ENVIRONMENTAL DEGRADATION IN HALIFAX HARBOUR:

AN HISTORICAL PERSPECTIVE

USING BENTHIC FORAMINIFERA

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ABSTRACT

Foraminiferal assemblages fom sediment surface samples collected in Bedford Basin, Halifax Harbour, in August 1992, have been investigated and compared to foraminiferal data from 1970 to determine faunal changes resulting from environmental degradation within the highly polluted estuarine system. The assemblages were related to contaminants such as organic matter and increased metal concentration (that are among the highest in economically developed countries around the world). Using foraminiferal data from two cores collected in 1996, faunal changes were determined between the subrecent and modern fauna.

Foraminiferal abundance and diversity was mostly lower in the present assemblages compared to 1970, and an evident decrease in calcareous species diversity was noted that is probably caused by an increased organic matter influx from anthropogenic sources. In sediments with enhanced metal concentration, the foraminiferal abundance was decreased.

The cores, comprising about a century in time, show almost an absence of calcareous fauna. The abundance was lowest in the top cm. The species *Eggerella advena,* known for an affinity to organic pollution, increased in both cores towards the top.

Key Words: benthic foraminifera, Halifax Harbour, estuarine, organic matter, pollution, heavy metal pollution, historical perspective, Canada.

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CHAPTER 1 INTRODUCTION

1.1 Background

Many different methods of monitoring the marine environment are known and have been applied in many coastal inlets (e.g. chemical analysis, organic matter determination). Benthic organisms can detect environmental changes by living on and in the substrate in contact with the surrounding water mass where they react to changes and thereby reflect the prevailing conditions.

Benthic foraminifera are common in most marine sediments. Even in relatively highly polluted environments where other meiofauna (e.g. ostracods, molluscs or polychaetes) would show a barren zone, some opportunistic species of foraminifera can persist (e.g. Bandy, 1965). Their tests are preserved and they provide the possibility of the investigation of present as well as past conditions (Alve, 1991; Scott et al., 1995), and thereby supply a biological monitor together with physiochemical tracers.

1.2 Purpose

The purpose of this thesis is to document the present foraminiferal assemblages in Bedford Basin and to relate them to various kinds of contaminants such as organic matter pollution through sewage discharge, and increased metal concentrations resulting from solid waste dumping, and effluent discharge from industrial point sources.

Gregory (1970) first recorded the foraminiferal distribution in Halifax Harbour. His study serves as background data for an historical perspective of the faunal changes over the last twenty-five years.

Using foraminiferal data from two cores collected in and just seaward of Wrights Cove (Fig. 1.2), faunal changes are determined between the subrecent and modern foraminiferal fauna. The subrecent fauna in the lower part of the core gives background data for comparison with the modern foraminiferal assemblages in the core surface and to evaluate the effect of increased pollution stress.

1.3 Previous Work

Many studies on benthic foraminiferal responses to various kinds of marine pollution have been listed and reviewed by Alve (1995). Previous publications have dealt with impact sources such as sewage (e.g. Schafer, 1970, 1973; Alve, 1990; Collins et al., 1995), pulp-and papermills (e.g. Schafer et al., 1991), chemicals, oil, heavy metals (Alve, 1991), aquaculture sites (e.g. Scott et al., 1995) and effects such as oxygen depletion (e.g. Alve, 1990, 1995) and thermal differences.

Foraminiferal assemblages in "unimpacted" estuaries of eastern Canada have been characterized by numerous workers (e.g. Schafer and Cole, 1978; Scott et al., 1980). Since it is impossible to obtain background values of an anthropogenically unaffected foraminiferal distribution in Halifax Harbour (except for core data), the work of Gregory (1970) on the foraminiferal population of the inlet serves as a baseline for comparison with the recently collected surface samples. However, this work was completed in 1970 and certainly does not represent the natural environment that would have been present prior to human occupation of the Halifax area.

Among over 230 survey and research reports on Halifax Harbour, various studies give insight about water and sediment properties and impact sources (e.g. Buckley and Hargrave, 1989; Buckley and Winters, 1992; Halifax Harbour Task Force, 1990; Petrie and Yeats, 1990) . The available geochemical data, especially regarding increased metal concentration within the study area, provide a possibility for correlation of these data with possible foraminiferal responses.

1.4 Pollution

Since the establishment of Halifax in 1749, the Harbour has been used increasingly as a waste and sewage disposal site for the adjacent communities and industries.

1.4.1 Sources

The main sources of anthropogenically induced contamination are domestic sewage, commercial and small industrial facilities, institutions such as research laboratories, universities, schools, military bases and hospitals and large industries (refineries, Halifax-Dartmouth Industries Ltd., and Nova Scotia Power Corporation at Tufts Cove). Non-point sources include river discharge, run-off from streets, ship-related discharges and atmospheric input (Halifax Harbour Task Force, 1990). In addition, surface drainage from landfill sites (Buckley and Winters, 1992) and solid waste dumping into the Harbour (Fader et al., 1991) have contributed to the present state of pollution in the inlet.

1.4.2 Organic Carbon Concentration

The highest organic carbon contents are recorded from sediments adjacent to the major sewage outfalls (e.g. Tufts Cove 17.2 %). Approximately 4200 t of carbon per year are contributed from these sources (Buckley and Winters, 1992).

1.4.3 Metal Concentration

Geochemical analyses of total metal concentrations in the sediments of Halifax Harbour are among the highest recorded in marine harbours and estuaries in economically developed countries around the world (Buckley and Winters, 1992).

Within Bedford Basin and Tufts Cove, where the samples for this study were collected, the highest values of Cu, Zn, Pb, Cd and Hg were found (Buckley and Winters, 1992).

High values of Cu (279 ppm), Zn (up to 472 ppm) and Hg (2.19 ppm) were recorded in Mill Cove, probably originating from municipal and domestic sewage. At a site in the centre of the Basin, increased concentrations of Cu (1913 ppm), Zn (652 ppm), Pb (1237 ppm) and Hg (1.51 ppm) occurred, suggesting deposition of inorganic waste in this area. An anomaly appeared in Wrights Cove with contamination of Cu (221 ppm), Zn (424 ppm), Pb (1442 ppm) and Hg (1.65 ppm). It probably originates from untreated sewage discharging from various outfalls into the Cove and from input of solid waste and industrial chemicals. An area close to Seaview Point in proximity to a former city dump and landfill site shows increased metal concentration of Cu (150 ppm), Zn (490 ppm), Pb (344 ppm) and Hg. Also, increased values of Cu, Zn (490 ppm), Pb (432 ppm) and Hg (1.53) were found in Tufts Cove a major outfall area for domestic and various kinds of industrial sewage from nearby Burnside Industrial Park. The geochemical data above are taken from Buckley and Hargrave (1989).

1.5 Study Area

1.5.1 Physical Environment

Halifax Harbour is a N-W striking embayment on the east coast of Nova Scotia. Erosion from glacial ice and water formed the inlet possibly along a structural fault. The Harbour can be divided into three parts: Outer Halifax Harbour, Inner Halifax Harbour including the North-West Arm and Eastern Passage, and Bedford Basin including Bedford Bay (Fig. 1.1). The inlet is 25 km long and has a surface of approximately 931 hectares (Nova Scotia Dep. of Environ. and Metro. Area Commission, 1986).

The samples for this study were collected from Bedford Basin, a bowl-shaped depression 4 km wide and 7.5 km long with a maximum depth of 71 m. The Basin is separated from the Outer Harbour by a narrow channel, The Narrows. In the N-E section, the Sackville River drains into Bedford Bay, a shallow embayment at the head of Bedford Basin. Prominent indentations within the Basin are Long Cove to the East, Mill Cove to the West of Bedford Bay, Roach Cove and Wrights Cove to the East, Birch Cove to the West and Fairview Cove to the South of the central part of the Basin. Samples were also collected from Tufts Cove, an embayment in The Narrows (Fig. 1.2).

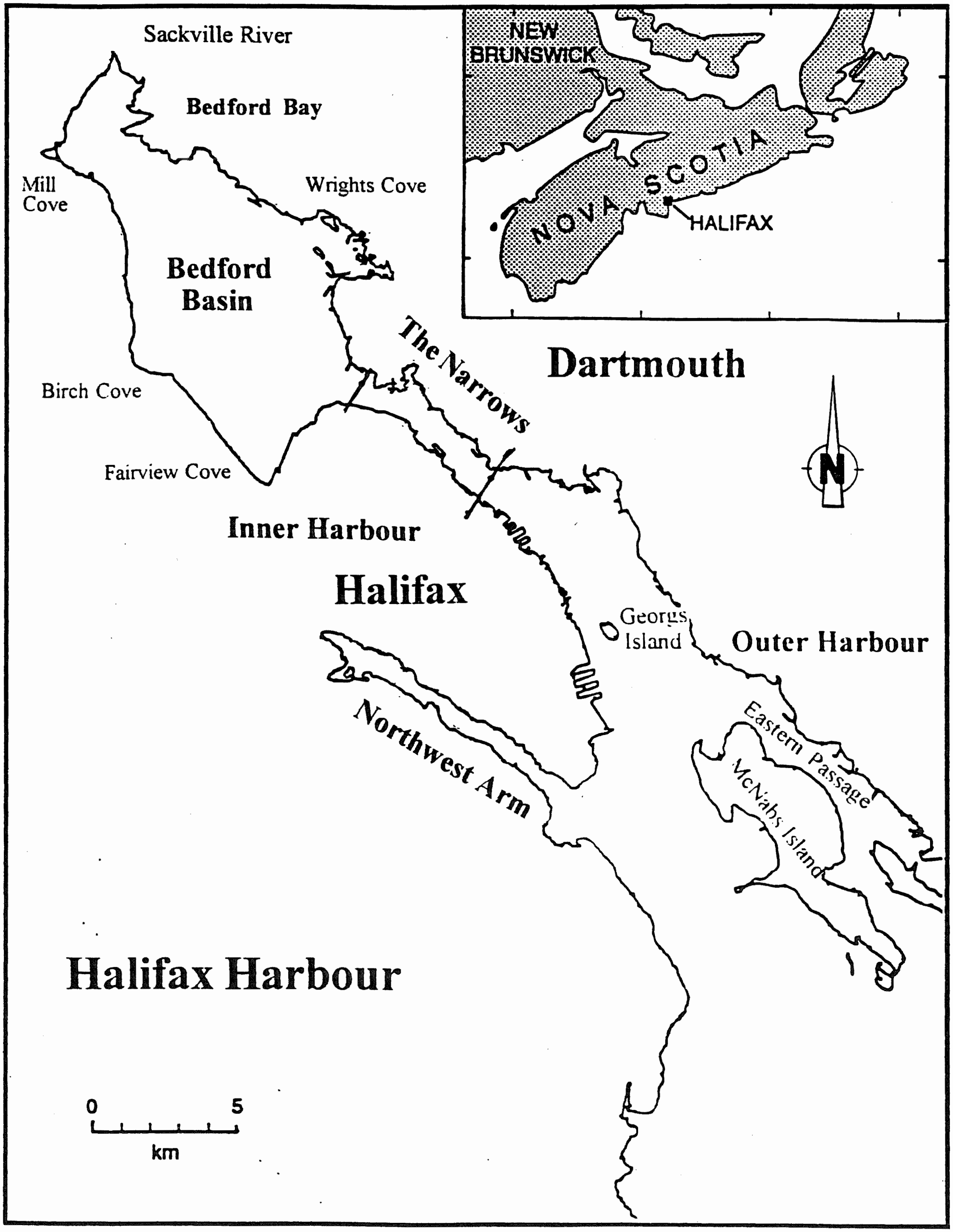


Figure 1.1: Location map of Halifas Harbour, Nova Scotia.

1.5.2 Surficial Geology

The surficial geology is summarized from Fader et al. (1991) and Fader and Buckley (1995). These surveys mapped the distribution of sediments and features of the harbour bottom.

Holocene mud, an average of 3-5 m thick, covers the surface of areas deeper than 20 m in the Bedford Basin. It is partly charged with biogenic methane in the N and S-W areas of the Basin. Like the Sackville River mud, it consists of sandy clayey silt to clayey sandy silt. The Sackville River mud is found mainly in Bedford Bay. Muddy-sandy, poorly sorted gravel in the cobble and boulder range is deposited in shallow areas near the shore, surrounding the Holocene mud in the inner areas of the Basin. Sills are composed of bedrock and/or till or gravel, and separate Fairview Cove and Bedford Bay from the main body of the Basin. Bedrock is found near Long Cove, at the basinward end of Bedford Bay, in Roach Cove and Wrights Cove.

The sediment surface of Bedford Basin is characterized by many anthropogenic features such as dredge spoils, anchor marks, shipwrecks, cables, pipelines, propeller scour marks, borrow pits and sewage outfall pipes and banks.

1.5.3 Bathymetry

Maximum depths of 20 m are common in Bedford Bay, Wrights Cove, Roach Cove and Birch Cove with shallower water depths in Long Cove, Mill Cove, the area adjacent to the Sackville River mouth and Tufts Cove in The Narrows. In Fairview Cove, inward from the Basin, at the northern part of the central area of the Basin and in The

Narrows, a broader area with depths ranging from 20 to 30 m can be found. The center of the Basin reaches a maximum depth of 71 m (Fig. 1.2).

1.5.4 Circulation

As Halifax Harbour is an estuary, circulation patterns are characterized by a typical two-layered flow. Heavier salt water enters the Harbour along the bottom while lighter water from freshwater discharge flows outward near the surface. The second major source of freshwater is sewage discharge from various outfalls in the Harbour of 2.1 m^3/s to 2.5 m^3/s throughout the year (Petrie and Yeats, 1990).

Currents and spatial circulation in Bedford Basin are weaker compared to other parts of the Harbour. Vertical exchange velocities in Bedford Basin are < 0.5 m/d (Buckley and Winters, 1992), and stagnation occurs in the deeper waters due to poor mixing and infrequent flushing (Halifax Harbour Task Force, 1990).

Observations of sediment transport show that particles generally move in a northerly direction towards Bedford Basin (Halifax Harbour Task Force, 1990). Tidal range in the Harbour is small with an average of 1.5 m (Gregory, 1970). The fine-grained mud which covers most of the Bedford Basin is evidence of low bottom current velocities.

1.5.5 Salinity and Temperature

Jordan (1972) noted mean annual salinities of 29.3 ‰ in 0-10 m depth, and 30.5 ‰ in 10-20 m water depth in Bedford Basin. Seasonally mean salinities vary from 29.5 ‰ (0-10 m) and 30.4 ‰ (10-20 m) in March-April to 30.3 ‰ (0-10 m) to 30.7 ‰ (10-20 m) in July-August. Salinities of bottom water in the Bedford Basin vary during the year between 31.4 $^0/_{00}$ and 31.9 $^0/_{00}$. Boyd and Cok (1963) measured salinities of 26 $^0/_{00}$ in Bedford Bay.

Temperatures from the surface water vary from 15-18 °C in the summer to often below 0 °C in winter. Temperatures of 4-10 °C are recorded at a depth of 20 m (Krauel, 1969).

1.5.6 Dissolved Oxygen Content and Redox Potential

Oxygen concentrations in the surface waters of Halifax Harbour range from 77 % to 120 % saturation (Halifax Harbour Task Force, 1990). Average oxygen concentrations of 50 % saturation at 60 m depth in Bedford Basin have been recorded by Krauel (1969). Since 1969, considerably decreased values, occasionally approaching zero, have been reported from this area (Halifax Harbour Task Force, 1990). Oxygen depletion near sewage outfalls was found in the Halifax Harbour Monitoring Program (Nova Scotia Dep. of the Environ. and Metro. Area Commission, 1986).

