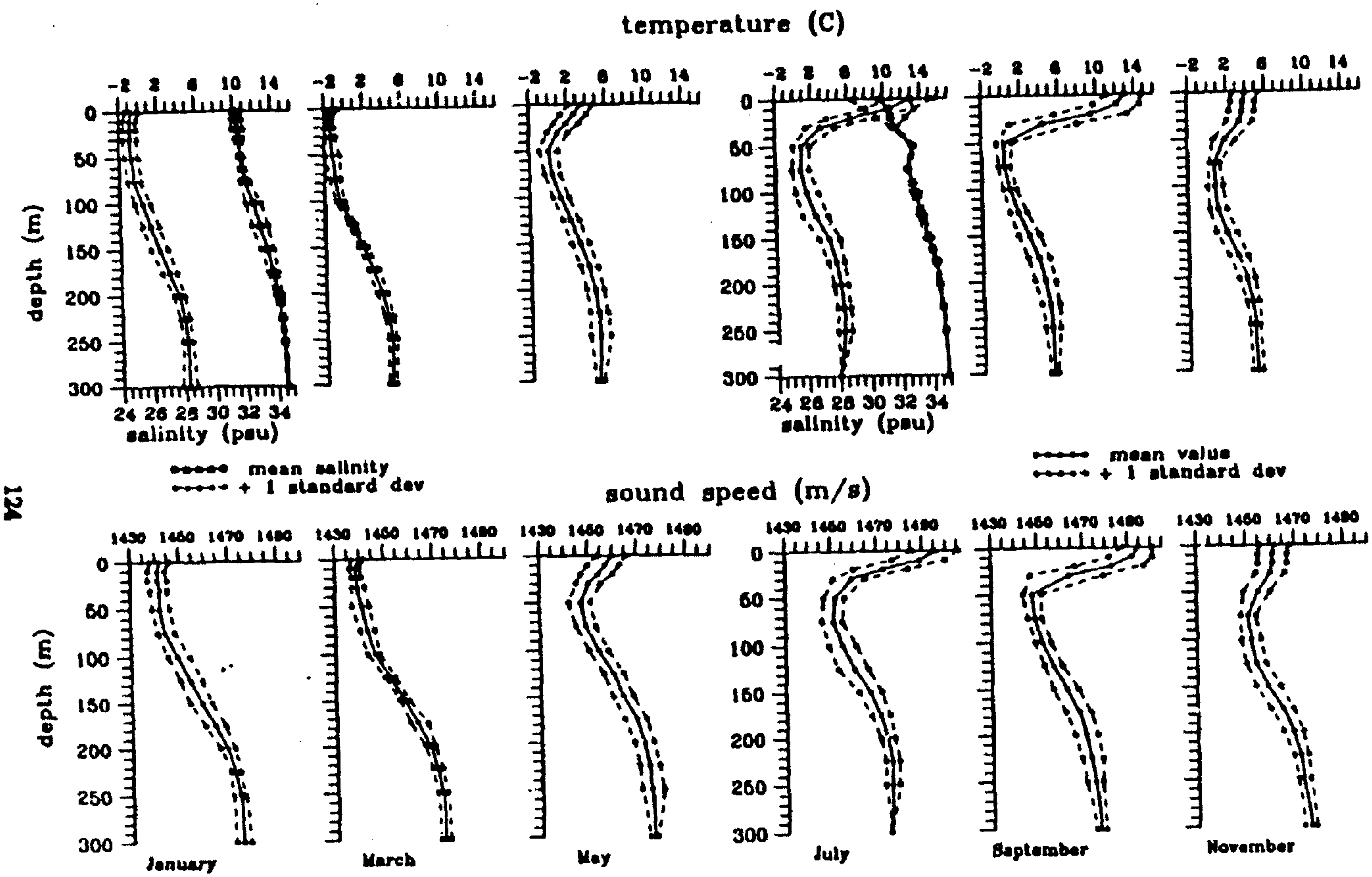


Figure 4.46: Temperature, salinity and sound speed profiles for the Gulf area # 10: Laurentian Channel, Central.

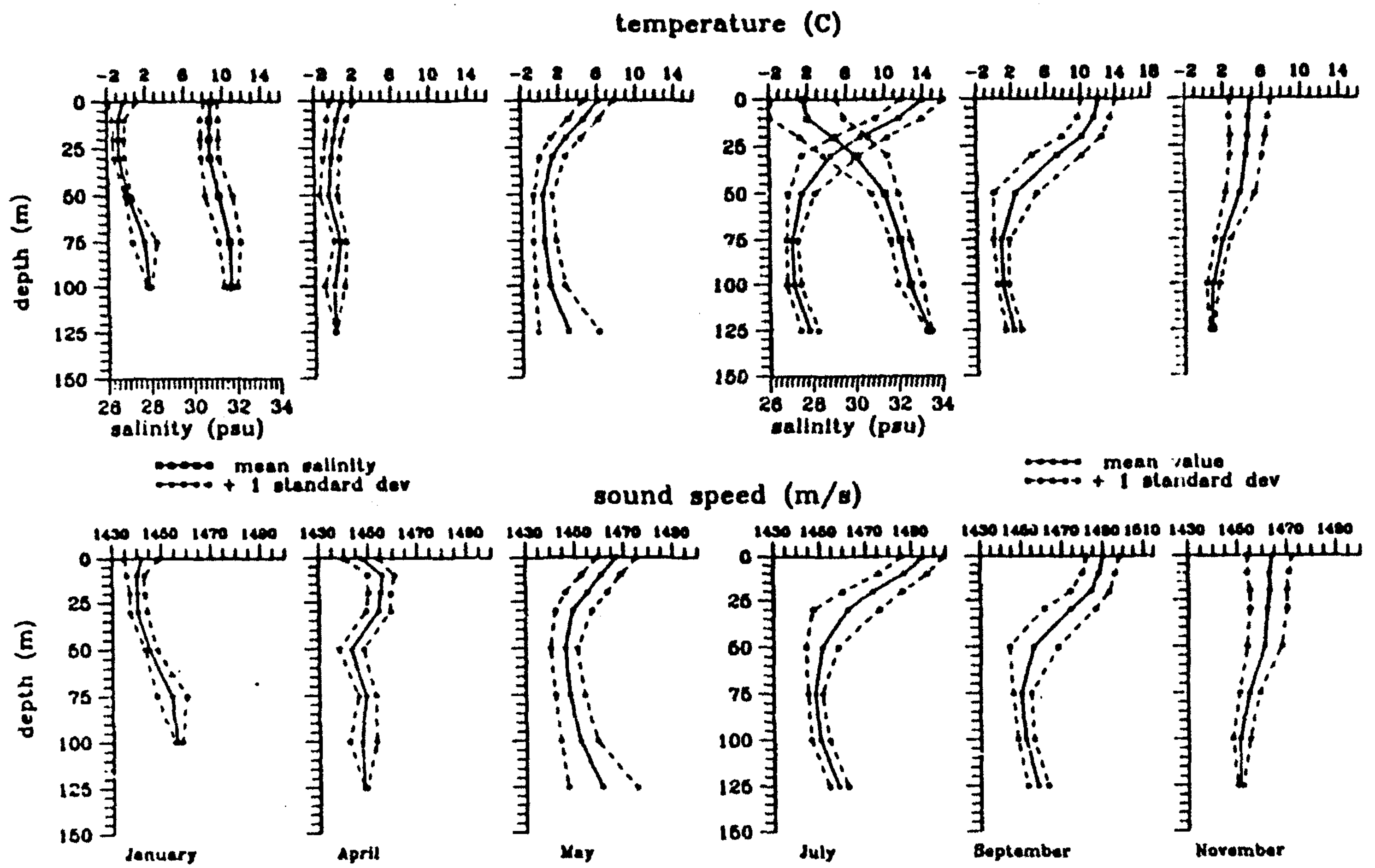


Figure 4.47: Temperature, salinity and sound speed profiles for the Gulf area # 11: Shediac Valley.

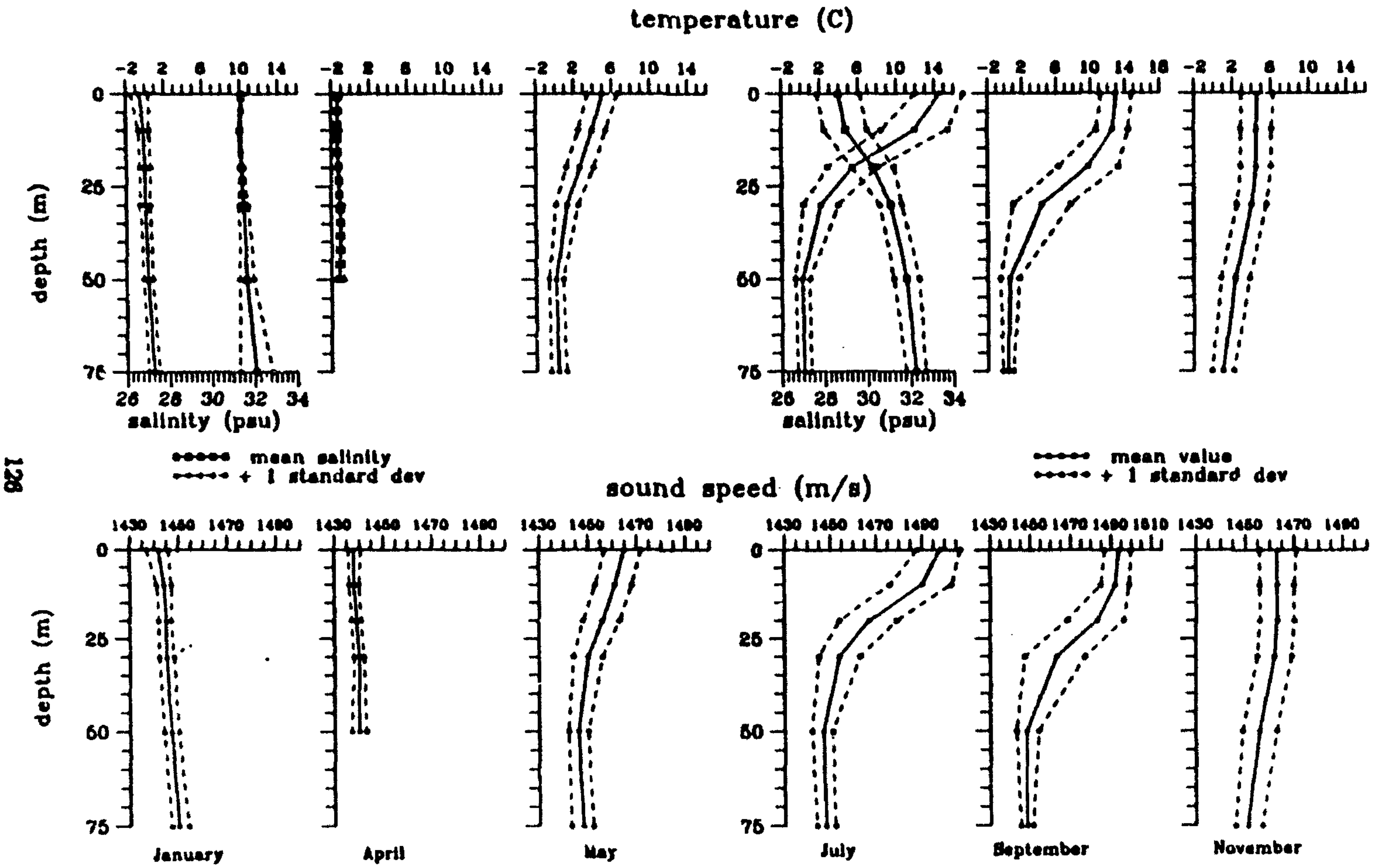


Figure 4.48: Temperature, salinity and sound speed profiles for the Gulf area # 12: Northwest Magdalen Shallows.

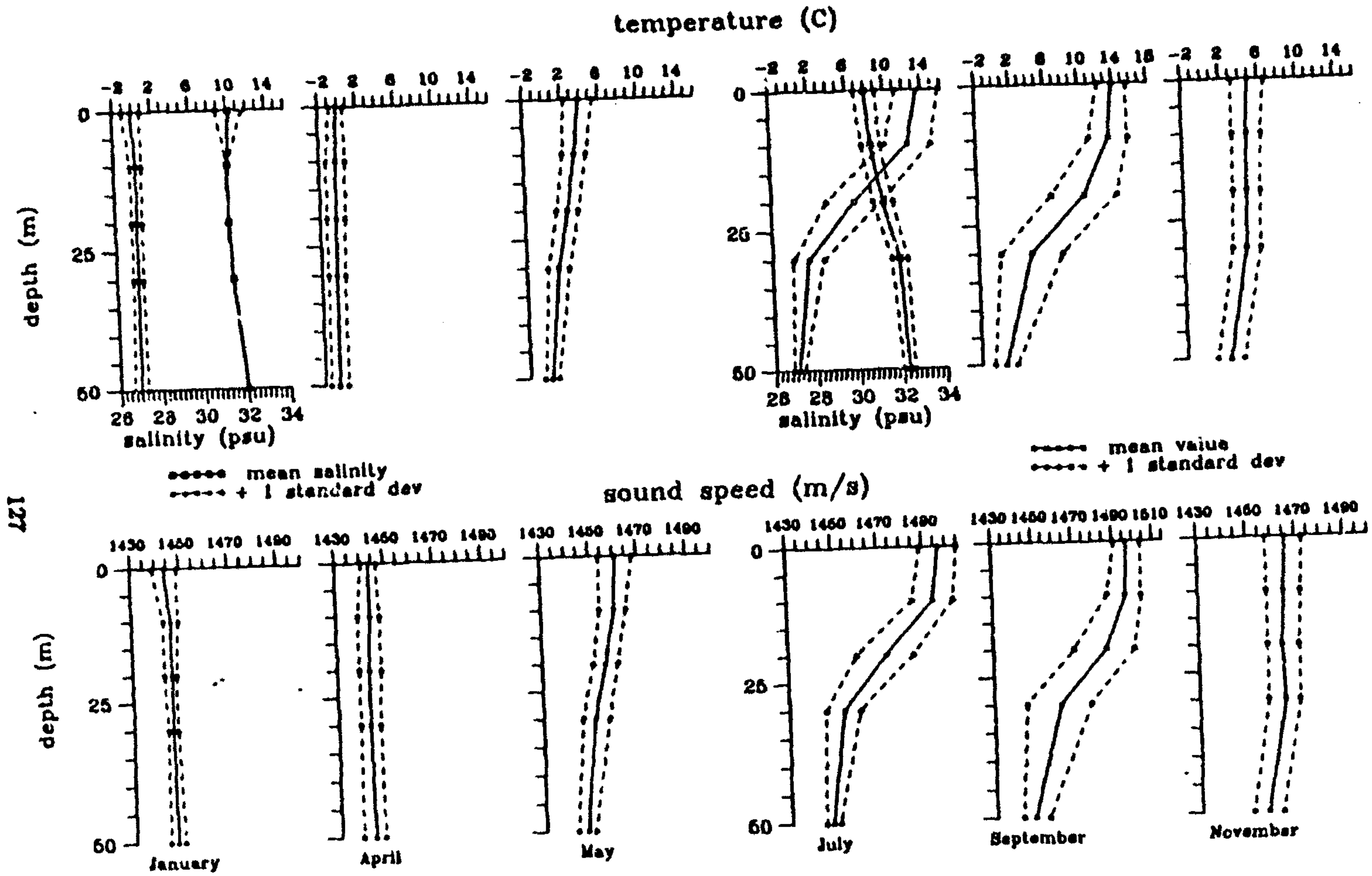


Figure 4.49: Temperature, salinity and sound speed profiles for the Gulf area # 13: Northeast Magdalen Shallows.

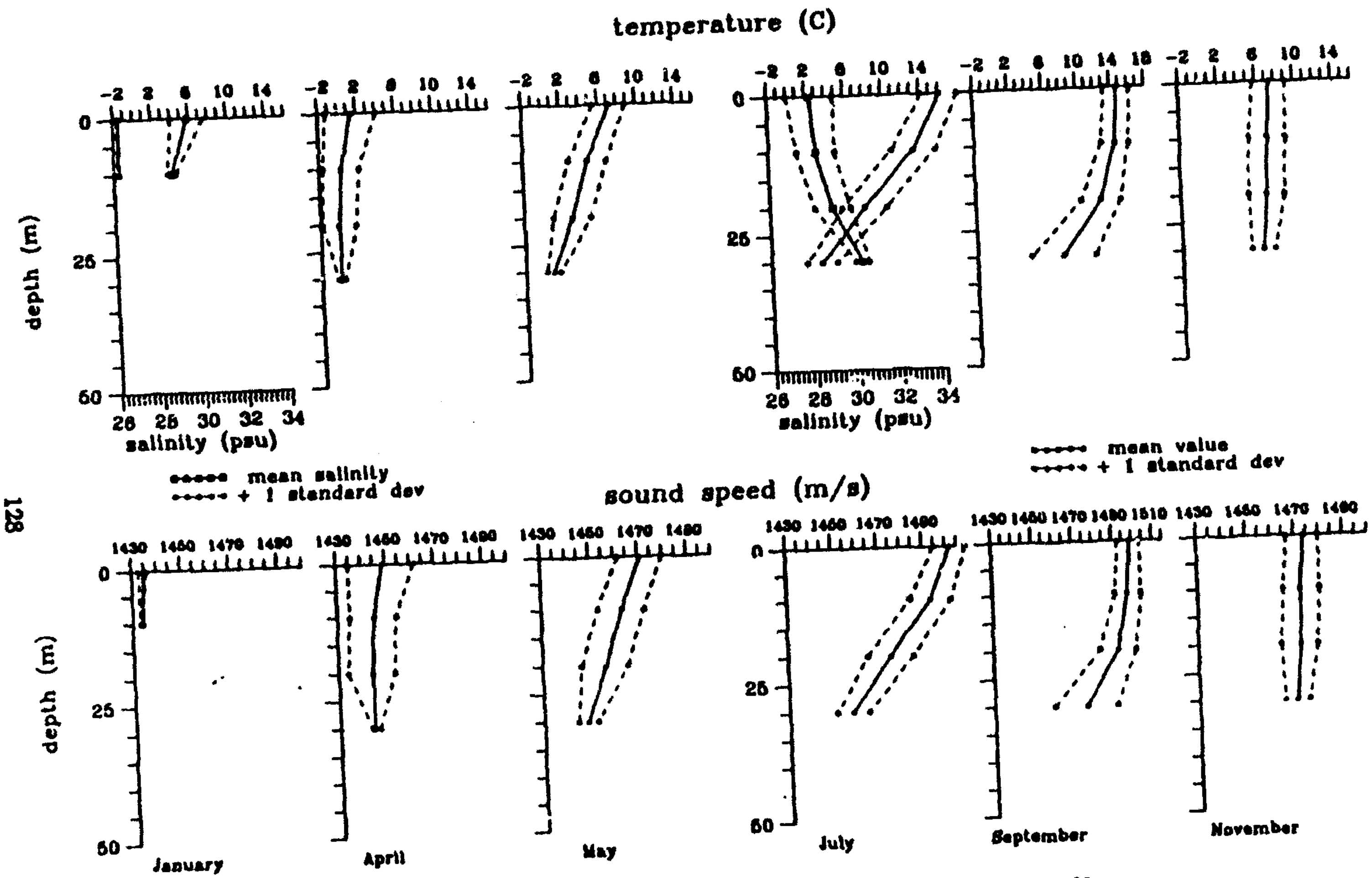


Figure 4.50: Temperature, salinity and sound speed profiles for the Gulf area # 14: Northcumberland Strait West.

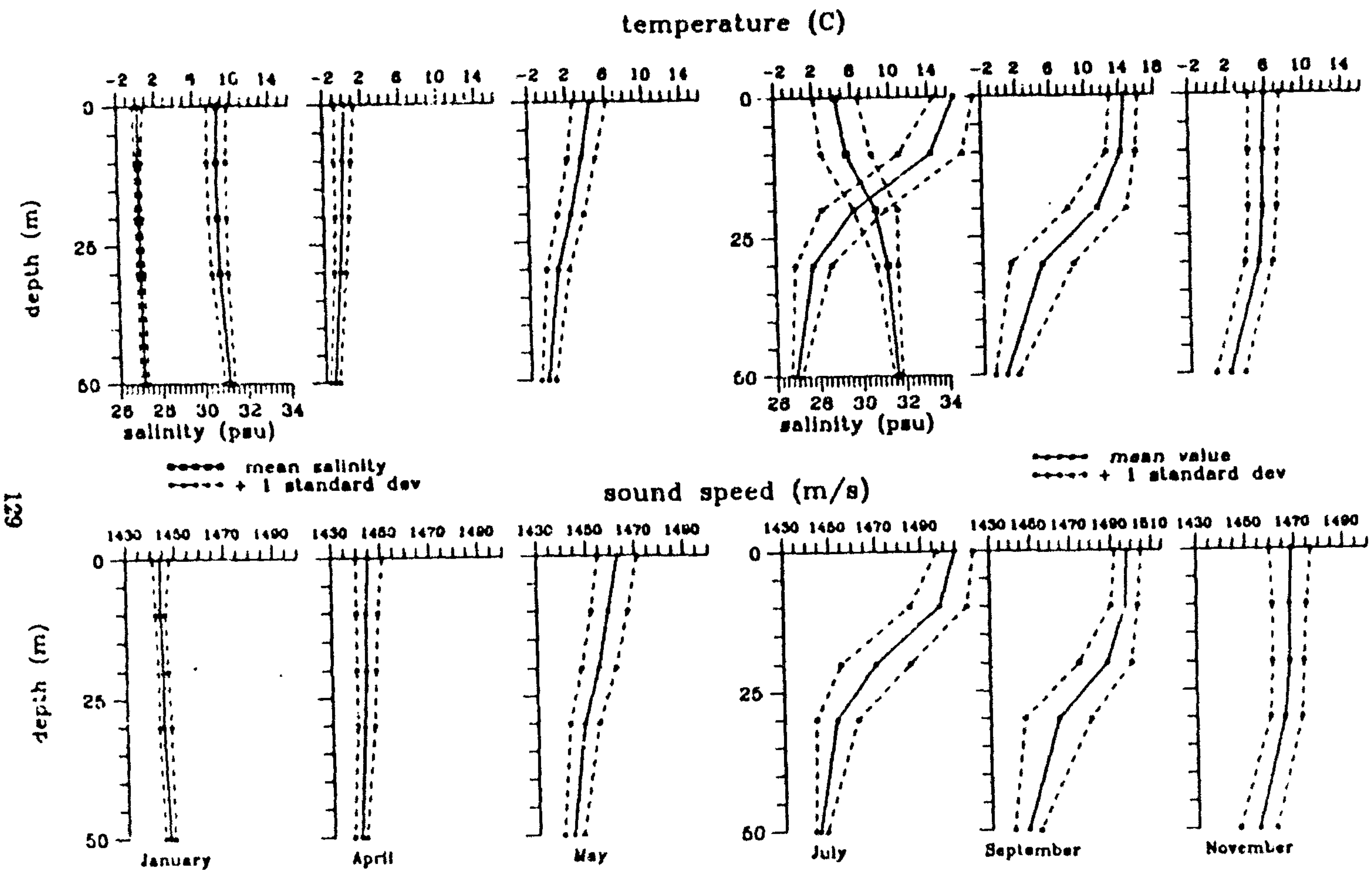


Figure 4.51: Temperature, salinity and sound speed profiles for the Gulf area # 15: Southern Magdalen Shallows.

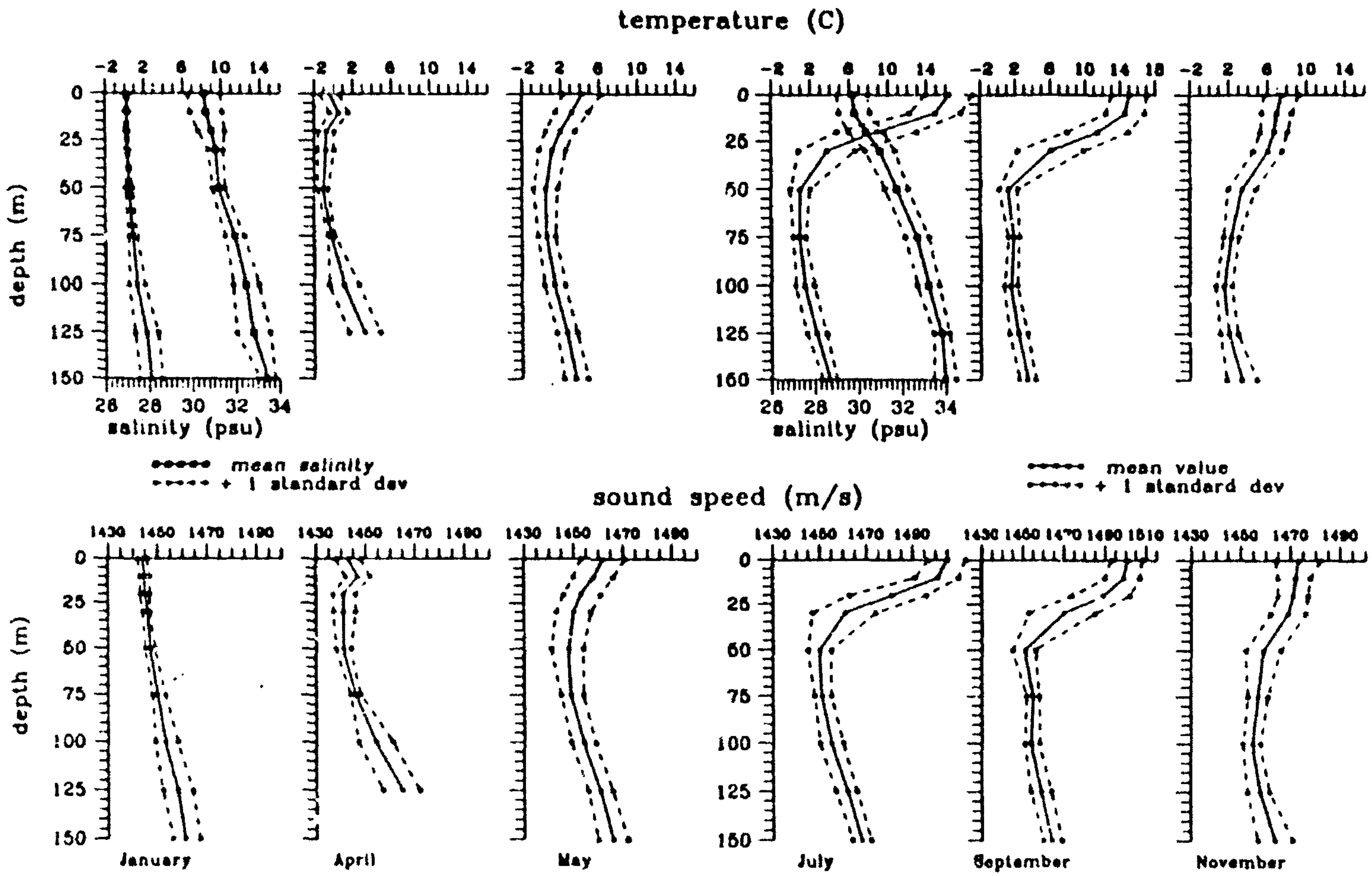


Figure 4.52: Temperature, salinity and sound speed profiles for the Gulf area # 16: Cape Breton Channel.

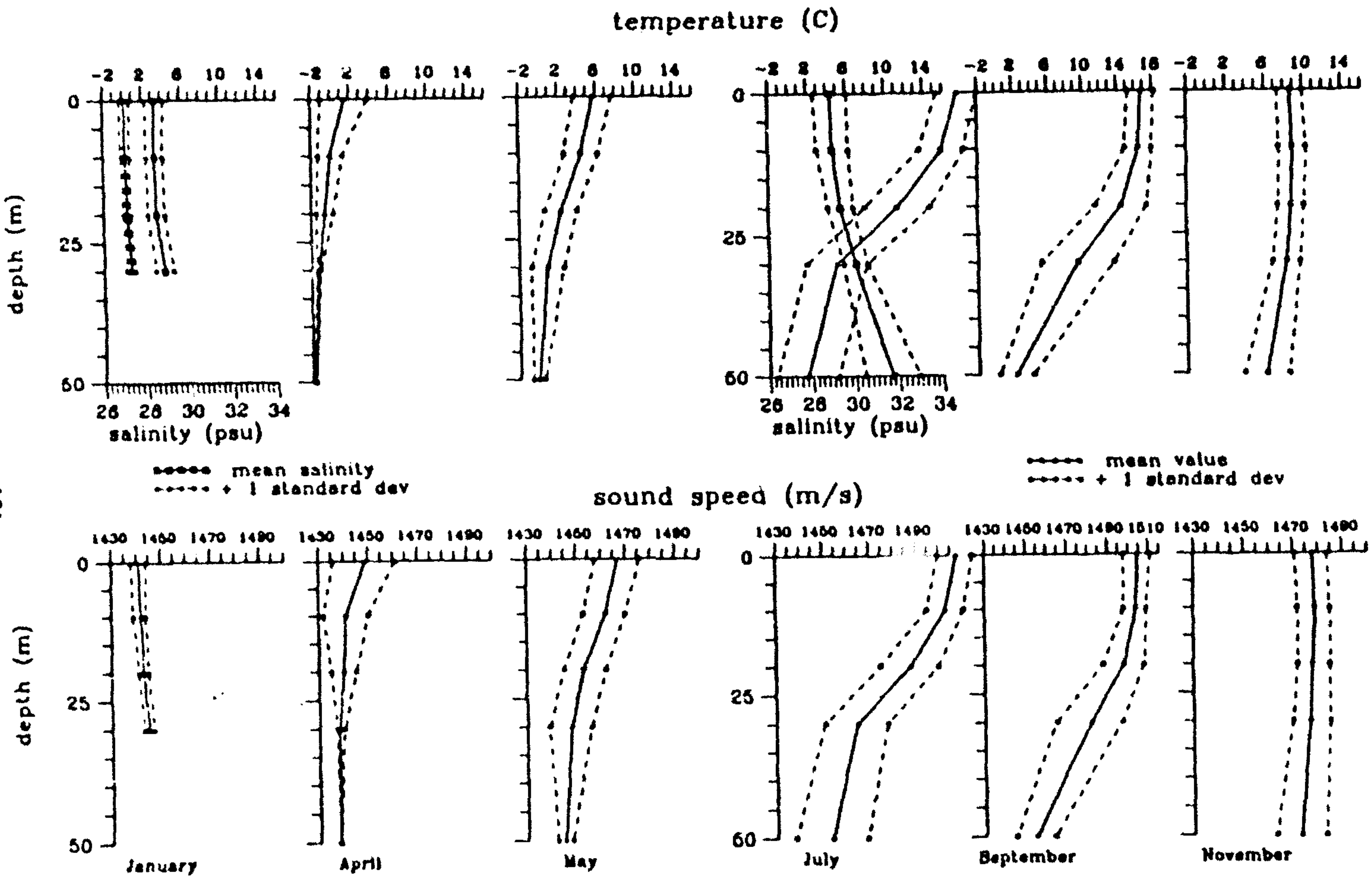


Figure 4.53: Temperature, salinity and sound speed profiles for the Gulf area # 17: Northcumberland Strait East.

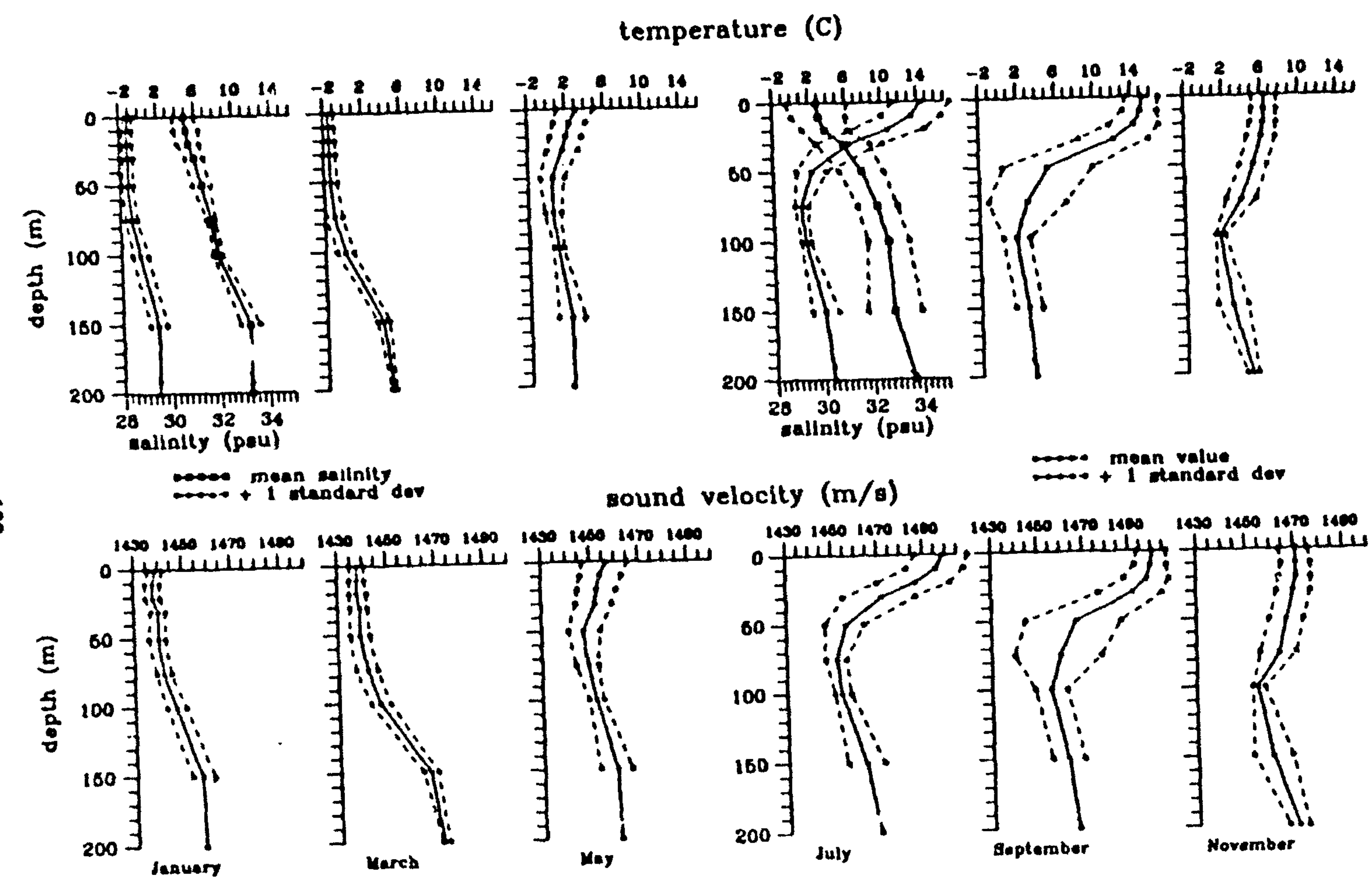


Figure 4.54: Temperature, salinity and sound speed profiles for the Scotian Shelf area # 1: Sydney Bight.

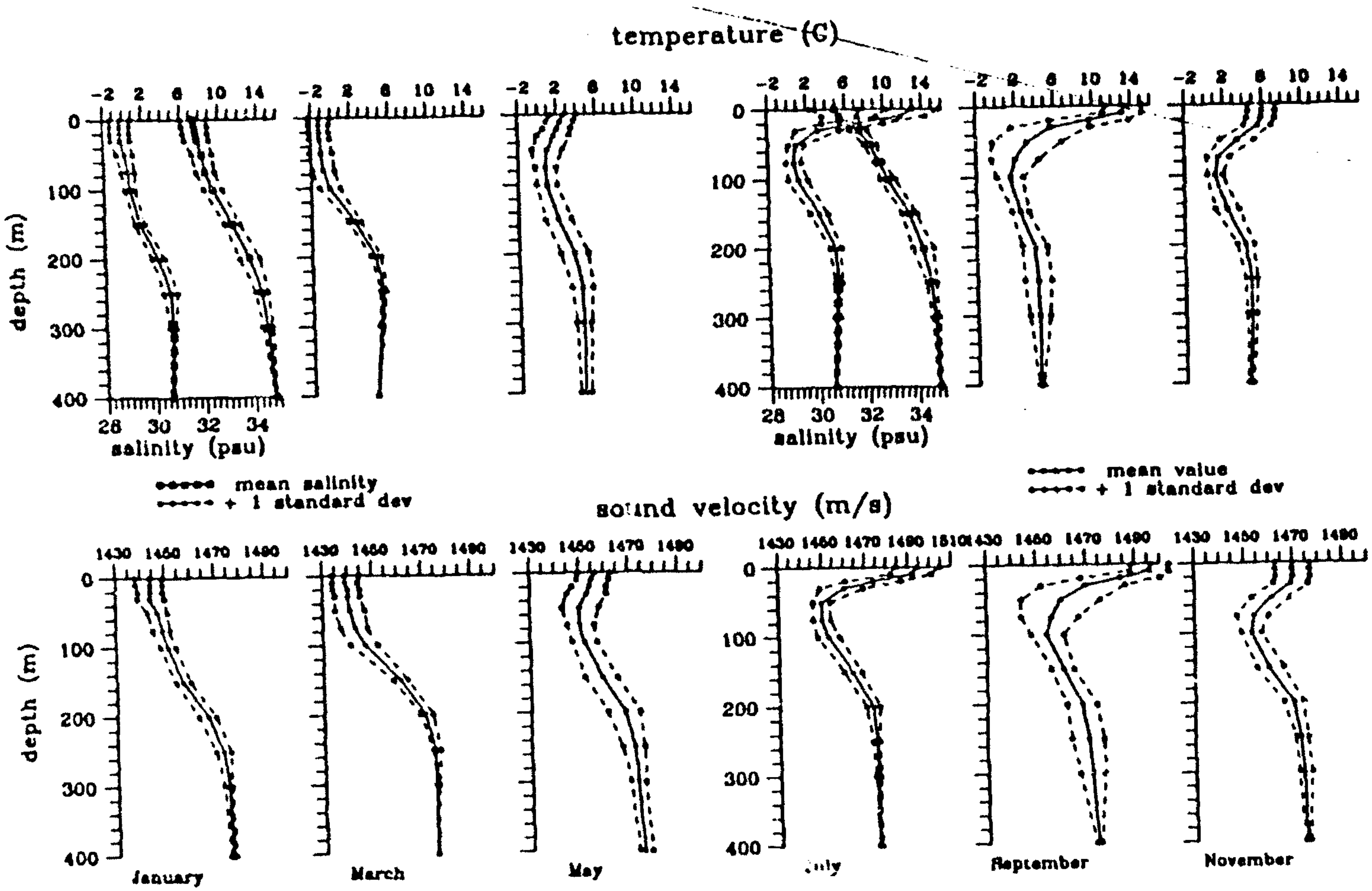


Figure 4.55: Temperature, salinity and sound speed profiles for the Scotian Shelf area #2: North Laurentian Channel.

