RECONSTRUCTION OF POLLUTION HISTORY AT MILL COVE, BEDFORD BASIN USING BENTHIC FORAMINIFERA

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ABSTRACT

The comparison of data from two cores collected in Bedford Basin, adjacent to the Mill Cove Sewage Treatment Plant, in August 1998, to data from 1968, 1993 and 1996, allows the impact of pollution to be determined. Benthic foraminiferal distributions respond to changing environmental conditions allowing these changes to be recorded in the fossil record.

Species diversity and abundance decreased dramatically from 1968 to 1993, and continued to decrease up to 1996. Degradation of the benthic community is the result of increased organic matter pollution. Remediation of the environment at this location is probable, as foraminiferal diversity increases with a decrease in organic matter. The abundance of *Eggerella advena*, a species indicative of pollution, has decreased since 1993, confirming a reduction in organic matter. Near normal conditions, determined by the presence of calcareous species, were noted at the bottom of core 1C, at 57-59cm depth. Increased pollution resulted in low oxygen conditions, determined by the abundance of organic linings in the top 12cm of sediment. Organic linings are remnants of calcareous tests, which have dissolved due to low oxygen and pH conditions in the sediments.

Lower organic matter concentrations in the 1998 samples and higher species diversity and abundance indicate that the benthic community is returning as the environmental conditions improve. These improvements follow a large outfall event in 1996 from the sewage treatment plant at Mill Cove.

Key Words: benthic foraminifera, estuarine environment, Mill Cove, organic matter, pollution impact, carbonate dissolution, recolonization.

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CHAPTER 1 INTRODUCTION

1.1 Objective and Thesis Statement

The objective of this study is to determine the history of pollution impact at a sewage outfall near Mill Cove in the Bedford Basin, Nova Scotia. Benthic foraminifera are being used as proxies to illustrate how the environment has changed since the placement of the Mill Cove Sewage outfall in 1969. Results from this study will be compared with previous work of Gregory (1971), Haury (1996) and Asioli (unpubl. data) to determine how the environment in this area has changed.

1.2 Study Area

1.2.1 Physical Environment

Halifax Harbour is a long, narrow, irregular bay on the east coast of Nova Scotia. Glaciers in the Late Quaternary, which scoured the bedrock forming Halifax Harbour, covered an ancient river valley presently occupied by the Sackville River (Fader and Buckley 1995). The harbour is divided into three main components: the Outer Harbour, the Inner Harbour and Bedford Basin (Fig. 1.1). A 500 m wide and 22 m deep, shallow bedrock sill at the Narrows separates Bedford Basin from the Halifax Harbour. Bedford Basin is a 70 m deep bowl-shaped depression, approximately 6 km long and 4 km wide (Halifax Harbour Task Force 1990). The cores for this study were taken near a sewage outfall at Mill Cove, which is in Bedford Bay, part of the upper Bedford Basin (Fig. 1.2). Bedford Bay is a shallow extension of Bedford Basin, which has an average water depth of 25 m. A 10 m deep bedrock sill separates Bedford Bay from Bedford Basin (Fader et al. 1991).