Most surface sediments within the Harbour are reducing, showing low Eh-potentials of < +100 mV (Buckley and Hargrave, 1989). Lowest values occurred near sewage discharge points in Mill Cove, Wrights Cove and Tufts Cove (Buckley and Hargrave, 1989). These are indicative of anoxic conditions (Buckley and Hargrave, 1989).

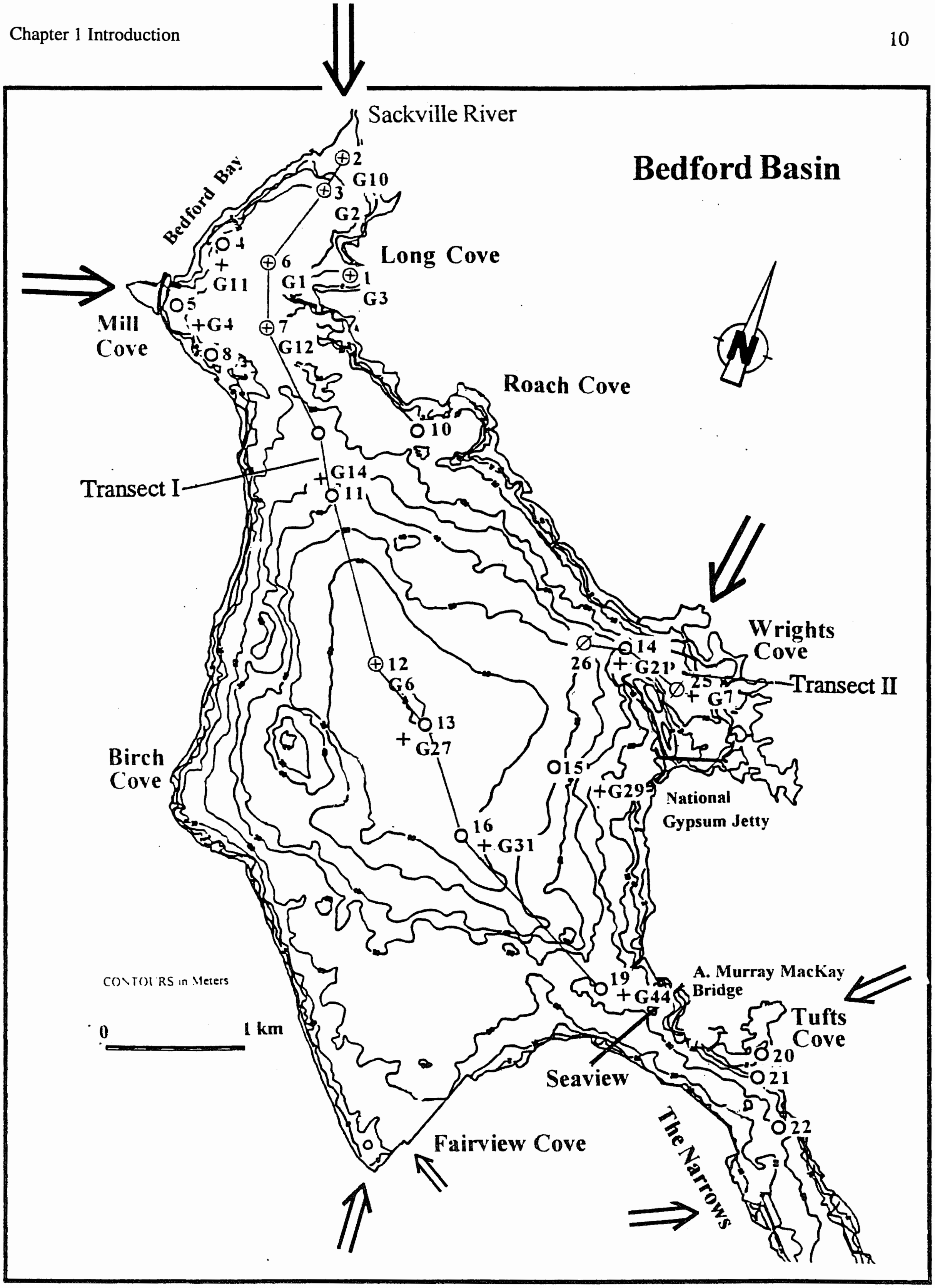


Figure 1.2: Bathymetry map of Bedford Basin; sample locations and transects are indicated, as well as sewage and surface drainage outfall points; O 1-19 surface sample sites (present), ∅ 25, 26 core locations, + surface sample sites from 1970 (after Gregory), — transect lines, ⇐ sewage and surface drainage outfall points.

CHAPTER 2 MATERIAL AND METHODS

2.1 Field Sampling

Surface samples and cores where collected throughout Bedford Basin (Halifax Harbour) aboard the research vessel CSS IBIS in August 1993 and October 1995 at over 20 stations (Fig. 1.2). A Shipek sampler and a Benthos Gravity Corer were used for recovering surface sediment and sediment cores, respectively. Samples were taken from stations in Bedford Bay, from Long Cove, Mill Cove, the central part of the Basin, Wrights Cove, and Tufts Cove, located in The Narrows. The water depth of the sampling sites ranged from 42 m in the central part of the Basin, to 2 m near the Sackville River mouth. The sample locations were determined within 5 m precision by radar systems, which track known sites on land. Locations from the radar were transferred to a bathymetric chart on board.

Two vials with 10 cc subsamples from the top 1-2 cm of surface sediments were collected for foraminiferal analysis and percentage organic matter determination. Of the cores collected in 1995, only two are included in this study. They were taken in Wrights Cove (St. 25) and seaward of Wrights Cove (St. 26).The length of the cores ranged from 22 cm (St. 25; core 3) to 19 cm (St. 26; core 4). After recovery from the sea floor they were capped onsite and transported back to Dalhousie University. They were stored in a cold room (4°C) before opening and sampling.

2.2 Laboratory Analyses

2.2.1 Foraminiferal Fauna

The cores were extruded at 1 cm intervals, cutting off successive 1 cm sections. From each interval a fraction was taken for the determination of the organic content. The remaining part was gently sieved with water through a 63-micron sieve to retain foraminifera and tintinnids, and to remove silt, clay and fine organics. A 10 % solution of buffered formaldehyde was added to each vial to prevent fouling. Before examination, the material was stained with Rose Bengal to distinguish living (stained) protoplasm and empty tests. After at least 8 hours of standing the samples were rinsed and alcohol was added for preservation.

2.2.2 Organic Matter

A fraction from each interval of the cores and from the surface samples was placed in an aluminium pan and air dried at room temperature. The pans were weighed and then combusted for one hour at 400 °C to obtain a loss on ignition value for organic matter.

2.3 Examination

2.3.1 Foraminiferal Fauna

All samples were suspended in water and alcohol and examined in a circular petri dish. Samples containing abundant foraminifera were split in 8 equal parts using a wet splitter (Scott and Hermelin 1993). From these fractions statistical counts were made until a number of 300 specimens was reached.

The high organic content does not allow drying of the material. This is favorable to retain organic linings, which would have been lost during the drying process. Also there might be a considerable loss of fragile foraminiferal tests such as *Reophax scottii*, when the samples are dried.

From the cores, analyses were made from the surface and the bottom sections, and within the core, from intervals where visible color or textural changes occurred.

The different foraminiferal, arcellacean and tintinnid species were identified and counted. Abundance in terms of number of individuals per 10 cc sediment, diversity as number of species per 10 cc, and living and dead ratios were determined.

2.3.2 Sediment

Before the cores were cut into 1 cm intervals, they were visually examined and colour and material changes were recorded.

2.4 Comparison of the Data

The data obtained here was compared to that of Gregory (1970), who recorded foraminiferal assemblages within Halifax Harbour from 1970. To facilitate correlation, counts of arcellaceans and organic linings were not considered in Table II (Appendix B). From the original table of Gregory (1970), only stations corresponding to the present locations were included (Table II). *Elphidium orbiculare* and *Reophax curtus* were renamed as *Haynesina orbiculare* and *Reophax scorpiurus,* since names have been updated since 1970. For comparison the species *Cribrostomoides crassimargo* and *Cribrostomoides jeffreysi* are referred to as *Cribrostomoides spp.* in Table II.

Trochammina spp. comprise individuals of *T. ochracea*, *T. inflata*, *T. macrescens* and *T. lobata* that were not identifiable to species level, and these were not considered in the comparison.

It is necessary, when comparing these two data sets, to take into consideration the different preparation techniques that have been applied. In 1970, concentration of foraminifera from the residue was achieved by carbon tetrachloride flotation (Gregory, 1970), after drying of the samples, a step not taken here. This almost certainly alters the results obtained in the later study versus those of Gregory (1970). Through drying, for example, some individuals of delicate species such as *Reophax scottii* can be lost.

CHAPTER 3 RESULTS

3.1 Surface Samples

3.1.1 Bedford Basin-Transect I

3.1.1.1 Bedford Bay (Stations 2,3,6,7)

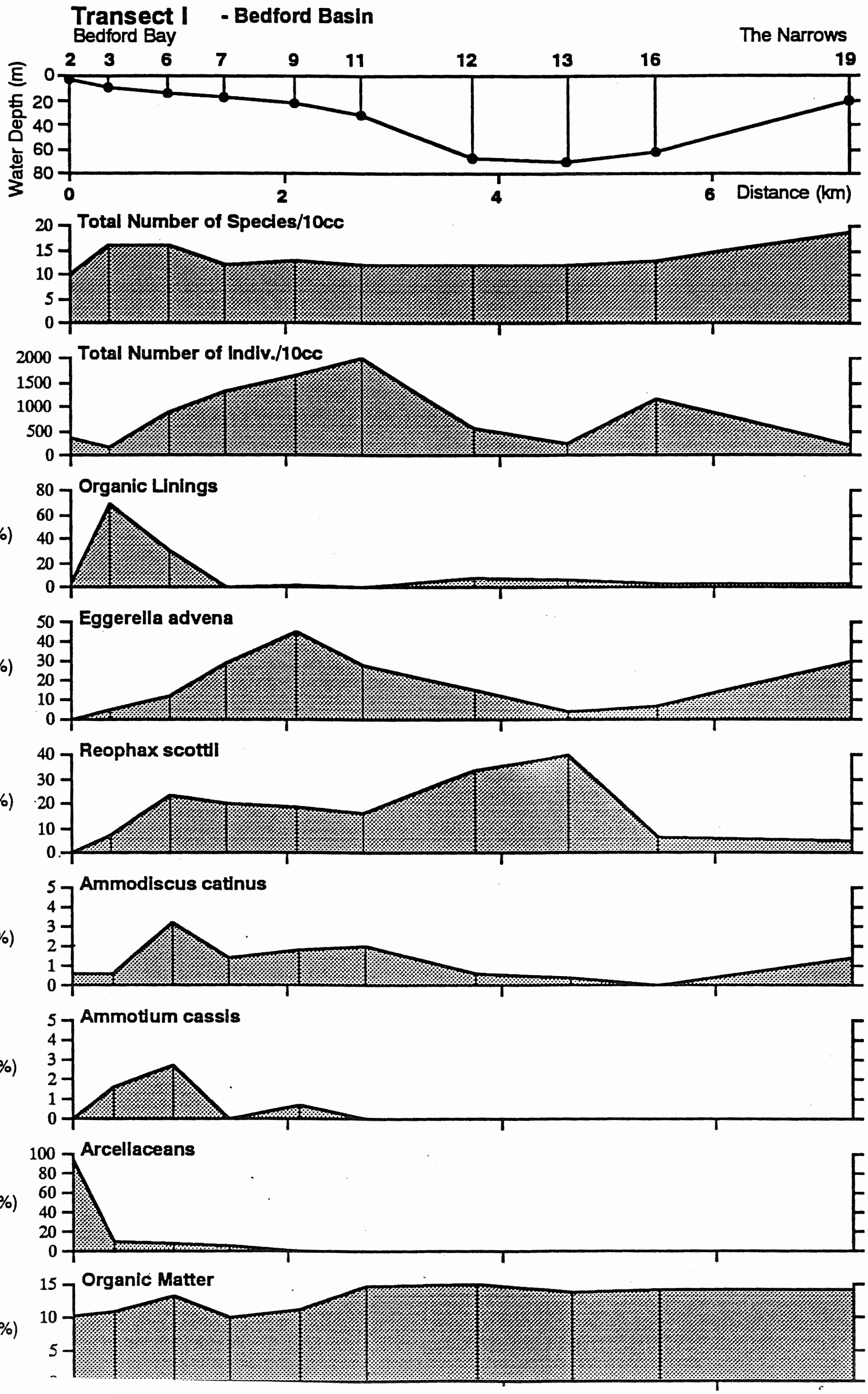
The total abundance of foraminifera and arcellaceans (living organisms plus empty tests) was low compared to other parts of the Basin, ranging from 364 ind./10 cc (st. 2) to 1320 (st. 7). The number of individuals decreased towards the Sackville River mouth. Arcellaceans (*Centropyxis aculeata*) were the dominant protozoans in this area, probably as a result of inflowing freshwater from the Sackville River. Near the river, (st. 2, 3) the diversity and abundance of foraminifera were lowest, increasing with distance from the river mouth (Fig. 3.1, Table I). The content of organic linings was high at station 3 (68 %) and 6 (42 %), indicating a significant amount of dissolved calcareous species. Dominant foraminiferal species were *Eggerella advena* (st. 6, 7), *Reophax scottii* (st. 3, 6, 7) and *Cribrostomoides crassimargo* (st. 7). No living species were found near the river. Tintinnids (*Tintinnopsis rioplatensis*) occurred in high numbers with a maximum of 212 ind./10cc at station 6 in the middle of the Bay. All samples showed a high organic matter content, ranging from 10.01 % at station 7 to 13.1 % at station 6.

3.1.1.2 Central Area (Station 9,11,12,13,16,19)

The total diversity remains nearly constant at stations in the central area, whereas the number of individuals per 10 cc rises towards the centre of the Basin and drops at sites 12, 13, and towards The Narrows (Fig. 3.1). The species *Eggerella advena*, *Reophax scottii*, *Spiroplectammina biformis* and *Textularia torquata* were dominant in the assemblages of station 9, 11 and 12, towards the Basin centre. The percent of calcareous

FIGURE 3.1.: Transect I-Bedford Basin

Transect through Bedford Basin from the Sackville River mouth to The Narrows (Fig. 1.2).
Presented are the depth of sample sites, total number of species (diversity), total number of individuals (abundance), percent organic matter content and relative abundance of foraminiferal species selected from Table I .



Transect I - Bedford Basin
Bedford Bay
The Narrows
2 3 6 7 9 11 12 13 16 19
Water Depth (m)
0 20 40 60 80
0 2 4 6 Distance (km)
Total Number of Species/10cc
20 15 10 5 0
Total Number of Indiv./10cc
2000 1500 1000 500 0
Organic Linings
(%)
80 60 40 20 0
Eggerella advena
(%)
50 40 30 20 10 0
Reophax scottii
(%)
40 30 20 10 0
Ammodiscus catinus
(%)
5 4 3 2 1 0
Ammotium cassis
(%)
5 4 3 2 1 0
Arcellaceans
(%)
100 80 60 40 20 0
Organic Matter
(%)
15 10 5

species increased from the centre (st. 12) towards the end of the transect, whereas organic linings remained consistently low throughout the central area of Bedford Basin (Table I).

3.1.2 Mill Cove (Station 5)

A low total abundance and low diversity were found at this station compared to other parts of the Basin. Besides a very high percentage of organic linings (50.7 %), the foraminiferal species *Eggerella advena*, *Trochammina ochracea* and *Ammotium cassis*, as well as the arcellacean species *Centropyxis aculeata*, made up the major part of the assemblage. Tintinnids were found in a considerable quantity (73 ind./10 cc). The organic matter content was high (14.85 %) at this site.