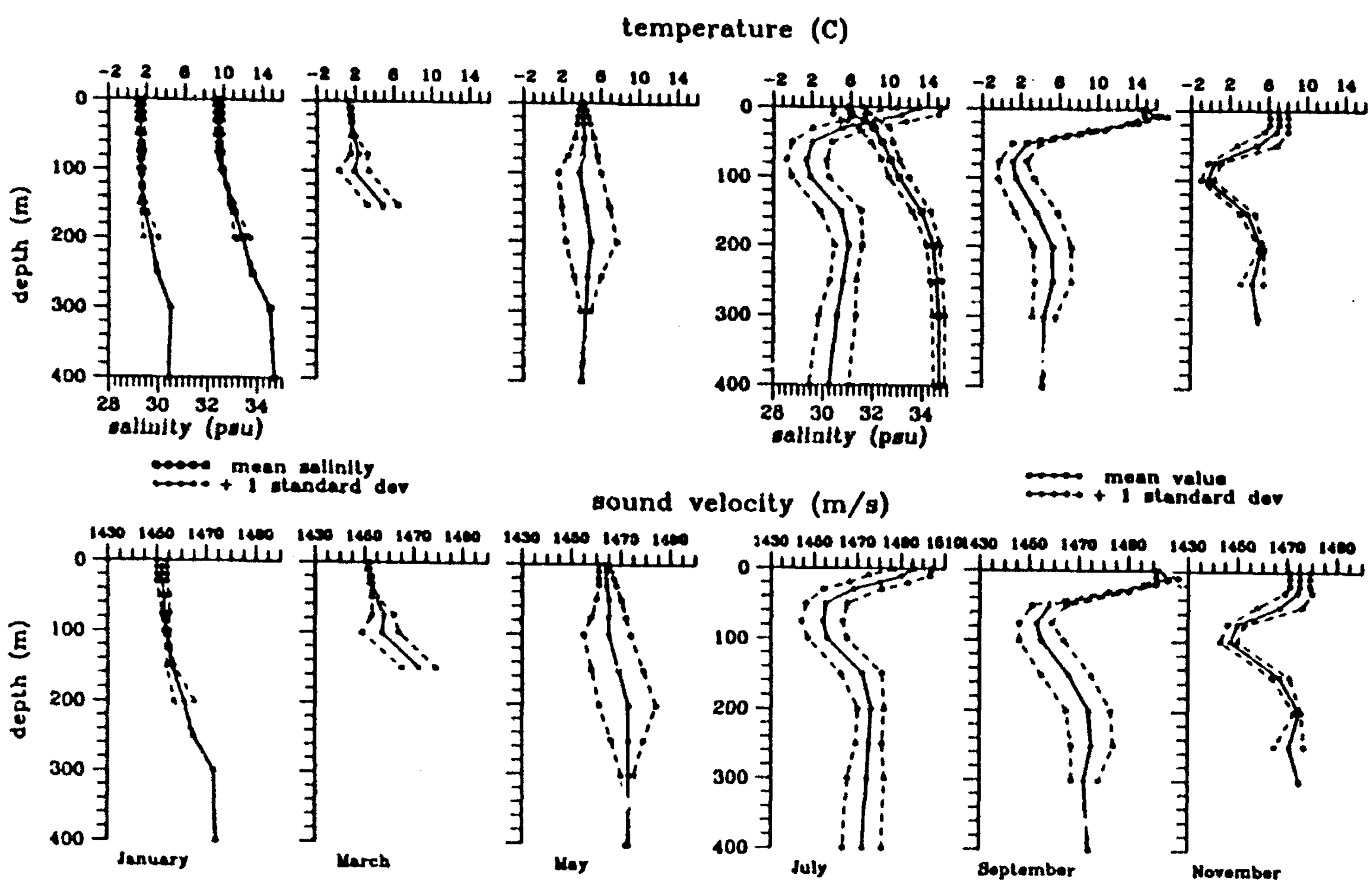


Figure 4.56: Temperature, salinity and sound speed profiles for the Scotian Shelf area # 3: South Laurentian Channel.

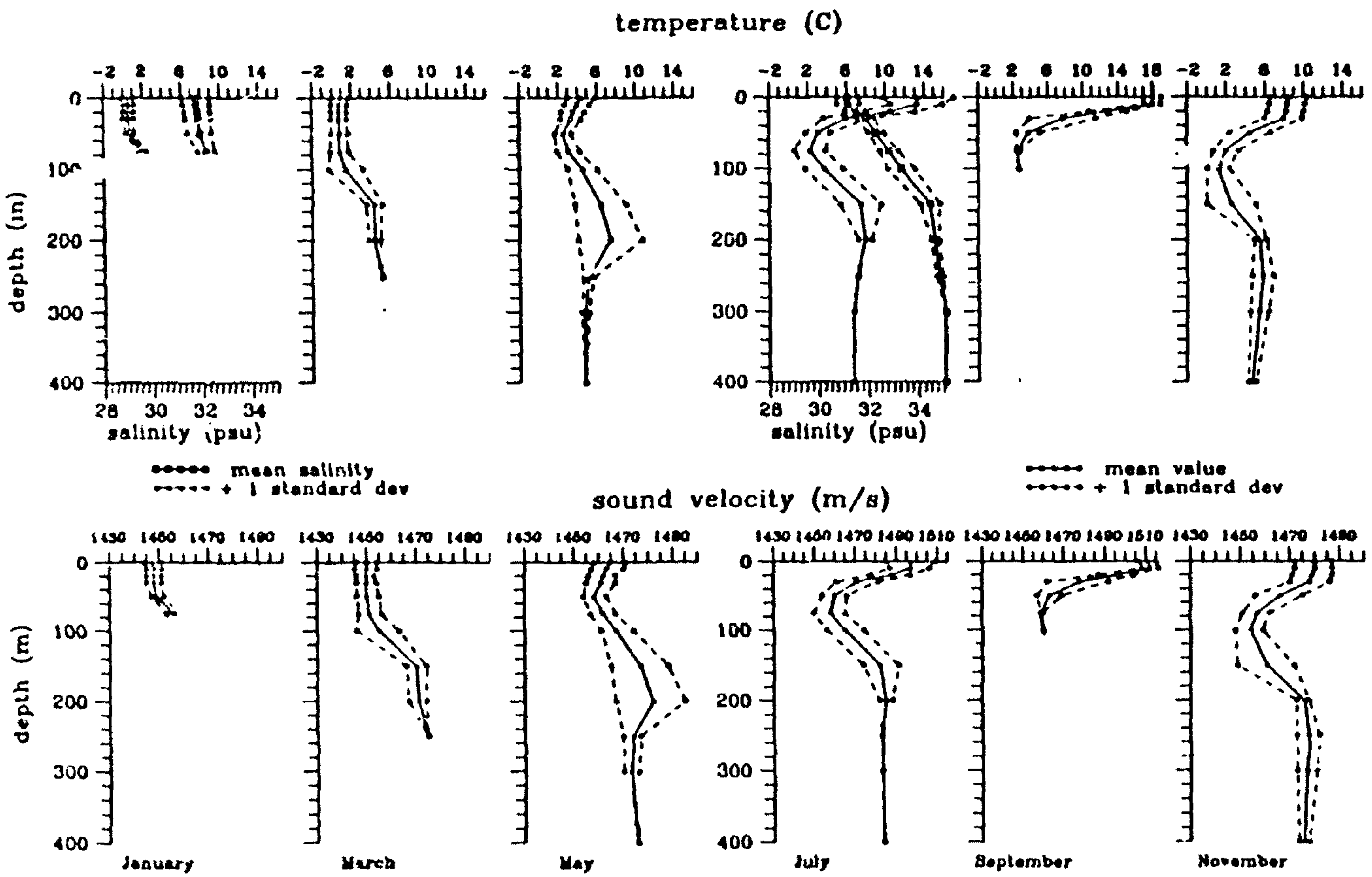


Figure 4.57: Temperature, salinity and sound speed profiles for the Scotian Shelf area #4: Banquereau.

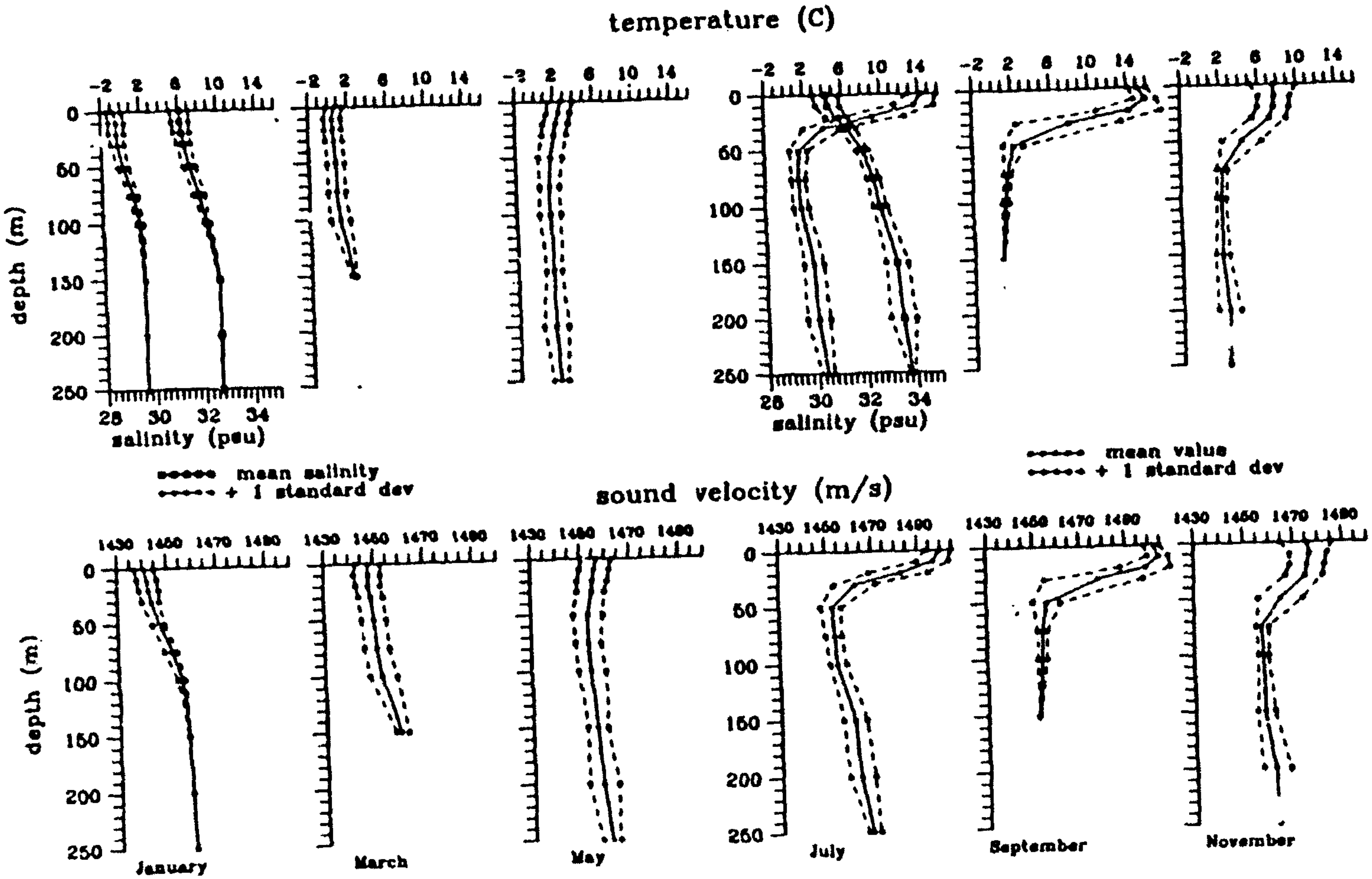


Figure 4.58: Temperature, salinity and sound speed profiles for the Scotian Shelf area # 5: Misaine Bank. (Can be used for Area # 7.)

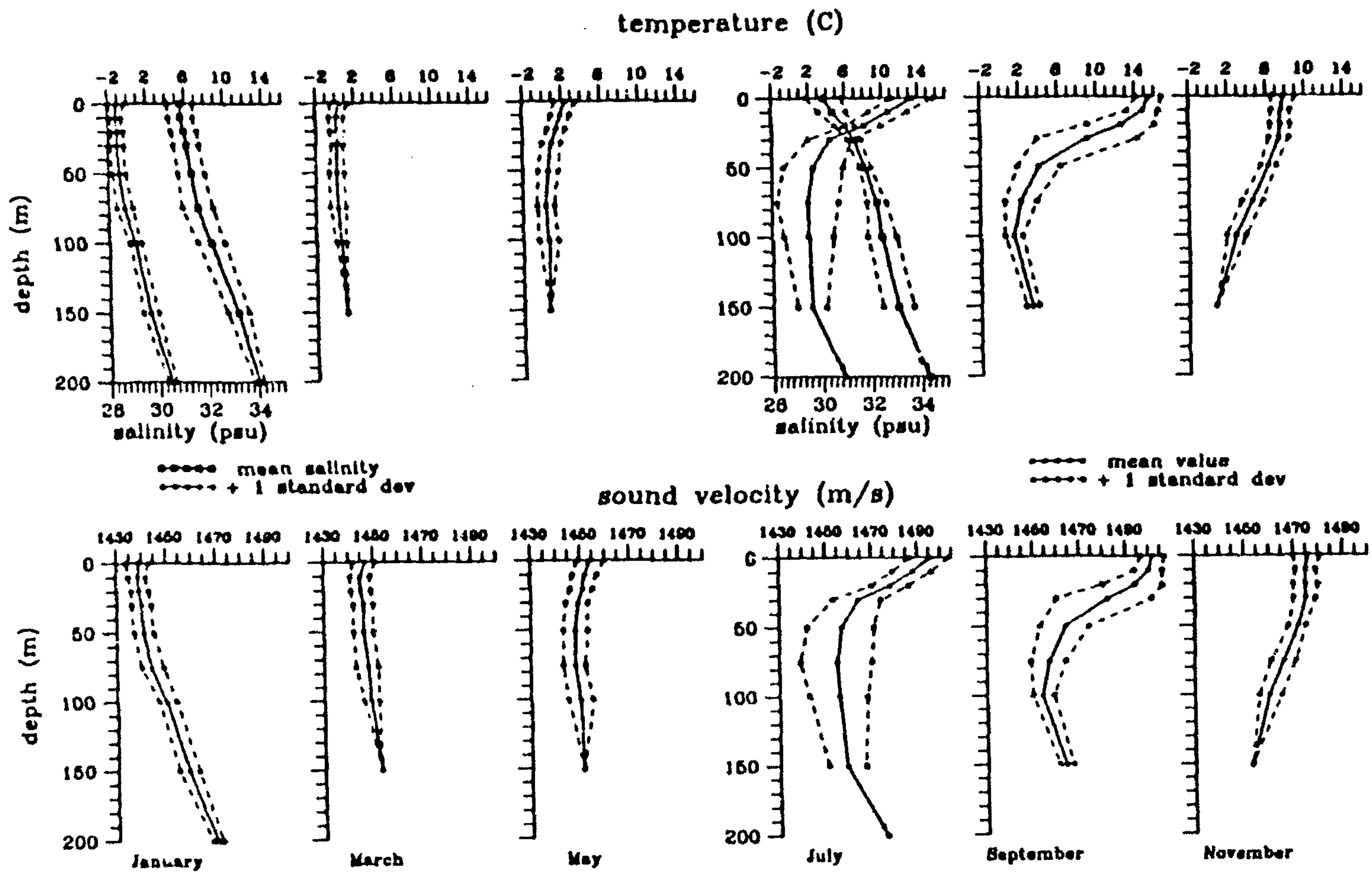


Figure 4.59: Temperature, salinity and sound speed profiles for the Scotian Shelf area # 6: Canso. (Can be used for Area # 13.)

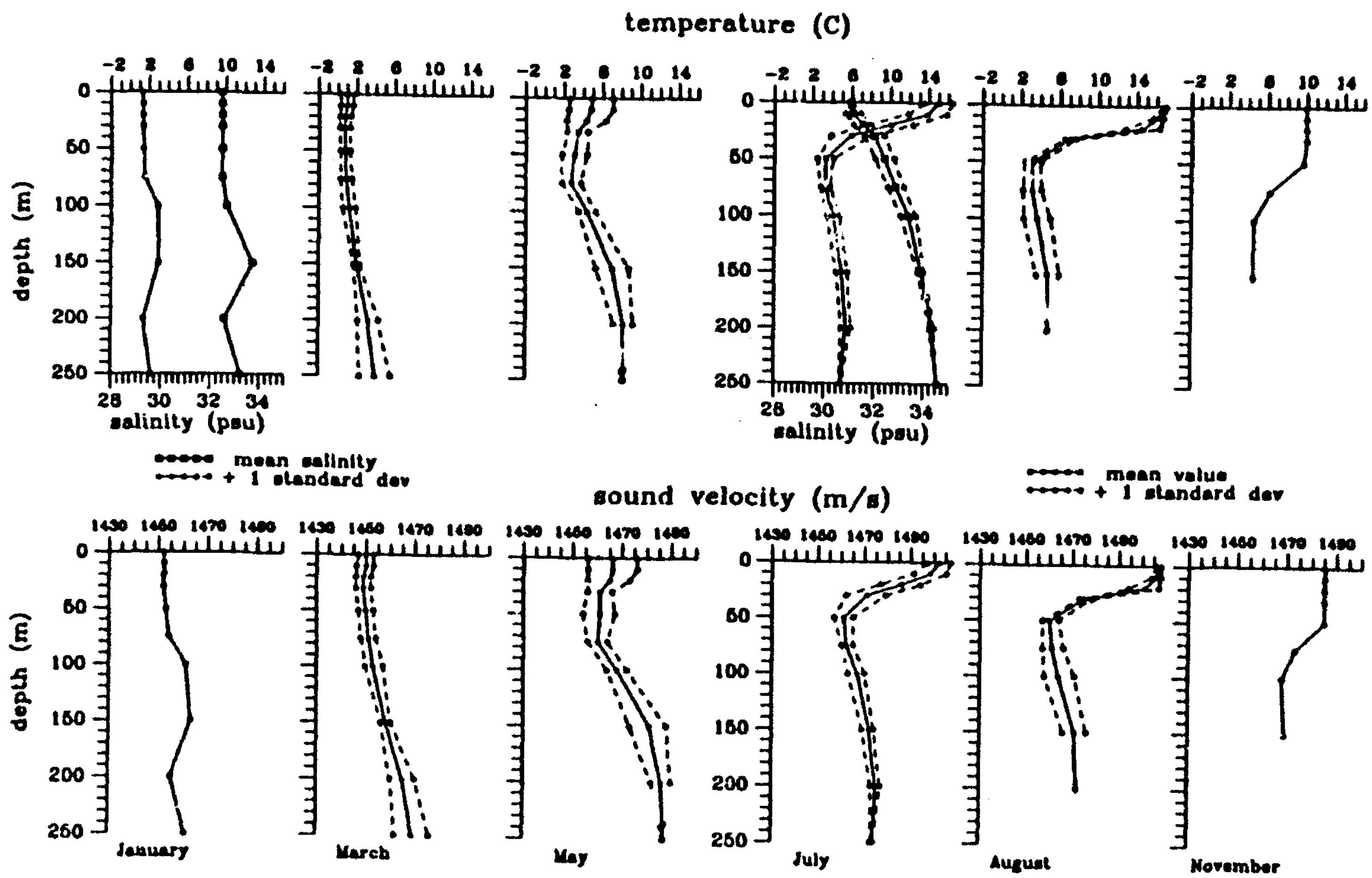


Figure 4.60: Temperature, salinity and sound speed profiles for the Scotian Shelf area # 8: The Gully.

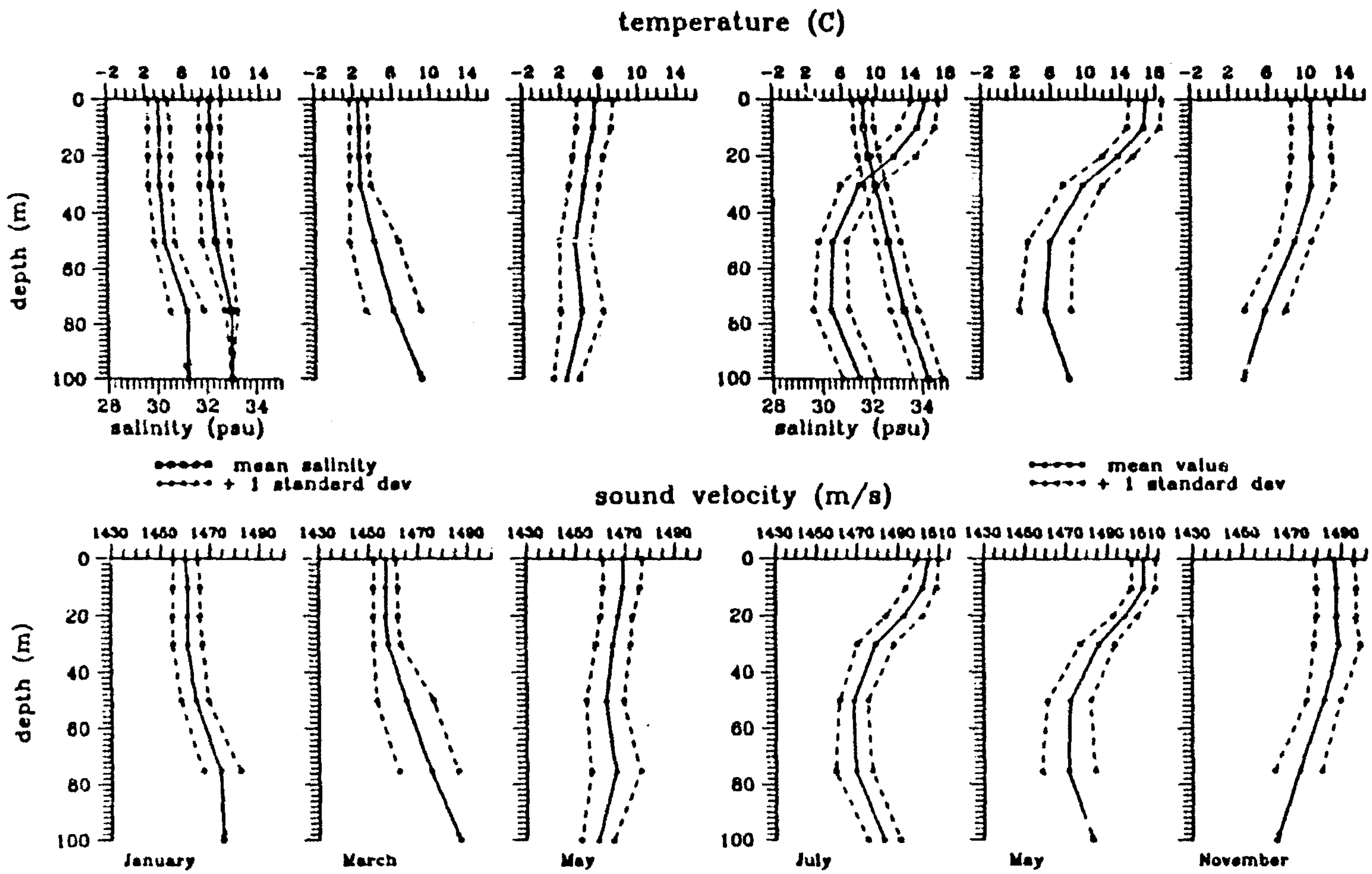


Figure 4.61: Temperature, salinity and sound speed profiles for the Scotian Shelf area # 10: Western Bank. (Can be used for Area # 9.)

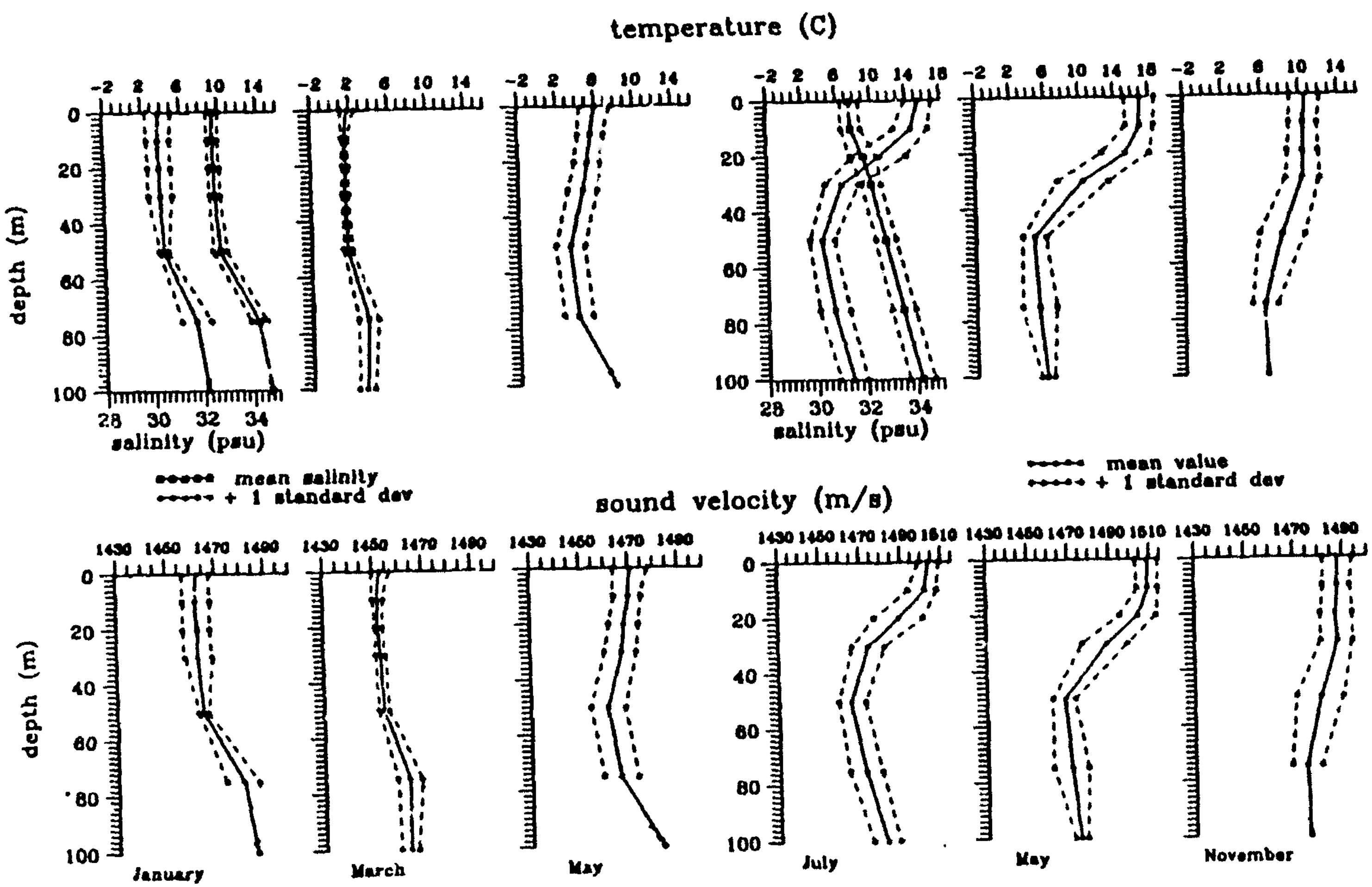


Figure 4.62: Temperature, salinity and sound speed profiles for the Scotian Shelf area # 11: Emerald Bank.

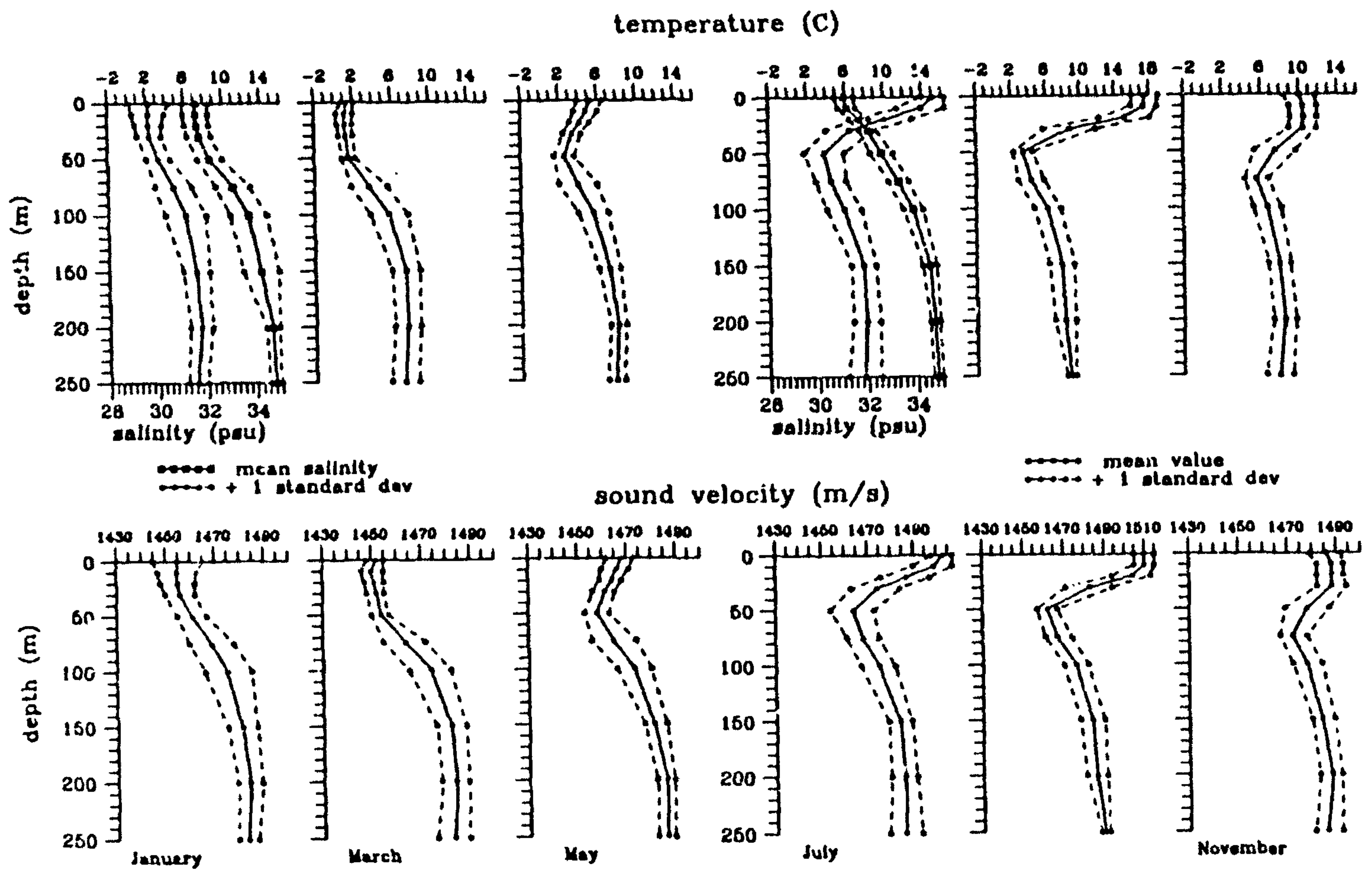


Figure 4.63: Temperature, salinity and sound speed profiles for the Scotian Shelf area # 12: Emerald Basin. (Can be used for Area # 15.)

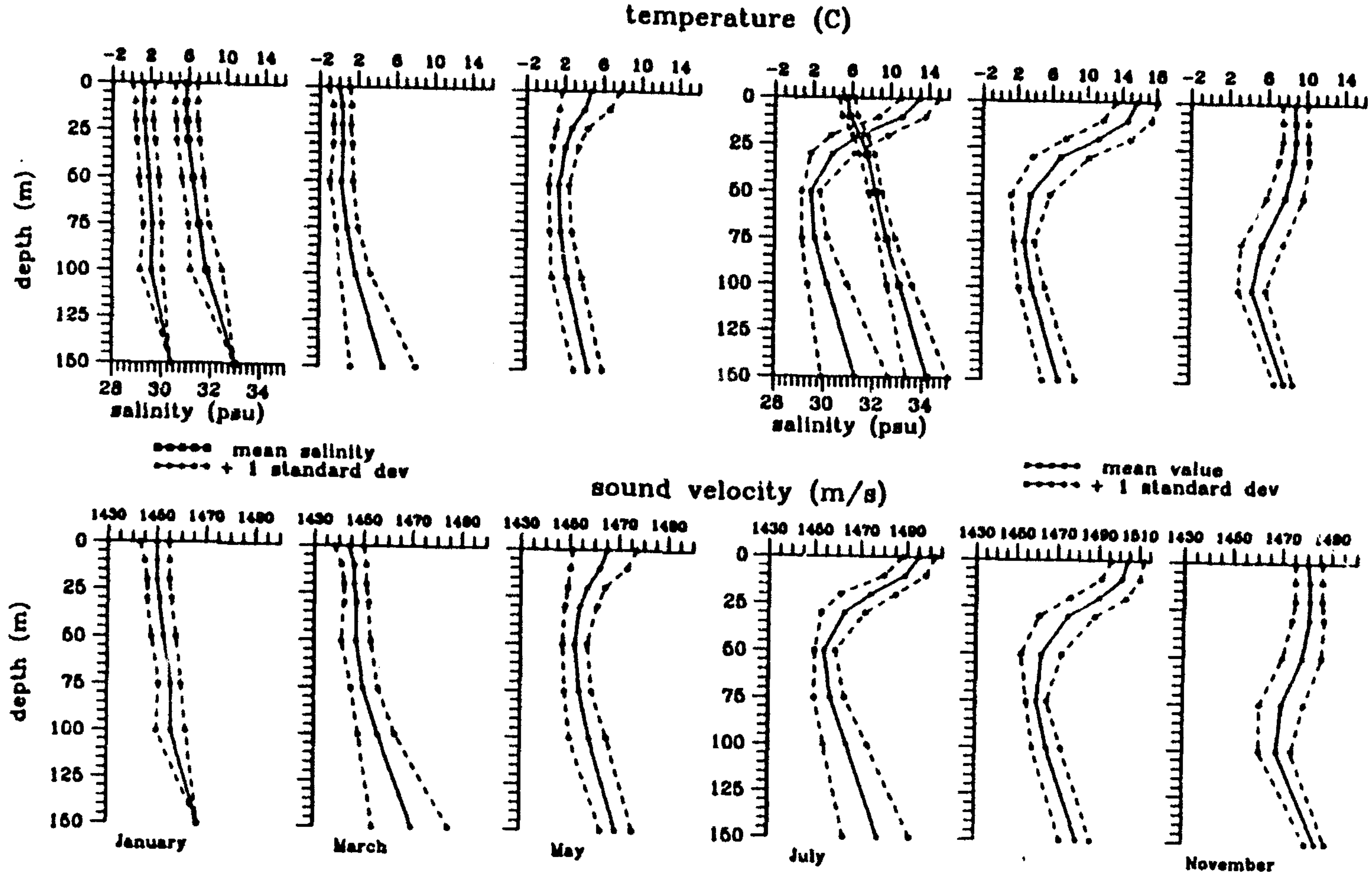


Figure 4.64: Temperature, salinity and sound speed profiles for the Scotian Shelf area # 14: South Shore. (Can be used for Area # 20.)

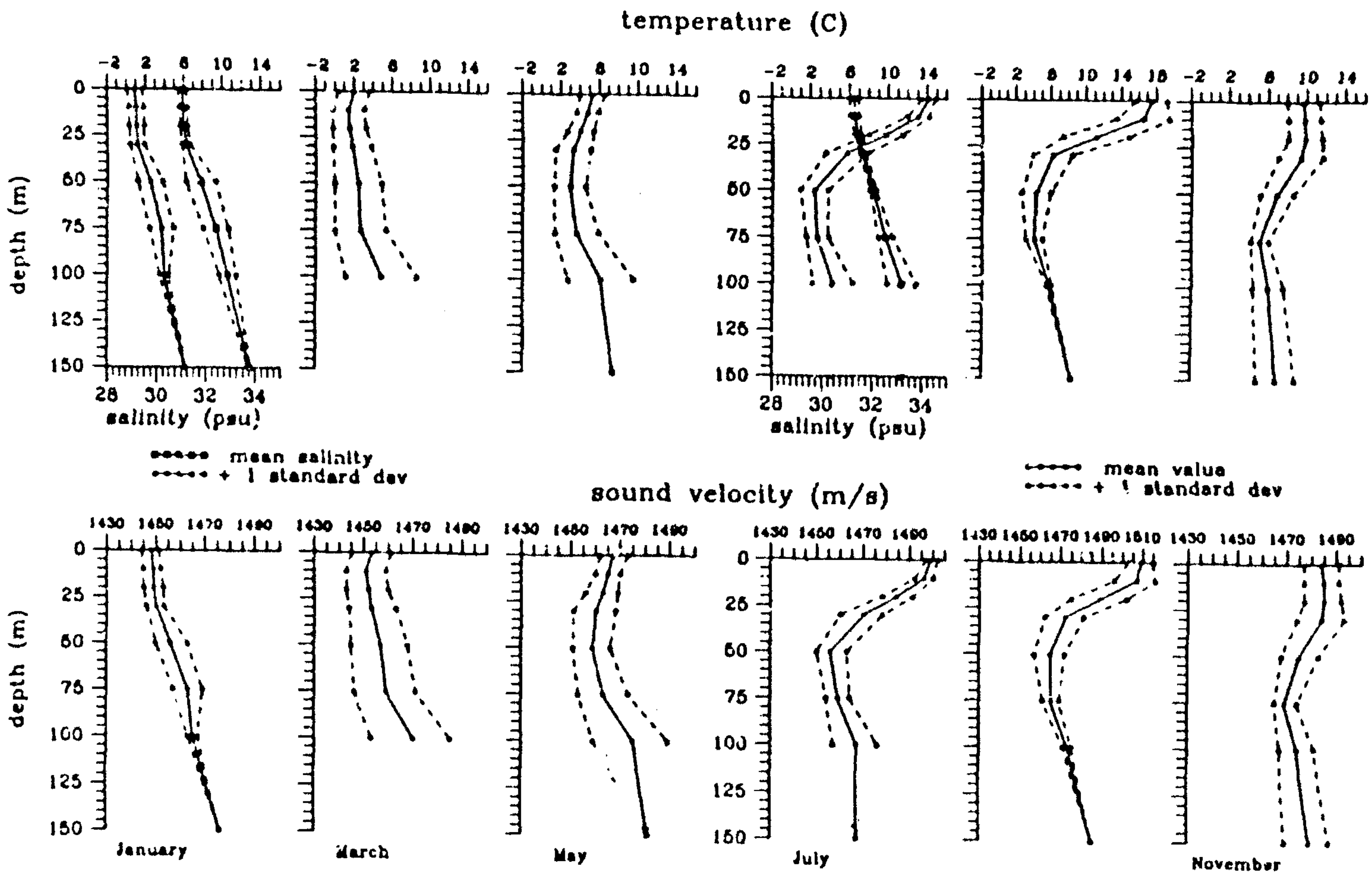


Figure 4.65: Temperature, salinity and sound speed profiles for the Scotian Shelf area # 17: LaHave Bank. (Can be used for Area # 16.)