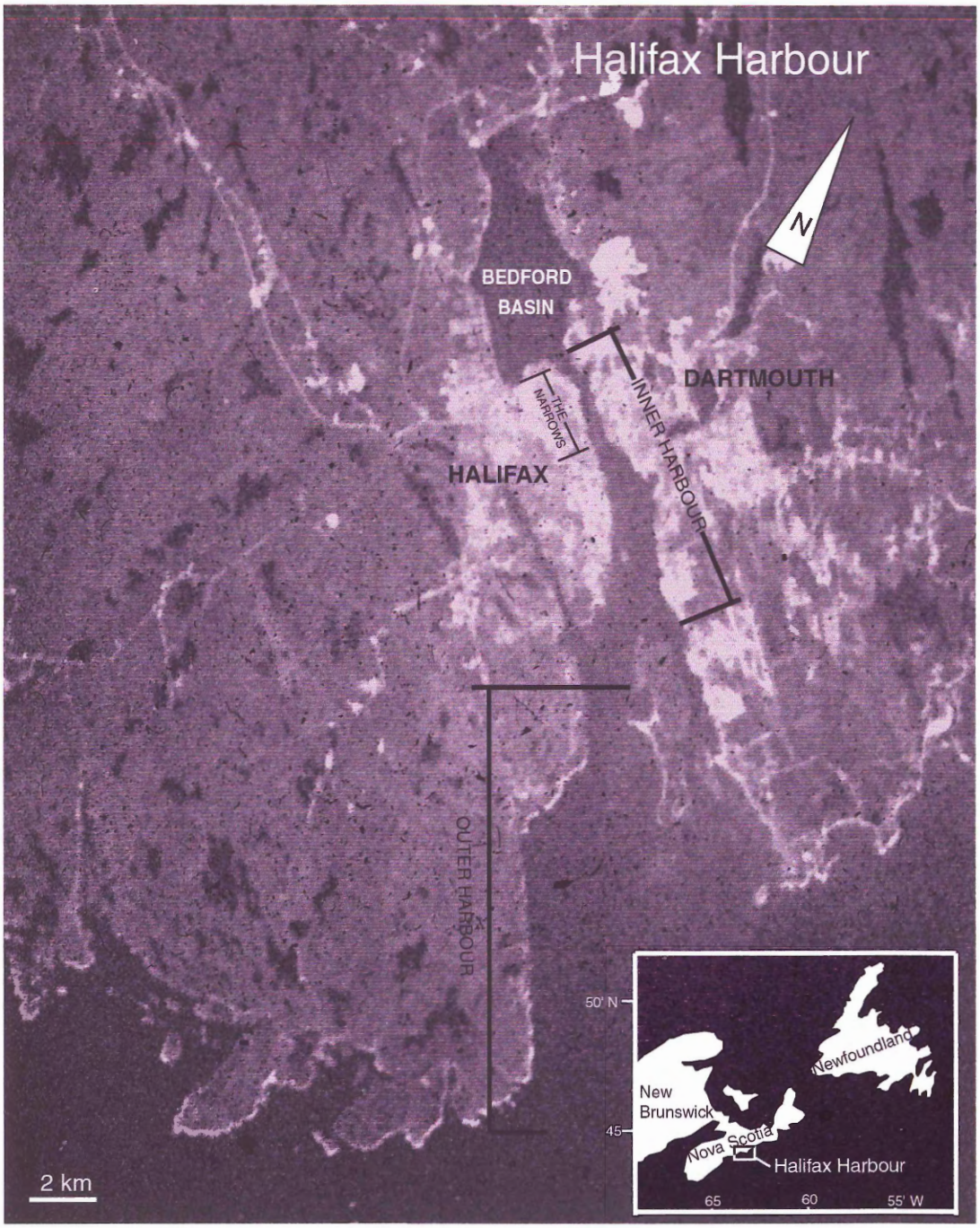


Figure 1.1 Air photograph of Halifax Harbour showing the physiographic subdivsions of the outer harbour, inner harbour and Bedford Basin.