3.1.3 Long Cove (Station 1), and Station 4, 8

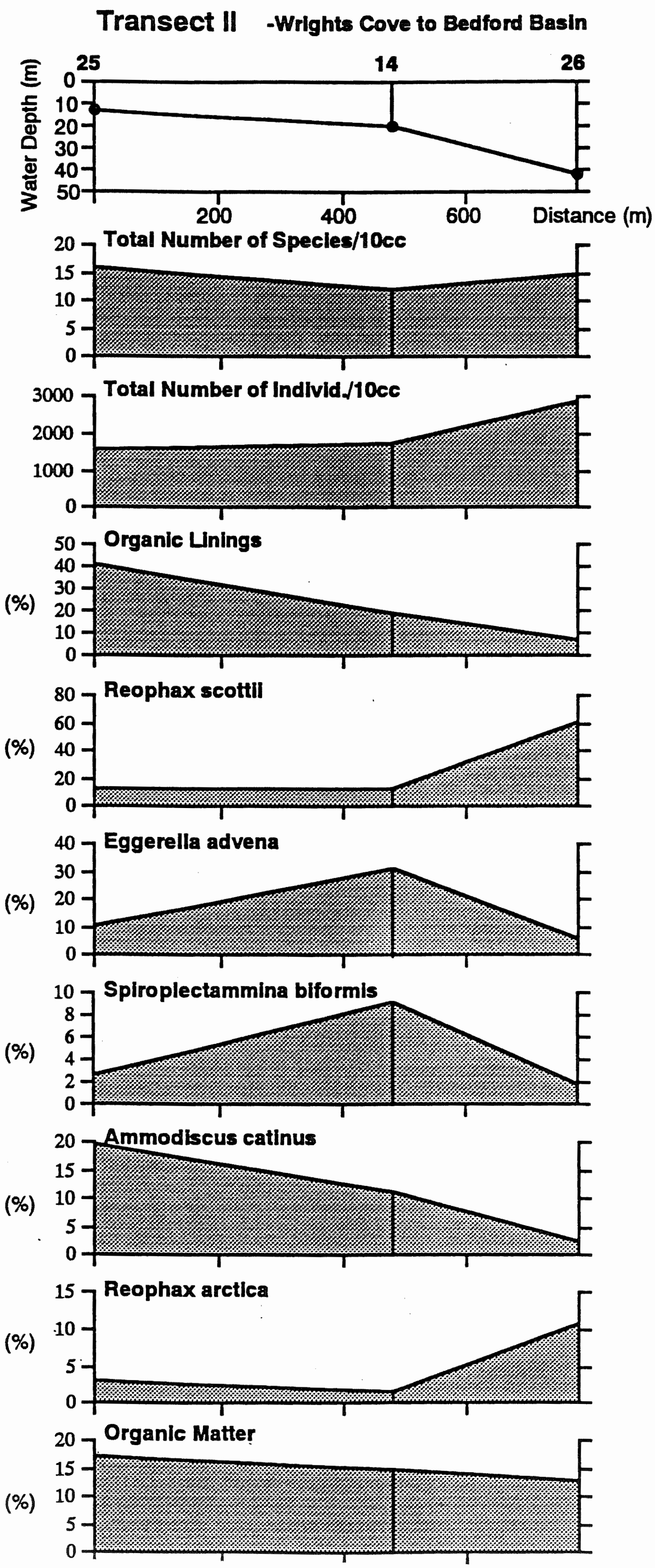
In Long Cove and at station 4 and 8, the total abundance was higher than at the adjacent sites in the centre of Bedford Bay and in Mill Cove. In Long Cove no arcellaceans were present. At site 4 a relatively high percentage of calcareous species such as *Elphidium spp.* occurred, as well as a dominance of *Haynesina orbiculare* and a high content of organic linings. Site 1, 4 and 8 show a relatively low percentage of *Reophax scottii*, that appears at most other stations as the dominant species. The lowest organic matter content in Bedford Basin was found at station 4 (8.19 %).

3.1.4 Wrights Cove-Transect II. (Station 25,14,26)

The total number of individuals per 10 cc was high, ranging from 1756 (st.14) to 2872 ind./10 cc (st. 26). Also a high total diversity was observed, with the lowest value at the middle of the transect (12 species/10 cc at station 14). In the Cove (st. 25) *Ammodiscus catinus*, *Reophax scottii, Eggerella advena* and organic linings were most common. Seaward from Wrights Cove the dominance of *Eggerella advena*, organic

FIGURE 3.2.: Transect II-Wrights Cove

Transect from inside Wrights Cove to Bedford Basin (Fig. 1.2).
Presented are the depth of sample sites, total number of species (diversity), total number of individuals (abundance), percent organic matter content and relative abundance of foraminiferal species selected from Table I .


Transect II -Wrights Cove to Bedford Basin
25
14
26
Water Depth (m)
0
10
20
30
40
50
200
400
600
Distance (m)
Total Number of Species/10cc
20
15
10
5
0
Total Number of Individ./10cc
3000
2000
1000
0
Organic Linings
(%)
50
40
30
20
10
0
Reophax scottii
(%)
80
60
40
20
0
Eggerella advena
(%)
40
30
20
10
0
Spiroplectammina biformis
(%)
10
8
6
4
2
0
Ammodiscus catinus
(%)
20
15
10
5
0
Reophax arctica
(%)
15
10
5
0
Organic Matter
(%)
20
15
10
5
0

linings, *Reophax scottii* and *Ammodiscus catinus* (st.14) changed to an absolute dominance of *Reophax scottii* and *Reophax arctica* (st. 26). There is an evident peak of *Spiroplectammina biformis* in the middle of the transect (st.14). *Reophax arctica* shows a trend to increase in direction out of the Cove. Throughout the assemblages almost no calcareous species were observed. The amount of tintinnids was high, with the most individuals in the Cove at site 25 (344 ind./10 cc). The organic matter content ranged from 17.19 % (st. 25) to 12.85 % (st. 26).

3.1.5 Tufts Cove (Station 20,21,22)

The abundance varied from 57 ind./10 cc in the Cove near the outfall area (site 20) to 400 at station 21. The total diversity was higher at sites 21 and 22 outside the Cove. In all three samples *Eggerella advena*, organic linings and *Reophax scottii* were dominant. *Trochammina ochracea* showed a high occurrence at site 20. Organic linings and *Reophax scottii* appeared in relatively higher percentages outside the the Cove, reaching over 80 % of the assemblage at site 22. Strong test deformations have been observed at all three sites, e.g. bent *Eggerella advena* tests (Plate, Fig. 3), deformed tests of *Trochammina ochracea* (Plate, Fig. 2), and deformed tests of *Ammodiscus catinus* (Plate 1, Fig. 6). Tintinnids occurred at site 21 and 22, but not at site 20 adjacent to the outfall. Site 20 and 21 appeared to have the highest organic matter content of all the collected samples (63.98 % at st. 20, and 36.8 % at st. 21). Also evident was a considerable quantity of artificial particles such as glassballs, polystyrene and colorful plastic particles at all sites.

3.2 Comparison to 1970

3.2.1 Bedford Basin- Transect I

3.2.1.1 Bedford Bay (Station G10;2, G2;3, G1;6, G12;7)

In 1970 the total abundance (living plus empty tests) ranged from 10 specimens/ 10 cc at station G10 to 730 (at st. G12). Near the Sackville River mouth the values appear to be lower in these samples, whereas they were higher in 1970 towards the entrance of Bedford Bay. The foraminiferal diversity was higher in 1970 especially near the river outfall, where at the same location, twenty-five years later, only 2 species were found. In 1970, 7 (site G1) to 14 (site G12) species were recorded. In both years arenaceous species dominated. However, in 1970 in total 5 calcareous species, with high percentages of *Elphidium excavatum* and *Buccella frigida,* were recorded, whereas in the present assemblages in Bedford Bay only a single calcareous species (st. 3, 6) occurred. Dominant arenaceous species for this area in 1970 were: *Eggerella advena*, *Cribrostomoides crassimargo* and *Saccammina atlantica*. Twenty-five years later *Reophax scottii* and *Ammodiscus catinus* occurred as a new dominant species. *Eggerella advena* remained as one of the most abundant species in this area.

3.2.1.2 Central Area (Station 9, G14;11, G6;12, G27;13, 16;G31, 19;G44)

The total abundance ranged from 750 (st. G14) to a minimum of 40 ind./10 cc at site G6. Foraminifera appeared to be generally more abundant in the present samples except for at station 13. Diversity ranged from 8 (st. G6) to 29 species/10 cc (st. G27). The foraminiferal diversity in the samples of 1970 was higher compared to the present except for site G6. Arenaceous foraminifera remained dominant for both times in respect to abundance. In total 28 calcareous species occurred in 1970, but only 10 calcareous

FIGURE 3.3.: Transect I-Bedford Basin

Comparison of Present Total Assemblages with those analyzed by Gregory 1970

This diagram shows a transect through Bedford Basin, from the Sackville River mouth to The Narrows (Fig. 1.2).
Presented are the depth of sample sites, total number of species (diversity), total number of individuals (abundance), percent organic matter content and relative abundance of foraminiferal species selected from Table II.

LEGEND:

—⊕— Graph (% Species) present (1995)
····◆···· Graph (% Species) 1970
⊕ 2 Station/ Number of st. present
◆ G 10 Station/ Number of st. 1970

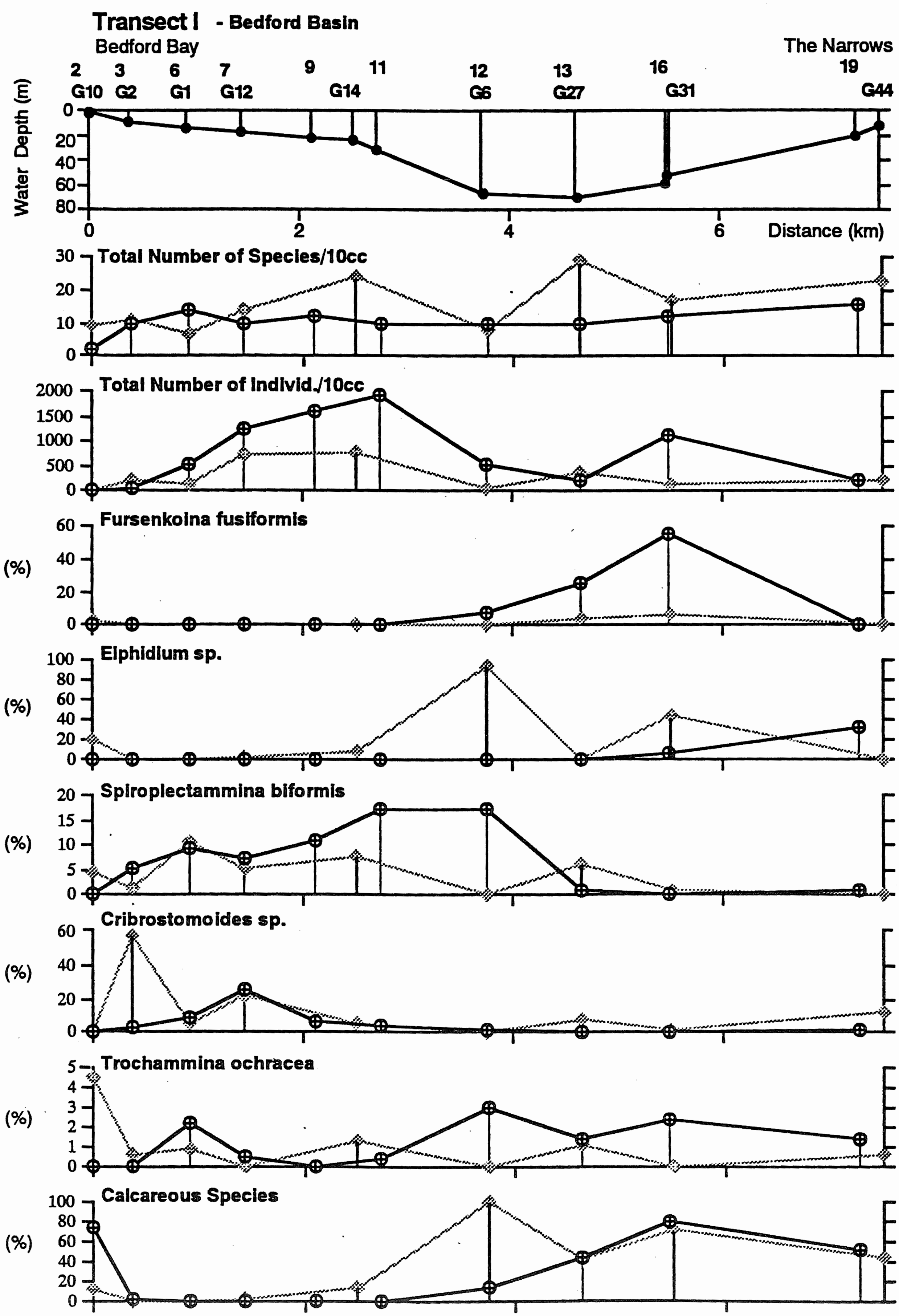

Transect I - Bedford Basin
Bedford Bay
The Narrows
2 3 6 7 9 11 12 13 16 19
G10 G2 G1 G12 G14 G6 G27 G31 G44
Water Depth (m)
Distance (km)
Total Number of Species/10cc
Total Number of Individ./10cc
Fursenkoina fusiformis
Elphidium sp.
Spiroplectammina biformis
Cribrostomoides sp.
Trochammina ochracea
Calcareous Species
(%)

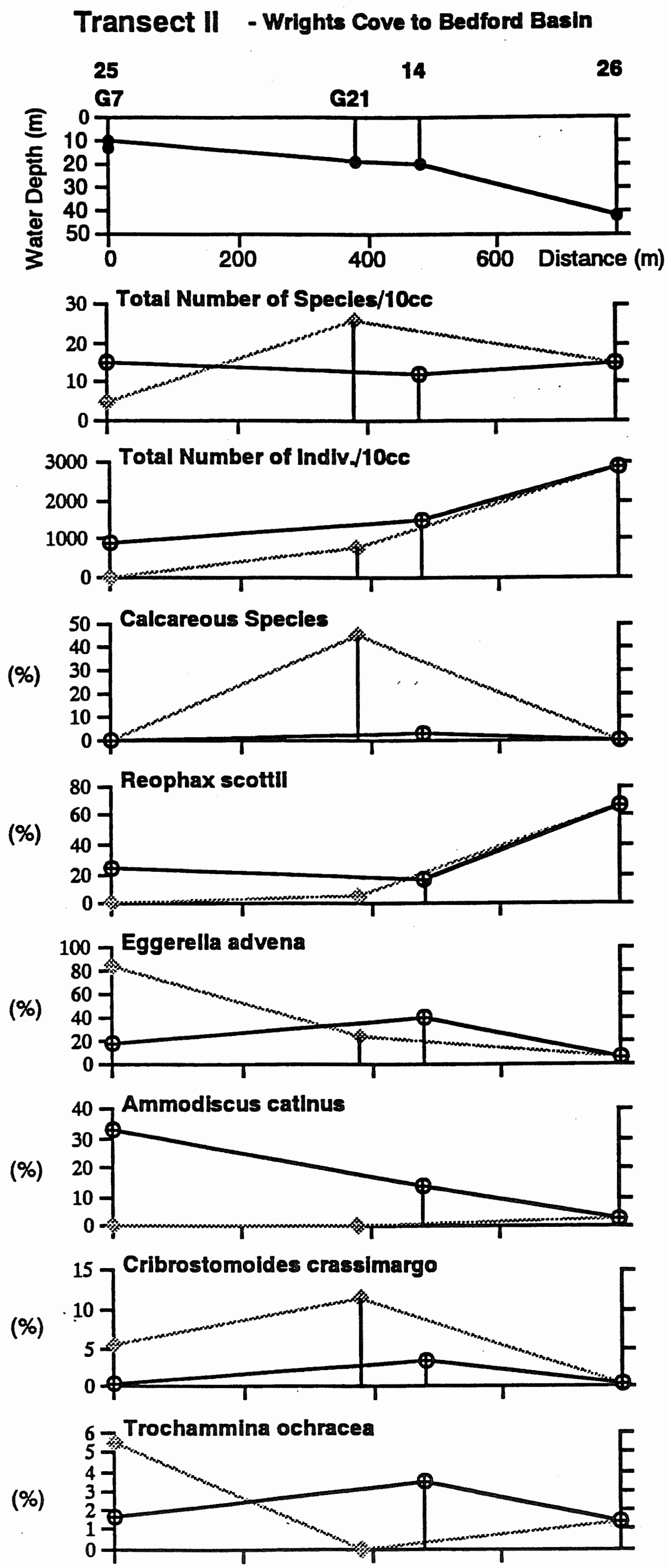
FIGURE 3.4.: Transect II-Wrights Cove

Comparison of Present Total Assemblages with those analyzed by Gregory (1970)

This diagram shows a transect from inside Wrights Cove into Bedford Basin. Presented are the depth of sample sites, total number of species (diversity), total number of individuals (abundance), percent organic matter content and relative abundance of foraminiferal species selected from Table II.