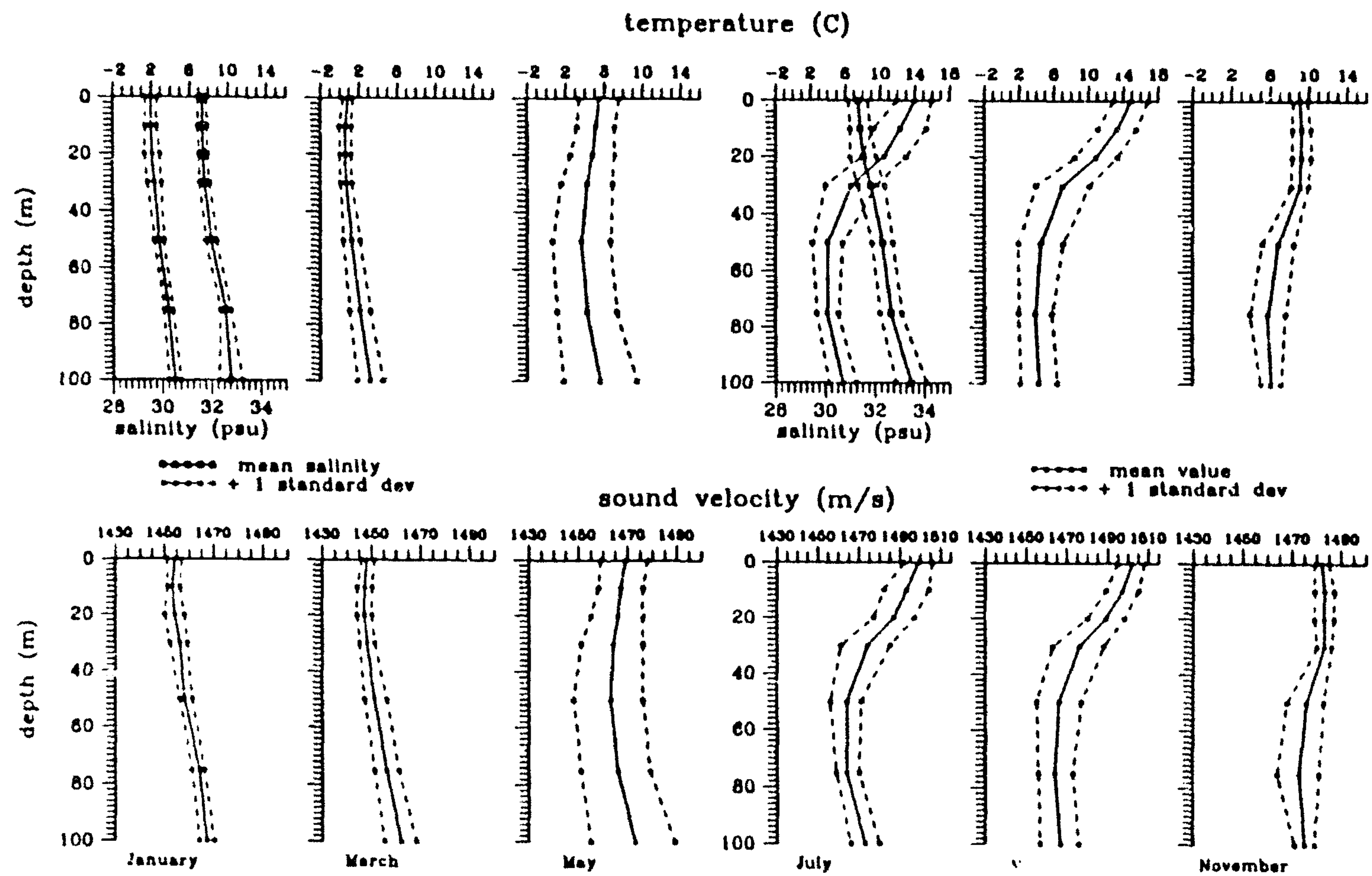


Figure 4.66: Temperature, salinity and sound speed profiles for the Scotian Shelf area # 18: Baccaro Bank.

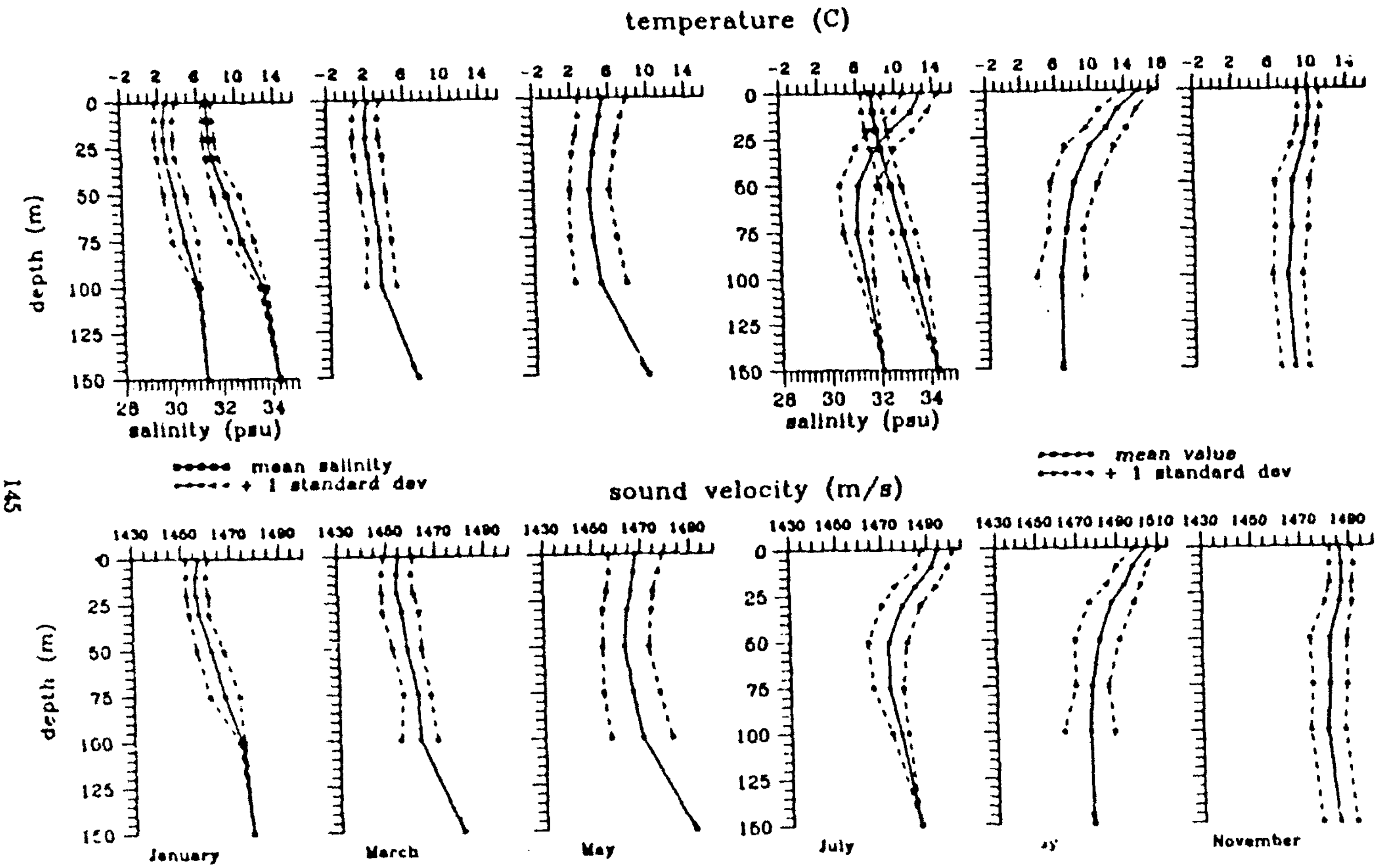


Figure 4.67: Temperature, salinity and sound speed profiles for the Scotian Shelf area # 22: Browns Bank. (Can be used for Area # 21.)

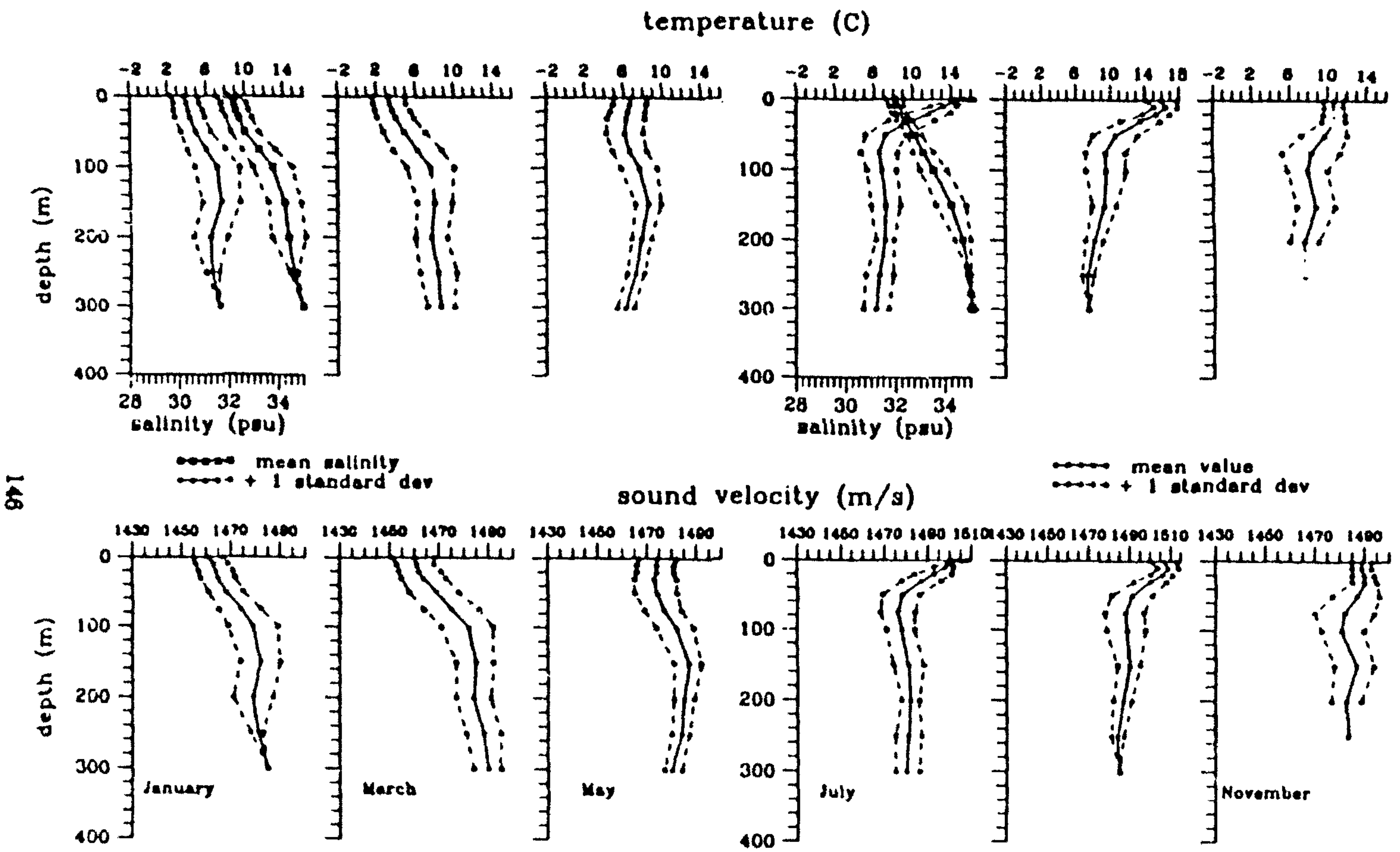


Figure 4.68: Temperature, salinity and sound speed profiles for the Scotian Shelf area #29: Northeast Channel.

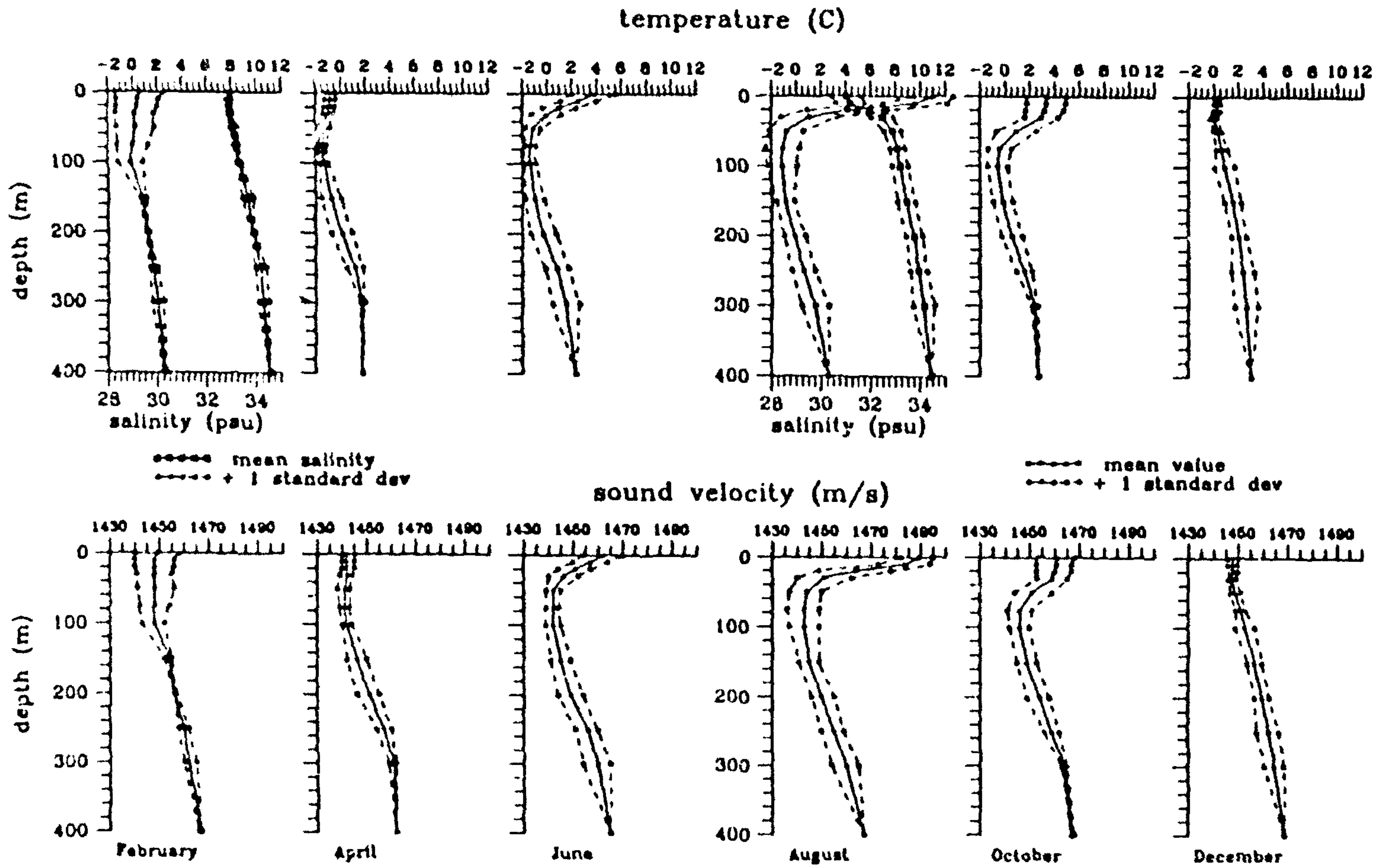


Figure 4.69: Temperature, salinity and sound speed profiles for the Grand Banks area # 1: Northeast Newfoundland Shelf (Inshore).

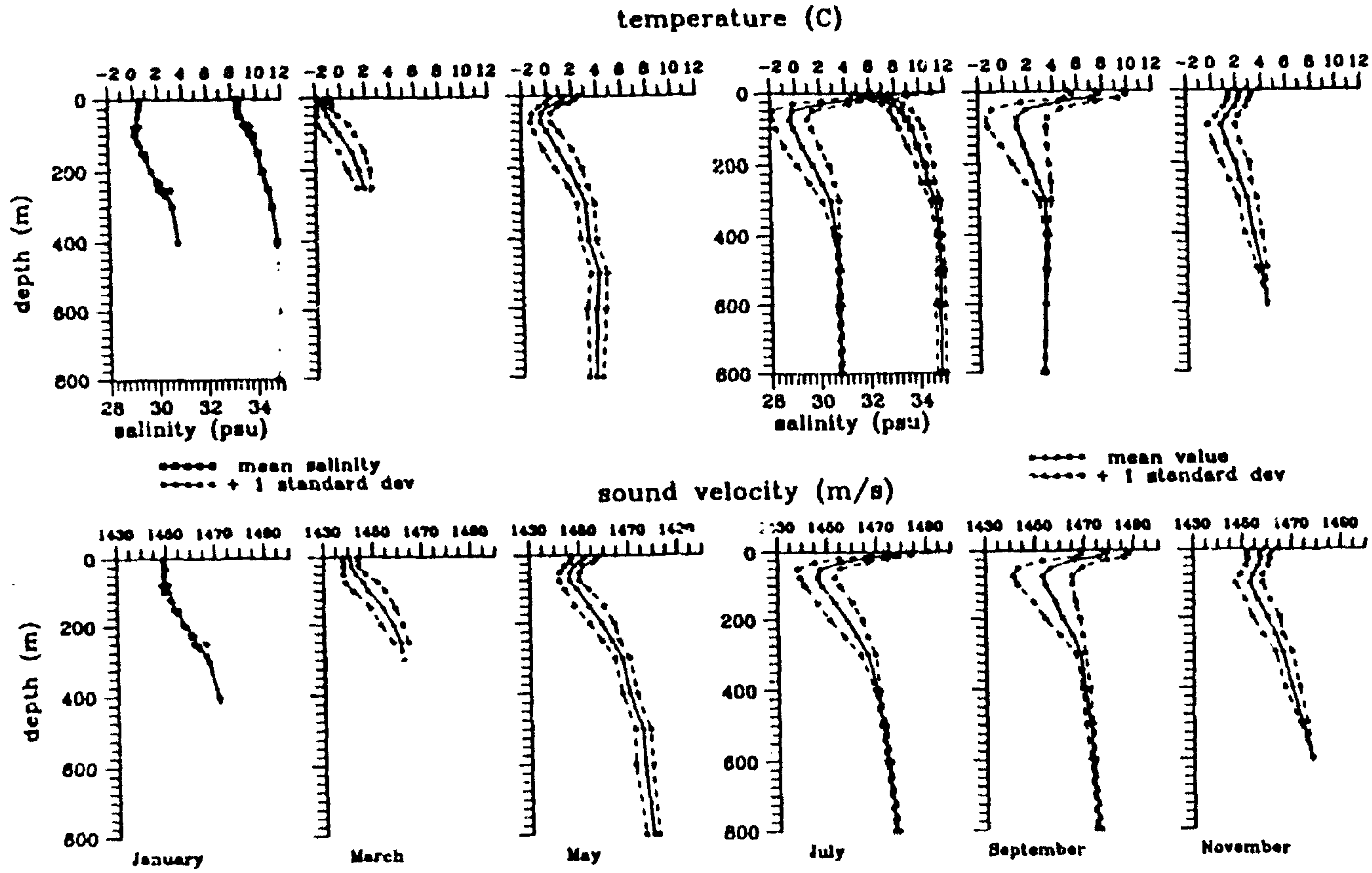


Figure 4.70: Temperature, salinity and sound speed profiles for the Grand Banks area # 2: Northeast Newfoundland Shelf (Offshore).

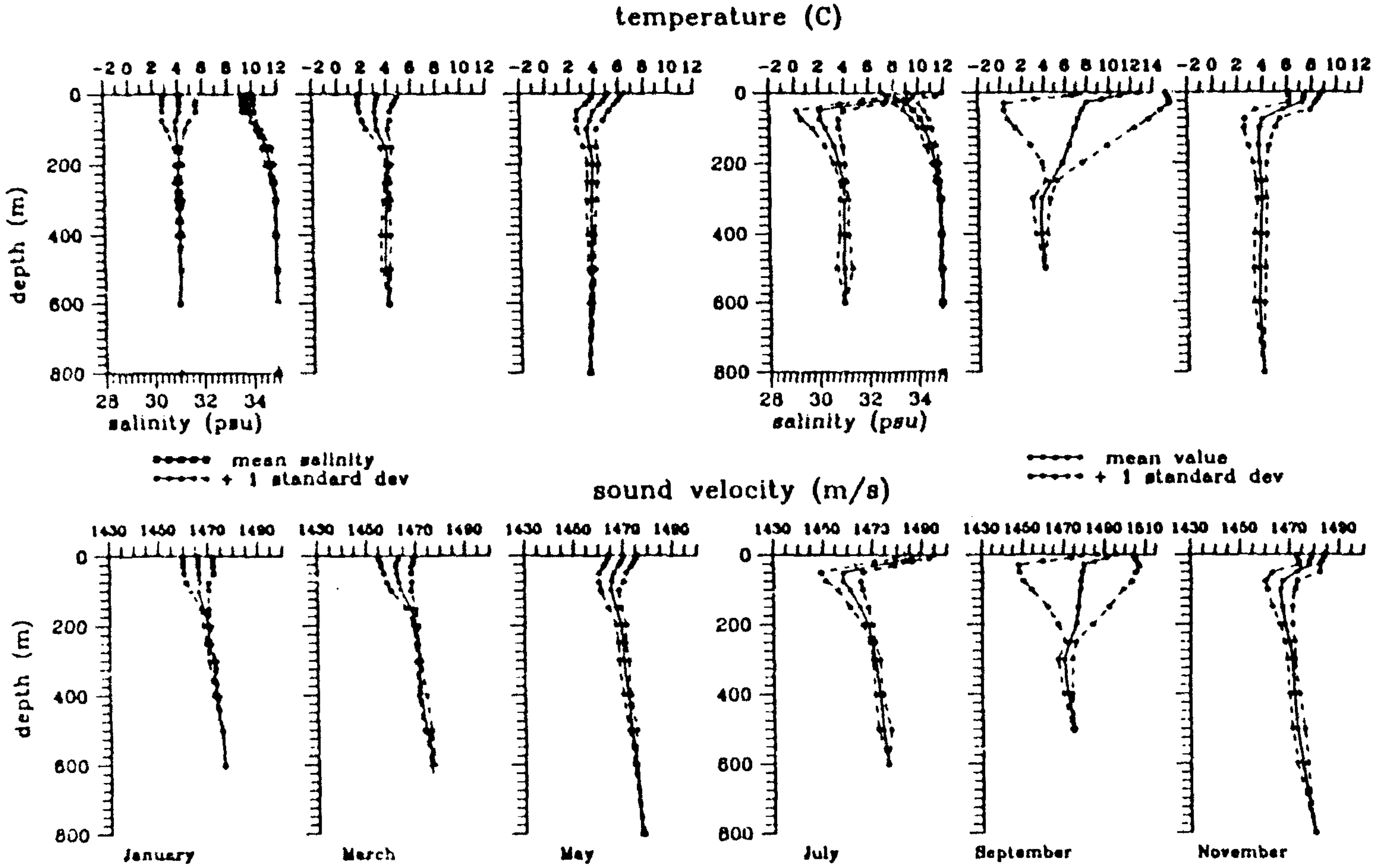


Figure 4.71: Temperature, salinity and sound speed profiles for the Grand Banks area # 6: Flemish Cap (N. Slope). (Can be used for Areas # 5 and 9.)

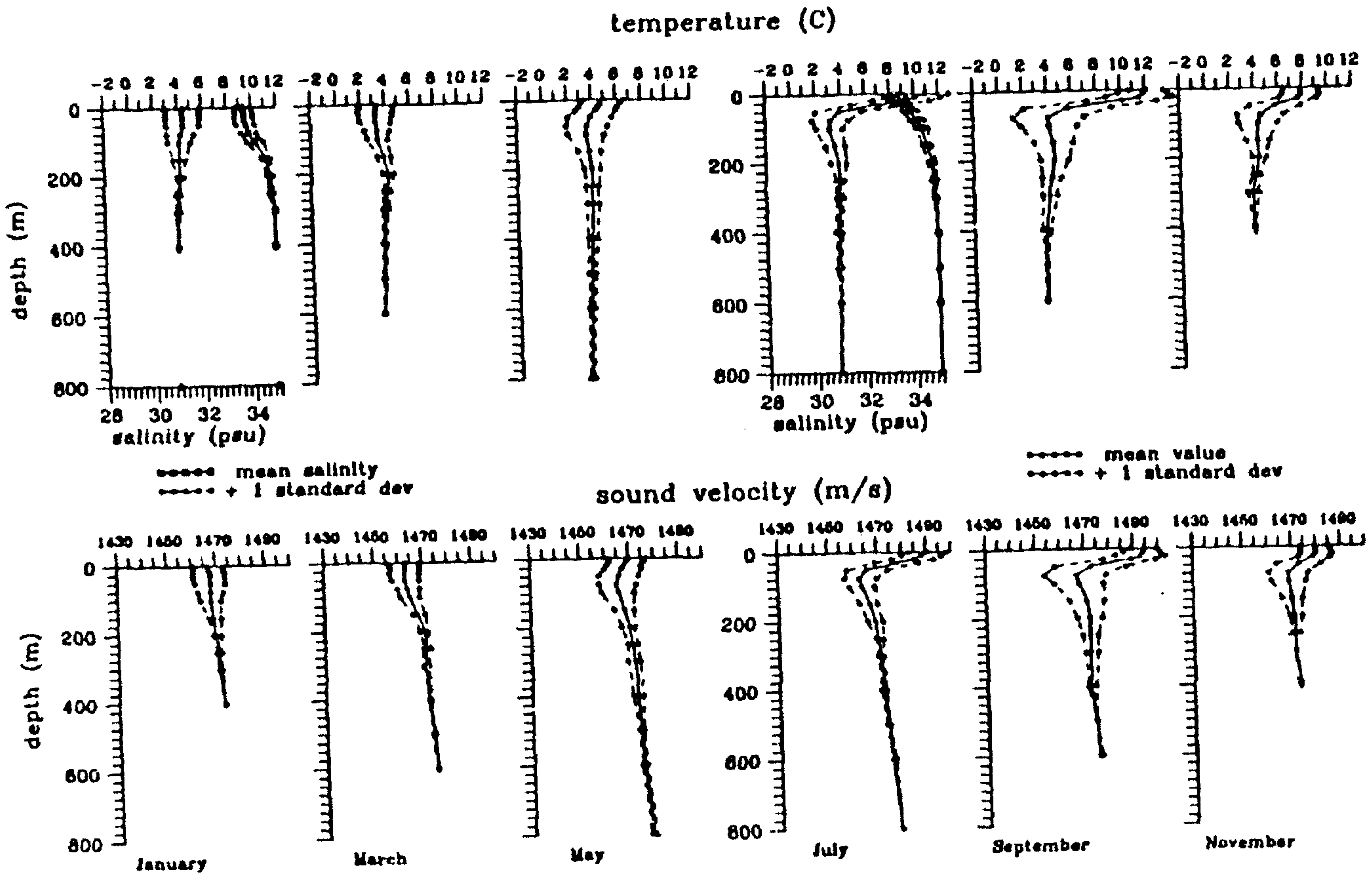


Figure 4.72: Temperature, salinity and sound speed profiles for the Grand Banks area # 7: Flemish Cap (W. Slope).(Can be used for Area # 13.)

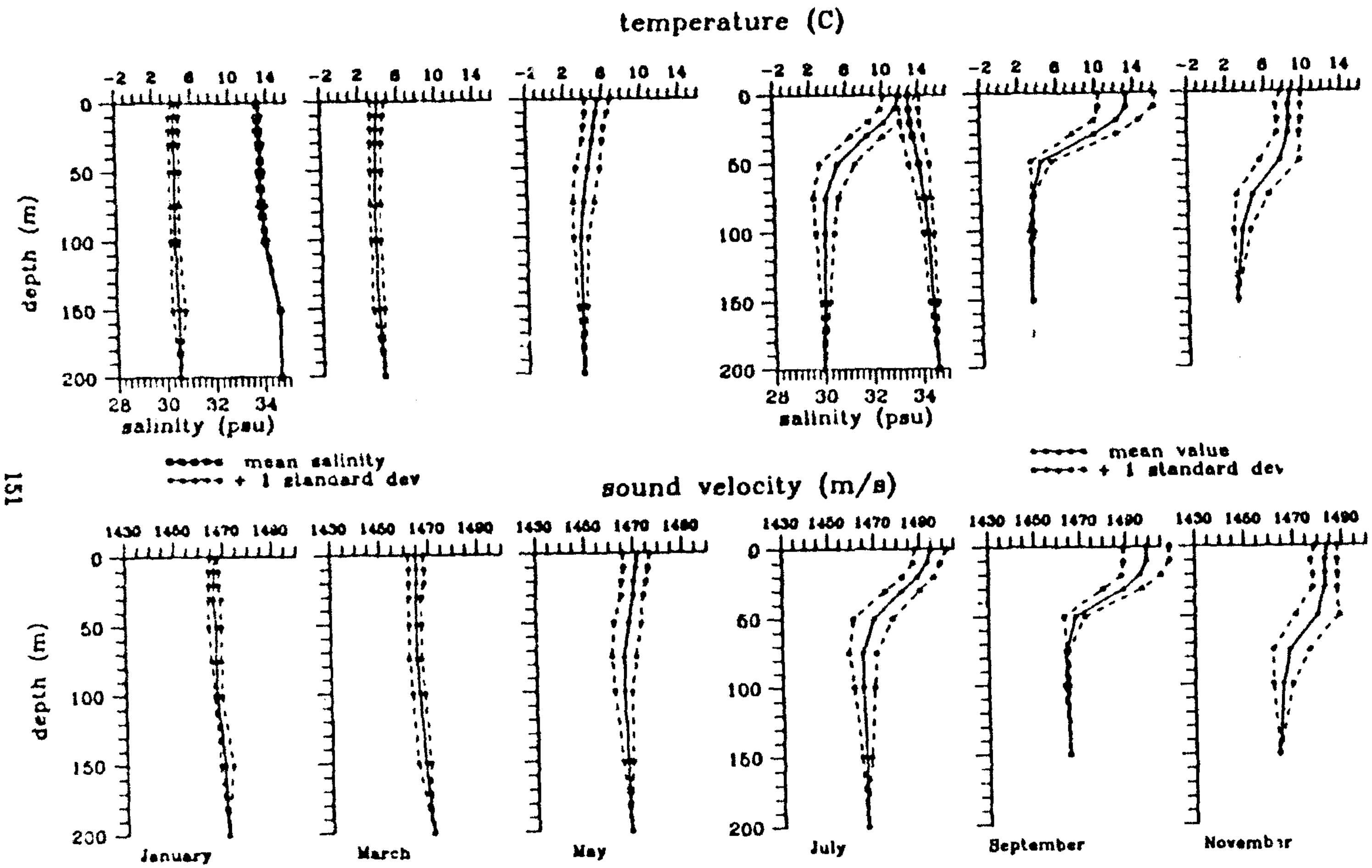


Figure 4.73: Temperature, salinity and sound speed profiles for the Grand Banks area # 8: Central Flemish Cap.

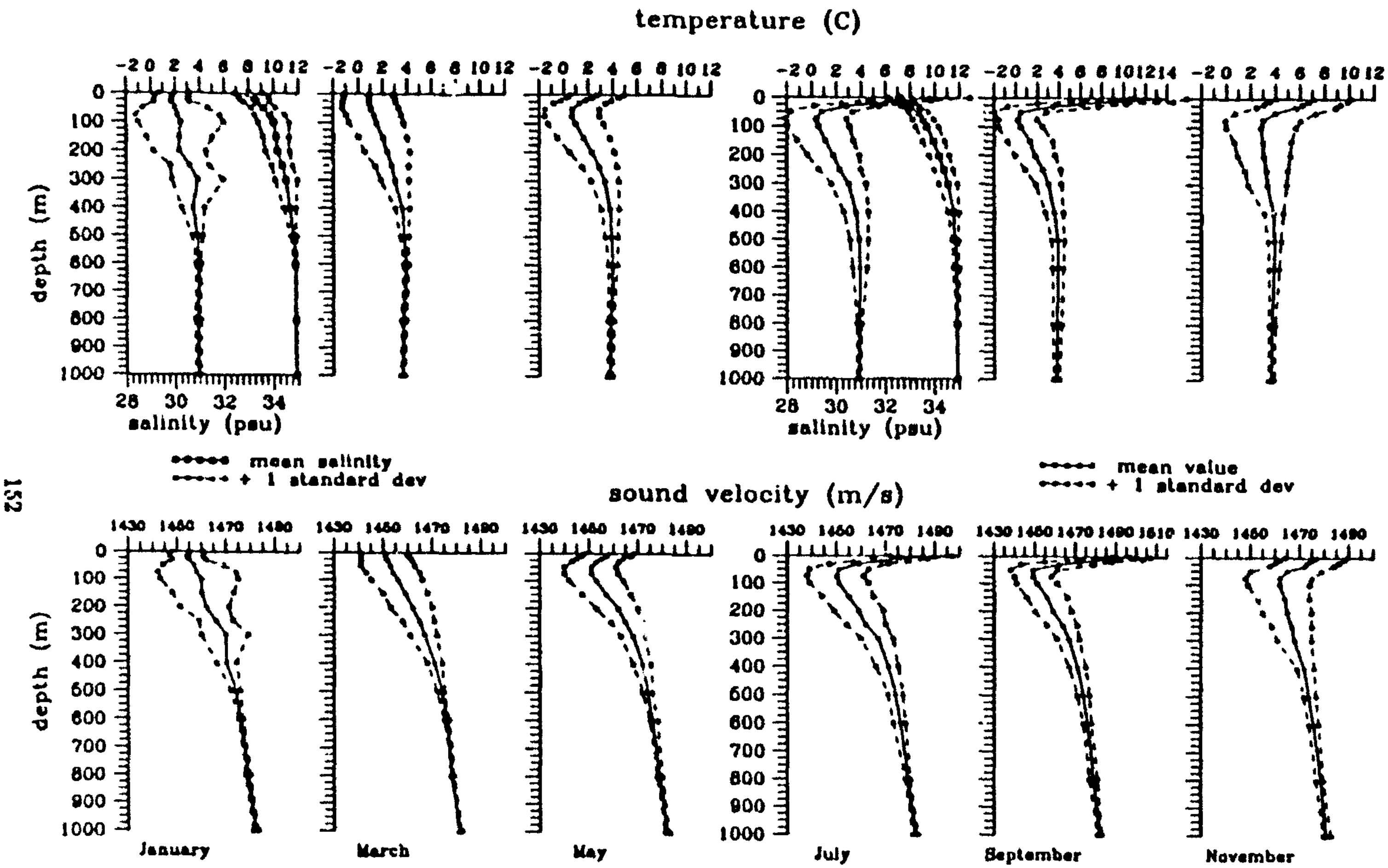


Figure 4.74: Temperature, salinity and sound speed profiles for the Grand Banks area # 12: East Slope.