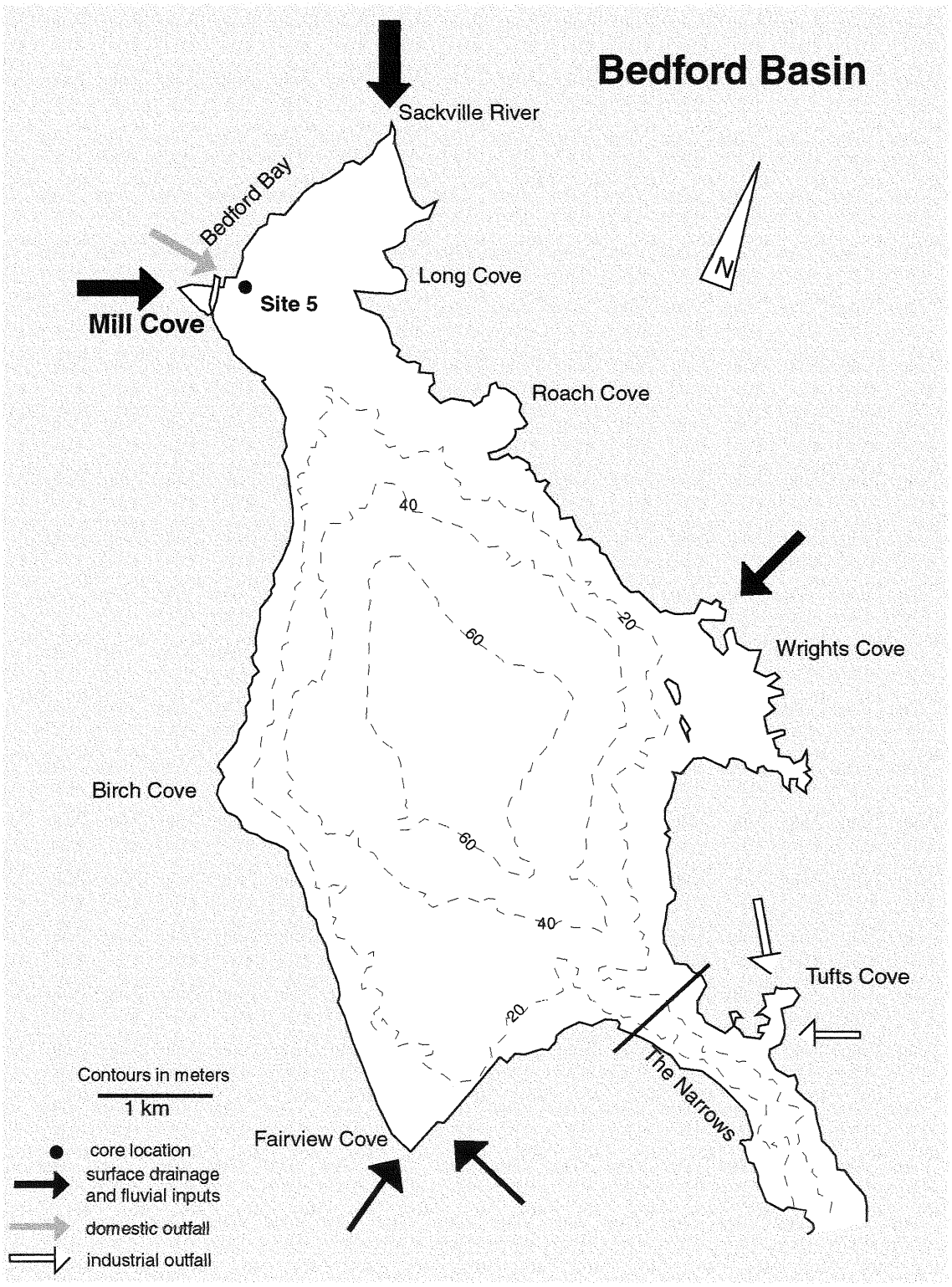


Figure 1.2 Bathymetry map of Bedford Basin showing some of the surface, domestic and industrial outfalls and the sample location at Mill Cove (Site 5) (after Scott et al. 1998).

1.2.2 Circulation

Halifax Harbour behaves as a stratified estuary, with fresh water from the Sackville River mixing with surface seawater, creating a two-layered system (Halifax Harbour Cleanup Project 1993). The lighter, fresh water flows on top of the seawater and flows out to the harbour while the heavy seawater flows along the bottom, into Bedford Basin. The Sackville River is a major source of fresh water into the harbour, having an average inflow of 5.3 m^3/s. Streams and sewers also add to the influx of freshwater, with a combined average total inflow of 11.6 m^3/s (Halifax Harbour Task Force 1990). Although the inflow and outflow remain as two separate layers, vertical mixing does occur at the interface. Due to the structure of the harbour and the layered flow system, deep-water exchange in Bedford Basin is slow and outflow from the basin is very weak (Fader and Buckley 1995). This often results in oxygen-depleted water, which may be a concern when dealing with pollution effects in the deeper parts of Bedford Basin.

1.2.3 Sediments

The distribution of sediments in the harbour is strongly dependent on circulation patterns and current strength. Bedford Basin acts as a trap for sediments because current strength is weak, allowing deposition of the sediments. The slow circulation also ensures that the sediments do not get flushed out.

Sediments in Bedford Basin vary from mud to gravel, with bedrock cropping out in a few areas. Most of the basin is covered with Holocene mud 3-5 cm thick, which may be up to 20 cm thick in the deepest parts of the basin. However, accurate measurements are difficult to obtain because the sediment is gas-charged which impedes seismic reflection (Fader et al. 1991). A dark olive-grey to black, muddy sand is found at

the head of the basin, where currents are weak. This changes to a silty mud to the south, towards the Narrows, and in the deep basin (Miller et al. 1982). Gravel is found on the margins of the basin where currents are stronger. Bedrock is exposed in various coves along the east side of Bedford Basin. Large amounts of reddish mud are released into the upper basin during flooding of the Sackville River.

1.2.4 Salinity and Temperature

Many studies have shown that, with the exception of shallow, nearshore bottom water and surface water, salinity and temperature in Halifax Harbour are relatively constant (Gregory 1971). In the deepest part of the Bedford Basin, the salinity of bottom water varies seasonally between 31.4 ‰ and 31.9 ‰. Surface temperatures vary seasonally, from 15-18°C in the summer to below freezing in the winter. Temperatures of 4°-10°C are commonly recorded for depths of 20 m or more (Gregory 1971).