LEGEND:

—⊕— Graph (% Species) present (1995)
---◆--- Graph (% Species) 1970
⊕ 14 Station/ Number of st. present
◆ G 21 Station/ Number of st. 1970


Transect II - Wrights Cove to Bedford Basin
25
G7
G21
14
26
Water Depth (m)
0
10
20
30
40
50
0
200
400
600
Distance (m)
Total Number of Species/10cc
30
20
10
0
Total Number of Indiv./10cc
3000
2000
1000
0
Calcareous Species
(%)
50
40
30
20
10
0
Reophax scottii
(%)
80
60
40
20
0
Eggerella advena
(%)
100
80
60
40
20
0
Ammodiscus catinus
(%)
40
30
20
10
0
Cribrostomoides crassimargo
(%)
15
10
5
0
Trochammina ochracea
(%)
6
5
4
3
2
1
0

species were recorded in the present sediments from this area. Within the calcareous species *Haynesina orbiculare* and *Fursenkoina fusiformis* replaced *Elphidium excavatum* and *Buccella frigida* from 1970. In 1970 dominant species were: *Eggerella advena* and *Elphidium excavatum* (with a peak at site G6, G31). Twenty-five years later *Eggerella advena* and *Reophax scottii* appear as dominant species and the occurrence of species belonging to the genus *Elphidium* appears to be shifted towards The Narrows.

3.2.2 Wrights Cove

In 1970, total abundance and total diversity was lowest inside the Cove, whereas at the entrance of Wrights Cove (st. G21), the values in terms of abundance increased from 800 ind./10 cc (st. G21) to 1508 ind./10 cc (st. 14), and the diversity increased from 5 species per 10 cc (st. G7) to 26 (st. G21). In the present samples the total abundance showed generally higher numbers within the transect, with the same trend, whereas total diversity remained almost constant and was lower, except for at station G7. This indicates a general trend to a strong dominance of opportunistic species at cost of diversity. The dominant species of 1970 (*Elphidium excavatum*, *Eggerella advena* and *Cribrostomoides crassimargo*) were replaced by *Reophax scottii* and *Ammodiscus catinus*, with *Eggerella advena* remaining as a dominant species.

3.2 Cores

3.2.1 Core 3 (Station 25)

3.2.1.1 Sediment

Core 3 was 22 cm long and consisted of fine, gelatinous and fetid mud, that emitted strong odors of H_2S. Change in colour occurred at 6 cm depth from black to dark

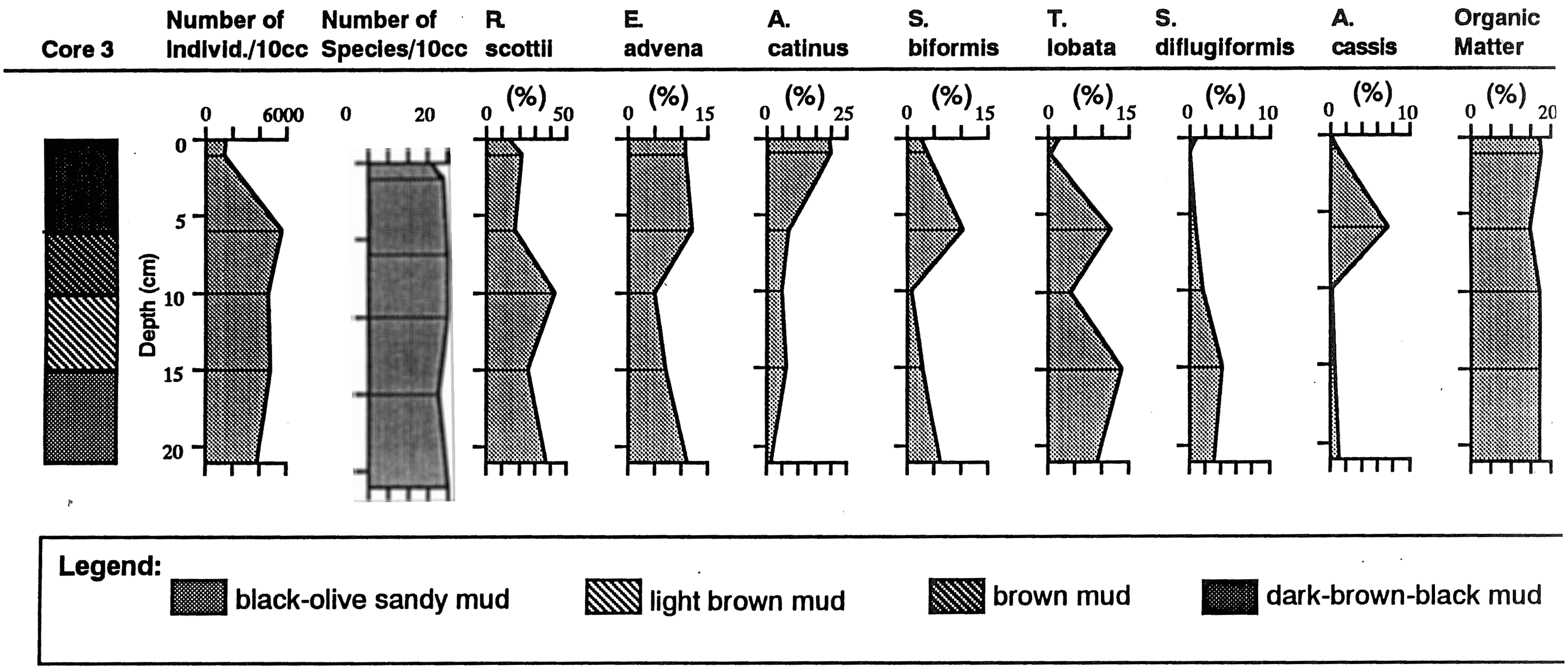


Figure 3.5 : Sediment properties, individuals, number of species, percent organic matter and percent abundance of common foraminiferal species selected from Table 3.

brown and to light brown at 15 cm. The lower section consisted of coarser material, which had a gray-olive colour. The organic matter content was high throughout the entire length, ranging from 17.57 % (at interval 1-2 cm) to 15.08 % (at interval 6-7).

3.2.1.2 Fauna

The total diversity was lowest in the first cm of the core, but was comparatively high throughout the core (16 to 20 species/10 cc). A considerable change in the total abundance from 1320 ind./10 cc to 5622 was evident from interval 1-2 cm to 6-7 cm. In all samples *Reophax scottii* and organic linings were dominant. *Ammodiscus catinus* and *Eggerella advena* occurred in high percentages in assemblages at the top of the core (interval 0-1 cm, 1-2 cm). In the interval 6-7 cm *Eggerella advena*, *Spiroplectammina biformis* and *Trochammina lobata* were dominant. A prominent peak of *Ammotium cassis* occurred at 6 cm core depth. A negligible amount of calcareous species was observed which, in conjunction with the abundance of organic linings, suggests that this environment is unfavorable for preservation of $CaCO_3$.

3.2.2 Core 4 (Station 26)

3.2.2.1 Sediment

The top 6 cm of core 4 consisted of black, fine, homogenous, odoriferous mud turning to a dark gray colour at 5 cm depth. At 16 cm the material changed to a sandy olive-gray mud with scattered black organic layers. The organic matter content was high, but decreased slightly towards the bottom.

3.2.2.2 Fauna

The number of species ranged from 11 to 15 species/10 cc. The abundance throughout the core was high. At 16 cm a marked increase of individuals occurred from

2816 to 6048 ind./10 cc. In the surface sample *Reophax scottii* was the dominant species. All other species occurred in percentages less than 10 %. Throughout the remainder of the core *Reophax scottii* and *Reophax arctica* comprised the major constituents of the foraminiferal assemblages. *Reophax arctica* and *Textularia torquata* increased with depth, whereas *Ammodiscus catinus* and *Eggerella advena* decreased. As in core 3, there was a minimal content of calcareous species. Organic linings were less abundant than in core 3.

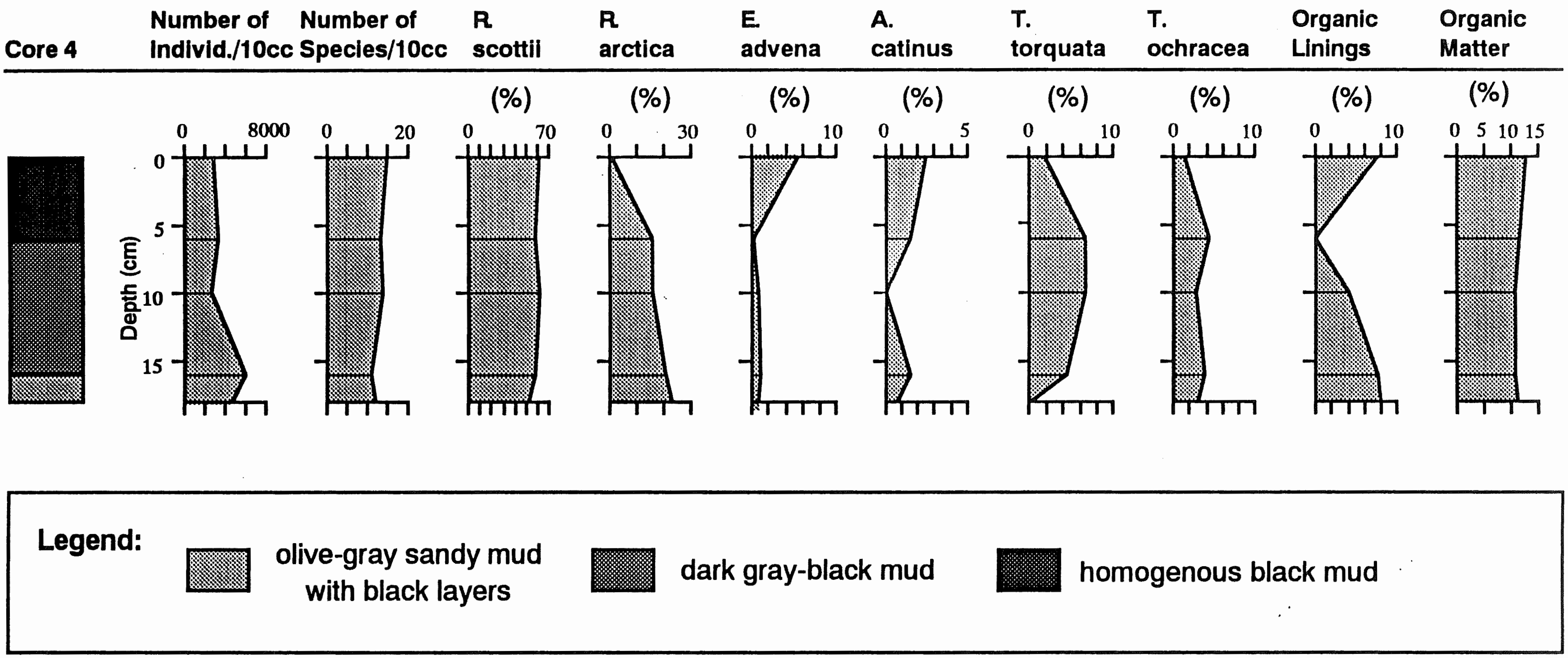


Figure 3.6 : Sediment properties, number of individuals, number of species, percent organic matter and percent abundance of common foraminiferal species selected from Table 4 .

CHAPTER 4 HISTORICAL PERSPECTIVE

4.1 Introduction

For more than 250 years Halifax Harbour has been used as a disposal site for raw sewage and solid wastes. Environmental degradation has increased with population growth and industrial enhancement in the last 30 years. These activities have altered the marine environment in many ways and have caused an apparent change in the foraminiferal fauna. The discharge of industrial or domestic effluents and run-off from land results in organic enrichment. Sewage mainly consists of carbohydrates, protein, fats, greases, oil, pesticides, nitrogen, phosphorus, various heavy metals and gases (Halifax Harbour Task Force, 1990).

During the Halifax Harbour Pollution Monitoring Project in 1986, hydrographic changes near major sewage outfalls within the Harbour were recorded, indicating oxygen depletion, lowered temperature and salinity decrease (Nova Scotia Dep. of Environ. and Metro. Area Commission, 1986). Organic enrichment caused by sewage discharge leads to oxygen deficiency and, in the extreme, to eutrophication of the environment (Josefson and Widborn, 1988).

Foraminiferal distribution patterns in natural settings are mainly related to salinity, temperature, oxygen content, substrate properties, depth and nutrient supply (Greiner, 1970). Foraminifera are opportunistic and less sensitive to hypoxia than other meiofauna such as ostracods, that would show a broad barren zone near pollution sources (Schafer et al., 1975). However an experiment with the foraminiferal species *Cribrostomoides subglobosus* under microcosmic conditions showed that this species was able to react very rapidly to varying conditions: after the input of a considerable quantity of food, the species showed an increase in the mean bodymass from 1.95 μg $C_{org.}$ to 3.68 μg $C_{org.}$ within 3 days (Altenbach, 1991).

The usual foraminiferal response to increased pollution is a decrease in diversity with an increase in abundance until only one opportunistic species remains. Foraminifera tend to build an abundance aureole around outfalls due to an increased nutrition availability (e.g. Bandy et al., 1965; Schafer, 1973). The number of living species usually increases with distance from the outfall area (Schafer, 1970; Bandy, 1965).

There is a fundamental difference between primarily toxic substrates (e.g. increased heavy metal concentration) and substrates with organic pollution that can be favorable for some species, even though there seem to be certain similarities in the faunal response (Alve, 1991). There is little information yet about effects of varying concentrations of different metals on the foraminiferal fauna.

4.2 Surface samples

Unfavorable conditions seem to presently prevail in the upper reaches of Bedford Basin, near the Sackville River, resulting in a nearly barren zone of foraminifera. In 1970 this site was mainly colonized by agglutinated species such as *Eggerella advena*, *Cribrostomoides crassimargo* and the calcareous species *Buccella frigida* and *Elphidium excavatum*. High suspended matter loadings, unstable salinity values and increased pollution through river discharge are probably the main factors causing this result. High occurrences of foraminiferal inner linings indicate that calcareous species were present but that their tests could not withstand the increased carbonate dissolution, possibly resulting from decreased salinities and/or increased organic loadings.