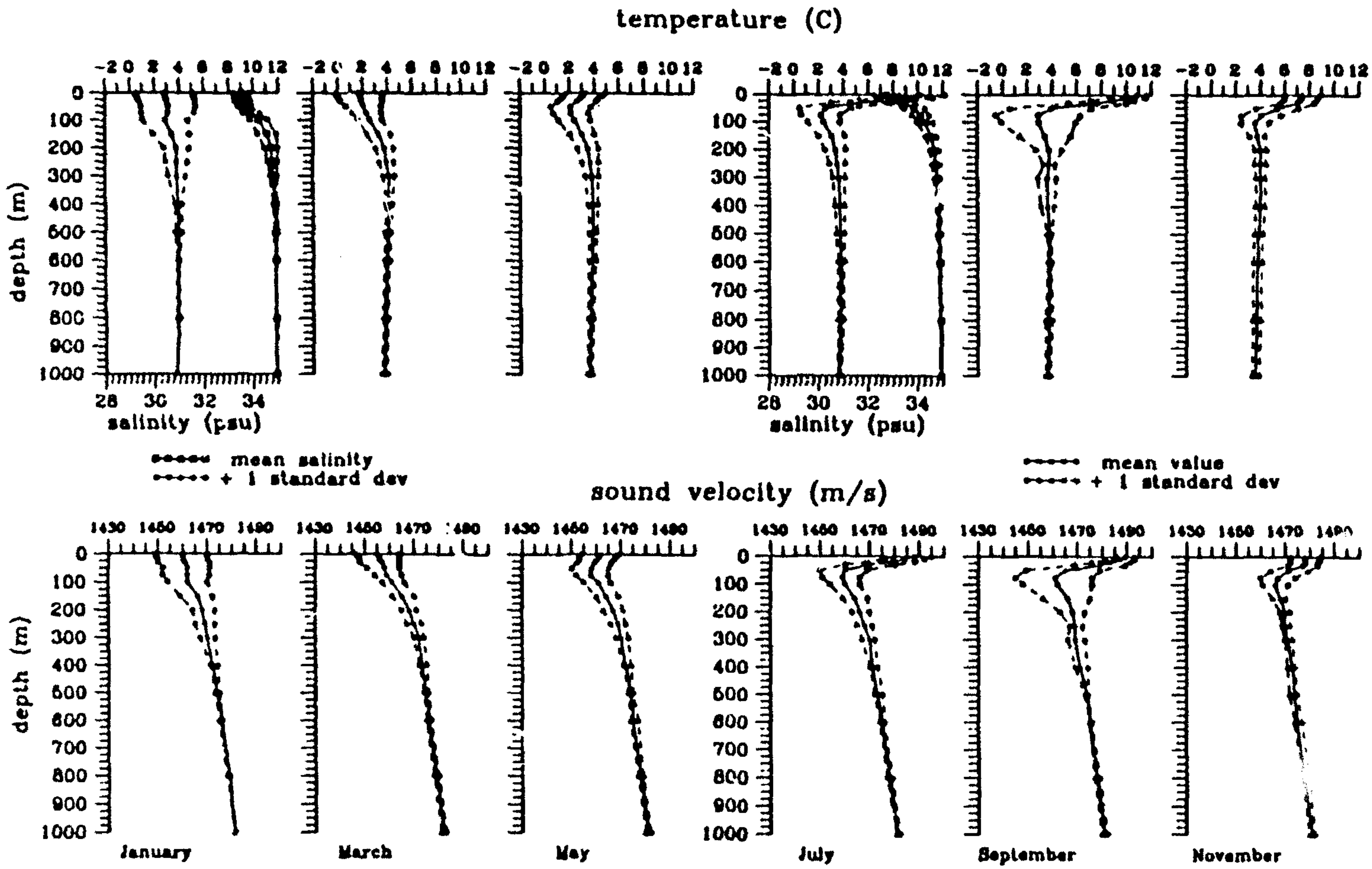


Figure 4.75: Temperature, salinity and sound speed profiles for the Grand Banks area # 13: Flemish Passage.

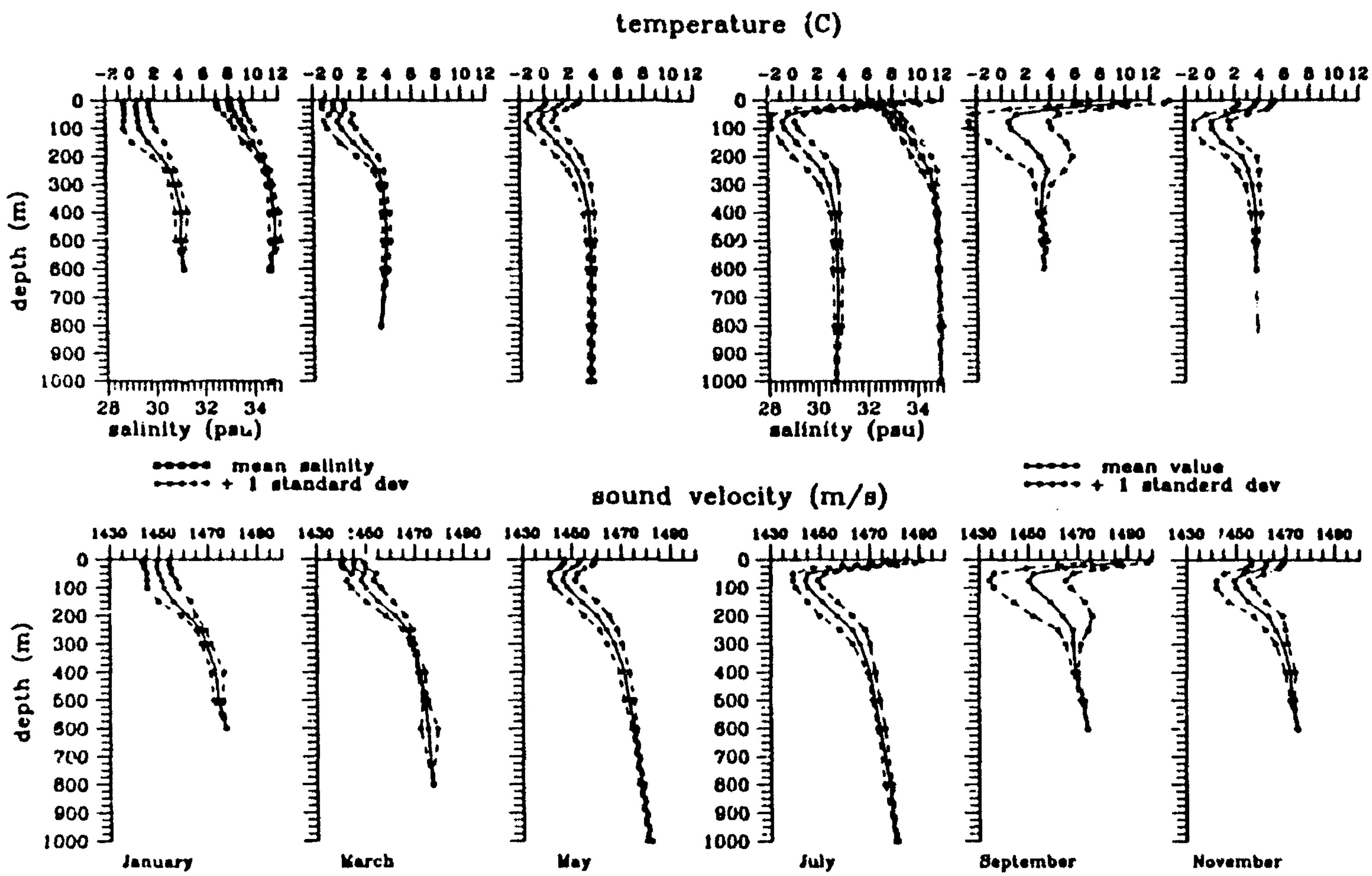


Figure 4.76: Temperature, salinity and sound speed profiles for the Grand Banks area # 14: Northeast Slope. (Can be used for Area # 15.)

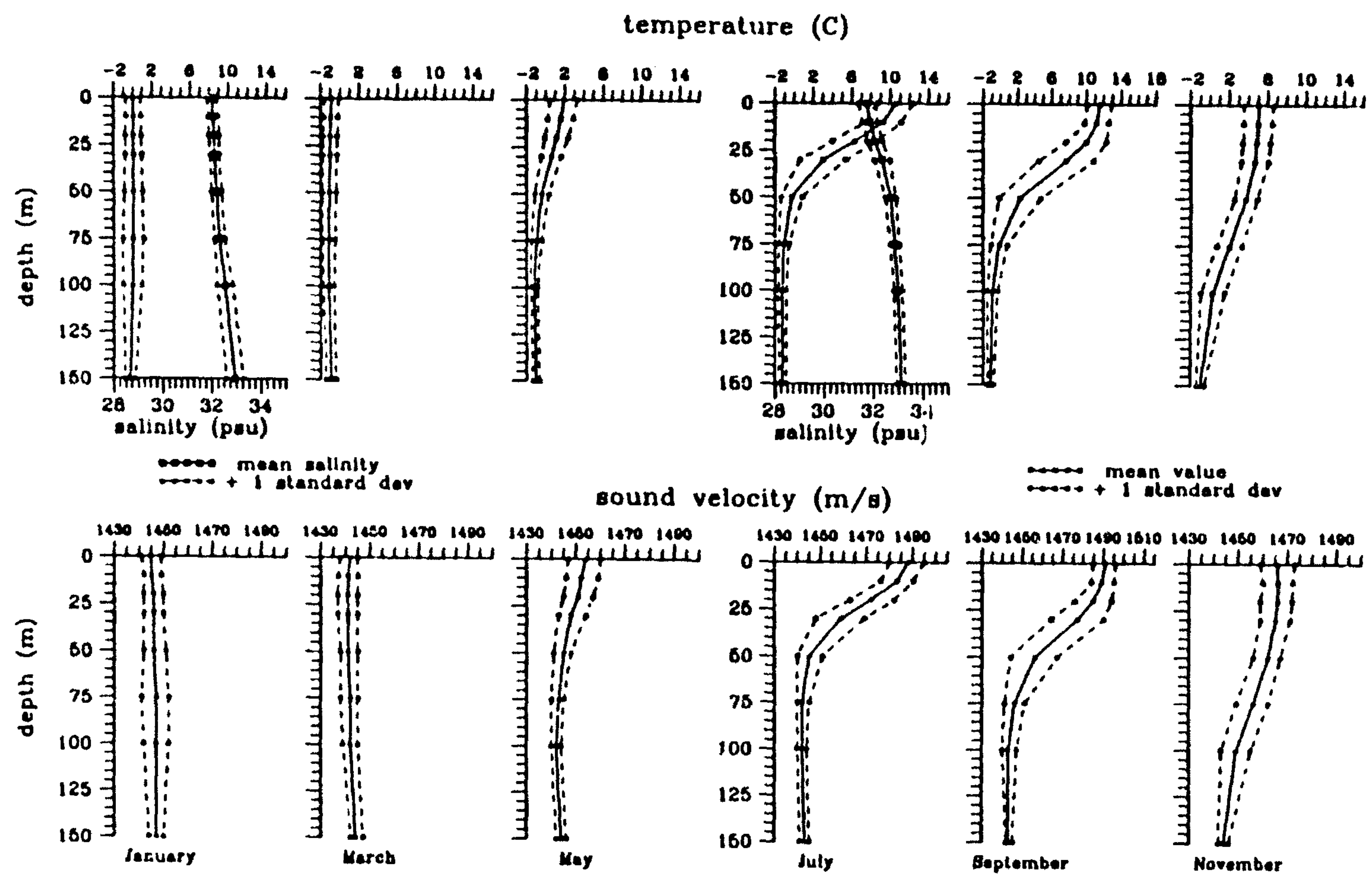


Figure 4.77: Temperature, salinity and sound speed profiles for the Grand Banks area # 17: North Avalon Channel. (Can be used for Area # 16 and 18.)

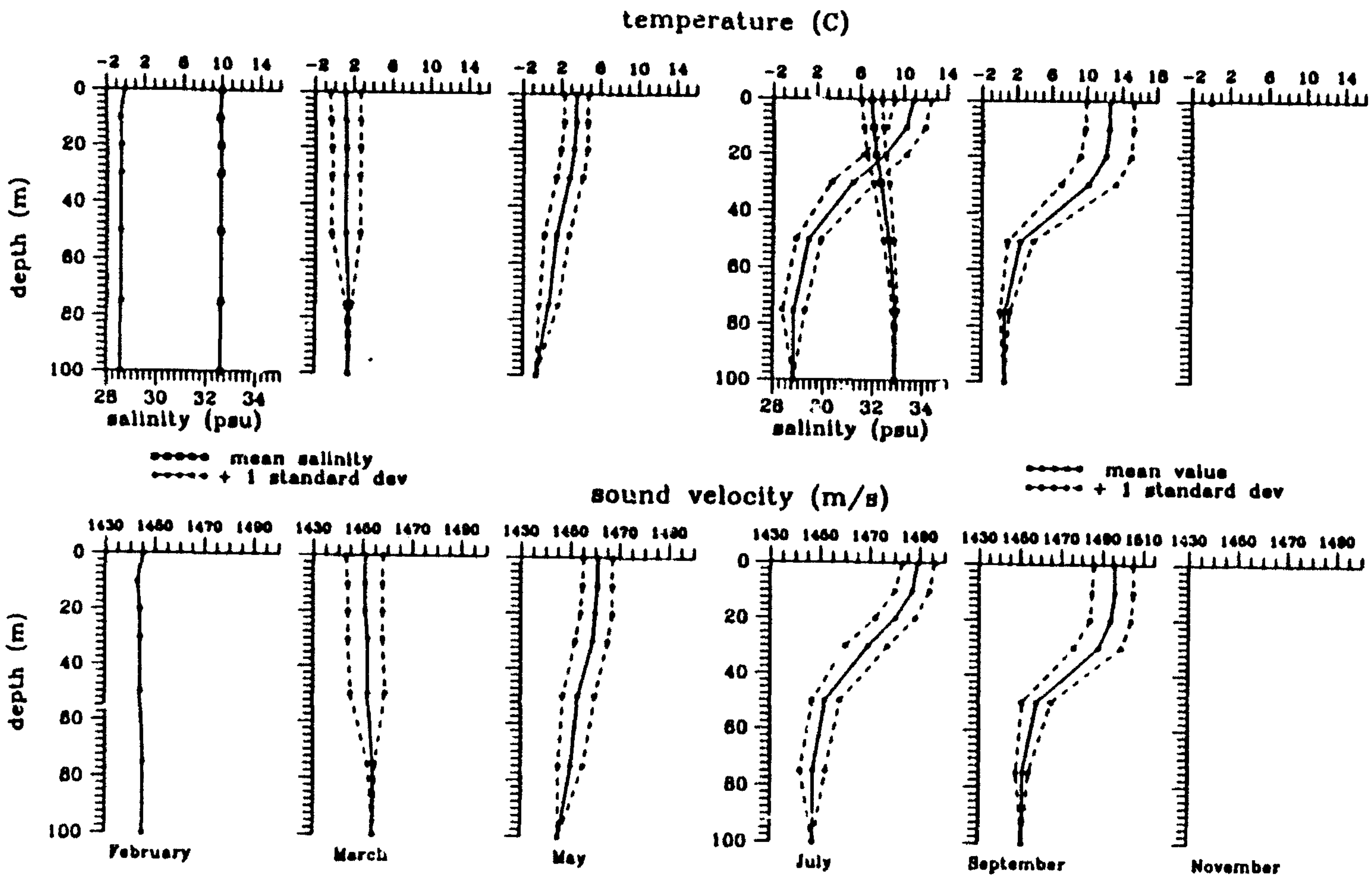


Figure 4.78: Temperature, salinity and sound speed profiles for the Grand Banks area # 19: Northwest Grand Banks.

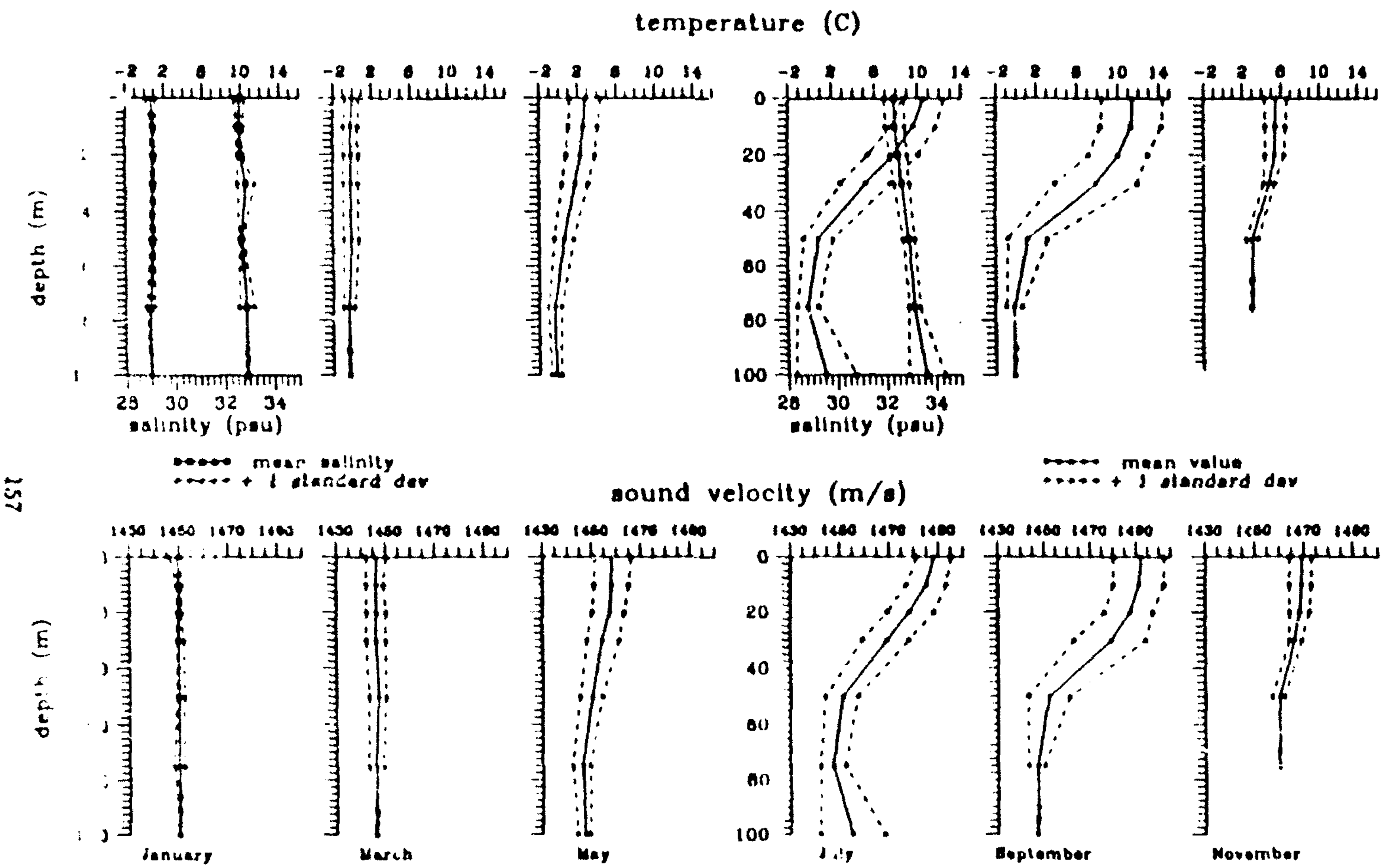


Figure 4.79 Temperature, salinity and sound speed profiles for the Grand Banks area # 20 Northeast Grand Banks

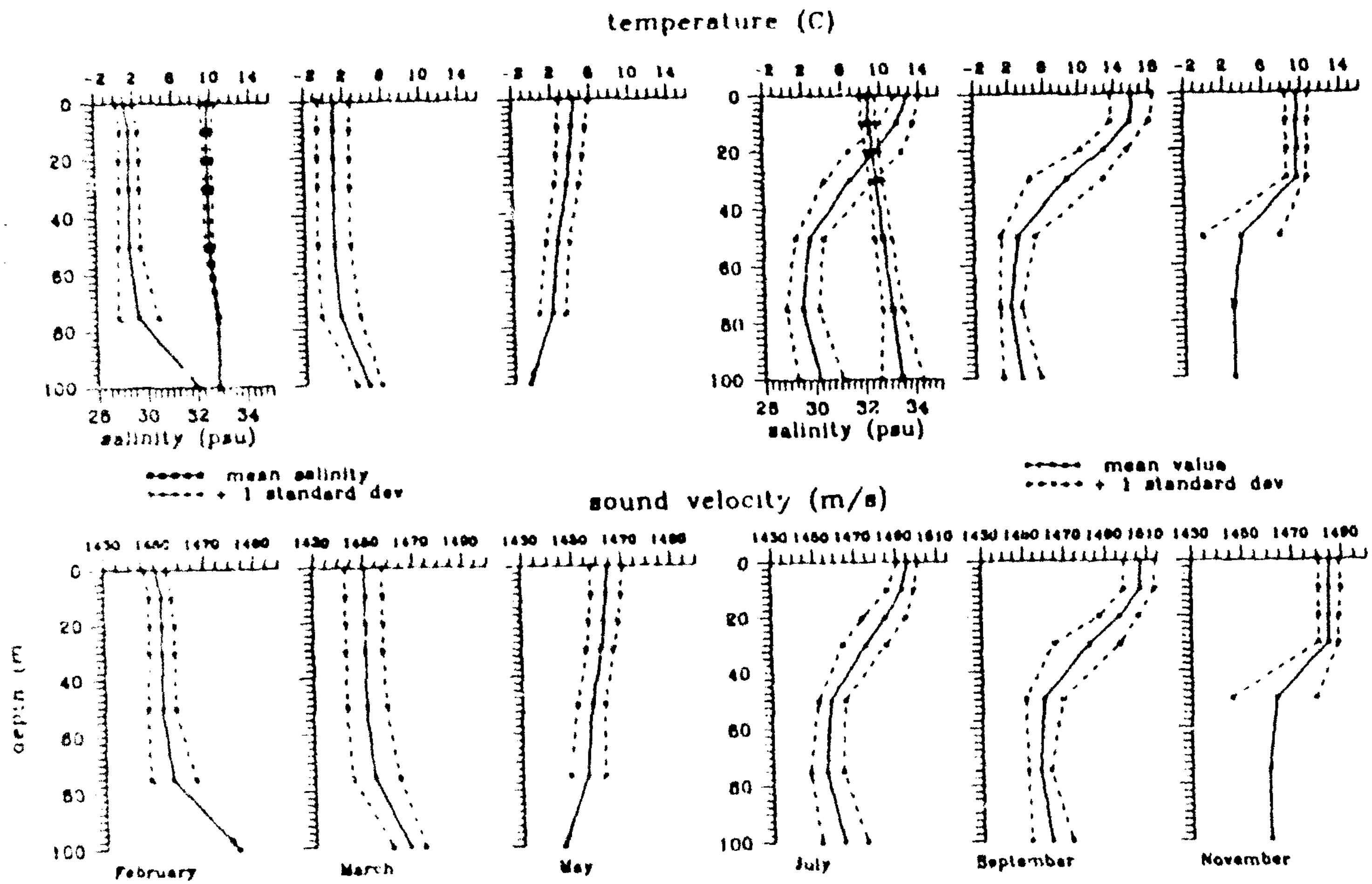


Figure 4.80 Temperature, salinity and sound speed profiles for the Grand Banks area # 22 Southwest Grand Banks (Can also be used for Areas # 21 and 23.)

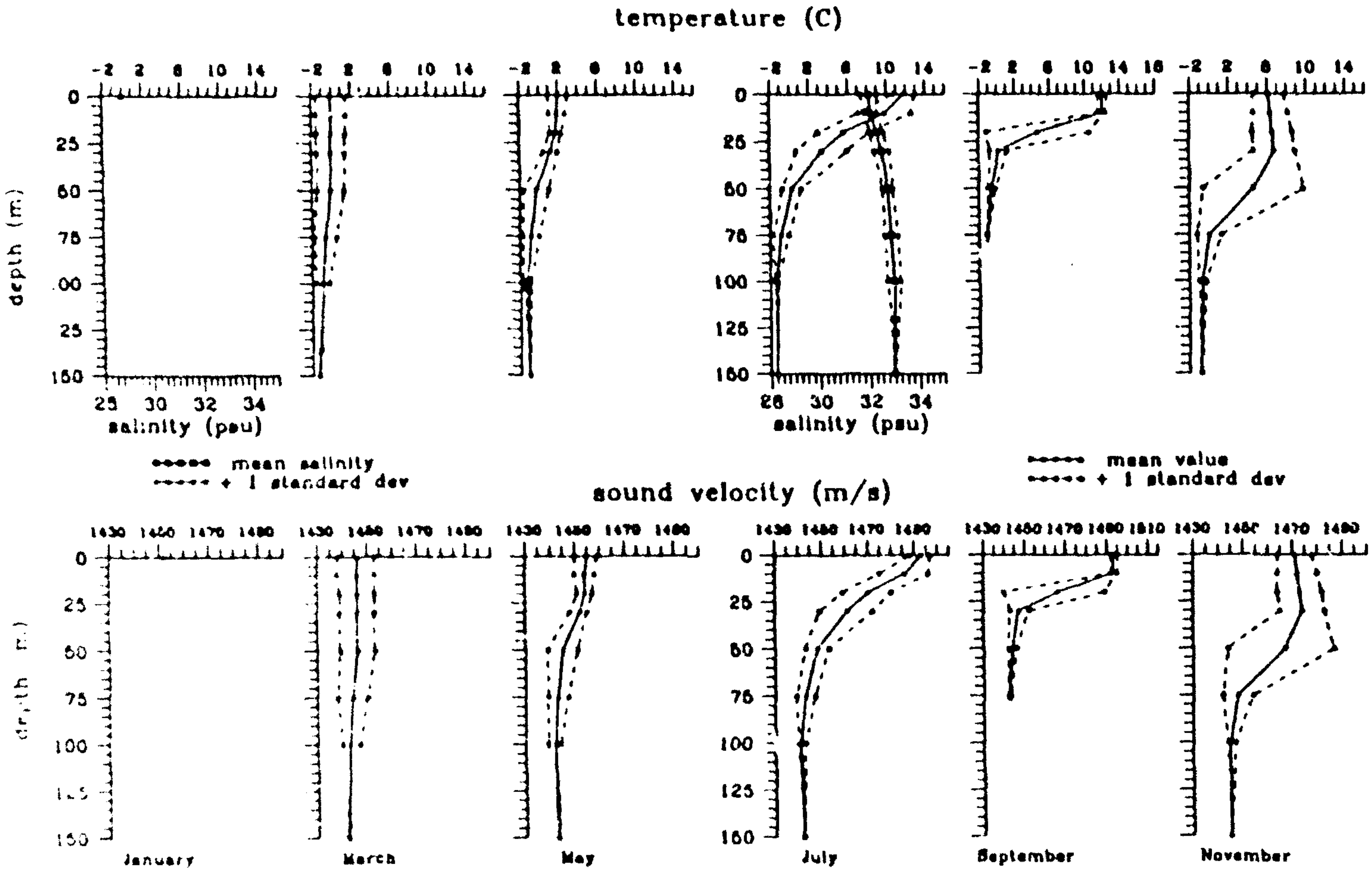


Figure 4.81 Temperature, salinity and sound speed profiles for the Grand Banks area # 24 South Avalon Channel.

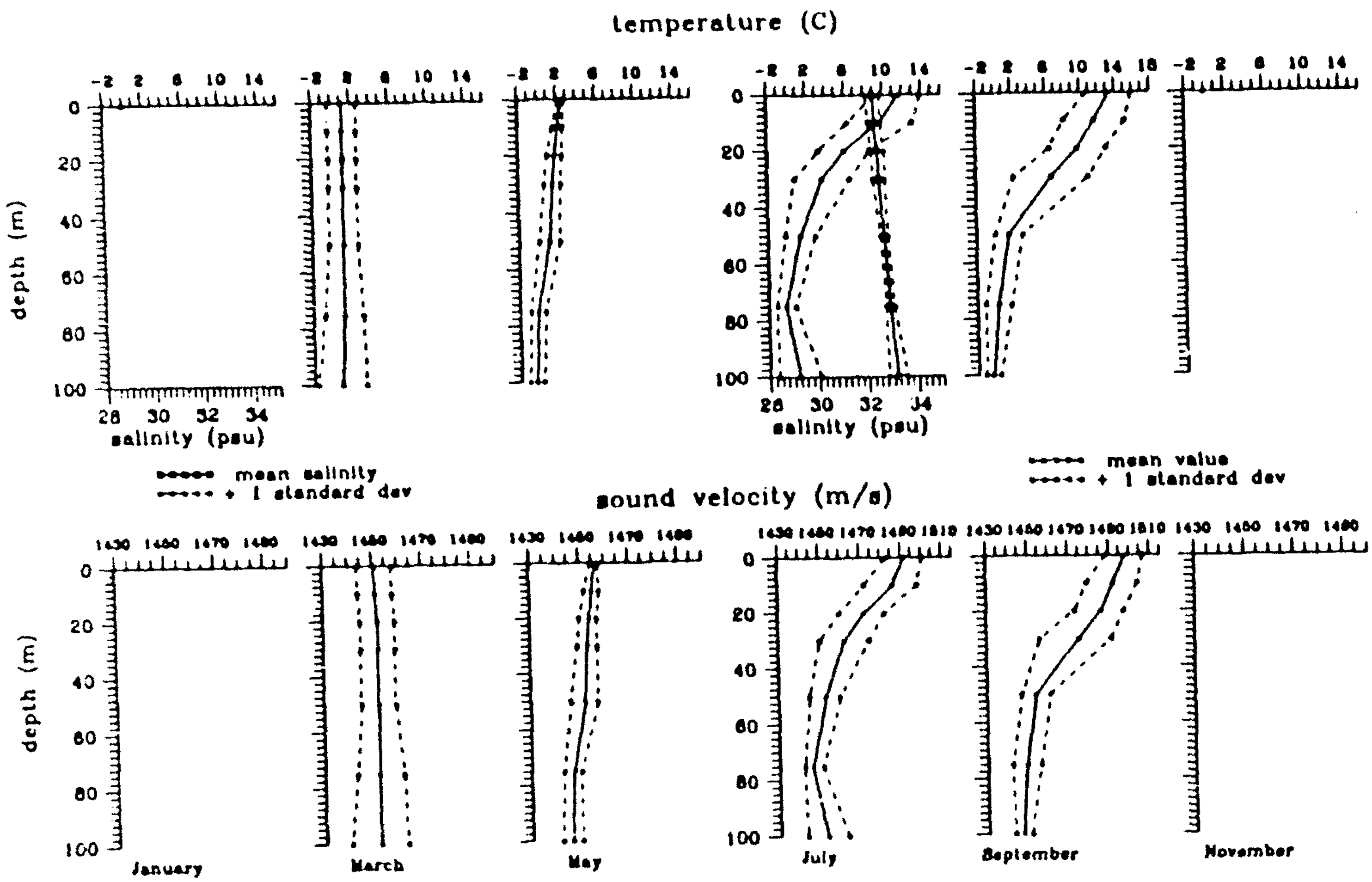


Figure 4.82. Temperature, salinity and sound speed profiles for the Grand Banks area # 25: Haddock Channel

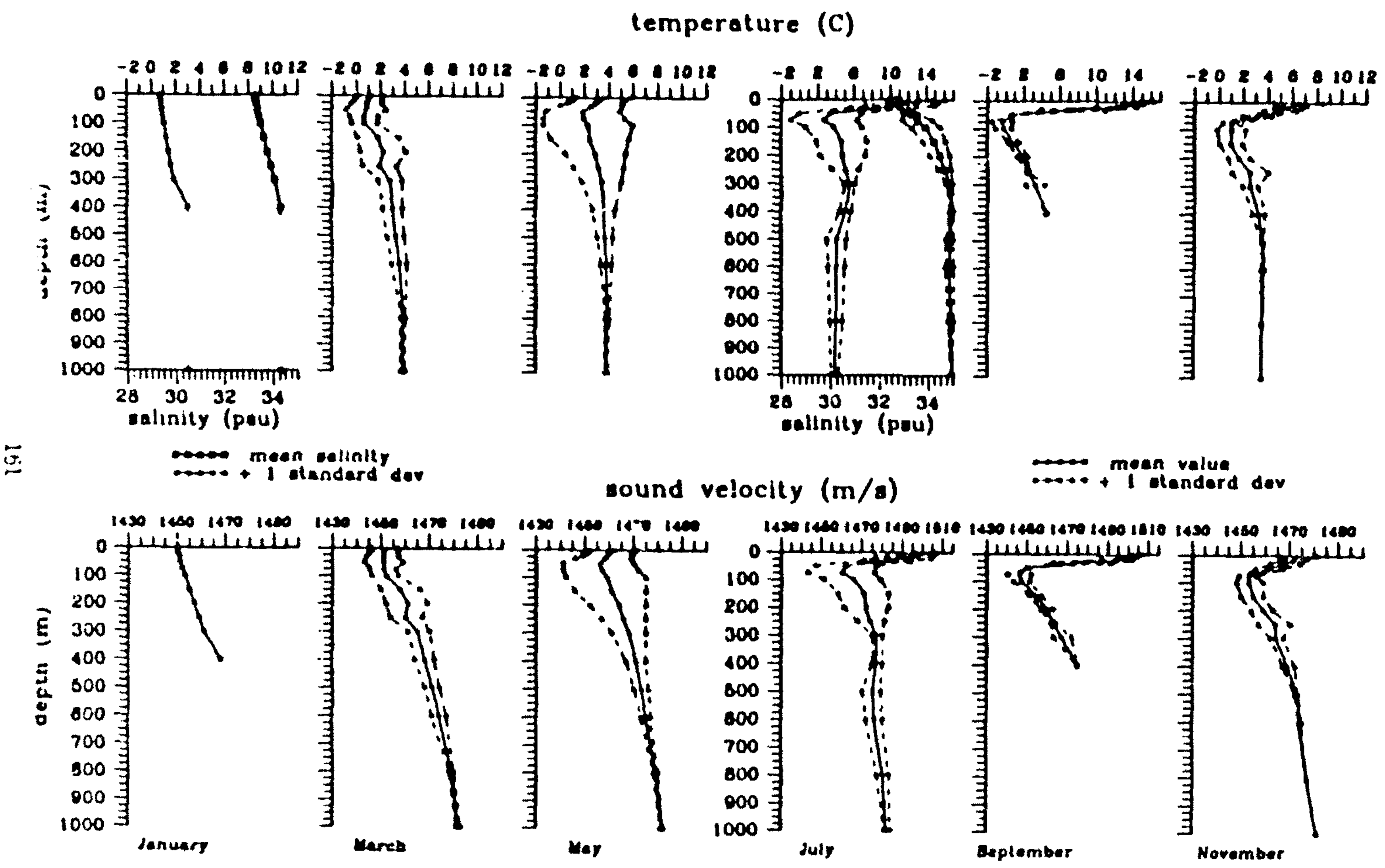


Figure 4.83: Temperature, salinity and sound speed profiles for the Grand Banks area # 27: South Slope. (Can be used for Area # 26 and 29.)

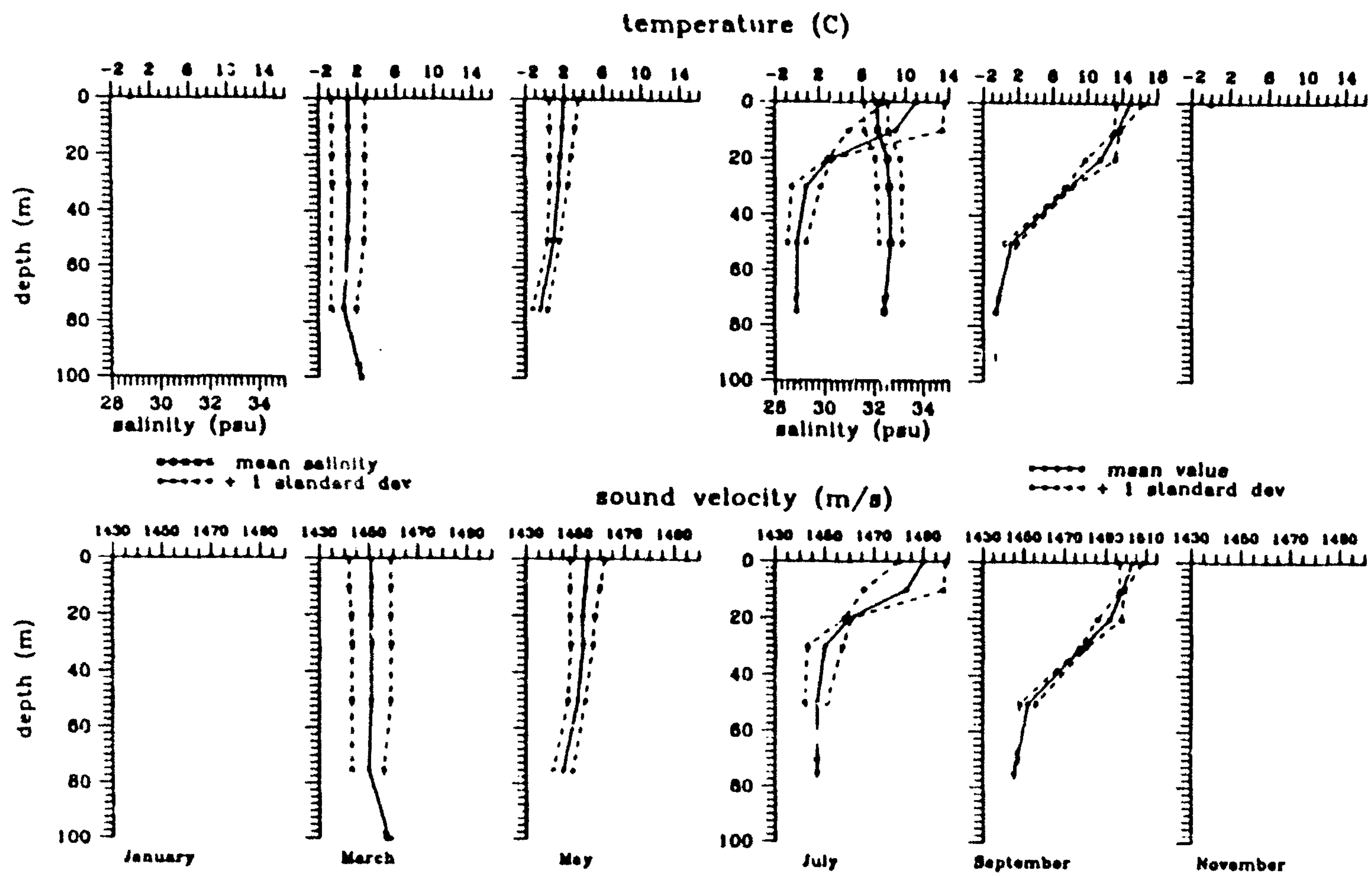


Figure 4.84: Temperature, salinity and sound speed profiles for the Grand Banks area # 30: Green Bank. (Can also be used for Area # 31.)