1.2.5 Pollution

Halifax Harbour has been used as a waste disposal site since the establishment of Halifax in 1749. An increase in population over the last 250 years also means an increase in pollution. The main point sources of pollution reach the harbour via sewers and include domestic sewage, commercial and small industrial facilities, research institutions such as government laboratories, universities, military bases and hospitals, and large industries and refineries. Approximately 100 outfalls discharge effluents directly into the harbour. Thirty-nine of these are municipal outfalls, which discharge approximately 135 million liters of raw sewage per day, while 60 of the outfalls are commercial, industrial or institutional (Halifax Harbour Cleanup Project 1993). Non-point sources of pollution include atmospheric inputs and urban run-off. Examples of non-point sources are

contaminated sediments re-suspended in the water column by bottom disturbance, precipitation containing atmospheric pollutants and ship-related, on-land spills, which enter the harbour as run-off (Halifax Harbour Task Force 1990). The environmental degradation of the area has impacted the marine environment and will continue to do so. One purpose of this thesis is to evaluate what impact this pollution has had on part of the benthic community.

1.3 Foraminifera as Indicators

Foraminifera are good indicators of changes in the marine environment because they have short life spans, are sensitive to environmental changes and many are preserved as fossils, unlike other common marine invertebrates. Additionally, their abundance makes it possible to obtain sufficient numbers for analysis in small diameter cores, which allows long impact histories to be reconstructed in an area with little or no baseline data (Scott et al. 1998).

1.3.1 Foraminiferal Tests

The tests of foraminifera are used to identify particular species, therefore, preservation of the test in the sediment is important. Tests of foraminifera consist of various materials and it is this characteristic which forms the basis of classification schemes. Greiner (1970) described three major groups or suborders of foraminifera based on test composition and structure. Agglutinated forms cement clastic grains to an organic lining. Calcareous forms are made up of calcite crystals with a preferred orientation and numerous pores, and porcellaneous forms have a thick inner layer of randomly orientated calcite crystals and very fine pores. The composition of the test is an

important factor in determining where a species will live and be preserved as a fossil. Calcareous foraminifera secrete a $CaCO_3$ test that requires an environment that will preserve carbonates: moderately high salinity, high temperature and sufficient oxygen (Greiner 1970). Agglutinated foraminifera construct their test by cementing detrital material and do not require the presence of carbonate. These forms can survive in low salinity, low pH and low temperature environments (Greiner 1970). Porcelaneous foraminifera dominate high salinity, high temperature environments and require high availability of $CaCO_3$ (Greiner 1970).

Test deformation occurs more commonly in polluted areas than in non-polluted areas and may occur as a response to changes in salinity, nutrition levels or from various kinds of pollution (Alve 1995). Deformation may be shown in the form of compressed tests, contortion or inflation of chambers, or stunted growth.

1.3.2 Species Sensitivities

The spatial distribution of foraminiferal species in modern marine environments is related to species sensitivities. Species tolerance to changing environmental conditions depends on the limits of the natural environmental conditions (Alve 1995). Therefore, a high abundance does not necessarily imply tolerance, it may simply mean that near natural conditions exist. Opportunistic species, however, have the ability to quickly recolonize environmentally disturbed areas. These species may not be very tolerant to change, but once change has occurred they respond quickly.

1.3.3 Impact of Organic Matter

The composition and texture of organic matter varies from a solid to a dissolved form and from biodegradable to a refractory form depending on the source. Although

organic matter is not harmful itself, it may create low oxygen and thus reducing conditions that are harmful to some organisms. These anaerobic conditions can often be detected in the marine environment by an absence of benthic organisms (Schafer et al. 1995). However, organic matter may positively benefit a community by providing nutrition to an otherwise nutrient deficient area, provided decay of the organic matter does not utilize excessive oxygen. Domestic sewage and organic compounds from agriculture and aquaculture are some sources of anthropogenically derived organic matter in the marine environment.

Some foraminiferal species appear to thrive in areas with an increase of organic matter. This may be because of the ability of foraminifera to use the biodegradable organic matter as food or it may be due to a reduction in competition. Other indicator species, such as polychaetes, also utilize organic matter. Polychaetes do not leave distinctive fossil remains, but comparison with other benthic biota, such as foraminifera, allows possible relationships to be evaluated (Schafer et al. 1995).