Arcellaceans occur in high percentages in Bedford Bay. They were probably transported with freshwater and sediment discharge from the Sackville River into the Bay.

In Transect I an anomalous low in foraminiferal abundance occurs at site 12 and 13 in both 1970 and 1995. These sites correspond to an area where highest concentrations of Cu, Zn, Pb and Hg were found, probably due to solid waste dumping (Buckley and Winters, 1992). Alve (1991) reported a similarly impoverished foraminiferal abundance caused by heavy metal pollution in Sorfjord, western Norway. The very low foraminiferal abundance found in Mill Cove (87 ind./10 cc)and in Tufts Cove (57 ind./10 cc) is probably a result of sewage run-off and increased metal concentration (Cu, Zn, Hg and Pb).

Due to rare occurrences of living specimens in all samples, I believe that the low content of living organisms might be an irregularity of preservation, and because of this, living species are not considered in the discussion.

The total diversity shows little variance in the present samples. Compared to 1970 the diversity was lower in all but one location (st. 6, G21). Other authors observed in organically polluted environments, that abundance can either decrease or increase, but species diversity usually shows a consistent decrease (Schafer et al., 1991).

The present foraminiferal assemblages in the Bedford Basin are dominated by agglutinated species. Organic pollution favors agglutinated assemblages (e.g. Nagy and

Alve, 1987), because they are more tolerant to reduced salinity, terrestrial influences and lower temperatures (Alve, 1991), all of which act to drive up $CaCO_3$ solubility. Calcareous species in the present samples have only been found in the deeper parts of the Basin at site 12, 13, 16 and 19. At Wrights Cove, Mill Cove and Tufts Cove no calcareous species were present. This is probably due to the increased organic matter content, which leads to oxygen demand, lowered pH and increases $CaCO_3$ dissolution (lower pH). Abundance of calcareous species is dependent on the availability of $CaCO_3$ within the habitat and favorable preservation conditions. Alternations in the $CaCO_3$ concentration can be caused by seasonal run-off and temperature fluctuations, as noted by Greiner (1970). The higher occurrence and diversity of calcareous species within the samples of 1970 are evident.

The high content of inner linings found in the present sediments which were presumably calcareous species indicates, that the number of dissolved calcareous specimens is highest in Bedford Bay, in Mill Cove, Wrights Cove and outside Tufts Cove.

High organic matter input causes oxygen depletion and a lowered pH-value in the sediment. Under these conditions SO_4 is reduced to H_2S, resulting in acidic porewaters and dissolution of $CaCO_3$ (e.g.Scott at al., 1980; LeFurgey and Jean, 1976). This further leads to the release of hydrogen sulfide gas causing increased stress, reduced growth and mortality (GESAMP, 1991).

Reophax scottii is typical in deep outer estuarine environments. These are characterized by low oxygen content and slightly lower salinity (Scott et al., 1980; Miller et al., 1982). The species is found to be one of the most dominant constituents of the assemblages in Bedford Basin. The tremendous increase of *R. scottii* in the central area of the Basin, as well as in Wrights Cove within the last twenty-five years is evident. A relation to an increase in organic matter input and accumulation of these organics seems probable. In other parts of the Harbour, as well as near aquaculture operations in Bliss Harbour, New Brunswick, *R. scottii* was shown to be sensitive to increases in organic matter (Edgecombe, 1994; Scott et al., 1995). However, losses of these delicate tests in the investigation in 1970, due to different preparation techniques might also be a factor in the comparison of the present results with those of Gregory (1970).

Eggerella advena is known as a pollution-tolerant species (e.g. Schafer, 1973). Bandy et al. (1965) recorded increased populations of this species near the Hyperion sewage outfall, Los Angeles. In Bedford Basin *E. advena* was the most dominant species in addition to *Reophax scottii* and organic linings. High percentages were recorded in the assemblages of Mill Cove, Wrights Cove (st. 14) and Tufts Cove. Environments adjacent to sewage outfalls favor the increase of this seemingly opportunistic species.

Studies from different nearshore environments on the Atlantic Coast of North America have shown that *Elphidium excavatum* is able to compete successfully in polluted habitats (e.g. Schafer, 1973; Schafer et al., 1975). These environments were mainly polluted by organic matter. In Bedford Basin *E. excavatum* was a dominant species in 1970, exceeding 90 % in the centre of the Basin (st.12). In the present samples its occurrence was rare and in low percentages. Schafer et al. (1991) noted an increased occurrence of *E. excavatum* in the summer months and its dominance directly below a sewage discharge in Saguenay Fjord, Quebec (Schafer et al., 1991). Even though the present surface samples were collected in the summer (August), the increase in occurrence of *E. excavatum* was not evident. This suggests that the diminished population must be due to an increase in environmental stress.

Fursenkoina fusiformis is characteristic of oxygen depleted environments (Alve, 1986). Edgecombe (1994) noted a decrease of *F. fusiformis* with decreased organic matter in Halifax Harbour. In Bedford Basin the main areas of occurrence of *F. fusiformis* are restricted to the center of the Basin (Station 12, 13), reaching a peak (52 %) at station 16. The enormous increase in proportion of this species compared to 1970 is probably a result of increased organic matter pollution and lower O_2 content within the Basin.

Haynesina orbiculare is characteristic of quiet nearshore environments of slightly lowered salinity. In Bedford Basin, it is mainly restricted to stations in the central area (st. 12, 13, 16) in the present samples. High quantities of organic linings, probably originating from this species, were found in Bedford Bay, indicating the tolerance of *H. orbiculare* to a decrease of salinity.

Spiroplectammina biformis is recognized as a pollution indicator species in Drammensfjord, SE Norway (Alve, 1990). It is also present under oxygen deficiency and reduced salinity (Scott et al., 1995). The species *S. biformis* has been observed in moderate quantities in the major part of the collected samples. In comparison to 1970 its importance has increased within the central area of the Basin and in Wrights Cove.

However, in Bedford Basin, it does not seem to serve as a pollution indicator species due to its relatively low occurrence.

Tintinnids are planktonic organisms that reflect conditions in the water column. Near an aquaculture site in Bliss Harbour, they have been observed to trace suspended organic matter in the water column (Scott et al., 1995). In Bedford Basin they occurred in highest numbers within a certain distance from the river mouth, reflecting the inflowing suspended matter from the Sackville River. Many tintinnids were also evident in Wrights Cove, Mill Cove and outside Tufts Cove, where a high amount of suspended organic matter comes from the adjacent sewage outfalls.

Foraminifera have been shown to reflect both natural and human induced alternations (e.g. Greiner, 1970; Scott et al., 1980). In Bedford Basin the faunal distribution pattern results from the combined effect of the typical hydrodynamic properties of the estuary, the influx of industrial and domestic sewage, anomalously high heavy metal concentration in the sediment, and the river discharge at the head of the Basin.

However, the patchiness of foraminiferal occurrence in Halifax Harbour observed by Gregory (1970) certainly plays a role in explaining in some cases, the extreme faunal shifts between 1970 and 1995. There is no doubt that increased degradation resulting from increased organic matter and heavy metal accumulation, decreased oxygen content in water and sediment, lowered temperature and salinity values had an noticable influence on the foraminiferal fauna.

4.3 Cores

The use of fossil material from core sediments is an alternative method to determine pollution effects on the foraminiferal fauna (e.g. Alve 1991; Grant et al., 1995). The assemblages can be altered by diagenetic processes (for example the dissolution of empty calcareous tests) and may not represent the original faunal composition. These effects have to be considered and distinguished from ecological effects (Alve, 1995; Schafer et al., 1991). Both cores indicate dissolution of the calcareous fauna throughout the entire length. However, a high number of agglutinated foraminiferal tests are preserved to allow the determination of faunal trends within the cores.

Bioturbation causes mixing of the sediment and can also lead to changes in the chronological record. The sediment cores show little evidence of bioturbation probably due to the reducing conditions of the sediment, that are not hospitable for bioturbating organisms (Buckley and Winters, 1992).

In dated cores (Buckley et al., 1995) from Bedford Basin, the mean deposition rate ranged from 21 to 24 cm $100y^{-1}$. The cores were dated by using isotopes ^{210}Pb and ^{137}Cs. Presuming an average deposition rate of 22 $cm100y^{-1}$ for core 3 and 4, and no disturbance through dumping of waste or dredge spoils, they may comprise slightly less than a century.

Through geochemical analyses for metal concentrations, the contamination history of Halifax Harbour was reconstructed (Buckley et al., 1995). Background values from sediments older than 100 years were compared to metal concentrations of younger sediments. It was found that significant contamination by most metals began in the mid 19th century. After 1940 the accumulation of metals such as Pb, Hg, Cu and Zn increased rapidly and reached a peak or plateau in the decades of 1960/70 (Buckley et al., 1995).

The strong smell of H_2S observed during the extraction process in both cores suggest reducing conditions. The high values and low variance in the organic matter content shows that these sites have always been environments with high organic matter input. As expected, the organic matter content was higher in core 3 because of its proximity to sewage outfalls.

According to the geochemical data and the proximity to the outfall, it is interpreted that increased metal concentration and organic matter pollution play a more important role at site 25 (core 3) located in Wrights Cove than at site 26 (core 4) (Fig.1.2). However both cores show a strongly decreased abundance towards the surface that indicates the influence of increased heavy metal accumulation in recent times on the foraminiferal fauna.

A tremendous increase in abundance in core 3 from 1320 ind./10cc to 5622 was evident between interval 1-2 to 6-7 (cm in core). Increased reproduction around effluent plumes due to richness in nutrients and phytoplankton have been noted elsewhere (Schafer, 1970; Bandy, 1965). The rapid population growth in the core is probably a response to changed conditions, also supported by the coincidence of a colour change in the sediment at the same interval. *Ammotium cassis* has shown an affinity to environments with high suspended loadings (Scott et al., 1977). Gregory (1970) found its occurrence in Halifax Harbour to be related to adjacent sewage outfalls. *A. cassis* shows apromineent peak together with a high total abundance in interval (6-7 cm). An increased nutrient availability due to higher sewage input or surface drainage, associated with suspended matter into the Cove, is probably the cause of this event.

The diversity was high and more or less stable in both cores, however a decrease in the top interval in core 3 was noticeable.

In both cores *Reophax scottii* was the most dominant species during the entire history. This shows again the affinity of this species to high organic and nutrient loading as mentioned before.

The high occurrence of *Eggerella advena* near sewage and aquaculture outfall sites noted by various authors (Clark, 1971; Bandy, 1975; Schafer, 1973) is thought to be due to the high nutrient demand of the species. *E. advena* increased in abundance in the upper parts of both cores and showed an evidently higher occurrence in core 3, indicating increased nutrient availability.

The occurrence of tintinnids increased in both cores towards the surface. In both cores a second high occurrence was found in the bottom sediments. The relatively high number of these delicate organisms at the bottom of the cores indicates good conditions for preservation.

CHAPTER 5 CONCLUSIONS

5.1 Conclusions

The present foraminiferal assemblages are affected by anthropogenic induced pollution and can be related to contaminants such as organic matter and increased heavy metal concentration.

Tremendous faunal changes over the last twenty-five years were observed. The overall decrease in diversity, in comparison to 1970, can be related primarily to an increase in organic matter pollution. Lowered foraminiferal abundance at site 12 and 13 in both years, as well as in Mill Cove and Tufts Cove, and strongly deformed organisms recorded from Tufts Cove result from increased heavy metal concentration. The nearly barren zone near the Sackville River is probably caused by high suspended matter loading, unstable salinity values and increased pollution from the river. The high occurrence of inner linings in Bedford Bay sediments indicates increased carbonate dissolution. In 1970 a much higher diversity and occurrence of calcareous species was found. The elimination of a major part of the calcareous fauna within twenty-five years, and a shift in dominance towards *R. scottii* in the central area as well as in Wrights Cove, is linked to a general increase of organic matter pollution within the Basin. The dominance of *E. advena,* mainly in Mill Cove, Wrights Cove and Tufts Cove, is due to the opportunism of this species under conditions that prevail near sewage outfalls. *Fursenkoina fusiformis* indicates oxygen depletion in the centre of the Basin. Tintinnids reflect particulate organic matter in the water column near the river and adjacent to sewage outfalls (Scott et al., 1995).

Faunal changes within the cores taken from Wrights Cove and just off Wrights Cove show both faunal changes in time due to organic matter pollution and increased metal concentration. Increased heavy metal accumulation in recent times probably lead to decreased abundance in the upper part of the cores. The increase in abundance of the pollution tolerant species *Eggerella advena* in the upper parts of the cores reflect increased pollution in recent times.

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SYSTEMATIC TAXONOMY

Faunal Reference List:

The systematic arrangement of the foraminiferal genera follows the classification of Loeblich and Tappan (1988). The classification of the arcellaceans is in accordance with Medioli and Scott (1983). The list includes species mentioned in figures and tables and are listed alphabetically by Genus.

FORAMINIFERA

Adercotryma glomerata (Brady)
Lituola glomerata BRADY 1878, v.1, p. 433, pl. 20, fig. 1a-c.
Adercotryma glomerata (Bardy)-LOEBLICH and TAPPAN 1953, v. 121, p. 26, pl. 8, fig. 1-4.-GREGORY 1970, p. 173, pl. 11, fig. 9-11.

Ammodiscus catinus (Hoeglund)
Ammodiscus catinus HOEGLUND 1947, p. 122, pl. 8, figs. 1, 7.-GREGORY 1970, p. 166, pl. 1, fig. 7.

Ammotium cassis (Parker)
Lituola cassis PARKER in Dawson 1870, p. 177, fig. 3.
Ammobaculites cassis (Parker)-CUSHMAN 1920, p. 63, pl. 12, fig. 5.
Ammotium cassis (Parker)-LOEBLICH and TAPPAN 1953, p. 33, pl. 2, fig. 12-18.-GREGORY 1970, p. 176, pl. 3, fig. 5.

Bolivina pseudopunctata Heron-Allen and Earland
Bolivina pseudopunctata HERON-ALLEN and EARLAND 1930, p. 181, pl. 3, figs. 36-40.-GREGORY 1970, p. 212, pl. 10, figs. 7-9.

Brizalina pseudopunctata Hoeglund
Brizalina pseudopunctata HOEGLUND 1947, p. 273, pl. 24, fig. 5, pl. 32, figs. 23, 24.-MILLER ET AL. 1982, p. 2365, pl. 2, fig. 21.

Buccella frigida (Cushman)
Pulvinulina frigida CUSHMANN 1922, p. 12, no. 144.
Buccella frigida (Cushman)- ANDERSON 1952, p. 144, figs. 4-6.

Cassidulina teretis Tappan
Cassidulina teretis BRADY in Barker 1960, p. 110, pl. 54, fig. 1.

Cibicides lobatulus (Walker and Jacob)
Nautilus lobatulus WALKER and JACOB 1798, p. 642, pl. 14, fig. 36.
Cibicides lobatulus (Walker and Jakob)-PARKER 1952a, p. 427, pl. 6, fig. 26.

Cribrostomoides crassimargo (Norman)
Haplophragmium crassimargo NORMAN 1892, p. 17.
Labrospira crassimargo (Norman)-HOEGLUND 1947, p. 11, fig. 1, text fig. 121-125.
Cribrostomoides crassimargo (Norman)-LESLIE 1965, p. 158, pl. 2, fig. 2a, b.

Cribrostomoides jeffreysi (Williamson)
Nonionia jeffreysi WILLIAMSON 1858, p. 34, pl. 3, fig. 72, 73.
Cribrostomoides jeffreysi (Williamson)-BARBIERI and MEDIOLI 1969, p. 855, fig. 4.