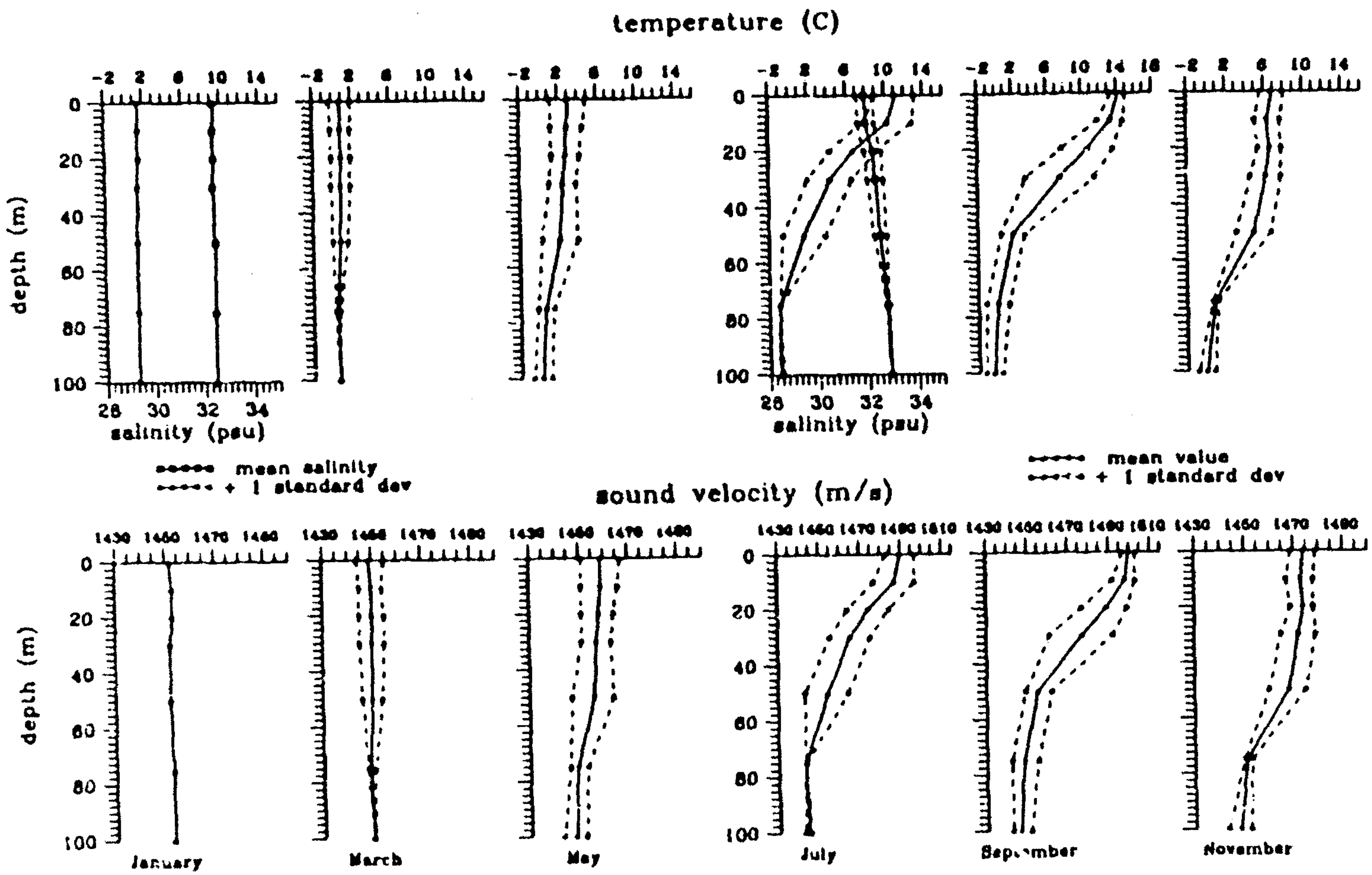


Figure 4.85: Temperature, salinity and sound speed profiles for the Grand Banks area # 33: St. Pierre Bank.

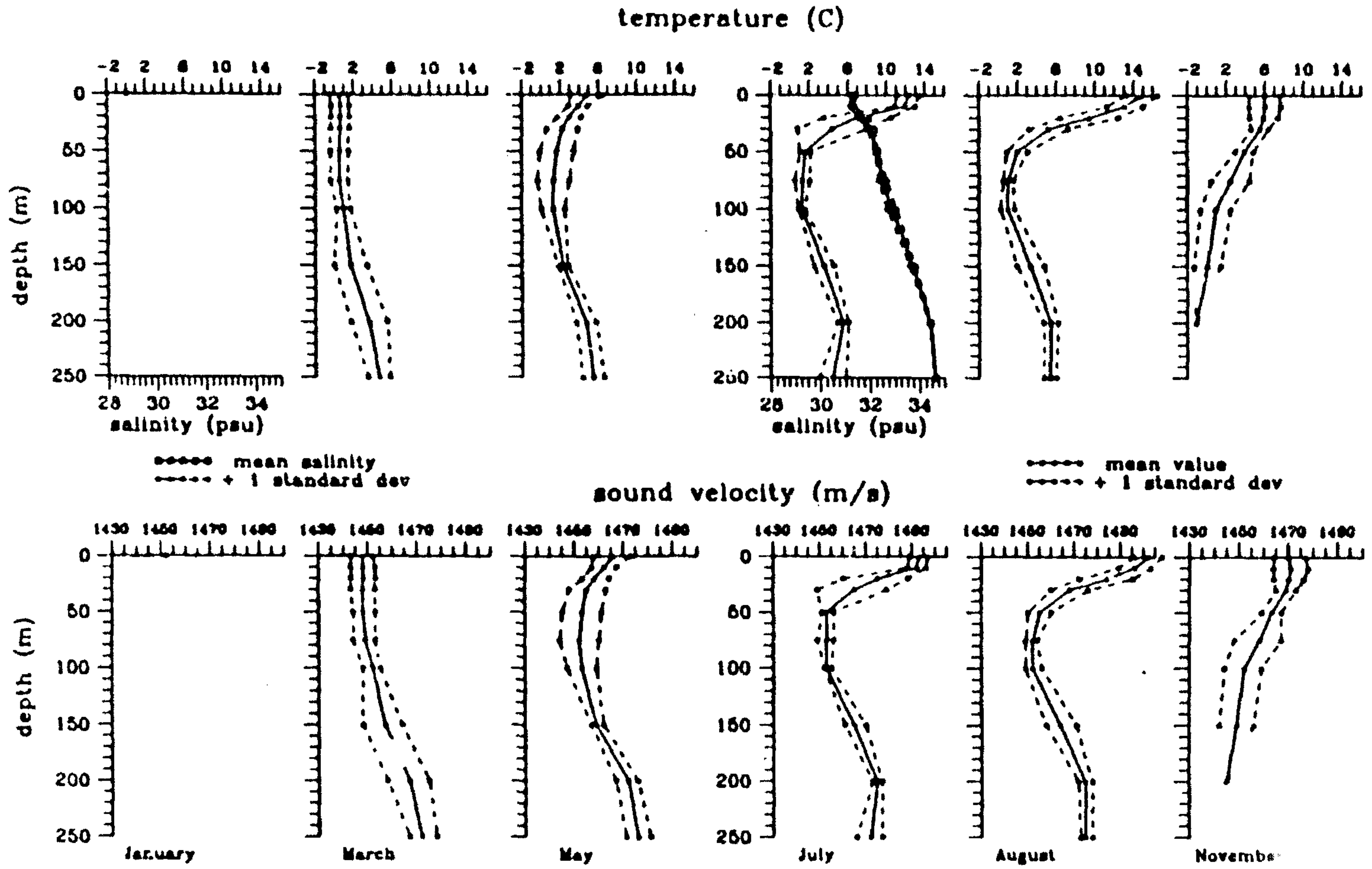


Figure 4.88: Temperature, salinity and sound speed profiles for the Grand Banks area #34. Hermitage Channel

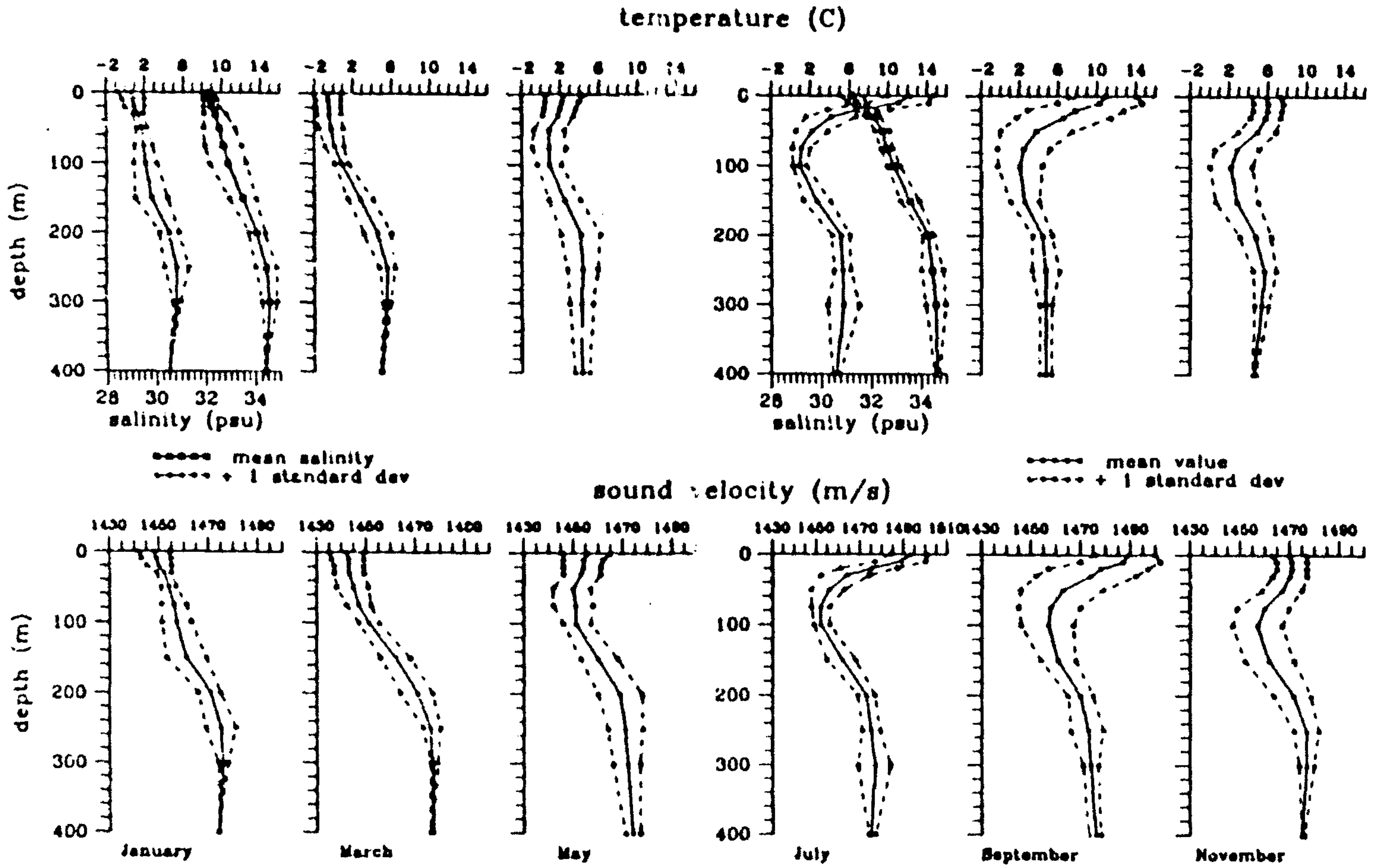


Figure 4.87: Temperature, salinity and sound speed profiles for the Grand Banks area # 38. Laurentian Channel.

Chapter 5

Biological Activity

5.1 Commercial Fish Species Distribution

The area under investigation contains some very rich fishing grounds. Numerous commercial fish species are found in large quantities.

5.1.1 Fisheries Statistics

The statistics for the fisheries of this area are regrouped geographically in the statistical divisions of the North Atlantic Fisheries Organization (NAFO) shown in Figure 5.1. The main commercial species are listed in Table 5.1 based on the nominal catches averaged for the years 1980 to 1986 and the projected Total Allowable Catch (TAC) averaged for 1987 to [illegible]. Further description of each stock and its importance is given in Tables 5.2 to 5.5.

5.1.2 Fishing Area Maps

The maps in Figures 5.2 and 5.4 (Groundfish) , Figure 5.6 (Flatfish), Figure 5.9 (Pelagic species), and Figure 5.10: (Shellfish), show the distribution of the main Canadian Atlantic commercial fishery species. Fishing areas, general distribution, as well as known key fishing areas and spawning areas are identified.

Species	*Mean Catches 1980-1986 ('000 tons)*	*Median TAC 1987-1993 ('000 tons)*	*Occurrences in Fishery*	
			Inshore	*Offshore*
Groundfish:				
Cod	598	655	Yes	Yes
Redfish	97	160	No	Yes
Silver Hake	70	100	Yes	Yes
Pollock	56	42	Yes	Yes
Haddock	51	23	Yes	Yes
Pelagic:				
Herring	203	232	Yes	No
Mackerel	40	351	Yes	No
Capelin	54	-	Yes	No
Flatfish:				
all (5 species)	107	210	Yes	Yes
Yellowtail	20	15	No	Yes
Plaice	59	55	No	Yes
Halibut	28	-	Yes	Yes
Shellfish:				
Lobster	34	-	Yes	No
Snow Crab	35	-	Yes	No
Sea Scallops	70	-	Yes	Yes

Table 5.1: Commercial fish species. Mean catches 1980-1986, median TAC 1987-1993. (From D. Rivard et al., 1988).

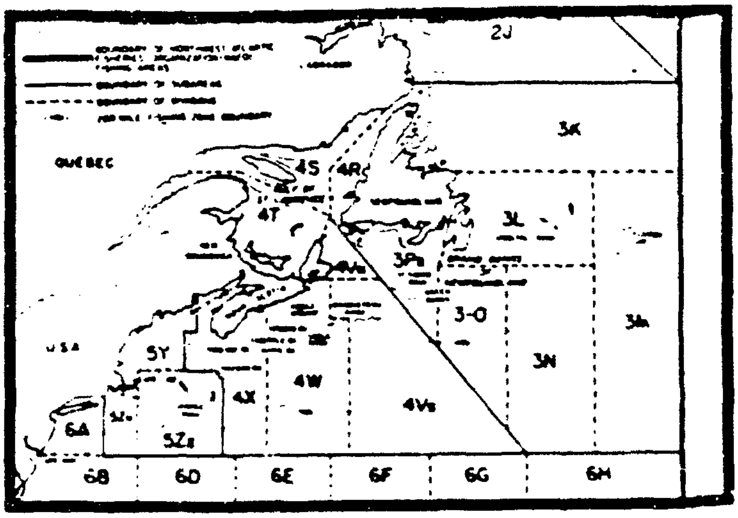


Figure 5.1: Statistical divisions of the NAFO convention area

Seasonal Distribution-Grand Banks

Seasonal fisheries activity for the main commercial species of the Grand Banks compiled by Mobil Oil [1984] from the available Fisheries and Ocean data has been included as follows:

- Figure 5.3 : Cod
- Figure 5.5: Redfish
- Figure 5.7: American Plaice
- Figure 5.8: Yellow Tail

Species / Fishing Area: Name	NAFO #	Catches 1980-1986 ('000 t)	TAC 1987-1993 ('000 t)	Migration Pattern	Remarks
Cod:				General migration pattern: inshore in May to September; offshore in the fall.	Fishery: 80% Domestic.
<u>Grand Banks</u>					Interannual variations in distributions associated with changes in water temperature.
North	2J-3KL	230	330	As above	
South	3NO	30	30	As above	
St. Pierre Bank	3Ps	40	46	As above	
Flemish Cap	3M	13	13	None known	
<u>Gulf of St. Lawrence</u>					
North and East	3Pn-4RS	93	80	Winter: north to Quebec north shore	
West	4TVn	60	60	Spring: Laurentian Channel to Magdalen Shallows. Fall: return.	Fishing: January to April
<u>Scotian Shelf</u>					
Sydney Bight	4Vn	11	-	Winter: Large migration from 4T to 4Vn (December) Spring: Reverse process.	
Banquereau-Sable I	4VsW	52	42	None known	
Browns Bank	4X	28	15	None known	
Pollock:					
<u>Scotian Shelf</u>	4VWX	56	42	Migrate in in late spring from the U.S. east coast. Return in late fall	95 % Domestic. Juveniles (< 2 years) inshore. Mature Offshore
Haddock:					63 % Domestic
<u>Scotian Shelf</u>					
Central	4VW	12	5	Winter into Gulf of St Lawrence. Back in April-May	Spawning: Emerald and Western Banks
Browns Bank	4X	22	11	Winter: Browns and Sable Island Banks. Summer: Southwestern coast of Nova Scotia.	

Table 5.2: Fish stocks statistics: cod-haddock-pollock. (From Rivard et al., 1988).

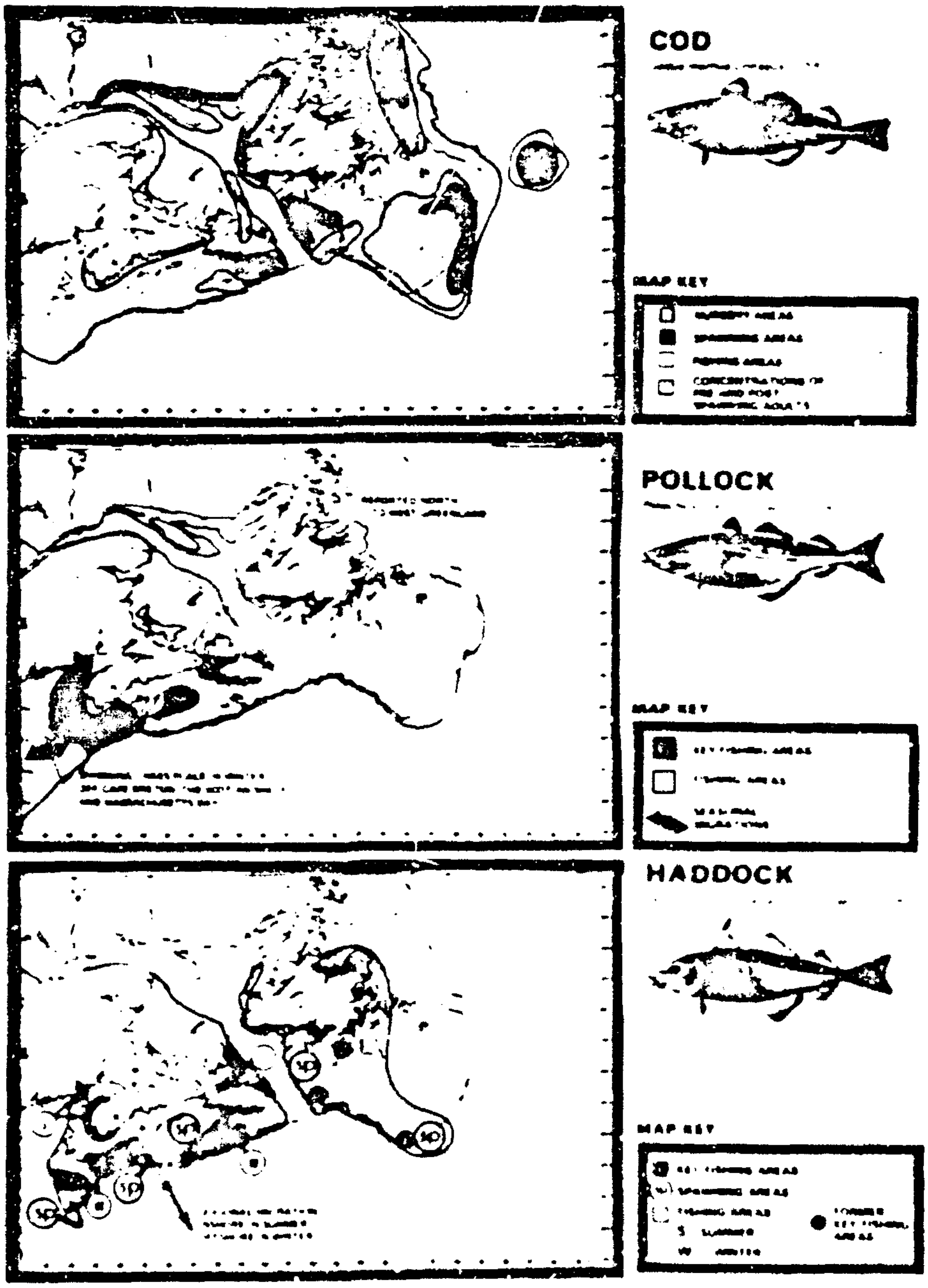


Figure 5.2: Key fishing areas: a) cod, b) pollock and c) haddock. (From Scarratt, 1982).

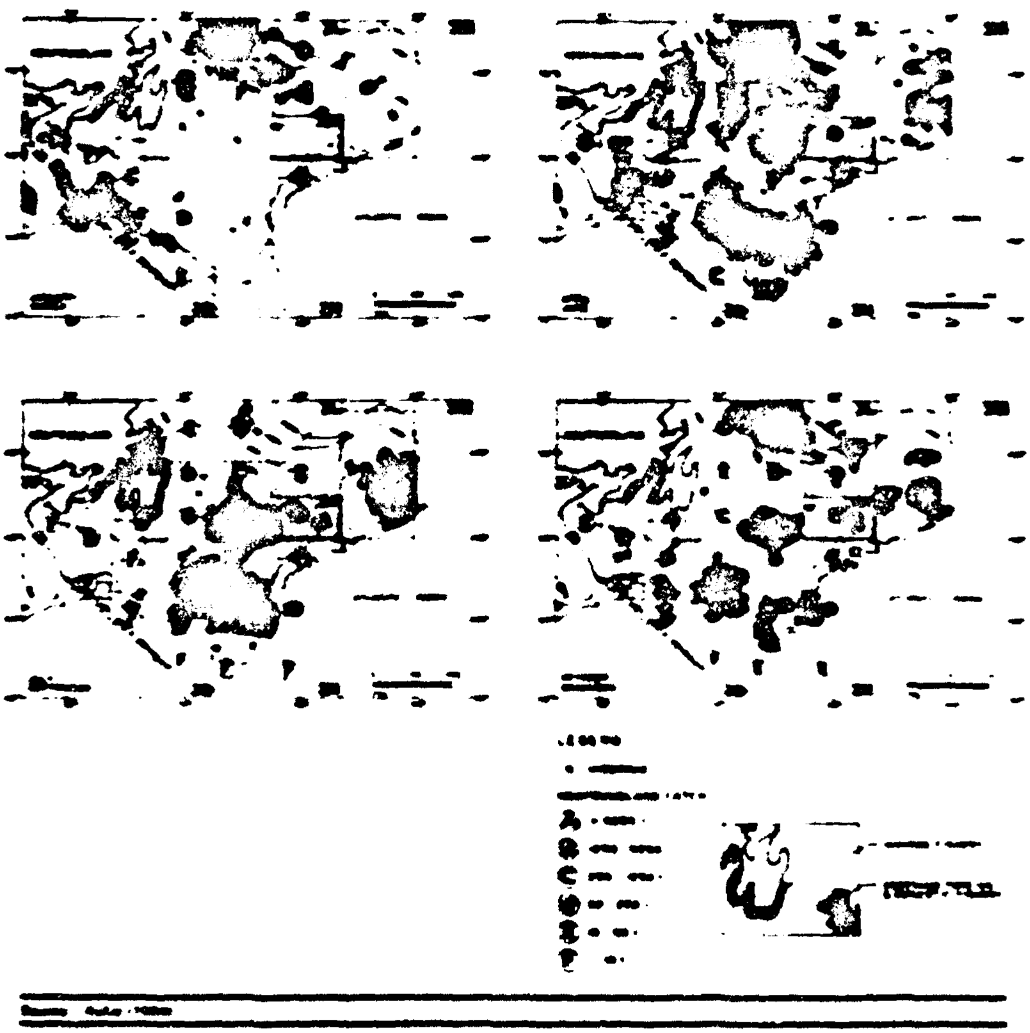


Figure 5.3: Seasonal distribution of the Atlantic cod - Grand Banks. (From Mobil Oil, 1984).

Stock		Catches	TAC	Migration	Remarks
Fishing Area		1979-1980	1979-1980	Pattern	
Name	NAFO div	('000 t)	('000 t)		
Redfish					
Grand Banks					80% Foreign fisheries
Flemish Cap	3M	[illegible]	[illegible]	Not known	
Eastern Bank	3LN	[illegible]	[illegible]	Not known	
South Western	3O	[illegible]	[illegible]	Not known	
St. Pierre Bank	3P	6	15	Seasonal in/from Gulf area.	
Gulf of St. Lawrence	4RST	27	[illegible]	Possibly from west of Newfoundland to Rose Blanche Bank in winter. Return in summer.	At depth of 100-400 m. High concentrations: Southern edge of the St. Lawrence
Scotian Shelf	4VWX	[illegible]	[illegible]	Not known	Basins and edges depth of 100 to 400 m. High concentrations: Southwest edge of Banquereau; LaHave and Emerald Basins.
Silver Hake					Mostly foreign
Scotian Shelf	4VWX	[illegible]	[illegible]	Summer: water depth of 100-200 m; Winter: deep basins	Fishing April to November; Concentrations on Banks

Table 5.3: Fish stocks statistics: redfish-silver hake. (From Rivard et al., 1988)

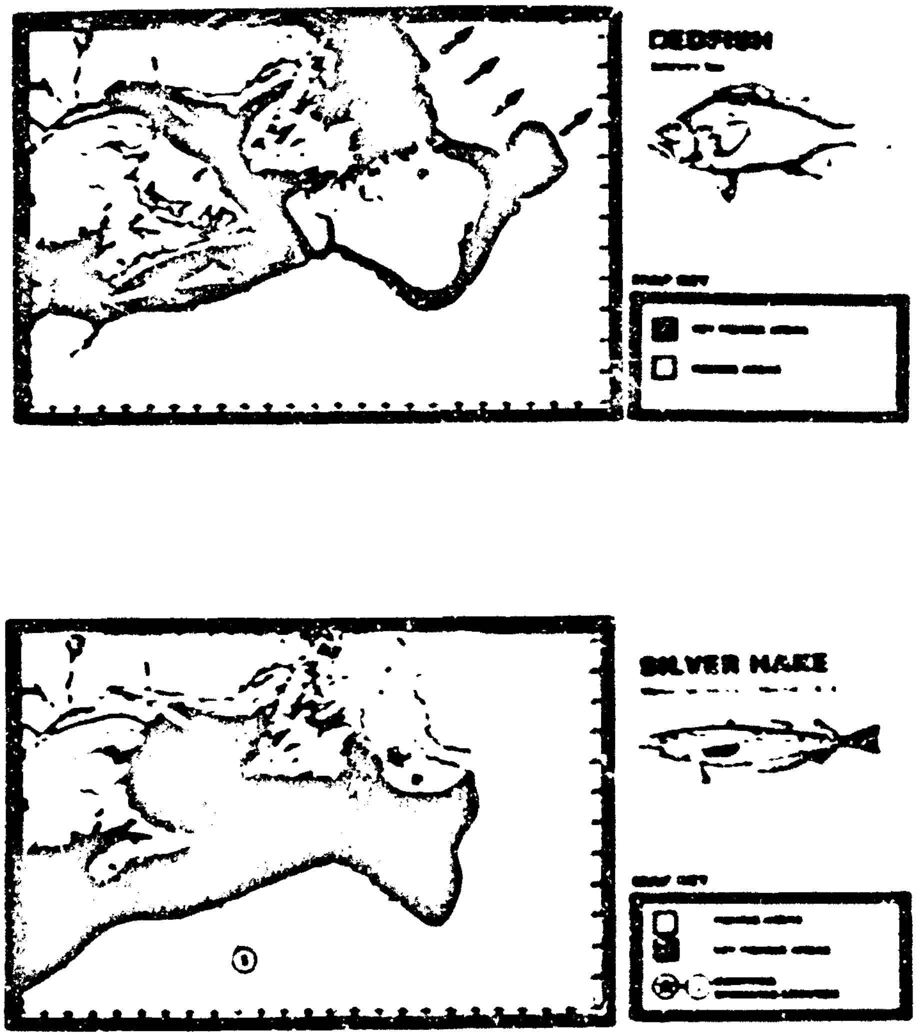


Figure 5.4: Key fishing areas: a) redfish, b) silver hake. (From Scarratt, 1982)

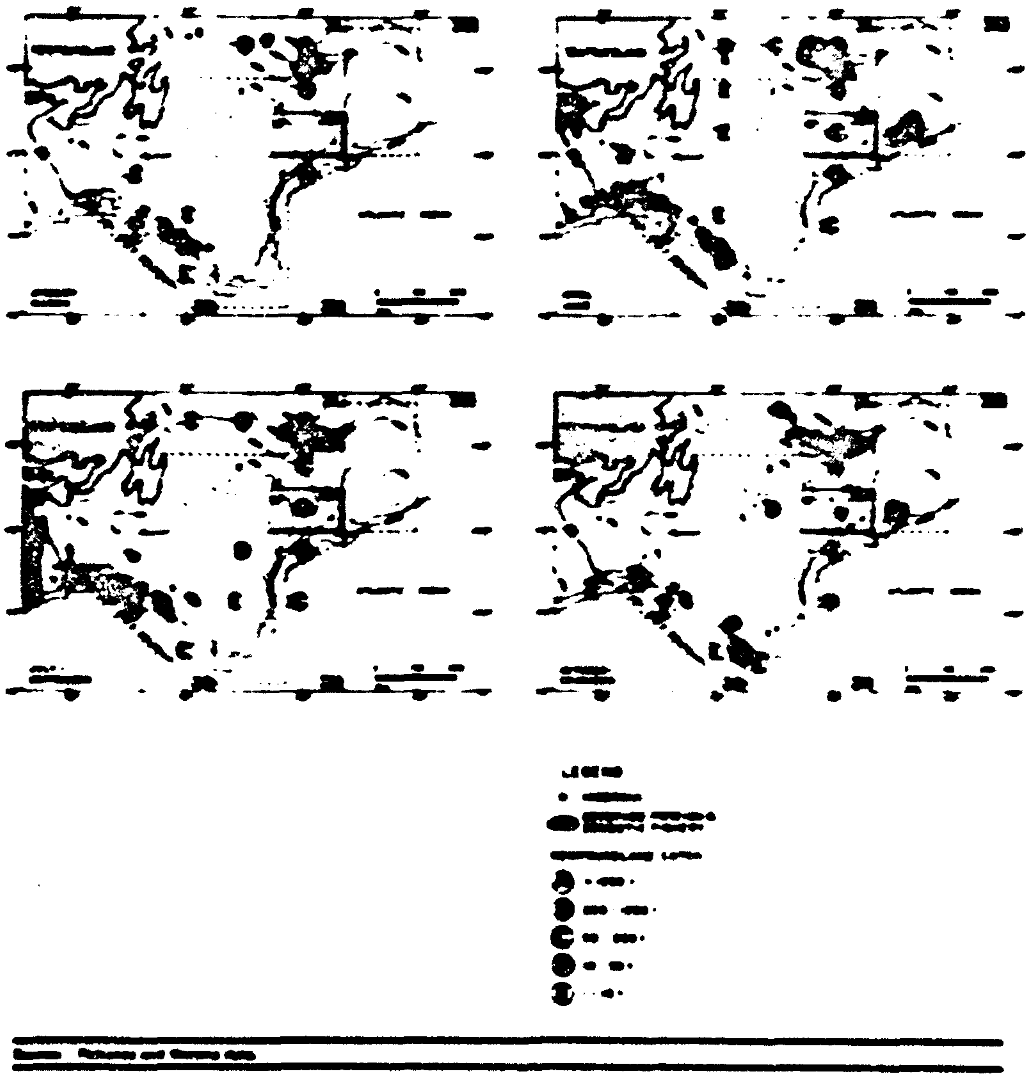


Figure 5.5: Seasonal distribution of the redfish - Grand Banks. (From Mobil Oil, 1984).

Species Fishing Area Name	NAFO #	Catches 1985-1986 ('000 t)	TAC 1987-1988 ('000 t)	Migration Pattern	Remarks
American Plaice					Foreign fisheries outside 200 nm only
<u>Grand Banks</u>					Mostly spring and summer fisheries.
Northeast	3K	2		None known	Concentrations:
Flemish Cap	3M	2	-	None known	- Hamilton Inlet
Grand Banks	3LNO	44	40	None known	- Grand, St. Pierre, Banks.
St. Pierre Bank	3Ps	3	5	None known	
<u>Gulf of St. Lawrence</u> Southern Gulf	4T	6	10	None Known	2 main concentrations - near Bay of Chaleur - southern side of Cape Breton Island.
Yellowtail					Mostly summer fisheries.
<u>Grand Banks</u>	3LNO	17	15	Shallower water in spring, deeper water in fall.	Mostly domestic, foreign outside 200 nm.
Greenland Halibut					
<u>Grand Banks</u> Northern	3KL	25	-	Some migration into the Gulf of St. Lawrence.	Older fishes deep water along slopes. Young shallow areas.
<u>Gulf of St. Lawrence</u>	4RST	3	-	Some migration from 3KL.	
Flatfish					Mostly by-catch fishery.
<u>Scotian Shelf</u>	4VWX	10	-	None known	Concentrations: [illegible], Misaine, Banquereau, Sable Island and Browns Bank.

Table 5.4: Commercial fish species- stock statistics: Flatfish. (From Rivard et al., 1988).

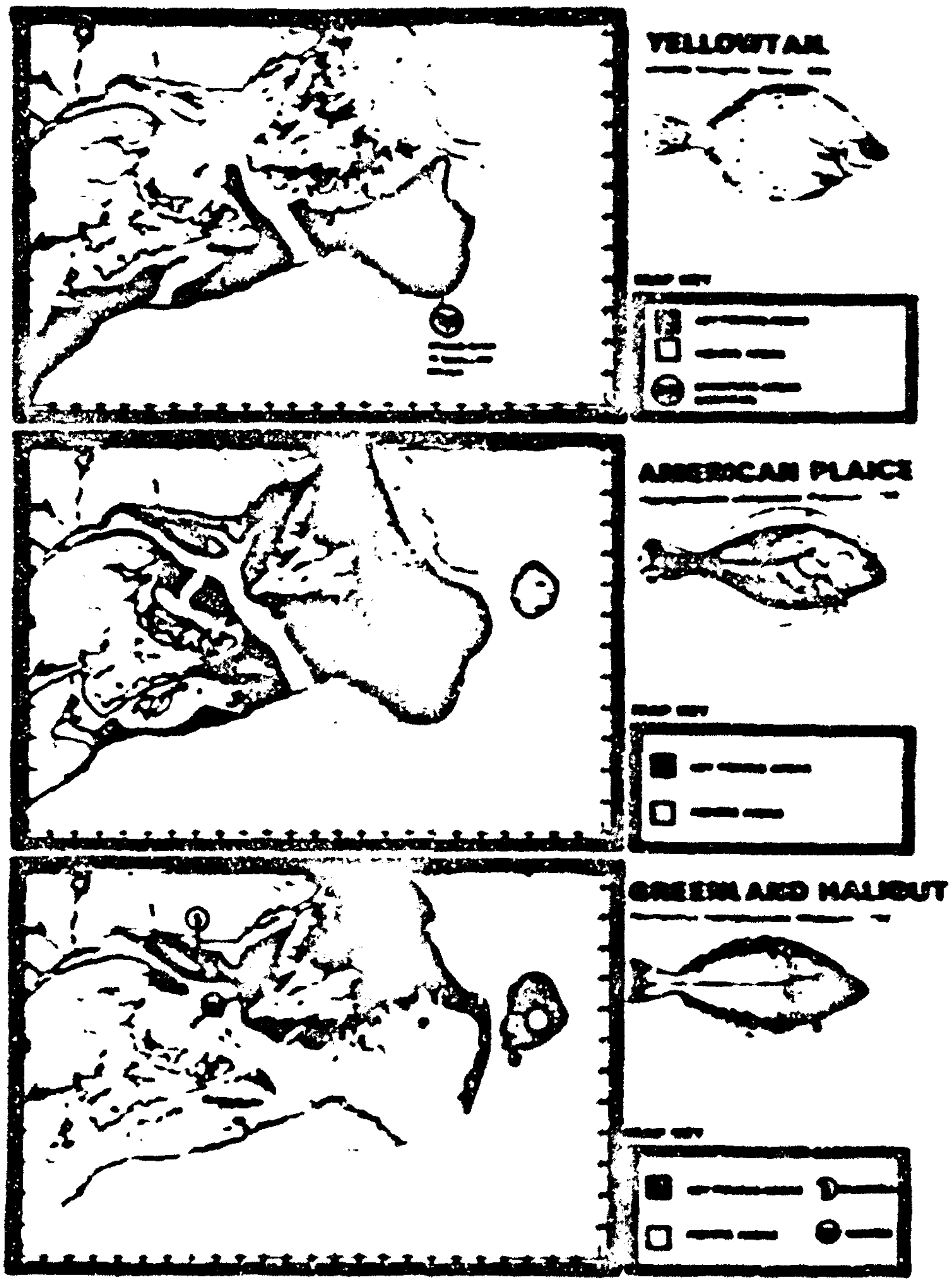


Figure 5.6: Key fishing areas: a) yellowtail, b) plaice , c) Greenland halibut. (From Scarratt, 1982)

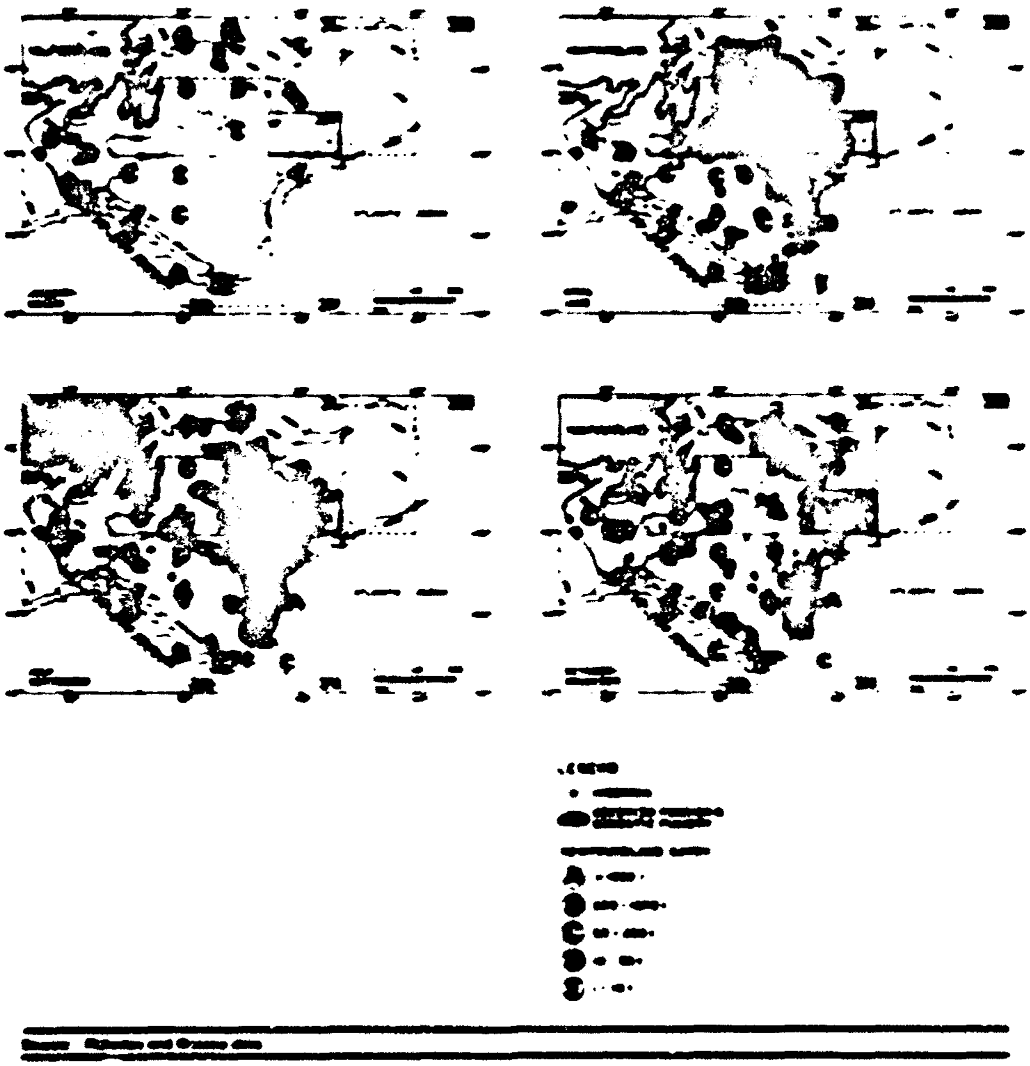


Figure 5.7: Seasonal distribution of the American plaice - Grand Banks. (From Mobil Oil, 1984).