CHAPTER 2 METHODS

2.1 Collection

Two short diver cores and two gravity cores were collected from the study site in August 1998 and were taken to Dalhousie University for storage. It is very important to maintain the water/sediment interface when collecting the samples. The use of SCUBA divers to obtain short cores has been established as an effective method for obtaining relatively undisturbed samples (e.g., Scott et al. 1995). The divers push short plastic tubing into the sediment and cap the tube once onboard the craft (Fig. 2.1). The gravity cores use weights to drive a barrel into the sediments. The barrel has a plastic inner tube, which contains the sample. The cores were stored in the freezer at Dalhousie, and remained frozen until they were opened and sampled.

2.2 Processing

The samples were frozen to preserve the placement of the material in the cores. The top layers of sediment are sloppy and might have intermixed if the cores had not been frozen. This method of storage also aided in sample preparation. The frozen cores were placed in a grip and split using a circular saw. Because the samples were frozen, the sediment remained in place during splitting, preventing mixing within the sample. Once the cores were split they were described, photographed and x-rayed. The cores were examined for changes in color, texture and material, and these changes were noted in the core log. Samples were taken at 1 cm intervals for the diver cores and at 5 cm intervals for the gravity cores, allowing 10 cm^3 of sediment to study foraminiferal distribution and 10 cm^3 of sediment for organic loss on ignition for each sample. Only