Eggerella advena (Cushman)
Verneuilina advena CUSHMAN 1922a, p. 141.
Eggerella advena (Cushman)-CUSHMAN 1937, p. 51, pl. 5, fig. 12-15.-SCOTT and MEDIOLI 1980, p. 38, pl. 2, fig. 7.

Eggerella bradyi (Cushman)
Verneuilina bradyi CUSHMAN 1911, p. 54, pl. 2.
Eggerella bradyi BRADY in Barker 1960, p.96, pl. 47, figs. 4-7.

Elphidiella arctica (Parker and Jones)
Polystomella arctica PARKER and JONES in Brady 1864, p. 471.
Elphidiella arctica (Parker and Jones)-GREGORY 1970, pl. 13, p. 250 figs. 1, 2.

Elphidium crispum (Linne)
Elphidium crispum LINNE 1767, pl. 110, fig. 6-7.-BRADY in Barker 1960, p. 226, p. 226, pl. 105, figs. 6, 7.

Elphidium excavatum (Terquem) group
(Includes several formae (*E. clavatum, E. excavatum, E. lidoensis, E. seleysis*)
Polyst*omella excavatum* TERQUEM 1876, p. 429, pl. 2, figs. 2a-d.
Elphidium excavatum (Terquem)-CUSHMAN 1944, p. 26, pl. 2, fig. 40.

Elphidium frigidum (Cushman)
Elphidium frigidum CUSHMAN 1933, p. 5, pl. 1, fig. 3.- GREGORY 1970, p. 227, pl. 14, fig.-SCHAFER and COLE 1978, p. 27, pl. 10, fig. 2a, b.

Elphidium subarcticum Cushman
Elphidium subarcticum CUSHMAN 1944, p. 27, pl.3, fig. 34, 35.-GREGORY 1970, p. 251, pl. 14, fig. 7.

Fursenkoina fusiformis (Williamson)
Bulimina pupoides (d'Orbigny) var. *fusiformis* WILLIAMSON 1858, p. 64, pl. 5, fig. 129, 130.
Bulimina fusiformis (Williamson)-HOEGLUND 1947, p. 232, pl. 20, fig. 3, text-fig. 219-233.
Virgulina fusiformis (Williamson)-PARKER 1952a, p. 417, pl. 6, fig. 3-6.
Fursenkoina fusiformis (Williamson)-GREGORY 1970, p. 232.-SCOTT ET AL. 1980, p. 228, pl. 3, figs. 9, 10.

Glabratella wrightii (Brady)
Discorbina wrightii BRADY 1881, p. 413, pl. 21, fig.6.
Eponides wrightii (Brady)-PARKER 1952b, p. 450, pl. 5, fig. 4a,b.
Glabratella wrightii (Brady)-LESLIE 1965, p. 161, pl. 10, fig. 7.

Haynesina orbiculare (Brady)
Nonionina orbicularis BRADY 1881, p. 414, pl. 21, fig. 5.
Haynesina orbiculare (Brady)-BANNER and CULVER 1978, p. 188.

Islandiella islandica (Norvang)
Cassidulina islandica NORVANG 1945, p. 41.
Cassidulina islandica NORVANG *forma minuta* NORVANG 1945, p.43, figs. 8a-c.
Islandiella islandica (Norvang) LOEBLICH and TAPPAN 1964, p. C556, text-fig. 439, 1-3.-GREGORY 1970, p.248, pl. 11, fig. 1.

Miliammina fusca (Brady)
Quinqueloculina fusca BRADY 1870, p. 47, pl. 11, fig. 1, 3.
Miliammina fusca (Brady)-PHLEGER and WALTON 1950, p. 280, pl. 1, fig. 19a, b.-SCOTT and MEDIOLI 1980, p. 229, pl. 3, fig. 4.

Miliolid

Nonionella auricula Heron-Allen and Earland
Nonionella auricula HERON-ALLEN and EARLAND 1930, p. 192, pl. 5, fig. a, 68-70.

Organic linings
This category includes unidentifiable inner linings of various calcareous species. They are largely unidentifiable.

Quinqueloculina seminulum (Linne)
Serpula seminulum LINNE 1758,p. 786.
Quinqueloculina seminulum (Linne)-D'ORBIGNY 1826, p. 303.-GREGORY 1970, p. 187, pl. 6, fig. 1.-SCOTT 1977a, p. 175, pl. 7, figs. 3-5.-SCHAFFER and COLE 1978, p. 29, pl. 12, fig. 4.
Miliolina semiculum (Linne)- WILLIAMSON 1858, p. 85, pl. 7, figs. 183-185.
Quinqueloculina seminula (Linne)-CUSHMAN 1929, p. 59, pl. 9, figs. 16-18.

Recurvoides turbinatus (Brady)
Haplophragmium turbinatus BRADY 1881, p. 50.
Recurvoides turbinsatus (Brady)-PARKER 1952b, p. 402, pl. 2, fig. 23, 24.-GREGORY 1970, p. 176, pl. 3, fig. 3,4.

Reophax arctica Brady
Reophax arctica BRADY 1881, p. 405, pl. 21, fig. 2a, b.-GREGORY 1970, p. 168, pl. 2, fig. 3.-SCHAFER and COLE 1978, p. 29, pl. 2, fig. 5.
Bigenerina arctica (Brady).-CUSHMANN 1948, p. 31, pl. 3, fig. 9.

Reophax nana Rhumbler
Reophax nana RHUMBLER 1911, p. 182, pl. 8, fig, 6-12.- SCOTT and MEDIOLI 1980, p. 43, pl. 2, fig. 6.

Reophax nodulosa Brady
Reophax nodulosa BRADY 1879, v. 19, p. 52, pl. 4, fig. 7, 8.

Reophax scorpiurus (de Montfort)
Reophax scorpiurus DE MONTFORT 1808, p. 330.

Reophax scottii Chaster
Reophax scotti CHASTER 1892, p. 57, pl. 1, fig. 1.

Saccammina atlantica (Cushman)
Proteoina atlantica CUSHMAN 1944, p. 5, pl. 1. fig. 4.-PHLEGER 1952, p. 85, pl. 13, fig. 1, 2.
Saccammina atlantica (Cushman)-VILKS 1967, p. 43, pl. 1, fig. 13.

Saccammina difflugiformis (Brady)
Saccammina difflugiformis (Brady)-TODD and BROENNIMAN 1957, p. 22, pl. 1, fig. 15.

Spiroplectammina biformis (Parker and Jones)
Textularia agglutinans (d'Orbigny) var. *biformis* PARKER and JONES 1865, p. 370, pl. 15, fig. 23, 24.
Spiroplecta biformis (Parker and Jones)-CUSHMAN 1927, p. 23, pl. 5, fig. 1.-GREGORY 1970, p. 177, pl. 3, fig. 6.

Textularia torquata Parker
Textularia torquata PARKER 1952b, p. 403, pl. 3, fig. 9-11.-GREGORY 1970, p. 179, pl. 4, fig. 1, 2.

Trifarina fluens (Todd)
Angulogerina fluens TODD in Cushman and Todd 1947, p. 67, pl. 16, figs. 6, 7.
Trifarina angulosa (Williamson)-GREGORY 1970, p. 217, pl. 11, fig. 5.
Trifarina fluens (Todd)-SCOTT 1977, p. 177, pl. 8, figs. 12, 13.-SCHAFER and COLE 1978, p. 29, pl. 7, fig. 3.

Tiphotrocha comprimata (Cushman and Broennimann)
Trochammina comprimata CUSHMAN and BROENNIMANN 1948, p. 41, pl. 8, fig. 1-3.
Tiphotrocha comprimata (Cushman and Boenninmann)-SAUNDERS, 1957, p. 11, pl. 4, fig. 1-4.-SCOTT and MEDIOLI, 1980, p. 44, pl. 5, fig. 1-3.

Trochammina inflata (Montagu)
Nautilus inflata MONTAGU 1808, p. 81, pl. 18, fig. 3.
Trochammina inflata (Montagu)-PARKER and JONES 1859, p. 347.-SCOTT and MEDIOLI 1980, p. 39, pl. 3, fig. 12-14.

Trochammina lobata Cushman
Trochammina lobata CUSHMAN 1944, p. 18, pl. 2, fig. 10.

Trochammina macrescens Brady
Trochammina inflata (Montagu) var. *macrescens* BRADY 1970, p. 290, pl. 11, fig. 5a-c.
Jadammina polystoma BARTENSTEIN and BRAND 1938, p. 381, fig. 1a-c, 2a-1.
Trochammina macrescens (Brady)-PHLEGER and WALTON 1950, p. 281, pl. 2, fig. 6, 7.-SCOTT and MEDIOLI 1980, p.39, pl. 3, fig. 1-8.

Trochammina ochracea (Williamson)
Rotalina ochracea WILLIAMSON, 1858, pl. 4, fig. 112, pl. 5, fig. 113.

Trochammina squamata PARKER and JONES, 1865, p. 407, pl. 15, fig. 30, 31. SCOTT and MEDIOLI, 1980, p. 45, pl. 4, fig. 4, 5.

Trochammina pacifica (Cushman)
Trochammina pacifica CUSHMAN, 1925, pl. 39, fig. 3.

ARCELLACEANS

Centropyxis aculeata (Ehrenberg)
Arcella aculeata EHRENBERG 1832, p. 91.
Centropyxis aculeata (Ehrenberg)-STEIN 1859, p. 43. MEDIOLI and SCOTT 1983, p. 39, pl. 7, fig. 10-19.

Centropyxis constricta (Ehrenberg)
Arcella constricta EHRENBERG 1843, p. 410, pl. 4, fig. 35, pl. 5, fig. 1.

Cucurbitella tricuspis (Carter)
Difflugia tricuspis CARTER 1856, p. 221, pl. 7, fig. 80.-MEDIOLI and SCOTT, 1983, p. 28, pl. 4, figs. 5-19.
Cucurbitella mespiliformis PENARD 1902, p. 311, text-figs. 1-9.
Cucurbitella tricuspis (Carter)-MEDIOLI ET AL., 1987, p. 42, pl. 1, figs. 1-10; pl.2, figs. 1-10; pl. 3, figs. 1-7; pl. 4, figs. 1-9.

Difflugia oblonga Ehrenberg
Difflugia oblonga EHRENBERG 1832, p. 90.-EHRENBERG 1838, p. 131, pl. 9, fig. 2. MEDIOLI and SCOTT 1983, p. 25, pl. 2, fig. 1-17, 24-26.

Lagenodifflugia vas (Leidy)
Difflugia vas LEIDY, 1874, p. 155, pl. 1, figs. 13-16.
Lagenodifflugia vas PATTERSON ET AL. 1985, p.129, pl.1, fig. 12.

Lesquerensia spiralis (Ehrenberg)
Difflugia spiralis EHRENBERG 1840, p. 199.
Lesquereusia spiralis (Ehrenberg)-PENARD 1902, p. 36, text figs. 1-10.

Pontigulasia compressa (Carter)
Difflugia compressa CARTER 1864, p. 22, pl. 1, fig. 5, 6.
Pontigulasia compressa (Carter)-RHUMBLER 1895, p. 105, pl. 4, fig. 13a, b. MEDIOLI and SCOTT 1983, pl. 6, fig. 5-14.

TINTINNIDS

Tintinnopsis rioplarensis Souto
Tintinnopsis rioplatensis SOUTO, 1973, p. 251, fig. 5-8.
Difflugia bacillariarum PERTY.-MEDIOLI and SCOTT, 1983, p. 20, pl. 5, fig.16-19, pl. 6, fig. 1-4.

APPENDIX A: Plate

Plate:

1. Deformed *Trochammina* species (additional chambers)- Station 20.

2. *Eggerella advena*- Station 12.

3. Deformed *Eggerella advena* (bent)- Station 20.

4. *Spiroplectammina biformis*- Station 12.

5. *Reophax scottii*- Station 9.

6. Deformed *Ammodiscus catinus* (irregular windings)- Station 25 core 3, interval 6-7.

7. Deformed Species (unidentifiable)- Station 20.

8. *Cibicides lobatulus*- Station 19.

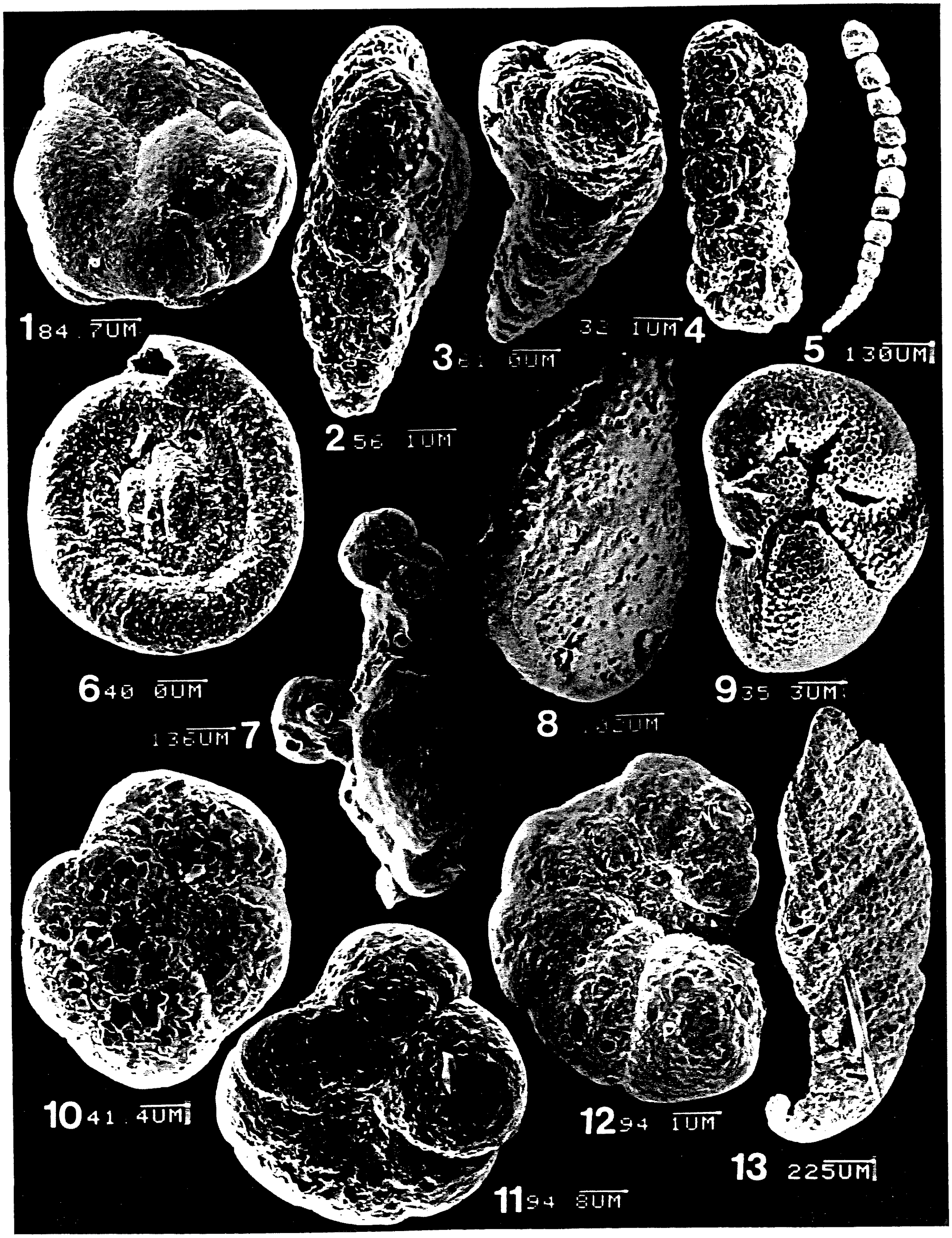
9. *Haynesina orbiculare*- Station 19.