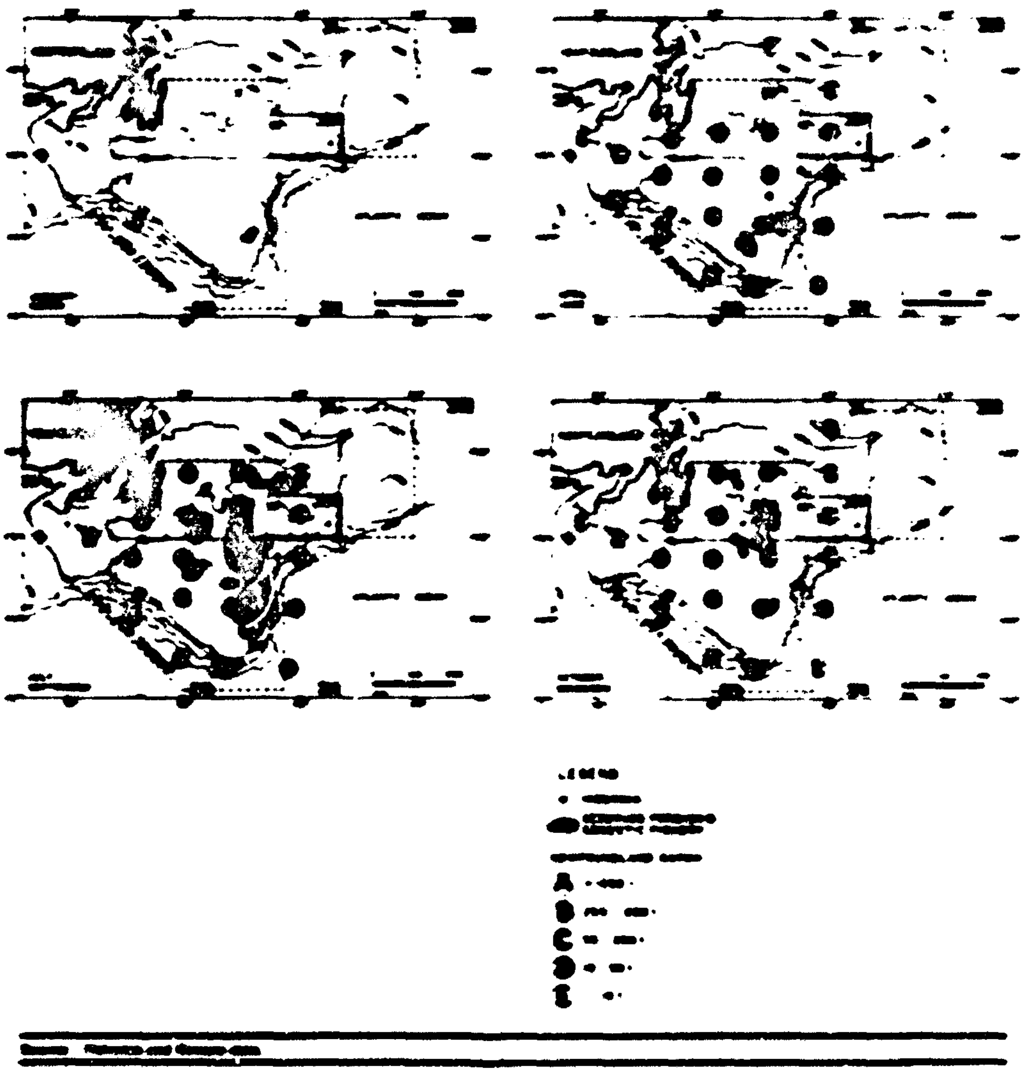


Figure 5.2: Seasonal distribution of the yellowtail flounder - Grand Banks. (From Mobil Oil, 1984).

Stock Fishing Area: Name	NAFO #	Catches 1988-1992 ('000 t)	TAC 1987-1992 ('000 t)	Migration Pattern	Remarks
Herring					Domestic only
<u>Grand Banks</u>					5 main stocks:
East and South Coast	3KLP	3	-	None known	1) White Bay & Notre Dame Bay 2) Bonavista Bay & Trinity Bay 3) Conception Bay & Southern Shore 4) St. Mary's Bay & Placentia Bay 5) Fortune Bay
<u>Gulf of St. Lawrence</u>					
North Shore of Quebec	4S	1	-	-	
West	4R	16	[illegible]	-	
South	4T	[illegible]	[illegible]	-	
<u>Scotian Shelf</u>					
Sydney Bight	4Vn	4	4	Migration from 4T and 4R	
South-West N.S. and Bay of Fundy	4WX	111	[illegible]	Adults migrate to the eastern Scotian Shelf	
Capelin					
<u>Grand Banks</u>					
N.E. Newfoundland	2J3K	[illegible]	-	Migrations from the North to southern part of Bank.	
North	3L	[illegible]	-		Inshore fishing only
South	3NO	1	[illegible]	Also, east and north-west populations migrate onshore to spawn on the east coast.	[illegible]
S Newfoundland	3Ps	1	[illegible]		Inshore fishery
<u>Gulf of St. Lawrence</u>					Spawning onshore
West Coast of Nfld	4R	2	2		from April to July
Mackerel				Migration into coastal waters in the [illegible]	Mostly July to September fisheries.
All areas	-	[illegible]	[illegible]	Returns to deeper waters to the south in the fall.	

Table 5.5: Commercial fish stocks statistics: pelagic species (From Rivard et al., [illegible])

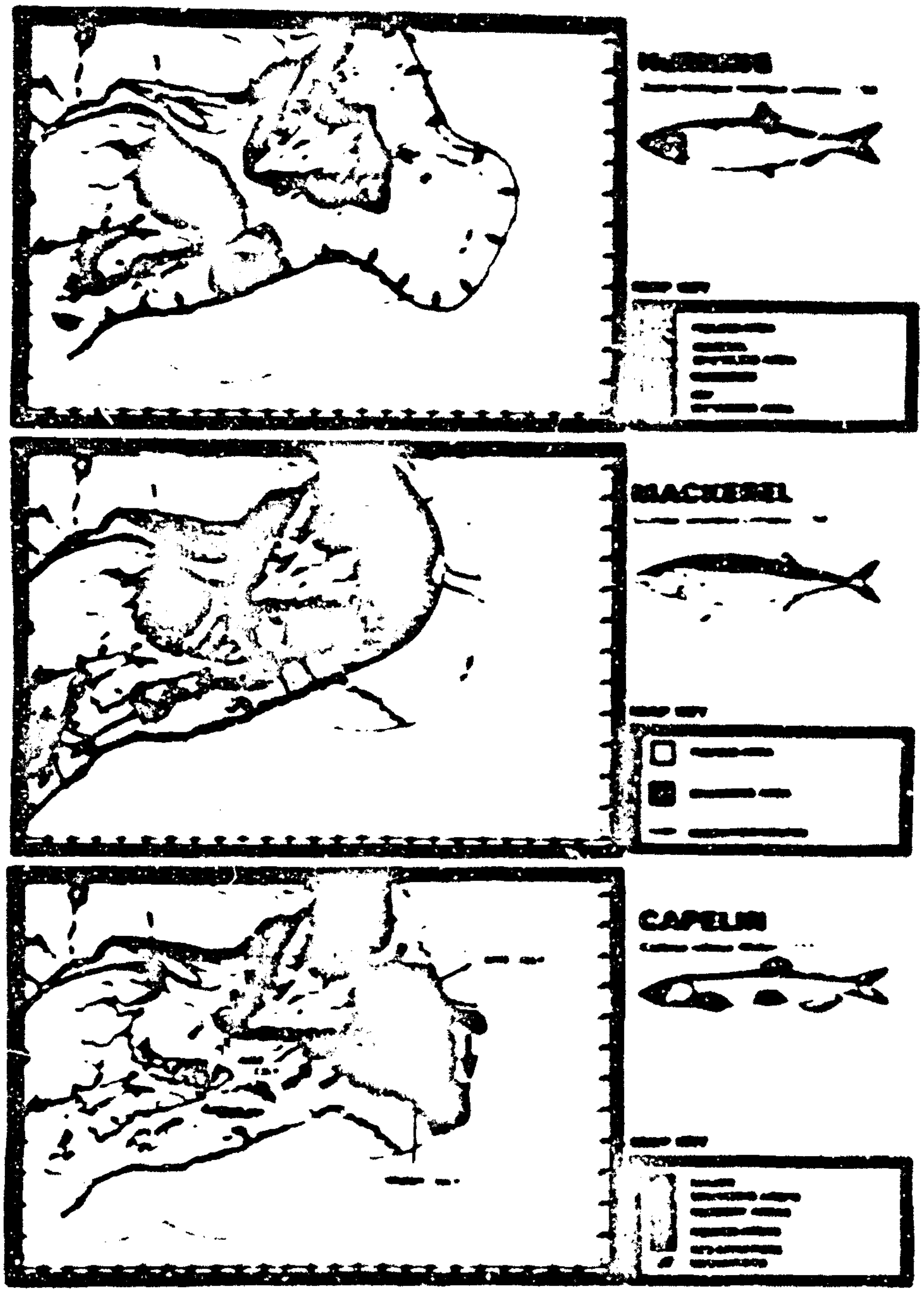


Figure 5.9: Key fishing areas: a) herring, b) mackerel and c) capelin. (From [illegible], 1982).

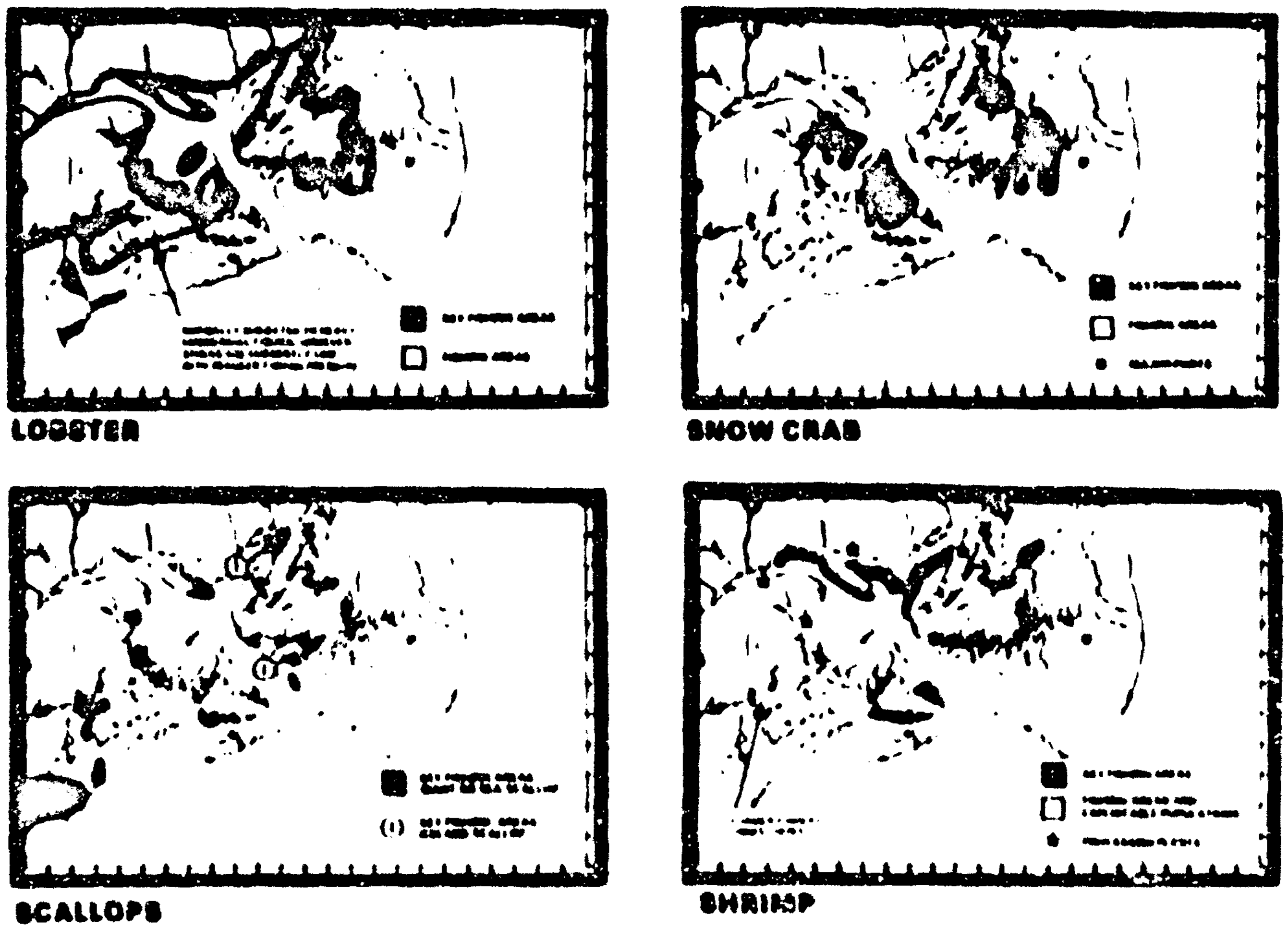


Figure 5.10 Key fishing areas a) lobster, b) snow crab and c) scallops and d) shrimp (From Scarratt, 1982)

5.2 Marine Mammals

5.2.1 Mammal Distribution

Most if not all mammal species present in the Northwest Atlantic can be seen in the area under study. Figure 5.11 shows the general distribution of the seals and cetaceans of the Canadian east coast. Table 5.6 lists those mammals and includes information on marine mammal distributions on the Grand Banks as compiled by Mobil Oil [1984]. Finally the data extracted from whaling activity records on the Scotian Shelf [Sutcliffe and Brodie, 1977] yield information on some of the species found on the Scotian Shelf (Table 5.7). Since whaling operations concentrated on large size species, these data pertain exclusively to a few large species that are common on the Scotian Shelf.

The data for the Scotian Shelf are sparse, but they reveal a few significant facts. Concentrations of baleen whales are located in some major inlets such as the entrances to the Emerald and Roseway Basins and the North East Channel. These whale concentrations are related to higher concentrations of zooplankton (and perhaps fish) on the edges of the banks rather than on top of them.

Seal distribution

Some information on seal species distribution is contained in Table 5.8.

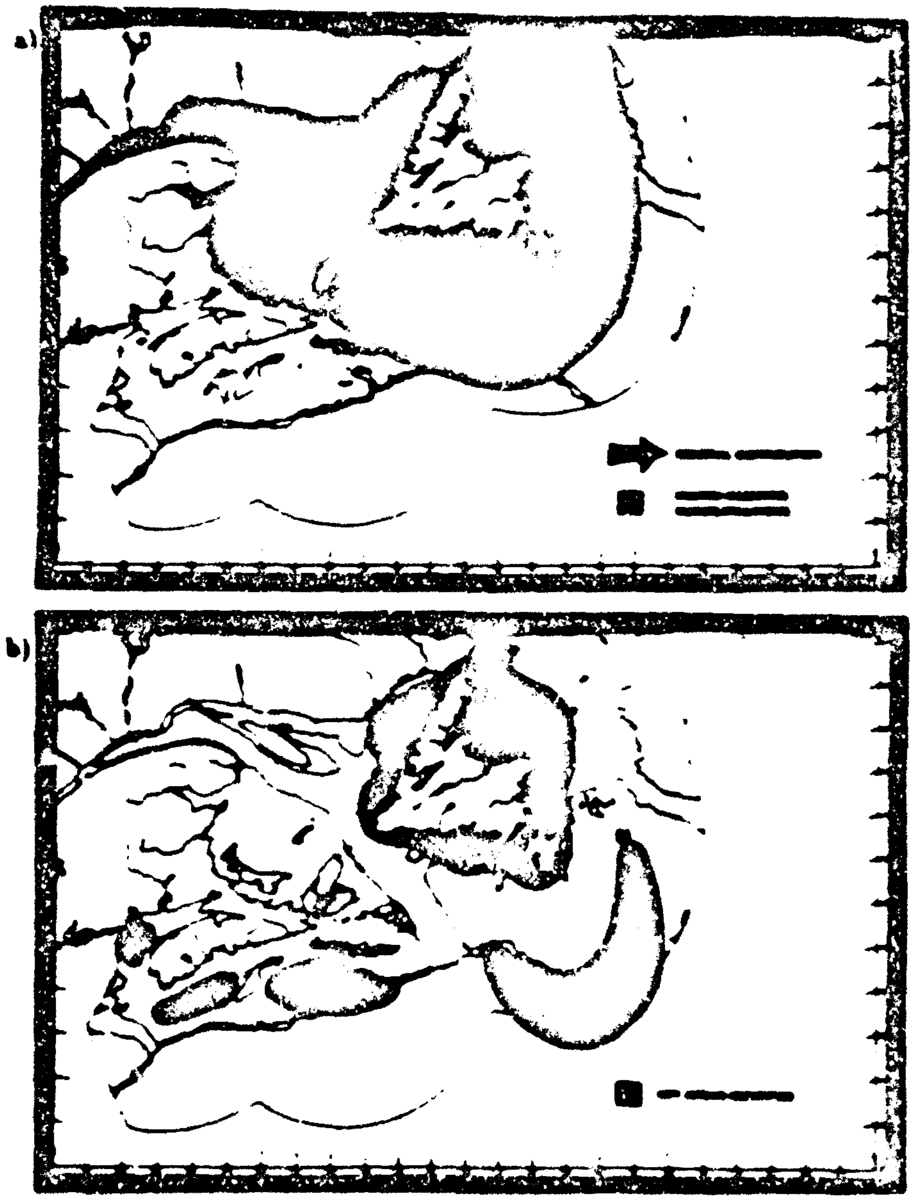


Figure 5.11: General distribution of a) seals and b) cetaceans off the east coast of Canada. (From Scarratt, 1982)

Species	Area Utilized		Peak Occurrence (month)	Relative Occurrence	Estimated Stock Size	Presence	[illegible]	[illegible]
	Coastal	Offshore						
Baleen Whales								
Minke whale	■	■	May-July	Common	.	■		Summer
Fin whale	■	■	June-Aug	Common	[illegible]	■	.	Summer
Blue whale	■	■	Feb-Nov	Rare	.	■	Spring Summer	.
Sei whale	■	■	June-July Sept-Oct	Rare	[illegible]	.	Late summer	.
Humpback whale	■	■	May-Sept	Common	[illegible]	■	.	Summer
Right whale	.	■	Spring Summer	Rare	.	•	•	•
Bowhead whale	•	■	•	Rare	.	•	•	•
Toothed Whales								
Pilot whale	■	■	June-Oct	Common	>[illegible]	.	.	All year
Sperm whale	-	■	May Aug-Oct	Rare	.	■	.	Summer
Bottlenosed w.	■	■	May-Aug	Rare	.	■	.	Summer
Killer whale	■	.	June-July	Rare	.	■	.	Summer
Beaked whales	•	•	.	Rare	.	•	•	.
Pigmy Sperm w.	•	•	.	Rare	.	•	•	.
Beluga	•	•	.	Rare	.	•	•	.
Narwhal	•	•	.	Rare	.	•	•	.
Dolphins/Porpoises								
Harbour porpoise	■		Summer	Common	.	.	.	Summer
Atlantic white-sided dolphin	■		July-Oct	Common	.	.	.	Summer
White-beaked d.	■		Mar-Nov	Rare	.	■	.	Summer
Saddleback d.		•	June-Sep	Rare	.	.	.	Summer
Bottlenosed d.	•	•	.	Rare	.	•	•	
Seals								
Grey Seal	■	■	Summer	Common	.	.	Summer	
Harbour Seal	■	.	Summer	Common	.	.	.	All year
		■	Winter	Common	.	.	.	All year
[illegible] Seal	■	.	Winter	Rare	.	■	.	.
Hooded Seal	■	.	Winter	Rare	.	■	.	.

Table 5.4: Mammals in the Grand Banks area. (From Mobil Oil, 1984).

Species	Relative Occurrence	Season	Preferred Location
Sei whale	Common	June-July	Shelf Break, North-east Channel
		Sept-Nov	Roseway Basin area.
Fin whale	Common	July- Aug	Around Emerald Bank and entrance to Emerald Basin.
		Sept	Banks and channels west of Sable Island Bank.
		Oct-Nov	Roseway Basin area.
		Winter	East coast of Cape Breton Island.
Sperm whale	Common	June-Sept	Shelf Break
Minke whale	*	Summer	Scotian Shelf Banks
Blue whale	Rare	*	*

Table 5.7: Whale distributions in Nova Scotia waters. (After Sutcliffe and Brodie, 1977)

Species	Occurrence in Area	Estimated Stock Size	Main Concentrations
Harp Seal	Winter and early spring	[illegible] million	. Gulf of St. Lawrence, off northeast Newfoundland and in the vicinity of Magdalen Islands.
Hooded Seal	Winter	[illegible]	same as above
Harbour Seal	Permanent	[illegible]	Sable Island, Gulf of St. Lawrence, and along the south coast of Newfoundland.
Grey Seal	Permanent	[illegible]	Southern Gulf of St. Lawrence and Sable Island.

Table 5.8: Seal distribution on the east coast of Canada. (Source: Fisheries and Oceans data.)

5.3 Biological Sound Sources

5.3.1 Noise Characteristics of the Sound Producers

Several species are known to produce sound in the frequency bands that are covered by passive acoustic sensors. The main species contributing to ambient noise and some characteristics of the noise produced are described in Tables 5.9 and 5.10.

5.3.2 Specific Noise Producers

Fin whale

The fin whale which is suspected to produce a characteristic 20 Hz signal is known to frequent the coast of Nova Scotia in summer and fall. These 20 Hz blips show the following characteristics (frequency of occurrence in brackets) [Schevill et al, 1964]:

- - 12 s interval, equal amplitude(50-60%)
- - 22-15 s doublets: large amplitude pulse followed 15 s by a smaller amplitude pulse, the pair repeating 22 s later (20-30%)
- - miscellaneous (large variety of doublets (15-20 %).

Blue whale

The blue whale can produce the lowest and most powerful sounds emitted by a natural source: up to 37 s, 28 Hz, averaging 188 dB, with lowest frequencies recorded at 12 Hz (recorder limit).

5.3.3 False Target Characteristics

Fish

Values of target strength of fish for a 10 kHz sonar are given in Figure 5.12. Urick [1975] notes that fish without a swim bladder (e.g., mackerel) have

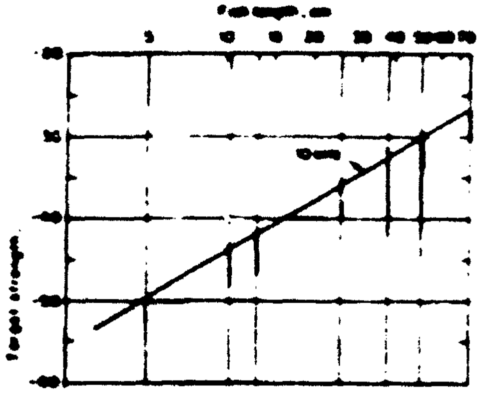


Figure 5.12: Target strength (dB) of fish as a function of fish length for a 10 kHz sonar. (After Urick, 1983)

a target strength some 10 dB lower than those that do, such as cod.

Mammals

Information on the target strength of whales is sparse. One observation showed that a small whale of approximately 10 m had a target strength of 2 dB at side aspect.

Additional information on the false target characteristics of some fishes or mammals is contained in the classified annex of this document.

5.4 Deep Scattering Layer

No specific information for this area is available.

5.5 Bioluminescence

Some information on the false target characteristics of some fishes or mammals is contained in the classified annex of this document.

Species	Sound Description	Frequency Range (Hz)	Peak Energy (Hz)	Peak Pressure (dB re 1µPa)	Notes
Invertebrates					
Lobster, Crabs (Snow, blue, rock, stone)	Rasps, scraping or snapping, slow, low-pitched.	40 to [illegible]	[illegible], [illegible], 2000 to [illegible]	-	Bottom dwellers, mainly within 200 m depth, on rock or gravel bottoms
Fish					
Schooling: Herring, mackerel, capelin.	Hydrodynamic swimming sounds of schools; thumps and knocks; [illegible] of pulsed grunts, and rumbling.	0 to [illegible]	75 to 150; [illegible], 400 to [illegible], [illegible]; 1200, 1500 to [illegible]	130	School in shallow water near shore around islands, and in bays, estuaries, inlets, and straits, often on or near bottom.
Solitary: Cod, pollock, haddock.	Grunts and choruses of grunts, thumps, knocks, clicks and humming.	0 to [illegible]	15 to 1500	144	Singly, pairs, or small groups, not organized, on or near bottom.
Silver Hake	Low knocks or rasp.	[illegible]			
Seals					
Bearded, grey, harbour, ringed, harp, hooded.	a) Clicks, paired or in series, up to 100 per second.	a) 0 to 10,000	a) 2000, 4000 to 12,000	a) -	Congregate in groups of hundreds or thousands near the Magdalen Islands and off northeastern Newfoundland in winter
	b) Calls, pulsed and tonal.	b) < 1000	b) < 2000	b) 130	
Dolphins and Porpoises					
Dolphins: Common, bottlenosed, white-beaked, and Atlantic white-sided.	a) Whistles and squeals, many [illegible] around [illegible], up to 1 s long	a) 100 to 100,000	a) 2000 to 20,000	a) -	Coastal to offshore ocean, year round. Maximum length 1 to 4 m. Speed cruising 2 to 6 km, sustained 6 to 16 km, maximum 20 to 30 km in bursts. Dives to 40 m for 1 to 20 minutes. Groups 2 to 200.
	b) Clicks, often pulsed, tonal. Usually [illegible], broadband	b) 0 to 200,000	b) 2000 to 3000; 10,000 to 20,000	b) 222	
Harbour porpoise, bottlenose dolphins.	a) Whistles, modulated, up to 1 s long.	a) 100 to 120,000	a) 2000 to 20,000	a) -	Inshore to coastal, [illegible] bays, inlets, estuaries, and large rivers. Never found beyond 200 m depth, year-round. Maximum length 1 to 3 m. Speed 2 to 6 km. Dives up to 40 m for less than 3 minutes. In small loose groups 2 to 20
	b) Clicks, often pulsed, 0.1 to 200 ms long.	b) 40 to 170,000	b) 1000 to 60,000	b) 220	

Table 5.9: Sound producers - Part I

Species	Sound Description	Frequency Range (Hz)	Peak Energy (Hz)	Peak Pressure (dB re 1µPa)	Notes
Baleen Whales Coastal: Minke, fin, humpback.	a) Moans, sporadic or pulsed, may oscillate in frequency (± 10Hz).	a) 13 to 200	a) 20 to 140	a) 1[illegible]	Coastal, upper 100 m, year-round. Maximum length: 8 to 28 m. Speed cruising 3 to 12 km, maximum 6 to 30 km. Groups 1 to 3, sometimes 10 to 40
	b) Clicks may be pulsed, rapid 6 to 7 per second.	b) [illegible] to 14,000	b) [illegible] to 14,000	b) 1[illegible]	
	c) Songs/sequences of moans, grunts, chirps and pulses of clicks 6 to 35 minutes long. Emitted only by lone males in winter breeding grounds.	c) 30 to 6000	c) [illegible] to 2000	c) 1[illegible]	
Offshore: Minke, fin, humpback, blue, sei, right, bowhead.	a) Moans, often in pairs, up to 40 s long, sometimes pulsed.	a) 12.5 to 200	a) 20, 25, 31.5	a) 1[illegible]	Offshore, same as above
	b) Clicks may be pulsed, often rapid, 6 to 7 per second.	b) [illegible] to 14,000, 28,000	b) [illegible] to 14,000, 28,000	b) 1[illegible], 1[illegible]	
	c) Same as c) above.	c) 30 to 6000	c) [illegible] to 2000	c) 1[illegible]	
Toothed Whales Coastal: Sperm, beaked, killer, pilot, beluga	a) Repeated clicks, to several hundred per second, 0.1 to 25 ms long.	a) 200 to 20,000	a) [illegible] to 20,000	a) 1[illegible]	Over the continental shelf, around coasts and islands, mostly from Sep. to Apr., some year-round. Maximum length 5 to 18 m. Speed cruising 3 to 6 km, maximum 10 to 30 km. Dives to 3000 m for 1 to 60 mins. Groups usually singles to 25
	b) Whistles or screams, pure or harmonic, constant or oscillating, 0.2 to 3 s long.	b) [illegible] to 10,000	b) [illegible], [illegible] to [illegible]	b) > 1[illegible]	
	c) Yelps, barks, squeaks, blasts and calls.	c) 200 to 20,000	c) [illegible] to 2000	c) 1[illegible]	
Offshore: Sperm, beaked, pygmy sperm, killer	a) Clicks, often pulsed, to several hundred per second, 0.1 to 0.25 ms long, repeated.	40 to 32,000	[illegible] to [illegible]	1[illegible]	Offshore, same characteristics as above

Table 5.10: Sound producers - Part II

Chapter 6

Commercial Activity

6.1 Shipping

6.1.1 Shipping Lanes

Important shipping activity takes place along routes leading to the main ports of the Maritime Provinces, Gulf of St. Lawrence and inland, along the St. Lawrence Seaway. Figures 6.1 and 6.2 show the main shipping lanes cutting the area.

An obvious seasonal difference is the reduced traffic in the gulf in winter due to ice cover and the southward displacement of the preferred shipping lanes over the Grand Banks to avoid icebergs. The ship density should be higher in the gu[illegible] vicinity of these routes and near the approaches to ports such as Halifax and St. John's, and in the southwest Nova Scotia region where the combined traffic [illegible] Gulf of Maine (Northern New England ports) and the Bay of Fundy [illegible] ing the ice free season [illegible] affic density will be high also in the gulf and particularly in the St. Lawrence Estuary.

6.1.2 Main Ports Charts

The main ports for each of the subareas are shown in Figures 6.3 for the Gulf of St. Lawrence, 6.4 for the Scotian Shelf and 6.5 for Newfoundland. Some ports in the Bay of Fundy and along the St. Lawrence River up to Montreal are

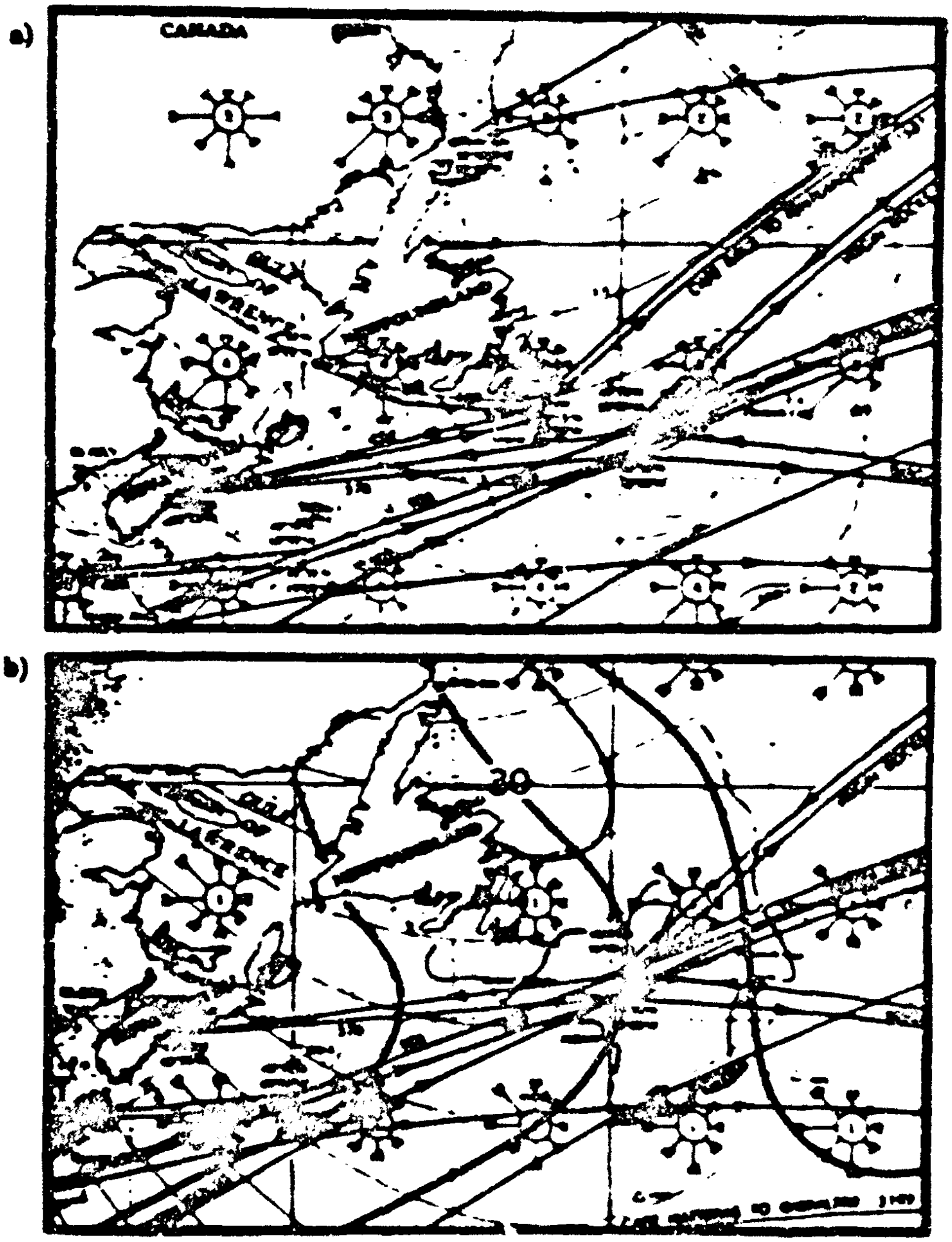


Figure 6.1: Preferred shipping routes: a) July to November and b) December and January. (Adapted from Defence Mapping Agency, 1980).

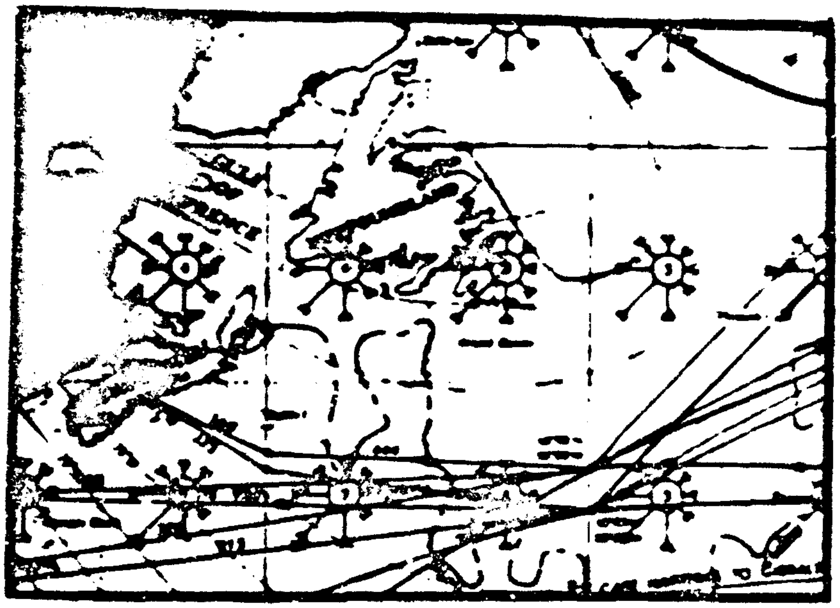


Figure 6.2: Preferred shipping routes from February to June. (Adapted from Defence Mapping Agency, 1980).

included since the traffic they generate will transit through the area of interest.

6.1.3 GIS Data

The preferred shipping lanes described in Section 6.1.1 are included in the GIS on a seasonal basis. The maps of the main ports from Section 6.1.2 have also been included in the GIS database.