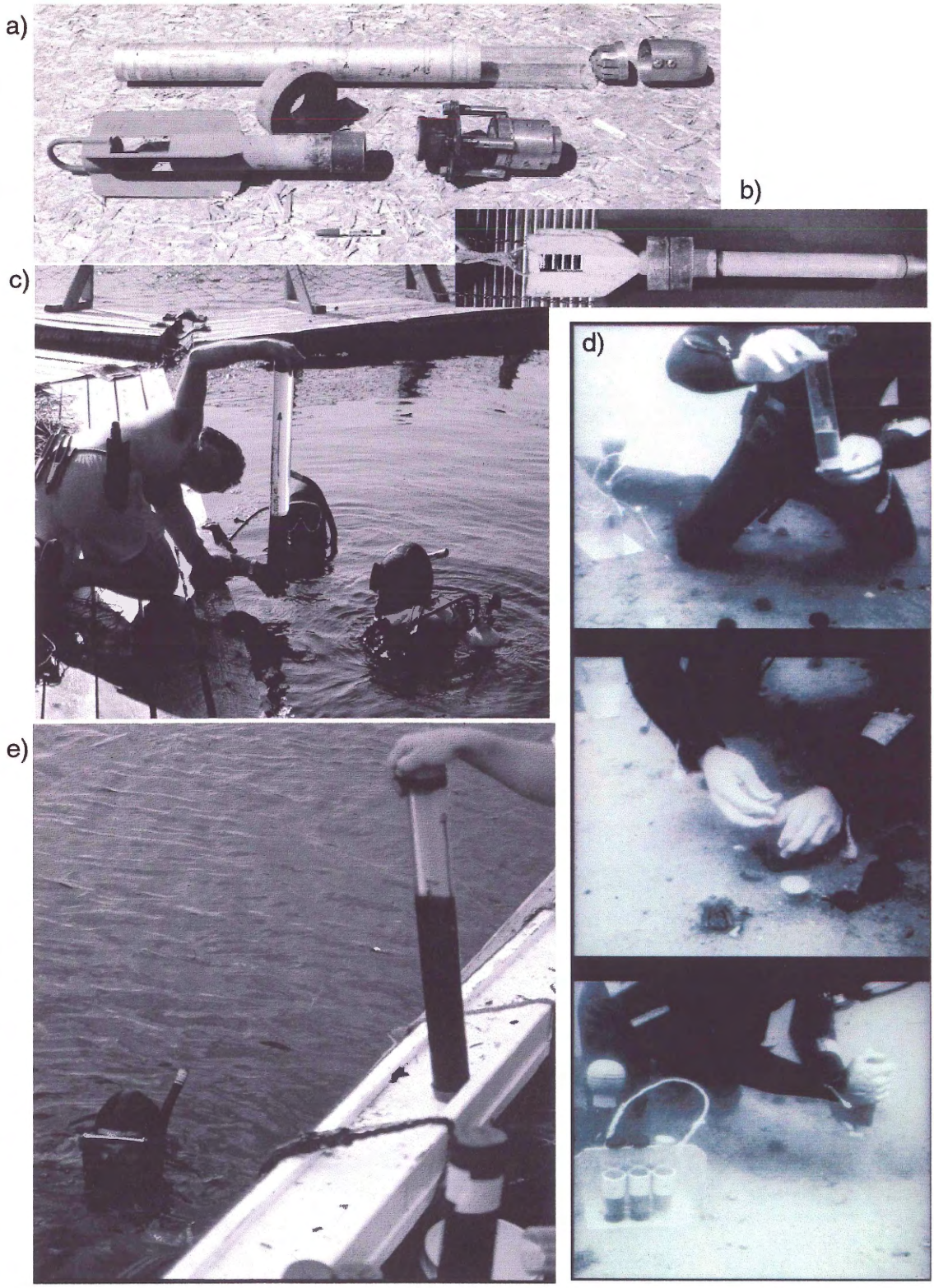


Figure 2.1 Sampling Methods used to obtain cores. a) Disassembled gravity core showing barrel, fin assembly, plastic inner tube, core cutter and extra weights. b) Assembled gravity corer. c) Divers placing hand-collected core in scientist's hand. d) Diver on the bottom collecting short core. e) Diver-collected core on deck.

one of the diver cores and one of the gravity cores were used for analysis. The remaining cores are stored in archives for future reference.

2.2.1 Photography

Photographs of the split cores as well as the core location at Mill Cove were taken with a 35 mm camera using Fuji 64T slide film. The core photographs were taken in the core laboratory, under 4-150 watt floodlights to emphasize the texture and color changes. Plate 1 consists of foraminifera, which were photographed with scanning light microphotography using 35 mm Fuji 64T slide film (Scott and Vilks 1991). These slides were then scanned, enhanced in Adobe Photoshop® and composed in Adobe Illustrator®.

2.2.2 Foraminiferal Analysis

The samples for foraminiferal analysis were washed through a 63 μm sieve to remove mud and silt while retaining foraminifera. Since the samples are highly organic a formaldehyde solution was added for preservation. Samples were then stained with Rose Bengal to differentiate between living specimens, empty tests and organic material (Walton 1952). After sitting for 24 hours the samples were rinsed and stored in alcohol until analyzed.

2.2.3 Organic Matter

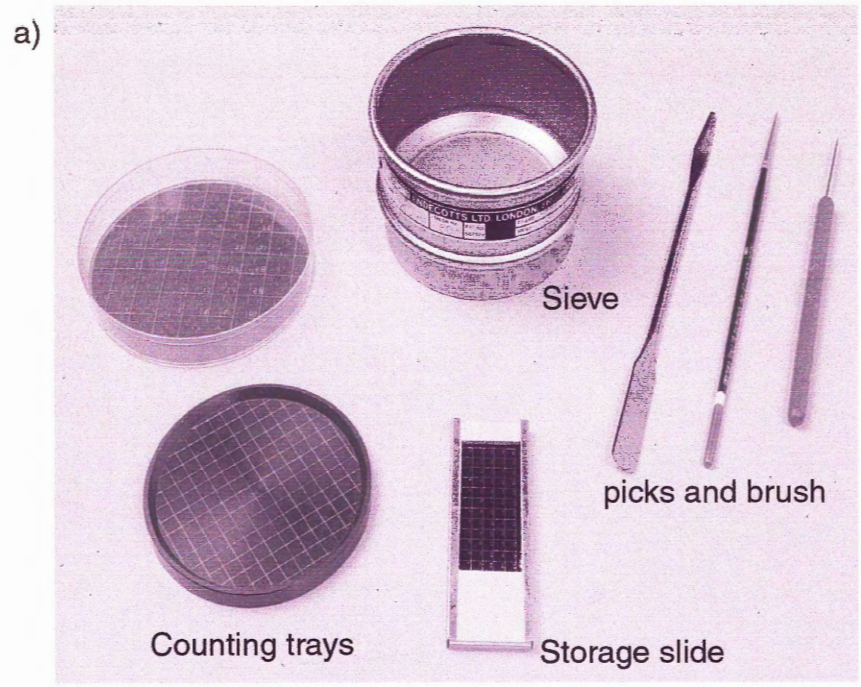
Organic matter concentrations were determined by placing 10 cm^3 samples in aluminum pans and allowing them to air dry at room temperature to remove moisture. The sample was then crushed to a fine powder and weighed in the pan. After being combusted for 2 hours, 15 minutes at 500°C the samples were re-weighed to obtain a loss on ignition value for the organic matter (Scott et al. 1995).