10. *Trochammina ochracea*- Station 26 core 4, interval 18-19.

11. Deformed *Recurvoides turbinatus* ? (with additional chamber)- Station 21.

12. Deformed *Cribrostomoides crassimargo* (irregular chamber size)- Station 21.

13. *Ammotium cassis*- Station 25 core 3, interval 6-7.


1 84.7UM
2 56 1UM
3
4
5 130UM
6 40 0UM
7 136UM
8
9 35 3UM
10 41.4UM
11
12
13 225UM

STATION NUMBER	1		2		3		4		5	
DEPTH (m)	6		3		10		10		10	
PERCENT ORGANIC MATTER	11.83		10.12		10.87		8.19		14.85	
(living/total)	L	T	L	T	L	T	L	T	L	T
NO. OF SPECIES	0	12	0	10	0	16	0	16	0	11
NO. OF INDIVIDUALS/10cc	0	423	0	364	0	183	0	468	0	227
FORAMINIFERA										
Ammodiscus catinus				0.6		0.6				
Ammotium cassis		3.1				1.6		1.3		3.1
Buccella frigida				1.7				0.3		
Cassidulina teretis										
Cibicides lobatulus										
Cribrostomoides crassimargo								0.7		
C. jeffreysi						0.6				
Eggerella advena		10.2				5.5		6.7		24.2
E. bradyi										
Elphidiella arctica										
Elphidium clavatum exc. f.								1.6		
E. crispum										
E. excavatum exc. f.										
E. lideonsis exc. f.								1.3		
E. selseyensis exc. f.								1		
E. subarcticum								1.3		
Fursenkoina fusiformis										
Glabratella wrightii										
Haynesina orbiculare		0.5				0.5		23.1		0.4
Islandiella islandica										
Miliolid								2.6		
Miliamina fusca						1.6		3.5		1.8
Organic linings		76.4		3.3		68.3		42.3		50.7
Quinqueloculina seminulum										
Recurvoides turbinatus										
Reophax arctica		0.9								
R. nana		0.5								
R. nodulosus		0.7				0.5				
R. scorpiurus										
R. scottii		0.5				7.7		1.6		0.4
Saccammina atlantica										
S. difflugiformis										
Spiroplectammina biformis		0.7				1.1				0.4
Textularia torquata		0.2				0.5				
Tiphotrocha comprimata										
Trifarina fluens										
Trochammina inflata										
T. lobata										2.2
T. macrescens		0.2								
T. ochracea		6.1						5.4		5.7
ARCELLACEANS										
Centropyxis aculeata				64.1		3.8		7		10.5
C. constricta				8.2		1.6				
Cucurbitella tricuspis				2.8		0.6				
Difflugia oblonga				7.7		3.3		0.3		
Lagenodifflugia vas				0.6		2.2				
Lesquerensia spiralis				2.2						
Pontigulasia compressa				8.8						0.4
Planctonic Foraminifera				2						
TINTINNIDS										
Tintinnopsis rioplatensis						24		3		73

STATION NUMBER	6		7		8		9		10	
DEPTH (m)	15		17		12		22		12	
PERCENT ORGANIC MATTER	13.1		10.01		15.62		11.06		15.37	
(living/total)	L	T	L	T	L	T	L	T	L	T
NO. OF SPECIES	0	16	0	12	1	14	1	13	1	15
NO. OF INDIVIDUALS/10cc	0	888	0	1320	8	962	6	1644	8	632
FORAMINIFERA										
Ammodiscus catinus		3.2		1.4		0.3		1.8		1.7
Ammotium cassis		2.7				1.6		0.7		1.3
Buccella frigida										
Cassidulina teretis										
Cibicides lobatulus										
Cribrostomoides crassimargo		5.2		24.1		2.5		6.6		3
C. jeffreysi										
Eggerella advena		12.4		29.5	100	21.5	100	44.9	100	40.9
E. bradyi										
Elphidiella arctica										
Elphidium clavatum exc. f.										
E. crispum										
E. excavatum exc. f.										
E. lideonsis exc. f.										
E. selseyensis exc. f.										
E. subarcticum										
Fursenkoina fusiformis								0.4		
Glabratella wrightii										
Haynesina orbiculare		0.7						0.4		
Islandiella islandica										
Miliolid										0.4
Miliamina fusca		0.5				1.4				
Organic linings		30		0.5		53		1.8		32.5
Quinqueloculina seminulum										
Recurvoides turbinatus										
Reophax arctica		3.8		4.5		0.8		0.7		0.4
R. nana										
R. nodulosus		0.7								
R. scorpiurus		0.9		0.5				0.4		
R. scottii		23.4		20.5		2.7		18.6		2.1
Saccammina atlantica										
S. difflugiformis		1.4		3.2		0.3		0.7		1.3
Spiroplectammina biformis		5.6		6.8		0.8		10.6		3.8
Textularia torquata				2.3				12.4		1.3
Tiphotrocha comprimata										
Trifarina fluens										
Trochammina inflata						1.1				0.4
T. lobata		0.2				1.1				1.3
T. macrescens										
T. ochracea		1.4		0.5		7.1				5.9
ARCELLACEANS										
Centropyxis aculeata		8.1		6.4		6				3.8
C. constricta										
Cucurbitella tricuspis										
Difflugia oblonga										
Lagenodifflugia vas										
Lesquerensia spiralis										
Pontigulasia compressa										
Planctonic Foraminifera										
TINTINNIDS										
Tintinnopsis rioplatensis		212		72		43				13

STATION NUMBER	11		12		13		14		15	
DEPTH (m)	32		66		70		20		55	
PERCENT ORGANIC MATTER	14.59		14.87		13.83		14.69		15.17	
(living/total)	L	T	L	T	L	T	L	T	L	T
NO. OF SPECIES	0	12	0	12	0	12	0	12	0	9
NO. OF INDIVIDUALS/10cc	0	1984	0	582	0	239	0	1756	0	2364
FORAMINIFERA										
Ammodiscus catinus		2		0.6		0.4		11.2		3
Ammotium cassis								0.2		
Buccella frigida		0.4				2.1				
Cassidulina teretis										
Cibicides lobatulus										
Cribrostomoides crassimargo		4		1.7				2.8		0.5
C. jeffreysi										
Eggerella advena		28.6		15.5		4.2		31.7		16.2
E. bradyi										
Elphidiella arctica										
Elphidium clavatum exc. f.										
E. crispum										
E. excavatum exc. f.										
E. lideonsis exc. f.										
E. selseyensis exc. f.										
E. subarcticum										
Fursenkoina fusiformis				6.9		23.8		2.8		
Glabratella wrightii										
Haynesina orbiculare				7.2		15.9				
Islandiella islandica										
Miliolid										
Miliamina fusca										
Organic linings		1.2		8.2		6.7		18.5		3.8
Quinqueloculina seminulum										
Recurvoides turbinatus								1.3		
Reophax arctica		8.5		4.5		4.2		1.7		5.1
R. nana										
R. nodulosus										
R. scorpiurus										
R. scottii		16.5		33.3		39.7		13		60
Saccammina atlantica								1.5		
S. difflugiformis		1.6								
Spiroplectammina biformis		16.9		15.5		0.8		9.3		5.8
Textularia torquata		18.5		2.4		0.4		2.2		4.1
Tiphotrocha comprimata								0.9		
Trifarina fluens										
Trochammina inflata										
T. lobata										
T. macrescens										
T. ochracea		0.4		2.7		1.3		2.8		1.5
ARCELLACEANS										
Centropyxis aculeata		1.2		1.4		0.4				
C. constricta										
Cucurbitella tricuspis										
Difflugia oblonga										
Lagenodifflugia vas										
Lesquerensia spiralis										
Pontigulasia compressa										
Planctonic Foraminifera										
TINTINNIDS										
Tintinnopsis rioplatensis		88		32		12		32		330

STATION NUMBER	16		19		20		21		22	
DEPTH (m)	62		20		3		14		15	
PERCENT ORGANIC MATTER	0		14.15		36.8		63.98		10.93	
(living/total)	L	T	L	T	L	T	L	T	L	T
NO. OF SPECIES	1	13	5	19	0	7	1	13	5	13
NO. OF INDIVIDUALS/10cc	3	1185	37	223	0	57	3	400	20	265
FORAMINIFERA										
Ammodiscus catinus				1.4				0.4		4.5
Ammotium cassis										
Buccella frigida		0.3		1.4						
Cassidulina teretis				0.5						
Cibicides lobatulus			5.4	18						
Cribrostomoides crassimargo				0.9				0.4	5	3
C. jeffreysi				0.5						
Eggerella advena		7	75.7	30.2	100	28	100	13.6	60.7	41.5
E. bradyi										
Elphidiella arctica				1.4						
Elphidium clavatum exc. f.										
E. crispum		0.3								
E. excavatum exc. f.		5.8	13.5	28.8				1.2		
E. lideonsis exc. f.										
E. selseyensis exc. f.										
E. subarcticum										
Fursenkoina fusiformis		52.5								
Glabratella wrightii										
Haynesina orbiculare	100	17.9								
Islandiella islandica			2.7	2.3						
Miliolid										
Miliamina fusca										
Organic linings		3.8		3.2		16		50.4		44.5
Quinqueloculina seminulum		0.5								
Recurvoides turbinatus				0.9						
Reophax arctica		1.8		0.5		5.6		1.2	5	3.8
R. nana										
R. nodulosus										1.5
R. scorpiurus		0.3		1.4						
R. scottii		7	5.4	5.4		16.7		18	20	86
Saccammina atlantica										
S. difflugiformis				0.5		2.7		0.4		0.8
Spiroplectammina biformis		0.5		0.9		2.7		1.9		1.5
Textularia torquata								4.4		1.5
Tiphotrocha comprimata								0.4		0.5
Trifarina fluens				0.5						
Trochammina inflata										
T. lobata										3.8
T. macrescens										
T. ochracea		2.3	2.7	1.4		28		6.4		1
ARCELLACEANS										
Centropyxis aculeata								1.3		
C. constricta										
Cucurbitella tricuspis										
Difflugia oblonga										
Lagenodifflugia vas										
Lesquerensia spiralis										
Pontigulasia compressa										
Planctonic Foraminifera										
TINTINNIDS										
Tintinnopsis rioplatensis		12						27		22

STATION NUMBER	25/core3	26/core4
DEPTH (m)	13	42
PERCENT ORGANIC MATTER	17.19	12.85
(living/total)	T	T
NO. OF SPECIES	15	16
NO. OF INDIVIDUALS/10cc	1556	2872
FORAMINIFERA		
Ammodiscus catinus	19.6	2.5
Ammotium cassis		
Buccella frigida		
Cassidulina teretis		
Cibicides lobatulus		
Cribrostomoides crassimargo	0.3	0.3
C. jeffreysi		
Eggerella advena	10.8	5.6
E. bradyi	0.5	
Elphidiella arctica		
Elphidium clavatum exc. f.		
E. crispum		
E. excavatum exc. f.		
E. lideonsis exc. f.		
E. selseyensis exc. f.		
E. subarcticum		
Fursenkoina fusiformis		
Glabratella wrightii		0.6
Haynesina orbiculare		
Islandiella islandica		
Miliolid		
Miliamina fusca		0.6
Organic linings	40.9	7.8
Quinqueloculina seminulum		
Recurvoides turbinatus		0.6
Reophax arctica	3.1	10.9
R. nana		0.3
R. nodulosus	1.5	
R. scorpiurus		
R. scottii	14.1	60.4
Saccammina atlantica	0.3	
S. difflugiformis	1	0.3
Spiroplectammina biformis	2.6	1.9
Textularia torquata	0.5	5.3
Tiphotrocha comprimata	0.3	
Trifarina fluens		
Trochammina inflata		0.3
T. lobata		0.6
T. macrescens	2.1	
T. ochracea	1.5	1.3
ARCELLACEANS		
Centropyxis aculeata		
C. constricta		
Cucurbitella tricuspis		
Difflugia oblonga		
Lagenodifflugia vas		
Lesquerensia spiralis		
Pontigulasia compressa		
Planctonic Foraminifera		
TINTINNIDS		
Tintinopsis rioplatensis	344	56

APPENDIX B: Faunal Distribution Data

TABLE II.: Distribution chart showing water depth, percent organic matter, total number of species and individuals, percentage frequency of foraminiferal species of Gregory (1970) next to present data (numbers without consideration of organic linings and arcellaceans); sites that are adjacent to present sites are indicated; X=present in low numbers, D=dominant, C=common, P=present, R=rare (applies to Elphidium)

STATION NUMBER (Haury, 1996)				1			2					3
CORESP.STATION NUMBER (Gregory, 1970)	G3					G10				G2		
DEPPTH (m)		5				1				9		
(living/total)	L	T	L	T	L	T	L	T	L	T	L	T
NO. OF SPECIES	5	8	0	11	2	9	0	2	4	11	0	10
NO. OF INDIVIDUALS/10cc	182	210	0	100	10	10	0	2	68	200	0	37
Ammodiscus catinus	X	0.6						25				2.7
Ammotium cassis				13								8.1
Bolivina pseudopunctata												
Buccella frigida					0.8	13.6		75				
Buliminella elegantisima												
Cassidulina teretis												
Cibicides lobatulus												
Cribrostomoides crassimargo	1.5	2.4							0.6	58		2.7
Cyclogyra involvens												
Dentalina ital												
Discorbis columbiensis												
Eggerella advena	81.7	90.8		43		34.1			31.5	80		27
E. bradyi												
Elphidiella arctica												
Elphidium barletti												
E. crispum												
E. excavatum					6.8	12.5						
E.frigidum												
E. idivensis												
E. margaritaceum						8						
E. selseyensis												
E. subarcticum												
Esosyrinx curta												
Fissurina cucurbitasema												
F. marginata												
Fursenkoina fusiformis						2.3						
Glandulina laevingata												
Globobulimina auriculata												
Gordiospira arctica												
Haynesina orbiculare				2								2.7
Hippocrepina indivisa												
Hyperammina elongata												
Islandiella islandica												
I. nocrossi												
Lagena gracillima												
L. mollis												
L.semilineata												
L. striata												
Laryngosigma hyalascida												
Miliammina fusca												8.1
Miliolid												
Miliolinella chukchiensis												
Nonionella auricula												
Nonionellina labradorica												
Oolina melo												
Quinqueloculina seminulum												
Recurvoides turbinatus												
Reophax arctica				4						0.6		
R. nana				2								
R. nodulosus				3								2.7
R. scorpiurus												
R. scottii				2								37.8
Robertionoides charlottensis												
Saccammina atlantica						18.1						
S. difflugiformis										X		
Spiroplectammina biformis	0.5	0.6		3		4.5			0.6	1.3		5.4
Textularia torquata				1								2.7
Tiphotrocha comprimata												
Trifarina angulosa												
T. fluens												
Trochammina inflata	1.8	4.8				2.3			1.3	8.4		
T. lobata		X								X		
T. macrescens		X		1						X		
T. ochracea		X		26		4.5				0.6		
T. spp.										0.6		
OTHERS										2.5		
Planctonic Foraminifera												