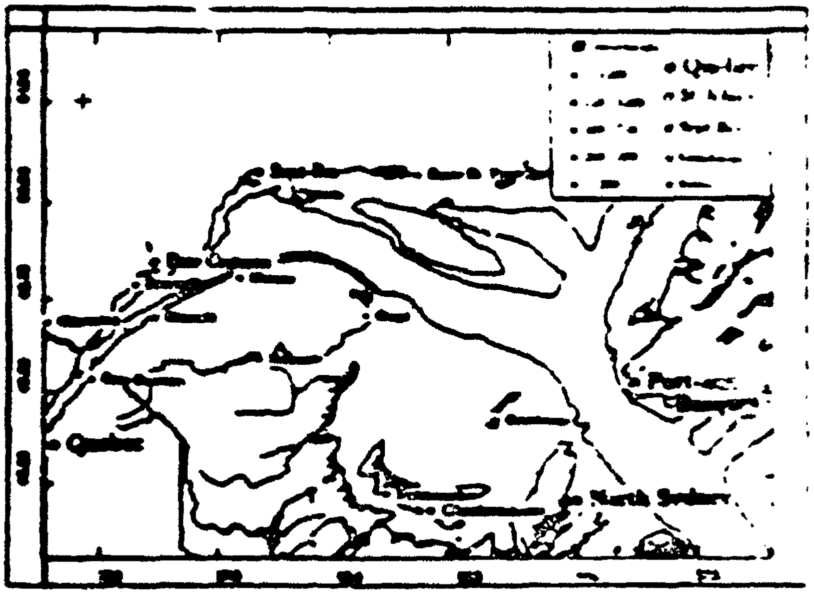


Figure 6.3: Main ports in the Gulf of St. Lawrence. (Data from Statistics Canada).

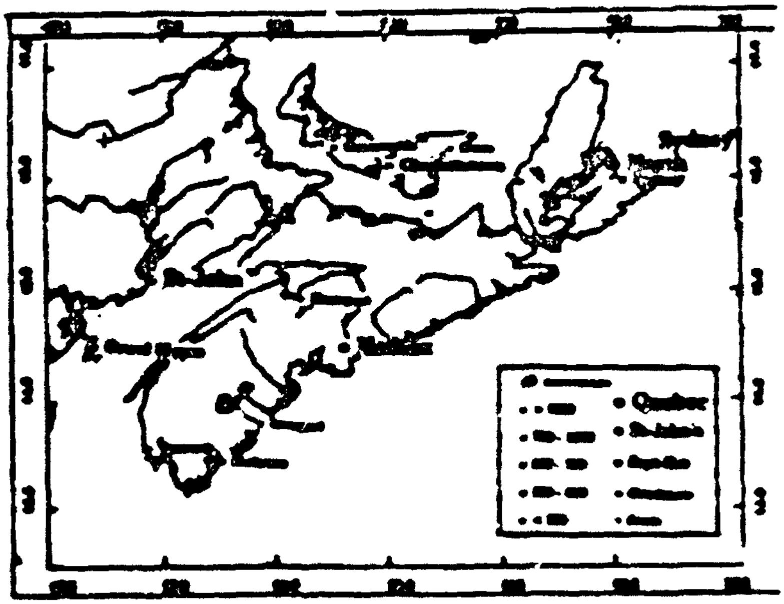


Figure 6.4: Main ports in Nova Scotia. (Data from Statistics Canada).

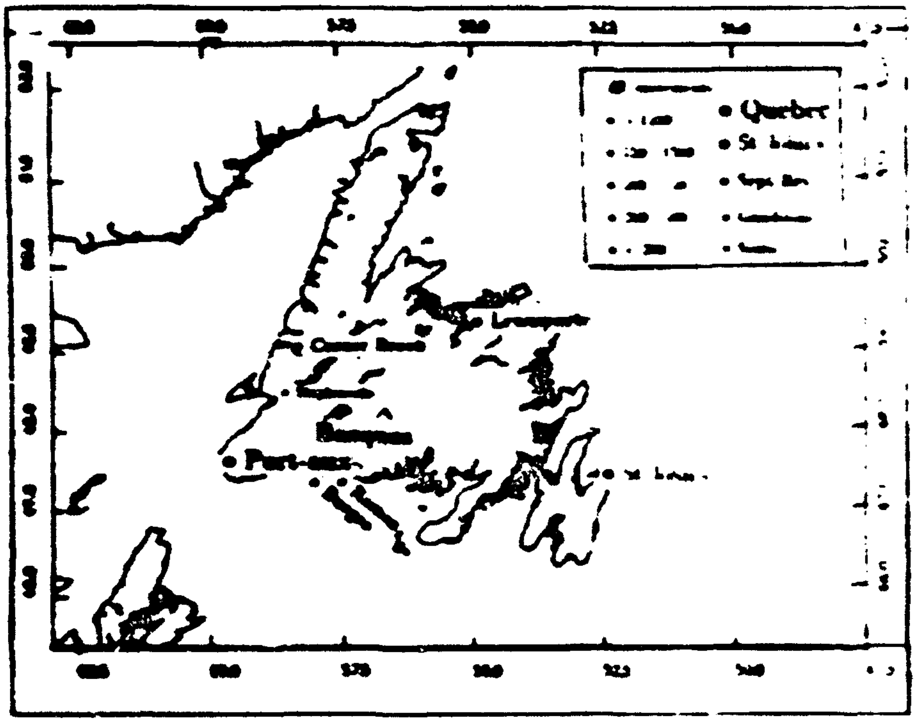


Figure 6.5: Main ports in Newfoundland. (Data from Statistics Canada).

6.2 Fishing

6.2.1 Fishing Activity Maps

The location and importance of fishing fleets depend on the location of the fish stocks. As a result, the information on the main commercial fish species distributions provided in Section 5.1 can be used as an indication of where the fishing effort will take place. In addition, Figures 6.6 and 6.7 attempt to summarize the overall fishing activity for both domestic and foreign fleets in the area of interest.

6.3 Offshore Petroleum Activity

6.3.1 Offshore Petroleum Rights Map

Figures 6.8 and 6.9 show the areas off Nova Scotia and Newfoundland where petroleum exploration or production are likely to occur during the next decade.

6.4 Oil Production

Two main areas have shown potential for commercial development on the east coast of Canada: the Sable Island region and the Hibernia field.

Hibernia field

The Hibernia field was discovered in 1979. It is located on the northeastern Grand Banks approximately 315 km southeast of St. John's (Figure 6.10). The field covers an area of approximately 220 square kilometres and is believed to contain between 525 and 600 million barrels of recoverable oil in two reservoirs - the Ben Nevis-Avalon and Hibernia Basins.

The development project was announced in 1988, with production planned to start in 1996 and peak in 1998 at 24,000 m^3 per day [EMR Canada, 1988]. The production will take place mostly from a large structure known as a gravity

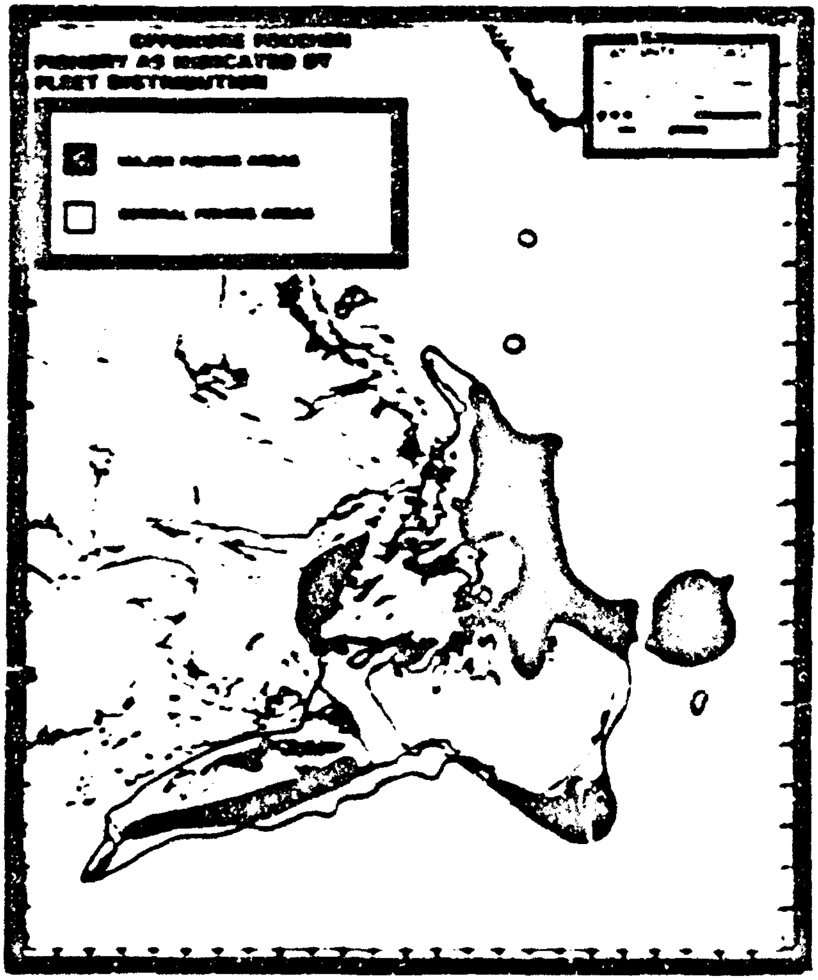


Figure 6.6: Foreign fishery indicated by fleet distribution over the year. (Data from Fisheries and Oceans).

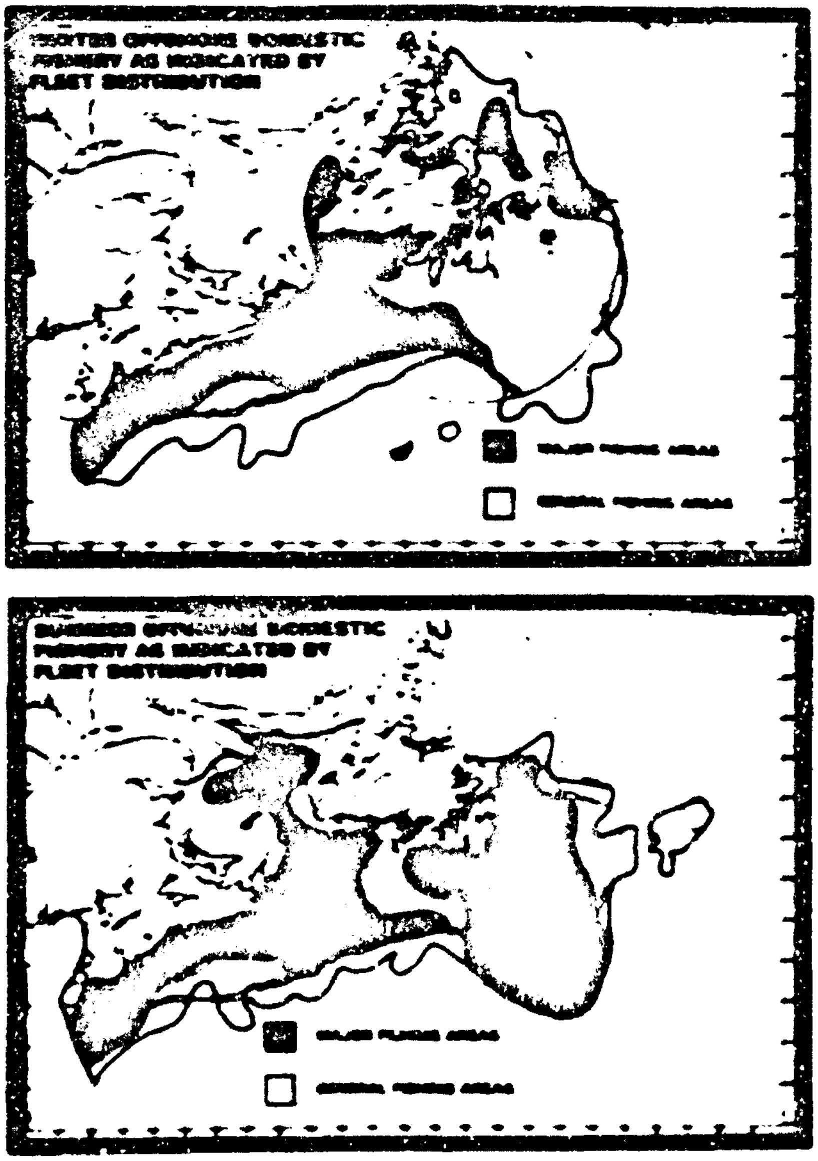


Figure 6.7: Domestic fishery indicated by fleet distribution: a) Summer, b) Winter. (Data from Fisheries and Oceans).

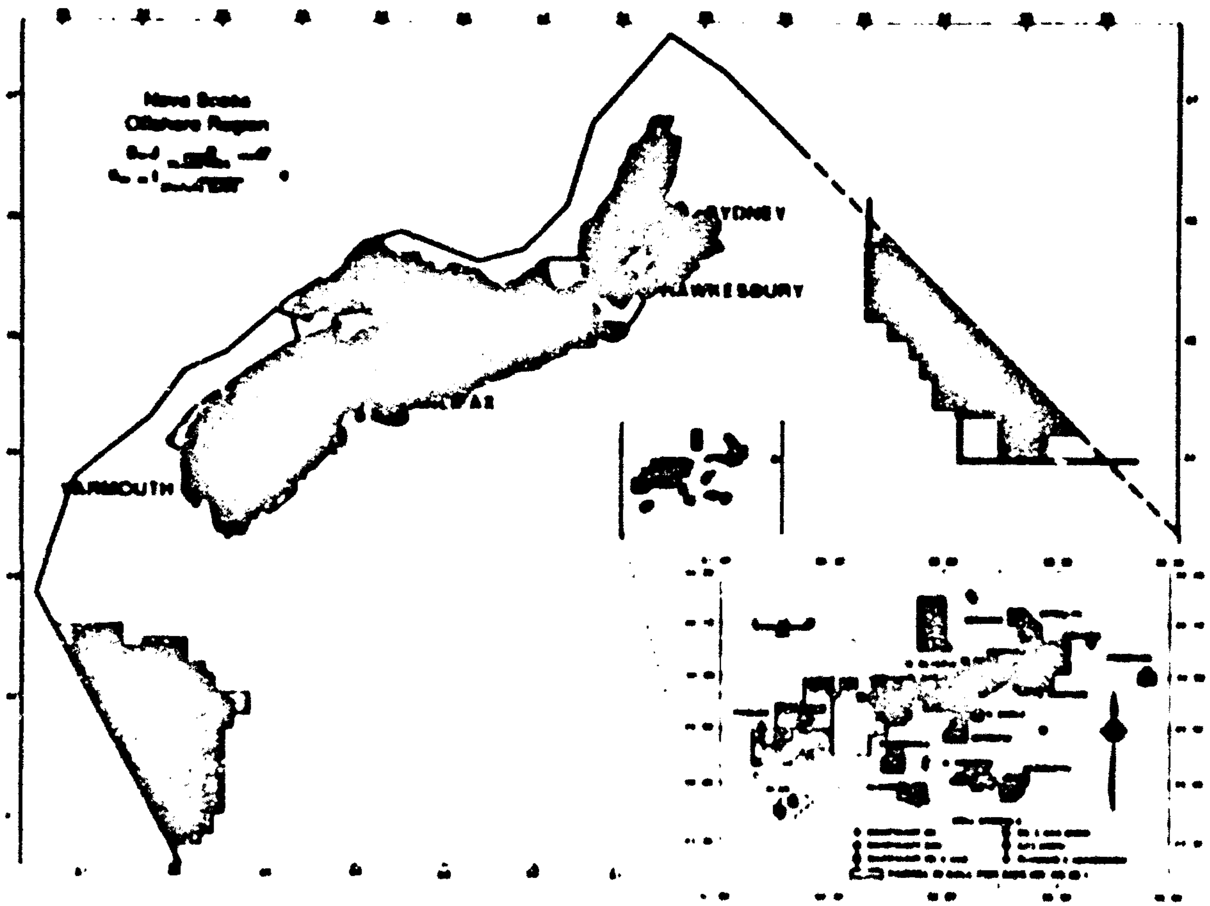


Figure 6.5. Offshore petroleum rights for the Nova Scotia region 1990. (From the Canada Nova Scotia Petroleum Board, 1990).

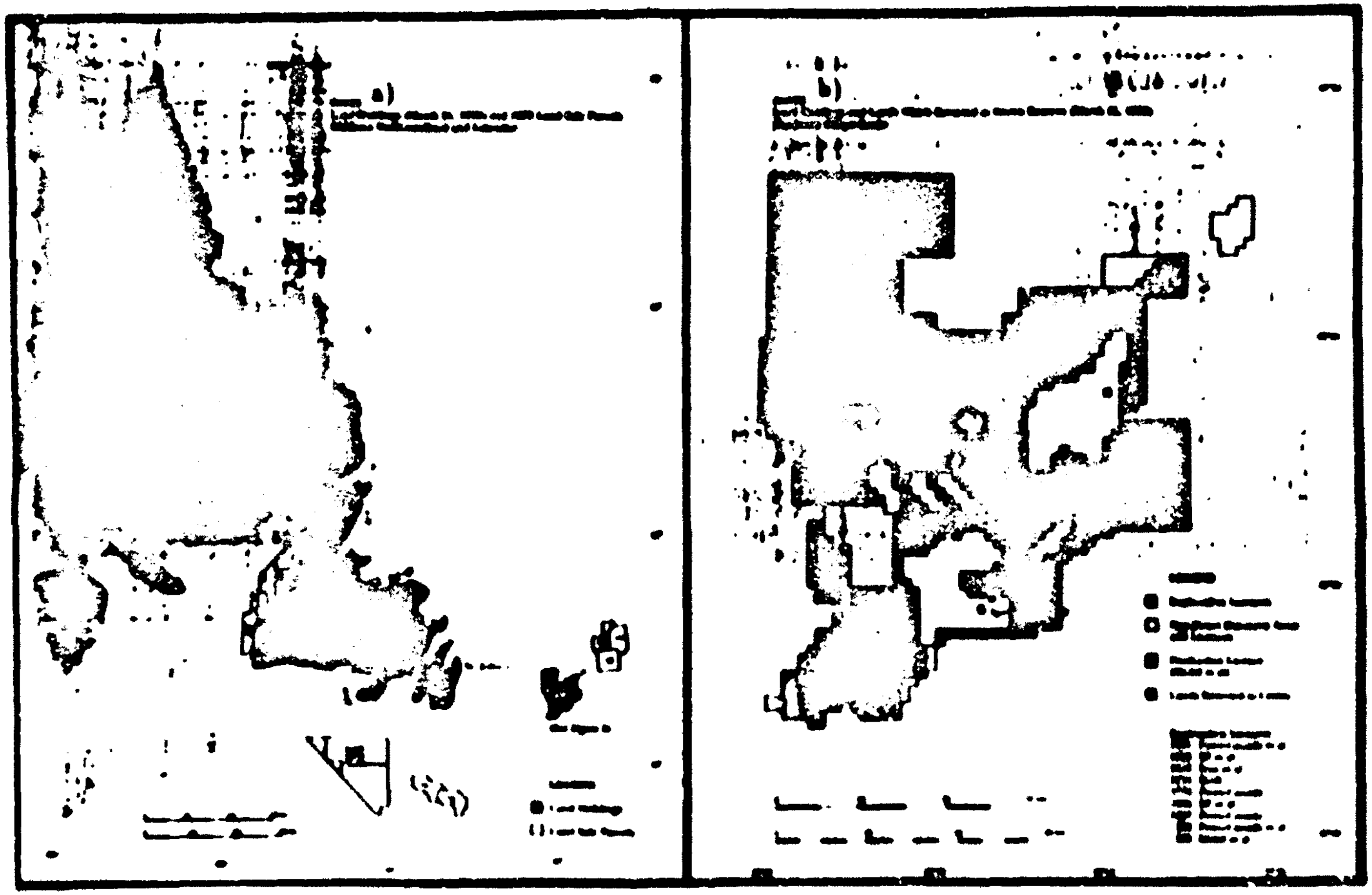


Figure 6.9: Offshore petroleum rights (1990) for a) the Newfoundland Region and b) enlarged Northeast Grand Banks section. (From the Canada-Newfoundland Petroleum Board, 1990)

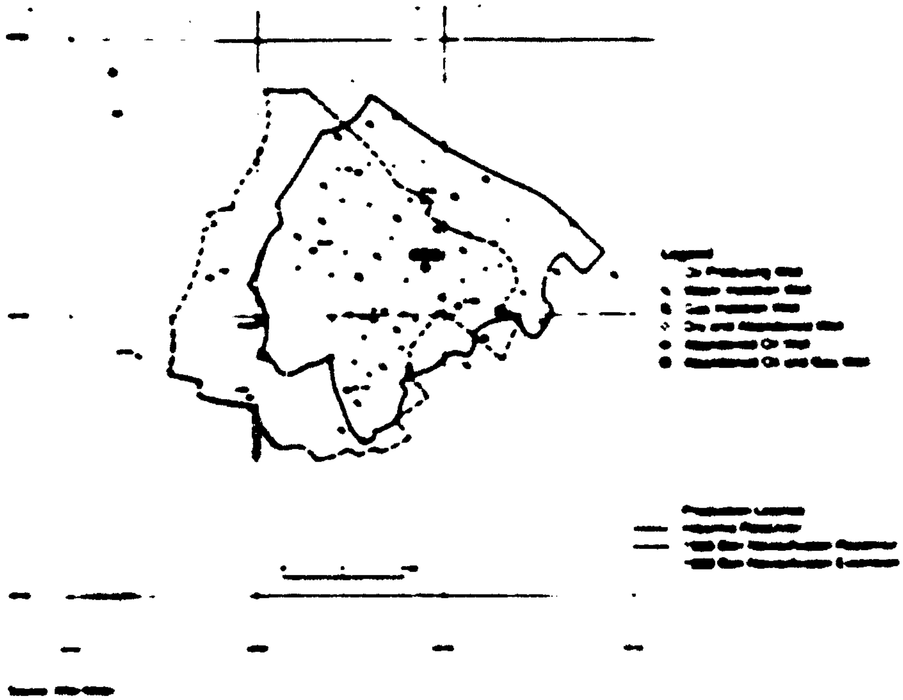


Figure 6.10: Hibernia reservoir map showing proposed development well layout. (From the Canada-Newfoundland Petroleum Board, 1986).

base structure (GBS) that will be towed to a site near 46°46'N and 48°46'W. The structure will weigh some 450,000 tonnes and will be able to store up to 1.3 million barrels of oil (Figure 6.11). Forty-eight wells will be drilled from the structure, and up to 35 additional wells may be drilled beyond the range of the platform by floating rigs. These wells will be fitted with a subsea wellhead and connected to the GBS by a subsea pipeline. Oil will be transferred to tankers through two offshore loading systems located two kilometres from the platform.

Shipping activity related to oil production will consist of a shuttle fleet of three supply vessels and three 120,000 deadweight tonne tankers which will be able to carry 850,000 barrels of oil.

An appreciable amount of noise generated by these activities is therefore expected during the 18 year life of the project.

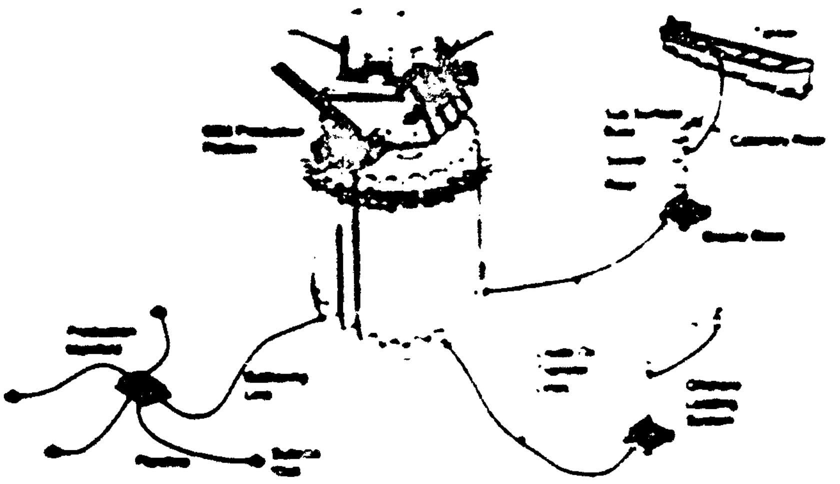


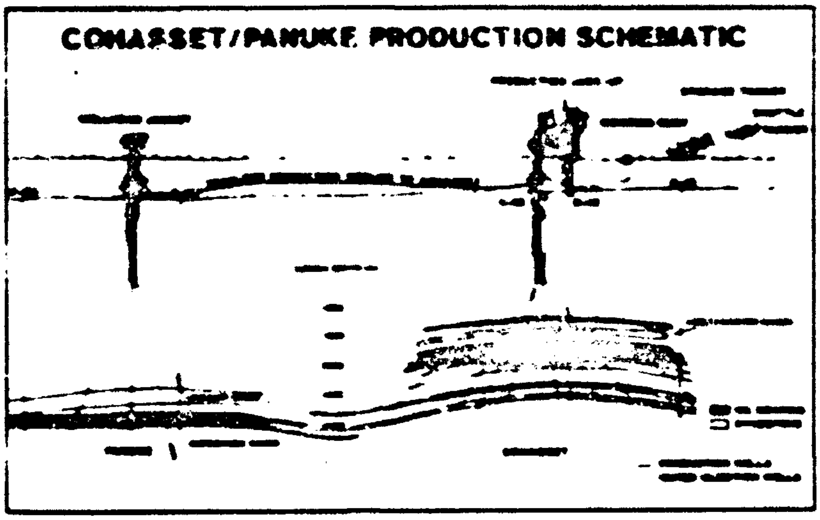
Figure 6.11: Hibernia production system components. (From the Canada-Newfoundland Petroleum Board, 19[illegible]).

Sable Island Field:

Oil exploration has taken place on the Scotian Shelf since 19[illegible]. Gas is the main resource in this area, with a current estimate of 102 $\times 10^9$ m^3. Oil discoveries are estimated at 23.7 $\times 10^6$ m^3 [COGLA, 19[illegible]]. The prime candidate for production is at the Cohasset/Panuke Field, where recovery of 5.5 $\times 10^6$ m^3 of light oil is planned (Figure 6.12).

6.4.1 Noise Characteristics

Oil rig noise characteristics are included in the classified annex to this guide.



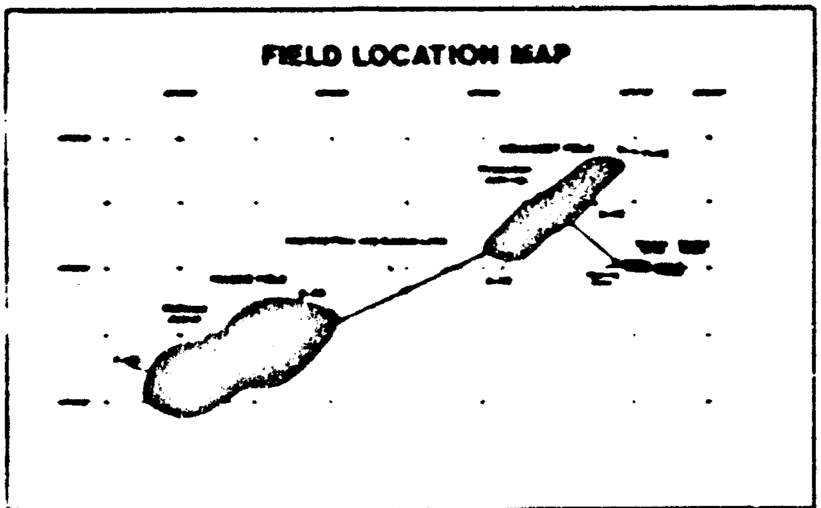


Figure 6.12: Cohasset/Panuke field map and production facility schematic. (From the Canada-Nova Scotia Petroleum Board, 1990).

Chapter 7

Acoustics

7.1 Bottom Provinces

Acoustic bottom loss provinces are determined from the results of ASW bottom loss surveys, or from the geoacoustic parameters of the sediments. In areas where no measurements have been made, provinces are determined by extrapolation from areas with similar acoustic characteristics such as bathymetry, physiography, and surficial geology.

7.1.1 High Frequency Bottom Loss

The high frequency bottom loss information is included in the classified annex to this document.

7.1.2 Low Frequency Bottom Loss

At low frequencies (< 100 Hz), the compilation of all bottom loss measurements available shows that these measurements tend to fall within ± 5 dB (1 standard deviation) of the mean value (Figure 7.1). The negative losses at low angles are due to upward refraction of some sound energy within the bottom, which results in an enhancement of the sound in the water [Urick, 1983].

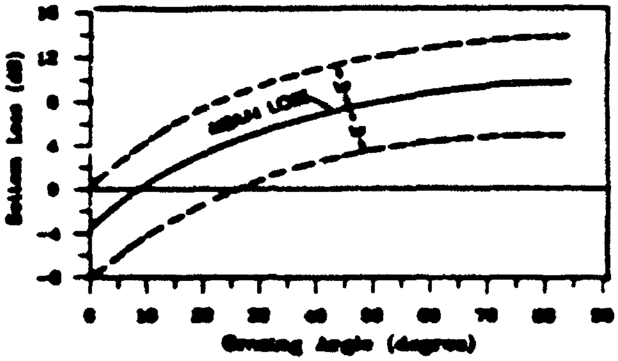


Figure 7.1: Results of compilation of low frequency (~ 100 Hz) measurements of bottom loss. The dashed curves show limits of one standard deviation. (From Christensen et al., 1975).

Additional low frequency bottom loss information is contained in the classified annex to this document.

7.2 Ambient Noise

Zakarauskas et al. [1987] completed an analysis of ambient noise level measurements made by researchers from the Defence Research Establishment Atlantic (DREA) between 1972 and 1986. The measurements were taken over the Scotian Shelf, the Laurentian Channel, the Grand Banks, and the Flemish Cap. The results consist of expected ambient noise levels at seven selected frequencies: 30, 45, 80, 150, 300, 600 and 900 Hz for the regions mentioned and, where possible, for different seasons. When several hydrophones were available, the ambient noise level from the hydrophone located at mid-depth, or the one closest to mid-depth, was selected.

Wind-noise correlation

A linear regression between the noise level and the wind strength was used to establish the wind dependency. Wind and shipping activity are usually the most important noise generating mechanisms. In shallow waters, however, ship

Frequency (Hz)	Mean noise level (dB//μPa^2/Hz)
30	62
45	65
80	65
150	71
300	72
600	70
900	67

Table 7.1: Average ambient noise power levels in the Laurentian Channel in January 1983 (From Zakarauskas et al., 1987).

generated noise has only a very limited spatial and temporal impact. The wind-noise correlation is therefore a more useful indicator of the origin of the measured noise [Zakarauskas et al., 1987].

7.2.1 Geographic Distribution

Laurentian Channel

One long-term ambient noise measurement made in the Laurentian Channel during January 1983 has produced the results listed in Table 7.1.

Grand Banks

Table 7.2 contains some statistics on ambient noise levels for the Grand Banks sites. The small number of measurements and their uneven temporal distribution did not allow an analysis on a seasonal basis.

Scotian Shelf

There were sufficient measurements from the Scotian Shelf region to obtain statistical values for two different seasons. Table 7.3 lists the statistics for ambient noise in winter and Table 7.4 the statistics for summer conditions.

Frequency (Hz)	Mean noise Level (dB/μPa^2/Hz)	Standard deviation (dB)	Wind-noise correlation
20	77.9	8.1	0.54
45	78.6	8.6	0.16
90	78.8	9.7	0.27
180	74.7	7.1	0.13
300	74.4	8.8	0.15
600	71.9	2.9	0.47
900	68.8	4.2	0.69

Table 7.2: Ambient noise statistics: year average for the Grand Banks (13 samples). The average wind speed was 9.4 knots. (From Zakarauskas et al., 1987).

Frequency (Hz)	Mean noise Level (Db/μPa^2/Hz)	Standard deviation (Db)	Wind-noise correlation
20	91.2	4.3	0.14
45	88.6	2.8	0.43
90	88.3	2.5	0.28
180	85.8	4.4	0.15
300	79.2	3.6	0.31
600	76.1	4.1	0.42
900	71.8	3.7	0.52

Table 7.2: Statistics for ambient noise: winter average for Scotian Shelf (7 samples). The average wind speed was 13.4 knots (From Zakarauskas et al., 1987).

Frequency (Hz)	Mean noise Level ($dB//\mu Pa^2/Hz$)	Standard deviation (dB)	Wind-noise correlation
10	87.1	7.5	0.65
40	[illegible]	4.5	0.51
50	87.4	3.8	0.32
100	[illegible]	4.5	0.65
200	74.3	4.7	0.51
[illegible]	[illegible]	3.2	0.69
[illegible]	[illegible]	4.7	0.51

Table 7.4: Statistics for ambient noise : summer average for Scotian Shelf (11 samples). The average wind speed was 9.2 knots (From Zakarauskas et al. 1987).

Flemish Cap

Table 7.5 gives the mean ambient noise observed from hydrophones located at two depths (98 and 146 m) on the Flemish Cap.

7.2.2 Cumulative Distributions

The cumulative distributions of the ambient noise levels for each selected frequency are shown in Figure 7.2 for summer, winter and the year average using data from all areas. On this type of graph, the normal distribution would appear as a straight diagonal line.

7.2.3 Remarks

Based on the results shown, Zakarauskas et al. [1987] made the following observations on the ambient noise characteristics in the present area of interest:

- The large scatter of the results can be due to the contribution of the ship noise and the influence of the local acoustic propagation.
- Ambient noise levels are from 3 to 9 dB lower in summer than in winter due to the poorer propagation conditions in summer, when the thermocline

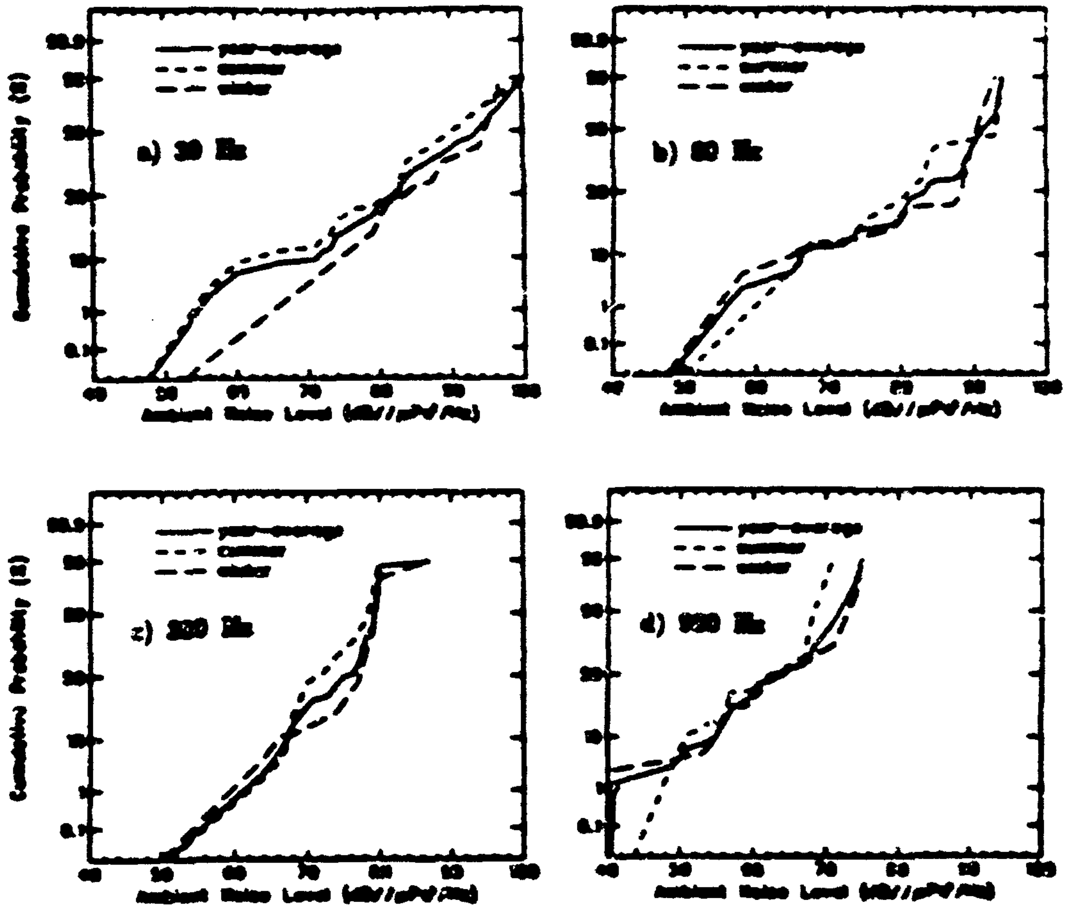


Figure 7.2: Cumulative distribution of ambient noise on the eastern Canadian continental shelf at a) 20 Hz, b) 80 Hz, c) 320 Hz and d) 950 Hz. (From Zakarauskas et al., 1987).

Frequency (Hz)	Mean noise power at 93m (dB//μPa²/Hz)	Mean noise power at bottom (dB//μPa²/Hz)
30	64	62
46	62	59
88	70	59
150	71	58
300	70	63
650	64	64
900	62	63

Table 7.5: Mean ambient noise levels for Flemish Cap, at 93 m and at the bottom (depth 145 m). The mean wind speed was 10 knots. (From Zakarauskas et al., 1987).

bends the propagating rays downward which increases the absorption of sound by the bottom.

- The ambient noise levels at frequencies of 150 Hz and below are much lower on the Grand Banks than on the Scotian Shelf; the levels differ by as much as 14 dB at 46 Hz. Zakarauskas [1986] concluded that a higher absorption by the bottom in the Grand Banks area was in large part responsible for these lower noise levels.

- The variability appears lower on the Scotian Shelf than on the Grand Banks; a more uniform ship distribution, and/or the propagation of ship noise from longer distances on the Scotian Shelf could explain this difference.

- Shipping noise may contribute to the ambient noise at frequencies of up to 900 Hz, particularly in winter. This indicates a very high shipping noise density and good propagation conditions.

7.2.4 Other Data Sets

Ambient noise levels obtained from other sources are included in the classified annex of this document.

7.3 Propagation Loss

Numerous acoustical experiments involving propagation loss measurements were conducted by researchers from DREA over the last 30 years on this part of the continental shelf. Some of the results obtained are included in this document. These examples of actual measurements are intended to provide a broad overview of the existing sound propagation conditions and their degree of variability. Furthermore, they illustrate the complex interaction of the different variables of the bottom, the water mass and the sea surface that affect sound propagation. Three categories of examples are used:

- Seasonal variations at one location
- Smooth-rough bottom comparison
- Typical conditions for geographic areas of interest.