2.3 Examination

Sufficient accuracy for most quantitative analysis requires a count of 300 specimens (Scott et al. 1998). Before analysis, samples are separated through 250, 210, 180, 125 and 90 μm sieves to aid examination. The specimens are suspended in water and counted in a petri dish. The sample is counted row by row, alternating from left to right and the count is tallied. When dealing with samples with an overabundance of microfossils or a lot of organic detrital material it is sometimes useful to split the sample using a wet splitter before sieving (Fig. 2.2). An abundance of organic material in a sample may cause difficulty in the identification process, as the organic material may conceal the microfossils. Splitting the samples into smaller subsamples reduces the strain of processing, caused by abundant microfossils and organic matter. Using the wet splitter, samples are suspended in a water column and take about one hour to settle to the bottom (Scott and Hermelin 1993). Water is drained off through the valve and the upper column is removed. The lower column is placed into the stand permitting easy access to the subsamples. Each division can be emptied by removing the rubber stopper and by thoroughly rinsing with a water bottle. Counts can be obtained from these fractions making this method a very effective way to process samples.

2.3.1 Identification

Previous studies were useful to help identify various species. Plates 1, 3, 5 and 6 in Scott (1977) and plates 1-5 in Scott et al. (1977) were used to identify foraminiferal species. Type slides (DAL2265-F, DAL2266-F and DAL2267-F) from a temperature experiment (Schafer et al. 1996) were also used to confirm identification. Figure 9 in Scott and Medioli (1983) was used to identify thecamoebians.



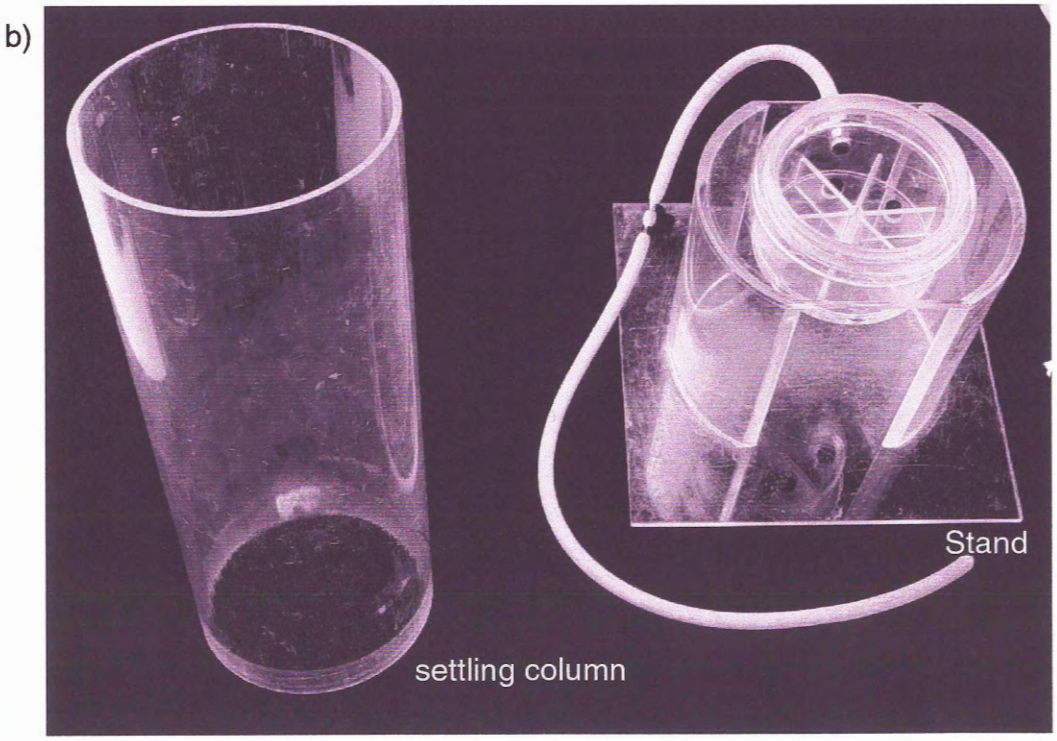


Figure 2.2 Sampling devices. a) Tools necessary for handling micropaleontological samples. b) Wet Splitter for splitting samples in liquid suspension, showing the upper settling column and the stand, with the lower column placed on it.

2.4 Data Presentation

Data tables are maintained in Microsoft Excel, where the total number of species and individuals per 10 cm^3 of sediment are calculated (Table 2, 3a and 3b). The total number of individuals includes all foraminiferal species and thecameobians identified in the samples. The total number of species indicates diversity of foraminiferal species and thecameobians. The percent abundance of foraminiferal species is determined from the total number of individuals per sample. These calculations are then graphically presented in Microsoft PowerPoint to indicate important changes with depth in the core.

CHAPTER 3 PREVIOUS WORK

3.1 Introduction

There are many foraminiferal studies of eastern Canadian estuaries (Fig. 1 in Scott et al. 1980). Some of these serve as the basis of comparison for this study (e. g., Gregory 1971; Haury 1996) while others give background information on foraminiferal distribution in estuarine zones (e. g., Schafer 1970; Scott et al. 1977, 1980). The impacts of pollution and aquaculture on benthic foraminifera have also been widely studied and Table 1 in Alve (1995) lists some of these studies.