STATION NUMBER (Haury, 1996)				4			(near) 5(&8)					6
CORESP.STATION NUMBER (Gregory, 1970)	G11				G4				G1			
DEPPTH (m)	9				10				14			
(living/total)	L	T	L	T	L	T	L	T	L	T	L	T
NO. OF SPECIES	5	18	0	13	4	11	0	8	4	7	0	14
NO. OF INDIVIDUALS/10cc	9	230	0	249	223	330	0	87	94	140	0	550
Ammodiscus catinus		X										5.1
Ammotium cassis		16.2		2.5				8				4.4
Bolivina pseudopunctata												
Buccella frigida				0.7	X	0.5						
Buliminella elegantisima												
Cassidulina teretis												
Cibicides Lobatulus												
Cribrostomoides crassimargo	0.7	9		1.3		3.6			0.9	4.7		8.4
Cyclogyra involvens												
Dentalina ital												
Discorbis columbiensis												
Eggerella advena	1.7	33.2		13.1	1	46.6		63.2	57.6	81.1		20
E. bradyi												
Elphidiella arctica												
Elphidium barletti		4.5										
E. crispum												
E. excavatum	0.5	20		3	4.7	21.2						
E.frigidum												
E. idivensis				2.5								
E. margaritaceum		2										
E. selseyensis				1.8								
E. subarcticum				2.5								
Esosyrinx curta												
Fissurina cucurbitasema												
F. marginata												
Fursenkoina fusiformis					0.5	1						
Glandulina laevingata												
Globobulimina auriculata												
Gordiospira arctica												
Haynesina orbiculare		X		45.8				1.1				1.1
Hippocrepina indivisa												
Hyperammina elongata												
Islandiella islandica												
I. nocrossi												
Lagena gracillima		0.3										
L. mollis												
L.semilineata												
L. striata												
Laryngosigma hyalascida												
Miliammina fusca				7				4.6		0.9		0.7
Miliolid				4.8								
Miliolinella chukchiensis												
Nonionella auricula												
Nonionellina labradorica												
Oolina melo												
Quinqueloculina seminulum										x		
Recurvoides turbinatus		0.2				1						
Reophax arctica												6.2
R. nana												
R. nodulosus												1.1
R. scorpiurus		0.7										1.5
R. scottii		1		3		3.1		1.1		1.9		37.8
Robertionoides charlottensis												
Saccammina atlantica	0.7	4				1						
S. difflugiformis												2.2
Spiroplectammina biformis		6.5				2.6		1.1	6.5	10.4		9.1
Textularia torquata												
Tiphotrocha comprimata												
Trifarina angulosa												
T. fluens												
Trochammina inflata		X										
T. lobata		1.2						5.7				0.4
T. macrescens		0.2										
T. ochracea	0.3	1.3		12.2		9.8		14.9	0.9	0.9		2.2
T. spp.												
OTHERS						9.3						
Planctonic Foraminifera										X		

STATION NUMBER (Haury, 1996)				7			(near)10				(near) 11	
CORESP.STATION NUMBER (Gregory, 1970)	G12				G17				G14			
DEPPTH (m)	20				15				24			
(living/total)	L	T	L	T	L	T	L	T	L	T	L	T
NO. OF SPECIES	5	14	0	10	4	16	1	13	11	24	0	10
NO. OF INDIVIDUALS/10cc	55	730	0	1230	3	50	8	403	92	750	0	1936
Ammodiscus catinus				1.5				2.6		1.3		2.1
Ammotium cassis		0.6			1.3	40		2		0.2		
Bolivina pseudopunctata												
Buccella frigida		X			1.3	2			1.9	4		0.4
Buliminella elegantisima						0.7						
Cassidulina teretis												
Cibicides Lobatulus												
Cribrostomoides crassimargo	0.4	22.1		25.9		1.3		4.6		4.8		4.1
Cyclogyra involvens										0.2		
Dentalina ital												
Discorbis columbiensis												
Eggerella advena	2.7	38.6		31.7	2	10	100	63	5.5	53.9		29.3
E. bradyi												
Elphidiella arctica												
Elphidium barletti										1.8		
E. crispum												
E. excavatum		1.9			2	31.3			1.3	6.2		
E.frigidum												
E. idivensis												
E. margaritaceum		P								X		
E. selseyensis												
E. subarcticum						X			X	X		
Esosyrinx curta										0.2		
Fissurina cucurbitasema												
F. marginata						0.7						
Fursenkoina fusiformis						0.7			0.2	0.6		
Glandulina laevingata												
Globobulimina auriculata												
Gordiospira arctica												
Haynesina orbiculare						X			0.1	0.9		
Hippocrepina indivisa										0.2		
Hyperammina elongata												
Islandiella islandica									0.2	1		
I. nocrossi												
Lagena gracillima												
L. mollis												
L.semilineata												
L. striata												
Laryngosigma hyalascida		X								0.2		
Miliammina fusca												
Miliolid								0.7				
Miliolinella chukchiensis												
Nonionella auricula												
Nonionellina labradorica												
Oolina melo												
Quinqueloculina seminulum												
Recurvoides turbinatus												
Reophax arctica		0.8		4.9		0.7		0.7		1.9		8.7
R. nana												
R. nodulosus						1.3				X		
R. scorpiurus	0.4	6.5		0.5					0.4	2.9		
R. scottii		X		22		1.3		3.3		2.1		16.9
Robertionoides charlottensis												
Saccammina atlantica	3.6	23.7							0.6	4		
S. difflugiformis				3.4				2				1.7
Spiroplectammina biformis		5.3		7.3		0.7		6	0.8	7.5		17.4
Textularia torquata	0.4	1.1		2.4		4		2	0.8	4.6		19
Tiphotrocha comprimata												
Trifarina angulosa												
T. fluens												
Trochammina inflata								0.7				
T. lobata		X						2				
T. macrescens												
T. ochracea				0.5		3.3		10		1.3		0.4
T. spp.												
OTHERS												
Planctonic Foraminifera												

STATION NUMBER (Haury, 1996)				12				13				14
CORESP.STATION NUMBER (Gregory, 1970)	G6				G27				G21			
DEPPTH (m)	70				80				19			
(living/total)	L	T	L	T	L	T	L	T	L	T	T	L
NO. OF SPECIES	1	8	0	10	12	29	0	10	10	26	0	13
NO. OF INDIVIDUALS/10cc	10	40	0	526	64	360	0	222	283	800	0	1508
Ammodiscus catinus		0.6		0.8				0.5				13.8
Ammotium cassis					0.5	0.7						0.3
Bolivina pseudopunctata									0.3	0.7		
Buccella frigida	0.7	1.5			1.4	6.8		2.3	3.3	9.5		
Buliminella elegantisima					X	0.4						
Cassidulina teretis												
Cibicides Lobatulus						0.4						
Cribrostomoides crassimargo				1.9	0.4	8			0.3	11.4		3.4
Cyclogyra involvens												
Dentalina ittai						0.4						
Discorbis columbiensis						1.1						
Eggerella advena				17.2	5.5	25.4		4.5	0.3	24.2		39
E. bradyi												
Elphidiella arctica												
Elphidium barletti		X								X		
E. crispum												
E. excavatum		95			5	28.1			0.7	25.9		
E.frigidum												
E. idivensis												
E. margaritaceum												
E. seiseyensis												
E. subarcticum						0.5				X		
Esosyrinx curta										0.3		
Fissurina cucurbitasema						0.4						
F. marginata						X				0.3		
Fursenkoina fusiformis		0.5		7.6	0.4	4		25.7	1	2		3.4
Glandulina laevingata										0.3		
Globobulimina auriculata		1								0.3		
Gordiospira arctica												
Haynesina orbiculare				8	0.2	3		17.1				
Hippocrepina indivisa												
Hyperammina elongata						X						
Islandiella islandica						0.7			0.7	1.7		
I. nocrossi		0.5				0.4				0.7		
Lagena gracillima										X		
L. mollis		0.5										
L.semilineata												
L. striata												
Laryngosigma hyalascida										0.3		
Miliammina fusca												
Miliolid												
Miliolinella chukchiensis					0.3	0.7						
Nonionella auricula										0.7		
Nonionellina labradorica										1.7		
Oolina melo												
Quinqueloculina seminulum												
Recurvoides turbinatus										0.3		1.6
Reophax arctica				5.1		1.8		4.5		3.9		2.1
R. nana												
R. nodulosus						X						
R. scorpiurus						2.5				3.3		
R. scottii				36.8		1.1		42.8		4.6		15.9
Robertionoides charlottensis												
Saccammina atlantica					1.1	4			0.4	1.6		1.9
S. difflugiformis												
Spiroplectammina biformis				17.2		6.2		0.9	0.7	6.9		11.4
Textularia torquata				2.7	0.4	1.8		0.5	1.3	8.5		2.7
Tiphotrocha comprimata												1.1
Trifarina angulosa						X				1		
T. fluens												
Trochammina inflata												
T. lobata												
T. macrescens												
T. ochracea				3	0.4	1.1		1.4				3.4
T. spp.						0.4						
OTHERS												
Planctonic Foraminifera						X						

STATION NUMBER (Haury, 1996)				16				19			25
CORESP.STATION NUMBER (Gregory, 1970)	G31				G44				G7		
DEPPTH (m)	42				13				10		
(living/total)	L	T	L	T	L	T	L	T	L	T	T
NO. OF SPECIES	8	17	1	12	3	23	6	17	3	5	15
NO. OF INDIVIDUALS/10cc	42	140	3	1140	40	220	37	1140	9	20	920
Ammodiscus catinus						0.3		1.4			33.1
Ammotium cassis											
Bolivina pseudopunctata	0.3	X									
Buccella frigida	10	20.7		0.3	1	9.6		1.4			
Buliminella elegantisima											
Cassidulina teretis								0.5			
Cibicides Lobatulus						0.5	5.4	18.6			
Cribrostomoides crassimargo		1.1				12.4		1.3		5.5	0.4
Cyclogyra involvens											
Dentalina ital						0.2					
Discorbis columbiensis		0.6									
Eggerella advena	2	21		7.4	5.6	32.1	76	31.2	3.3	83.3	18.3
E. bradyi											0.9
Elphidiella arctica								2.3			
Elphidium barletti	P	P				p					
E. crispum				0.3							
E. excavatum	15	39.9		6.2		C	29	29.6			
E.frigidum						R					
E. idivensis											
E. margaritaceum											
E. selseyensis											
E. subarcticum	1.1	4.1				P					
Esosyrinx curta											
Fissurina cucurbitasema											
F. marginata						0.4					
Fursenkoina fusiformis	2.2	6.1		54.9		0.9					
Glandulina laevingata											
Globobulimina auriculata											
Gordiospira arctica											
Haynesina orbiculare			100	18.4		P					
Hippocrepina indivisa											
Hyperammina elongata											
Islandiella islandica							2.5	2.3			
I. nocrossi											
Lagena gracilima											
L. mollis											
L.semilineata											
L. striata											
Laryngosigma hyalascida											
Miliammina fusca											
Miliolid											
Miliolinella chukchiensis											
Nonionella auricula											
Nonionellina labradorica						0.6					
Oolina melo						0.3					
Quinqueloculina seminulum				0.5		X				X	
Recurvoides turbinatus		0.2				0.3		0.9			
Reophax arctica		0.6		1.8		1		0.5			5.2
R. nana											
R. nodulosus											2.6
R. scorpiurus				0.3		1.4		1.4			
R. scottii		3.3		7.4		0.9	5.4	5.6			24
Robertionoides charlottensis											
Saccammina atlantica		0.6			1.9	6.4					0.4
S. difflugiformis								0.5			1.7
Spiroplectammina biformis		0.8		0.3				0.8			4.3
Textularia torquata						X					0.9
Tiphotrocha comprimata											0.4
Trifarina angulosa	0.3	X									
T fluens								0.5			
Trochammina inflata		0.3									
T. lobata		0.3									3.5
T. macrescens											2.6
T. ochracea				2.4		0.6	2.7	1.4	5.5	5.5	1.7
T. spp.									5.5	5.5	
OTHERS											
Planctonic Foraminifera											

APPENDIX B: Faunal Distribution Data

TABLE III.: Distribution chart of core 3 taken from Wrights Cove (station 25), displaying abundance, diversity, percent organic matter and foraminiferal percentages within the core.

DEPTH (cm)	0-1	1-2	6-7	10-11	15-16	21-22
PERCENT ORGANIC MATTER	17.19	17.57	15.08	17.19	17.49	17.19
NO. OF SPECIES	16	18	18	20	18	20
NO. OF INDIVIDUALS/10cc	1556	1320	5622	4728	4818	3750
FORAMINIFERA						
Adergotryma glomerata				0.2		
Ammodiscus catinus	19.6	20.3	6.8	4.8	6.2	1.4
Ammotium cassis		0.9	7.4	0.3	0.6	1.3
Brizalina pseudopunctata		0.9				
Buccella frigida				0.5		
Cribrostomoides crassimargo	0.3	0.3	5.3	0.5	2.1	1.4
C. jeffreysi				0.3	0.4	0.3
Eggerella advena	10.8	10.9	11.8	4.9	7	11.2
E. bradyi	0.5					
Miliammina fusca						0.3
Nonionella atlantica			0.1			
Organic linings	40.9	28.2	17.6	25.9	24	15.8
Recurvoides turbinatus		0.3	2	0.8	1	0.5
Reophax arctica	3.1	6.7	2	0.8	4.4	2.4
R. nana				0.2		
R. nodulus	1.5	0.9	0.3	0.5	0.2	0.3
R. scorpiurus		0.6	0.2		0.7	0.5
R. scottii	14.1	22.1	17.8	42.1	26.5	37.6
Saccammina atlantica	0.3					0.6
S. difflugiformis	1		1.1	1.7	4.4	3.2
Spiroplectammina biformis	2.6	3.6	10.6	1	3.1	6.2
Textularia torquata	0.5	0.6	0.5	0.8	0.7	1.1
Tiphotrocha comprimata	0.3	0.9	1	0.5	0.5	0.8
Trochammina lobata	2.1	0.3	11.6	3.9	13.6	9.1
T. macrescens	1.5	0.3	0.2	0.3	0.9	0.3
T. ochracea	1	1.8	3.6	7.8	3.6	5.4
T. pacifica		0.3				
TINTINNIDS						
Tintinnopsis rioplatensis	344	136	12	16		288

APPENDIX B: Faunal Distribution Data

TABLE IV.: Distribution chart of core 4 taken off Wrights Cove (station 26)

DEPTH (cm)	0-1	6-7	10-11	16-17	18-19
PERCENT ORGANIC MATTER	12.85	11.64	11.05	11.12	11.23
NO. OF SPECIES	15	11	14	11	12
NO. OF INDIVIDUALS/10cc	2872	3510	2816	6048	4806
FORAMINIFERA					
Ammodiscus catinus	2.5	1.5		1.6	0.7
Ammotium cassis					0.1
Cribrostomoides crassimargo	0.3	2.4	2.3		
C. jeffreysi		1			
Eggerella advena	5.6	0.3	0.9	1	0.9
Elphidium frigidum				0.2	
Fursenkoina fusiformis			0.6		
Glabratella wrightii	0.6				
Miliammina fusca	0.6				
Organic linings	7.8		4	7.8	8.1
Recurvoides turbinatus	0.6	0.3	1.4	0.2	0.2
Reophax arctica	0.9	15.9	15.9	20.6	23.3
R. nana	0.3				
R. scorpiurus		0.2	0.6		
R. scottii	61.4	57.3	62.2	58.3	52.6
Saccammina difflugiformis	0.3		0.6		
Spiroplectammina biformis	1.9	0.9	0.3		1
Textularia. torquata	1.8	6.8	6.8	4.4	
Tiphotrocha comprimata			0.9	1	0.2
Trochammina lobata	0.9		0.9	1.1	1.5
T. macrescens					0.2
T. ochracea	1.3	4.4	2.8	3.8	3.1
Planctonic Foraminifera		30			
TINTINNIDS					
Tintinnopsis rioplatensis	56	18	8	6	18