7.3.1 Seasonal Comparison

A series of propagation loss measurements made over a 175 km track on the Scotian Shelf is used to illustrate the variations in sound propagation caused by the seasonal changes in the sound velocity. The measurements were made over a section of the Outer Shelf physiographic region. Along the track, the water depth varies between 50 and 75 m, and the bottom is composed of two unconsolidated sediment layers which cover the bedrock basement. These layers consist of Sable Island Sand and Gravel (3 to 21 m thick) overlying a layer of Scotian Shelf Drift (2 to 13 m thick). Due to variations in the path of the source ship towards the receiver array, the summer and winter tracks were slightly different. Figure 7.3 shows the bathymetry and the bottom structure along the two tracks. The difference in the water properties is also shown. As expected, the winter sound velocity profile is slightly upward refracting, whereas the summer profile is characterized by the presence of a mixed surface layer above a well developed thermocline.

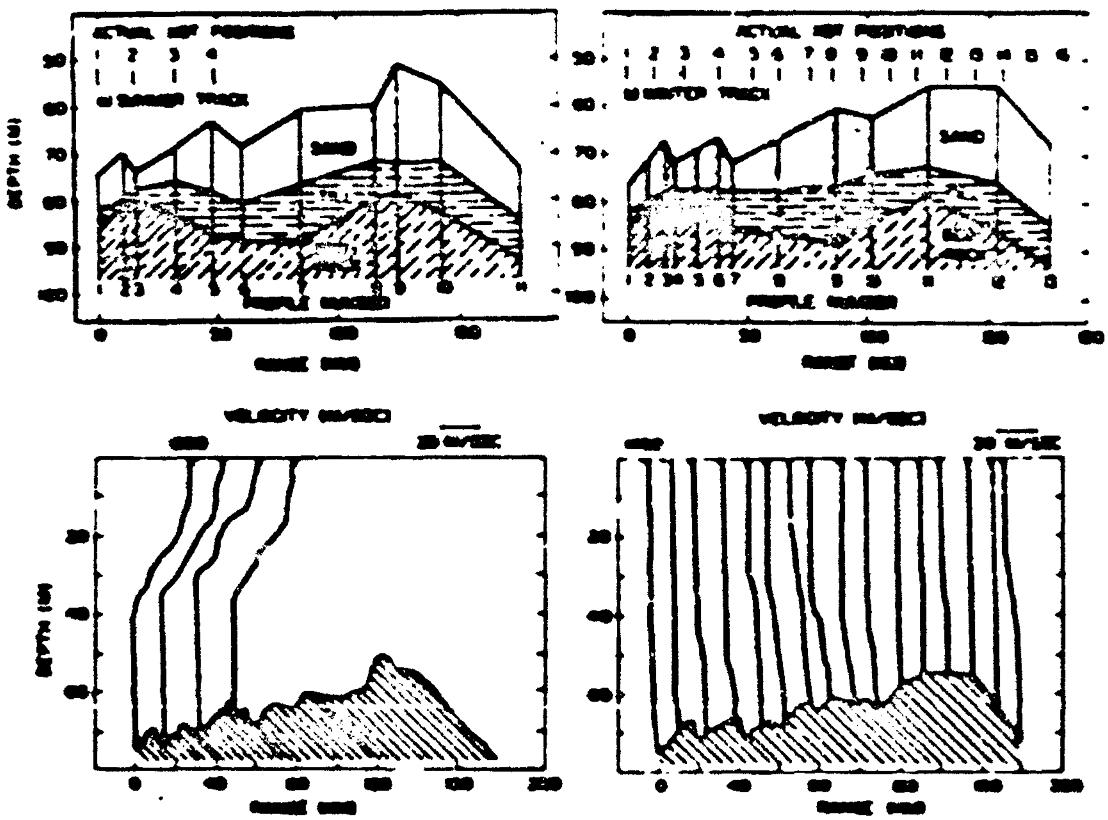


Figure 7.3: Schematic diagram of the bottom structure and bathymetry along the track followed during the propagation loss survey on the Scotian Shelf in a) summer and b) winter. The positions of the XBTs are also indicated. The resulting sound speed profiles along the track are shown for c) summer and d) winter. The tick marks at the top refer to a sound speed of 1450 m s^{-1} in winter or 1500 m s^{-1} in summer. The range at which the measurements were made is indicated by the intersection of the profiles with the bottom (From Chapman and Ellis, 1982).

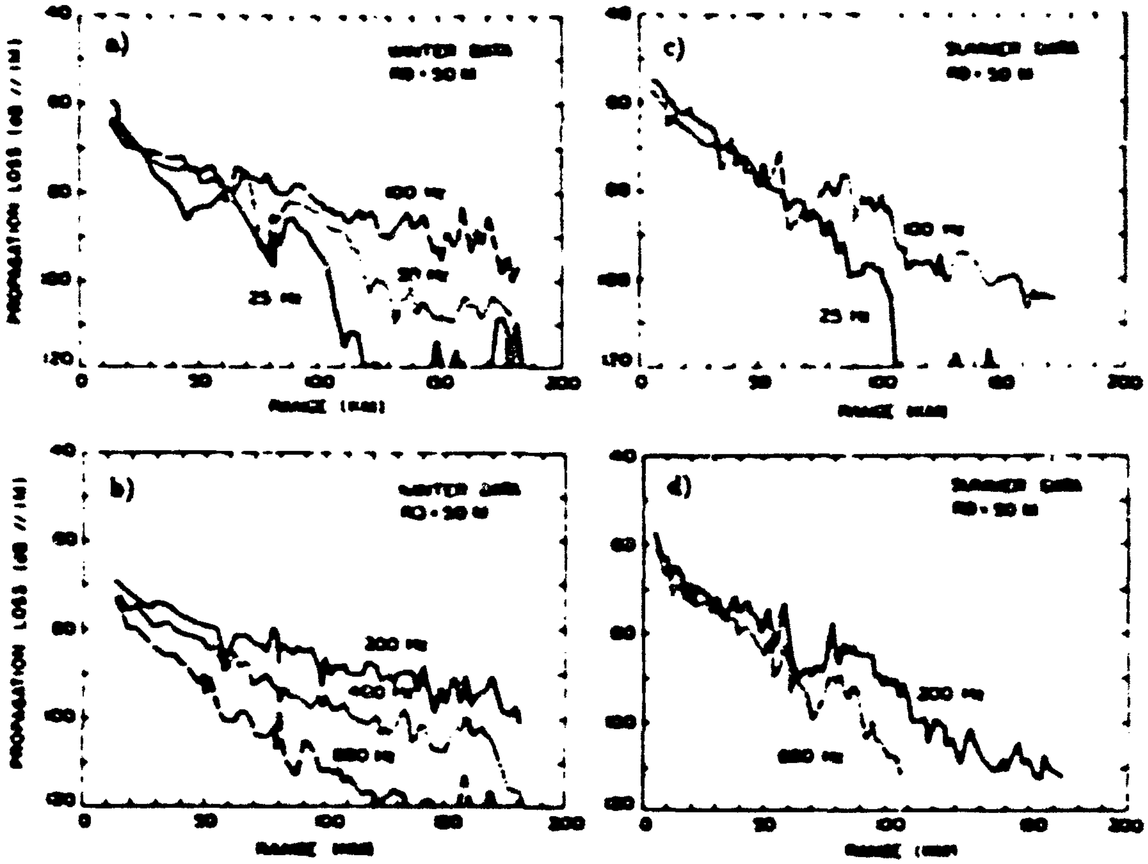


Figure 7.4: Measured propagation loss versus range over the Scotian Shelf, for selected frequencies: a) and b) winter; c) and d) summer. The source depth is 37 m and the receiver depth is 30 m. (From Chapman and Ellis, 1982).

The measured propagation loss versus range plots in Figure 7.4 show some significant differences. As expected, the propagation generally extends to longer ranges in winter due to the positive gradient of sound speed. In particular, the presence of a frequency range of optimum propagation between 100 Hz and 400 Hz at ranges beyond 30 km is noted. At higher frequencies however, the propagation appears to be better in summer; this could be related to the increased importance of the surface roughness as a loss mechanism at these frequencies. During the experiment, the wave height was estimated to be 1 m in winter and approximately 0.5 m in summer [Chapman and Ellis, 1982].

7.3.2 Topography Based Comparison

Another series of propagation loss runs was made along two radial tracks from a receiving array at a site on the Scotian Shelf. One track was over a smooth seabed and the other over a rough seabed (Figure 7.5).

Smooth seabed

Figure 7.6 shows the "frequency averaged" propagation loss versus range recorded from the bottom hydrophone. The "frequency average" is defined as the arithmetic mean of the propagation loss, in decibels, of the octave bands centred on 3.2, 6.4, 10.1, 16.0, 25.4, 40.3, 60.4, 101.6, 161.3, 256.0, 406.4, and 645.1 Hz. The seabed is rather flat along the track, but the sediment thickness increases gradually from a few metres to more than 100 m. The sound speed profiles indicate that a general downward refraction of the sound energy should occur and hence result in a strong bottom interaction. No obvious correlation between the propagation loss and the sediment thickness emerges.

The analysis of the propagation loss as a function of frequency (Figure 7.7) shows that at short ranges, the acoustic propagation loss increases with increasing frequency throughout the frequency domain. At longer ranges, the greatest losses occur in the region of 5 to 10 Hz. This is consistent with mode theory since the cut-off frequency for this depth of water is in this frequency band. Below 5 Hz, the reduction in propagation loss could be associated with compressional, shear or interface waves which propagate in the bottom layers [Staal and Desharnais, 1989].

Rough seabed

Figure 7.5(b) outlines the bottom topography and the sound speed structure for the second track. The topography shown is very rough and the sediment

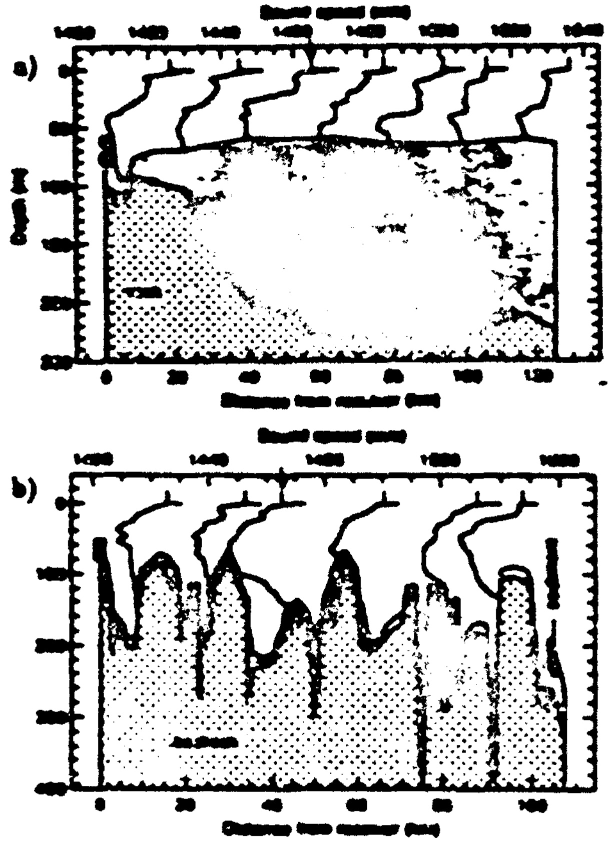


Figure 7.5: Seabed depth, bedrock depth and sound speed profiles as a function of distance from the receiving hydrophone array for the a) smooth seabed, and b) the rough seabed. The two hydrophones used are shown as ⊗ symbols. The sound speed profiles from the XBTs are also shown. The reference ticks drawn at the top of each sound speed trace indicate a value of 1465 m s^{-1}. (From Staal and Desharnais, 1989).

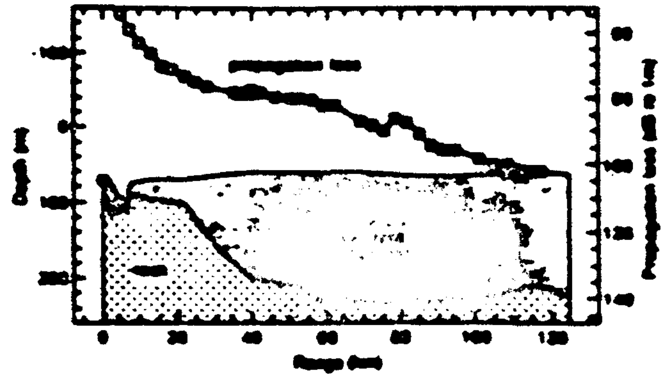


Figure 7.6: Average propagation loss for frequencies from 3 to 645 Hz, using the hydrophone at 75.6 m (marked with ⊕ symbol) as a function of range (smooth bottom). (From Staal and Desharnais, 1989)

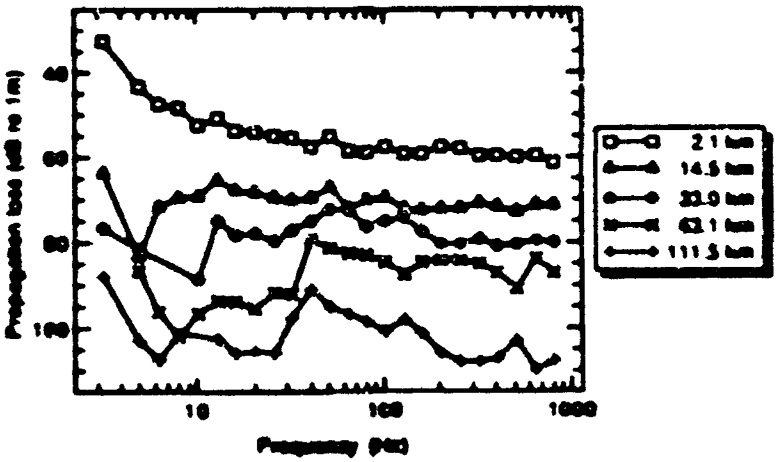


Figure 7.7: Measurements of propagation loss (one-third octave) versus frequency for various ranges over the smooth seabed. (From Staal and Desharnais, 1989)

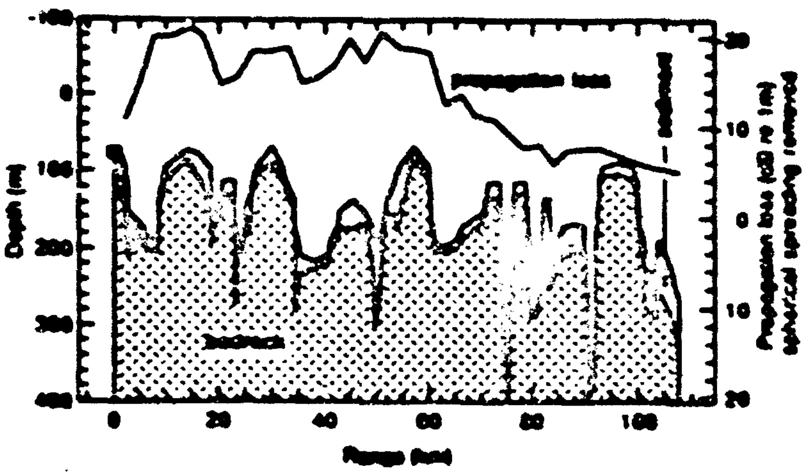


Figure 7.8: Average propagation loss for frequencies from 3 to 645 Hz with spherical spreading removed, to the hydrophone at 75.6 m (marked with ■ symbol), as a function of range (rough bottom). (From Staal and Desharnais, 1989)

layer is thinner (20 to 40 m) with a more complex distribution than along the smooth bottom track. The upper portion of the sound speed profile is similar to the profile shown in Figure 7.5 (a); however, in the deep troughs, there is a positive gradient which results in the formation of a sound channel. This sound channel is expected to reduce the interaction of sound with the seabed over the deep portion of the track.

The frequency averaged propagation loss as a function of range is shown in Figure 7.8. In order to better display the relationship between propagation loss and water depth, the spherical spreading portion (20 log [range in metres]) of the propagation loss was removed. Negative losses indicate better propagation than the spherical spreading law [Staal and Desharnais, 1989]. The comparison of the propagation loss and the seabed shows that the minimum propagation loss occurs at the location of minimum depth. The effect of the sediment thickness variations was not evident, possibly masked by the more pronounced effect of the bathymetry.

The propagation loss plotted as a function of frequency (Figure 7.9) shows the same propagation characteristics at short range as for the smooth seabed

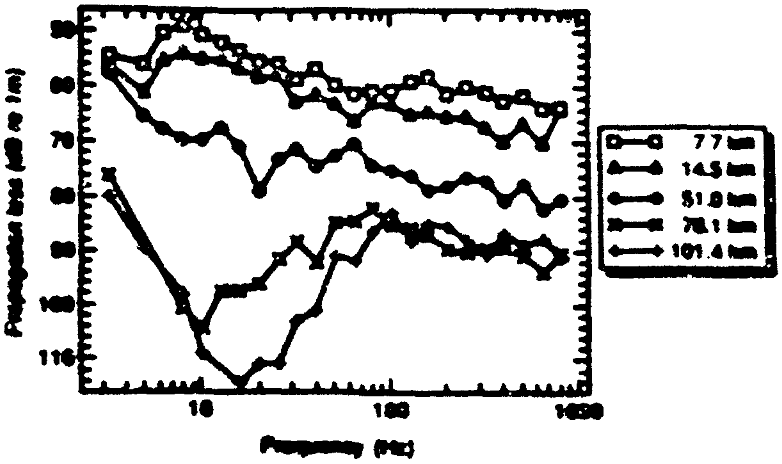


Figure 7.9: Measurements of propagation loss (one-third octave) versus frequency for various ranges over the rough seabed. (From Staal and Desharnais, 1989)

track. The low frequency maximum in propagation loss is however more pronounced (20 to 30 dB compared to 15 to 20 dB), and it occurs at slightly higher frequencies (4 to 20 Hz). In addition, at the longest ranges the propagation loss increases below 80 Hz, and then decreases again below 10-20 Hz. This is a behaviour similar to the propagation loss over rocky seabeds with little sediment cover which was reported by Staal et al.[1986].

Smooth-rough seabed comparison

Figure 7.10 shows the comparison of the propagation loss as a function of range for the two tracks at three frequencies. It can be seen that the propagation loss over the smooth seabed is nearly always higher (by 5 to 10 dB) than the loss over the rough seabed. This difference may be due to the presence of the sound channel along the track over the deeper rough bottom; more energy is trapped in the channel and there is less acoustic interaction with the bottom.

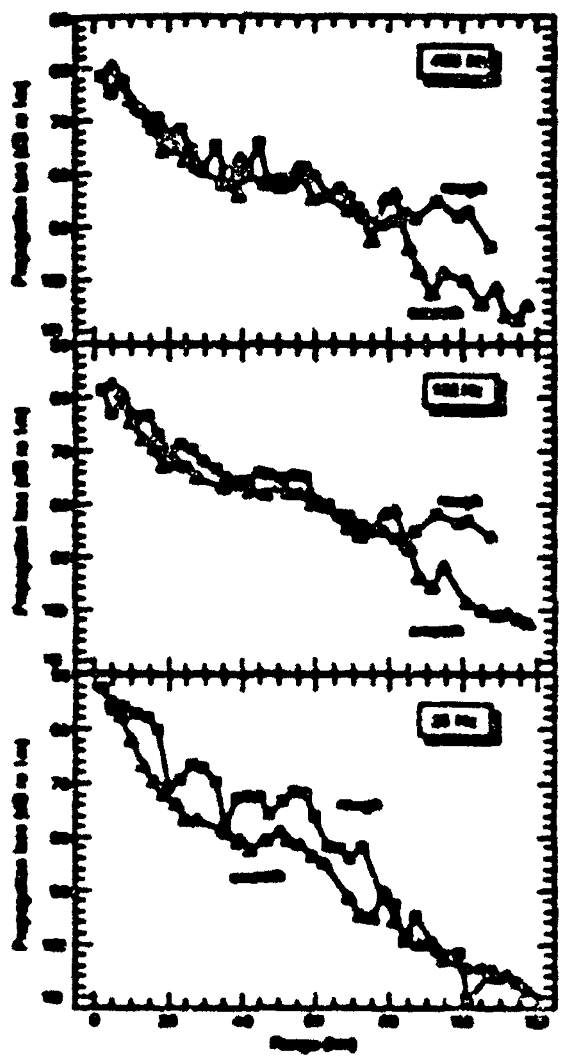


Figure 7.10: Comparison of propagation loss versus range for the rough and smooth seabeds for three frequencies: 25 Hz, 102 Hz and 406 Hz. (From Staal and Desharnais, 1989)

Figure 7.11: Map of propagation loss runs on eastern Canada continental shelf.

7.3.3 Geographic Locations of Interest

Additional results obtained from propagation loss runs conducted over different physiographic provinces of the eastern Canada continental shelf are included. Figure 7.11 shows the locations where these measurements were taken.

Central Scotian Shelf

The track along the axis which joins Roseway Bank and French Bank, runs over the LaHave and Emerald Basins, the deepest portions of the Scotian Shelf. The measurements were taken in winter (March 1985), and the sound speed profiles recorded are typical for that period of the year and show a positive gradient to approximately 130 m (Figure 7.12(a)). These conditions result in good propagation conditions as seen in Figure 7.12(b).

Laurentian Channel

The Laurentian Channel covers a relatively large area. Some important shipping activity takes place along its length. It is the deepest section covered in this guide, with water depths in excess of 400 m. Figure 7.13 shows the bathymetry and the sound speed profiles over the propagation track. The measurements were taken in summer and therefore a strong thermocline has de-

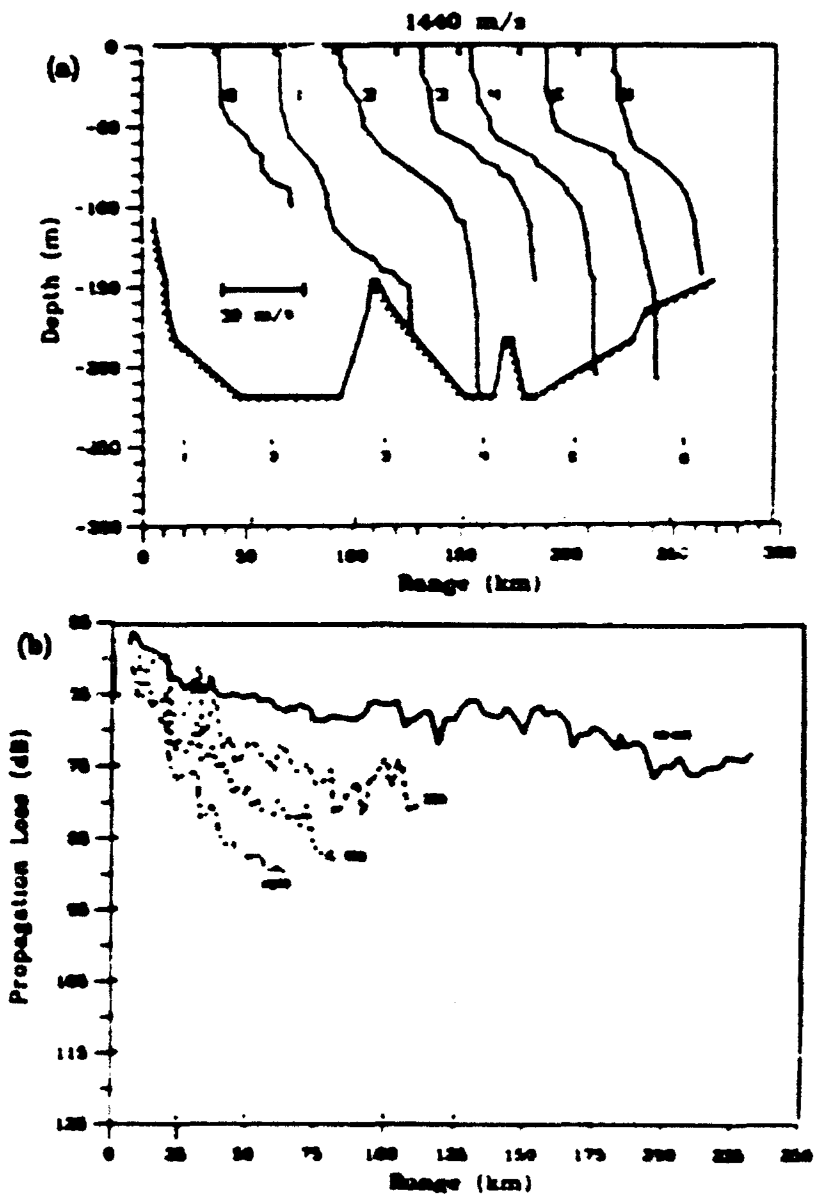


Figure 7.12: Propagation loss run over the Central Scotian Shelf, between 43.8°N 64.8°W and 44.7°N 61.8°W. Bathymetry and sound speed profiles along the track are shown in (a). Propagation loss results are shown in (b) for 40 Hz, 200 Hz, 512 Hz and 1380 Hz. The source was at 60 m and the receiver at 40 m. (From Ross and Adlington, 1976)

veloped which results in a sound channel with an axis at approximately 90 m. The source was at 60 m and the receiver at 40 m. This resulted in a large portion of the energy being trapped in the sound channel and in low propagation loss, particularly for the frequency range 40-800 Hz as seen in Figure 7.13.

Grand Banks

A propagation loss run was done in summer, over the relatively rough seabed of the southwest Grand Banks in water less than 100 m deep. The bathymetry and the sound speed profiles are shown in Figure 7.14(a). The source and the receiver were both at 60 m which was below the thermocline. The propagation losses (Figure 7.14(b)) with range are much more important than the previous examples, due to the much stronger interaction of the sound energy with the bottom.

Northeast Newfoundland Shelf

The final run was made in the summer north of the Grand Banks. The features observed are judged to be typical of a large area east of Newfoundland, including Notre-Dame Bay and Bonavista Bay. The source charges were detonated at depths between 60 and 100 m; the receiver was at 67 m. Bathymetry and sound speed profiles are shown in Figure 7.15(a). The seasonal thermocline is well developed and a sound channel is formed at a depth of about 70 m. The channel is not as pronounced as the one observed in the Laurentian Channel, yet a large portion of the sound energy is trapped in it which results in relatively low propagation loss (Figure 7.15(b)). Ross and Adlington [1976] reported that similar runs made at the entrance of the Strait of Belle Isle in northeast and southeast directions resulted in propagation losses generally within a few dB of those in Figure 7.15. Noise levels were in general much higher near the strait by as much as 10 dB at frequencies less than 1200 Hz due to the heavy shipping activity in this area.

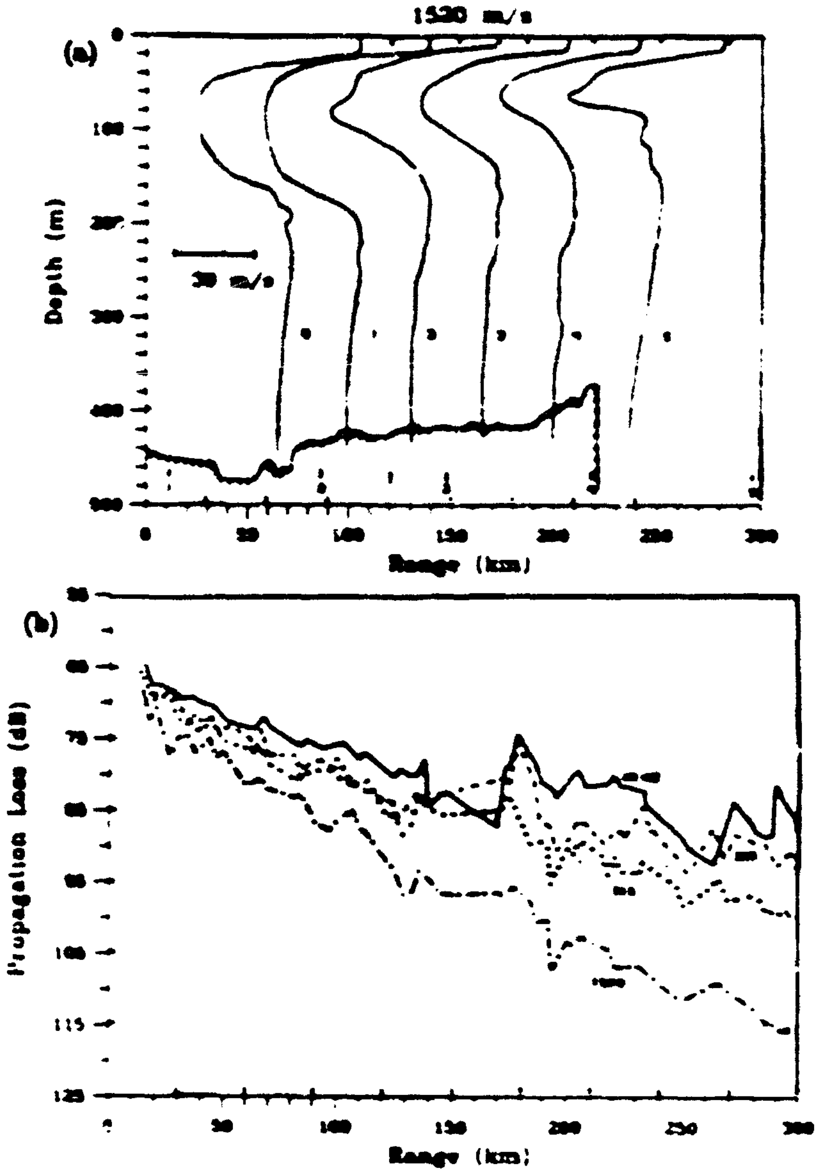


Figure 7.13: Propagation loss run over the Laurentian Channel, between 46.4°N 57.9°W and 44.2°N 56.2°W. Bathymetry and sound speed profiles along the track are shown in (a). Propagation loss results are shown in (b) for 40 Hz, 200 Hz, 512 Hz and 1280 Hz. The source was at 60 m and the receiver at 40 m. (From Ross and Adlington, 1976)

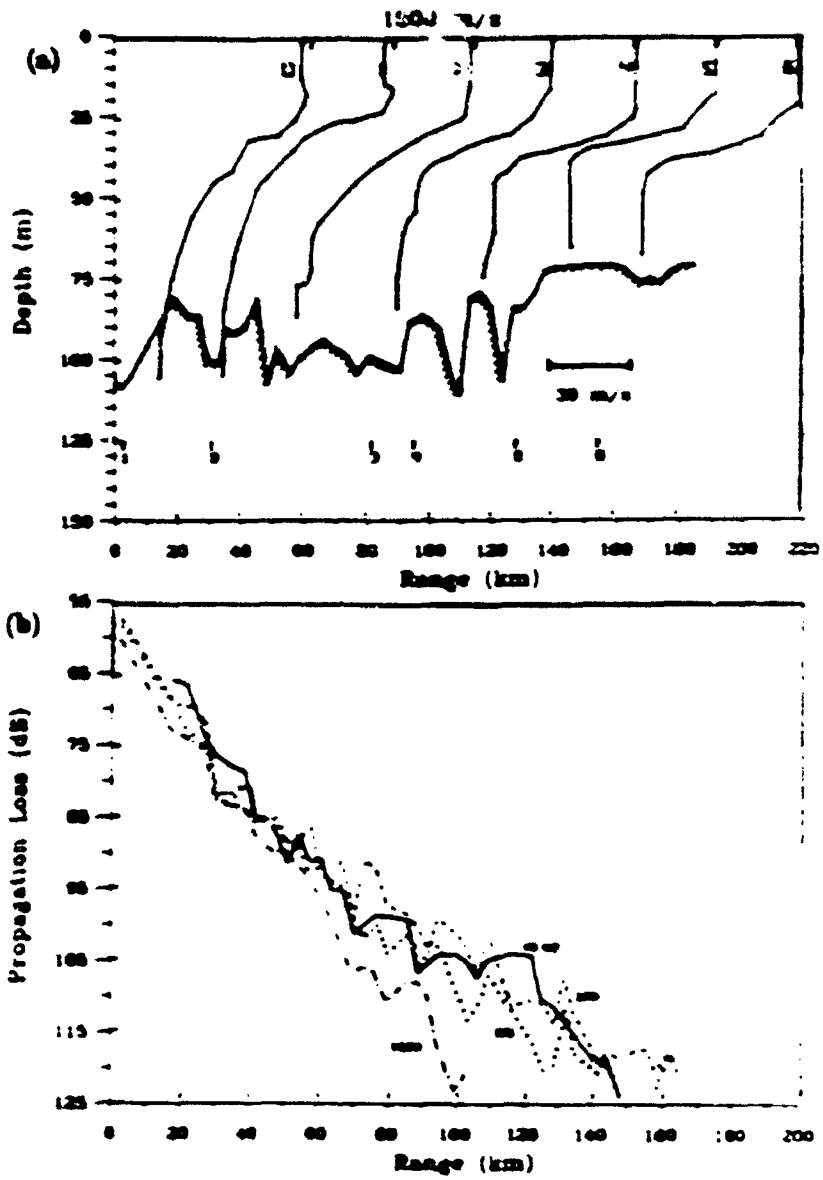


Figure 7.14: Propagation loss run over the Grand Banks, between 45.9°N 53.2°W and 45.1°N 51.8°W. Bathymetry and sound speed profiles along the track are shown in (a). Propagation loss results are shown in (b) for 40 Hz, 200 Hz, 512 Hz and 1228 Hz. Both the source and the receiver were at 60 m. (From Ross and Adlington, 1976)

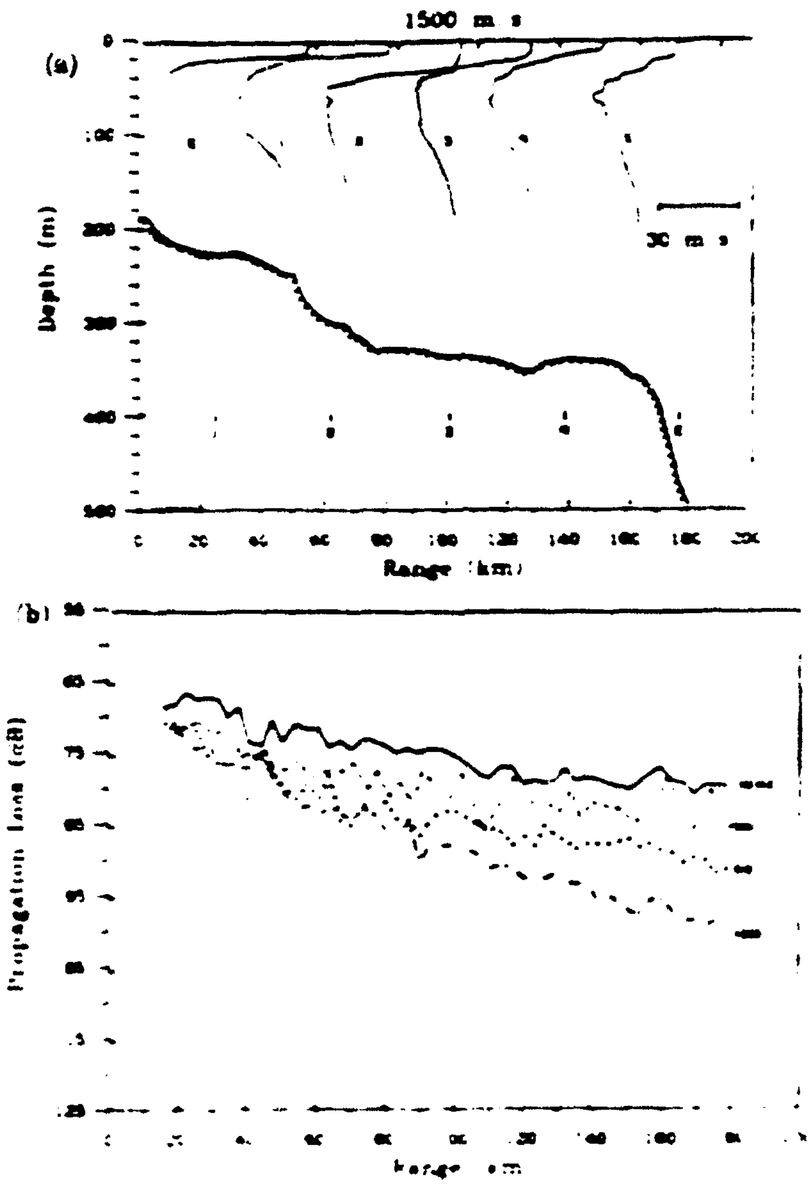


Figure 7.13 Propagation loss run north of the Grand Banks, between 48.5°N 50.5°W and 50.1°N 50.5°W. Bathymetry and sound speed profiles along the track are shown in (a). Propagation loss results are shown in (b) for 40 Hz, 200 Hz, 512 Hz and 1290 Hz. The source depth varied between 60 and 100 m during the run and the receiver was at 87 m. From Ross and Adlington (1976).

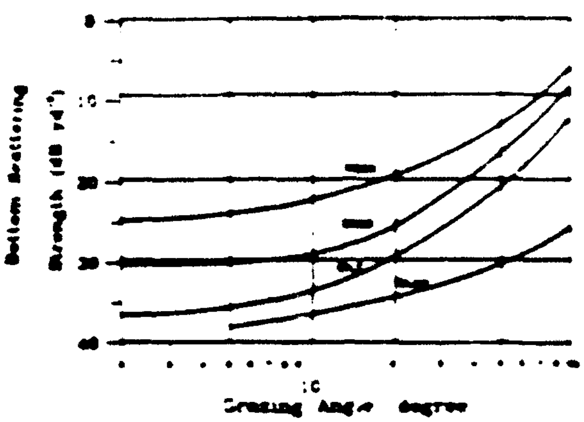


Figure 7.16: Curves of bottom backscattering strength vs. grazing angle for various bottom types. Valid for frequency range of 0.5- 100 kHz. Most measurements were within approximately 5 dB from these curves. (From Urick, 1982)

7.4 Scattering Coefficients

7.4.1 Bottom Backscattering Coefficients

There is no strong frequency dependence of the bottom backscattering coefficients for frequencies below 10 kHz. However, bottom types can be used as a reasonable classifier of the bottom scattering strength [Urick, 1983]. The coefficients shown in Figure 7.16 can therefore be used as a good first approximation.

Additional information on scattering coefficients is included in the classified annex of this document.

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Environmental Guide for ASW in Eastern Canadian Shallow Waters

Part I - An Assessment of the State of Knowledge

By

Capt Daniel Normand

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Environmental Guide for ASW in Eastern Canadian Shallow Waters

Part II - Environmental Data

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Environmental Guide for ASW in Eastern Canadian Shallow Waters

Part III - Classified Data

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