3.2 Local Studies

Over the last 30 years studies have examined foraminiferal distribution in the Halifax Harbour and Bedford Basin. Gregory (1971) initially recorded the foraminiferal distribution in this area and this study serves as the basis for subsequent work. Haury (1996) used these baseline data to compare the foraminiferal assemblages present in 1993 and 1995, and related assemblage changes to the environmental degradation of the harbour. In addition to these studies, two diver-collected cores from Bedford Basin show foraminiferal distribution in 1996 (Asioli, unpubl. data).

3.2.1 Foraminiferal Distribution in 1968

Gregory (1971) studied living and dead foraminifera from over 140 stations in Halifax Harbour and Bedford Basin (Fig. 6 in Gregory 1971) and identified over 90 species of benthic foraminifera. In 1968, bottom samples were taken at all stations using a small snapper grab and a larger Van Veen grab while a Phleger gravity corer was used to obtain short cores from 22 stations. Approximately 40-60 cm^3 of sediment was

obtained from the surface samples and placed in a plastic vial with Rose Bengal stain to distinguish living foraminifera at the time of collection. While Gregory studied many locations, only one will be used in this comparison. Station 11, from Figure 6 in Gregory (1971) corresponds to Mill Cove, Site 5 (this study). At this location, Gregory found approximately 300 individuals/10cc (0.9% living) and he identified 11 genera, 18 species and 5 living species. No porcelaneous forms were found at this station but 73.3% of the individuals were arenaceous (3.5% living) and 26.7% were calcareous (0.5% living). Unfortunately there is no core data from Gregory's study for this location.

Gregory (1971) concluded that "the benthic foraminiferal assemblage of Halifax Harbour exhibits sub-arctic and cool-temperate affinities" and the population closely resembles the open ocean and intertidal biofacies of St. Margaret's and Mahone Bays. Although there was discharge of raw sewage from numerous outfalls into the harbour, it seems that the similarity of the Halifax Harbour fauna with the St. Margaret's and Mahone Bay fauna indicates that there were no detectable impacts on the benthic community at the time of this study.

3.2.2 Foraminiferal Distribution in 1993 and 1995

Haury (1996) determined faunal changes in Halifax Harbour and Bedford Basin in an investigation of pollution. Surface samples from over 20 stations were collected in August 1993 using a Shipek sampler. Only the top 1-2 cm was sampled, with collection of two vials with 10 cc samples for foraminiferal analysis and organic matter determination. A Benthos gravity corer was used to obtain cores in October 1995, two of which are included in Haury's study. Figure 1.2 in Haury (1996) shows the sample locations of surface samples and cores, including station 5 (Mill Cove).

Table I in Haury (1996) shows the faunal distribution data at the sample sites, in which Haury identified 227 individuals/10 cc and 11 species at Mill Cove. Organic linings (indicative of dissolved calcareous forms) and *Eggerella advena* were dominant at this location with 50.7 % and 24.2 % abundance, respectively. The remainder of the foraminiferal assemblage included *Trochammina ochracea*, *Ammotium cassis*, *Trochammina lobata*, *Miliammina fusca*, *Haynesina orbiculare*, *Reophax scottii* and *Spiroplectammina biformis*. The thecamoebian *Centropyxis aculeata* was present with 10.5 % abundance, and 73 individuals of the tintinnid, *Tintinnopsis rioplatensis*, were noted. The sample has a high organic matter (14.85 %) content. Haury concluded that Mill Cove had a low abundance and low diversity compared to other stations in the basin, and compared to 1970 there is a decrease in diversity throughout the study area, which can be "related primarily to organic matter pollution".

3.2.3 Foraminiferal Distribution in 1996

Asioli (unpubl. data) looked at two cores from Bedford Basin, one from the domestic sewage outfall at Mill Cove and one from an industrial outfall at Tufts Cove. Figure 3.1 shows the foraminiferal distribution at Mill Cove in 1996. The lack of a published report for this study requires that the data be presented here to enable comparison with current data. From 0-12 cm depth in this core there is a barren zone in which few foraminifera are found. The total organic content doubles above 12cm depth and increases to the top of the core. From 12-15 cm depth the number of individuals and number of species/10 cc increases. Organic linings are dominant while *A. cassis*, *R. scottii* and tintinnids increase in abundance. *Eggerella advena* decreases in abundance

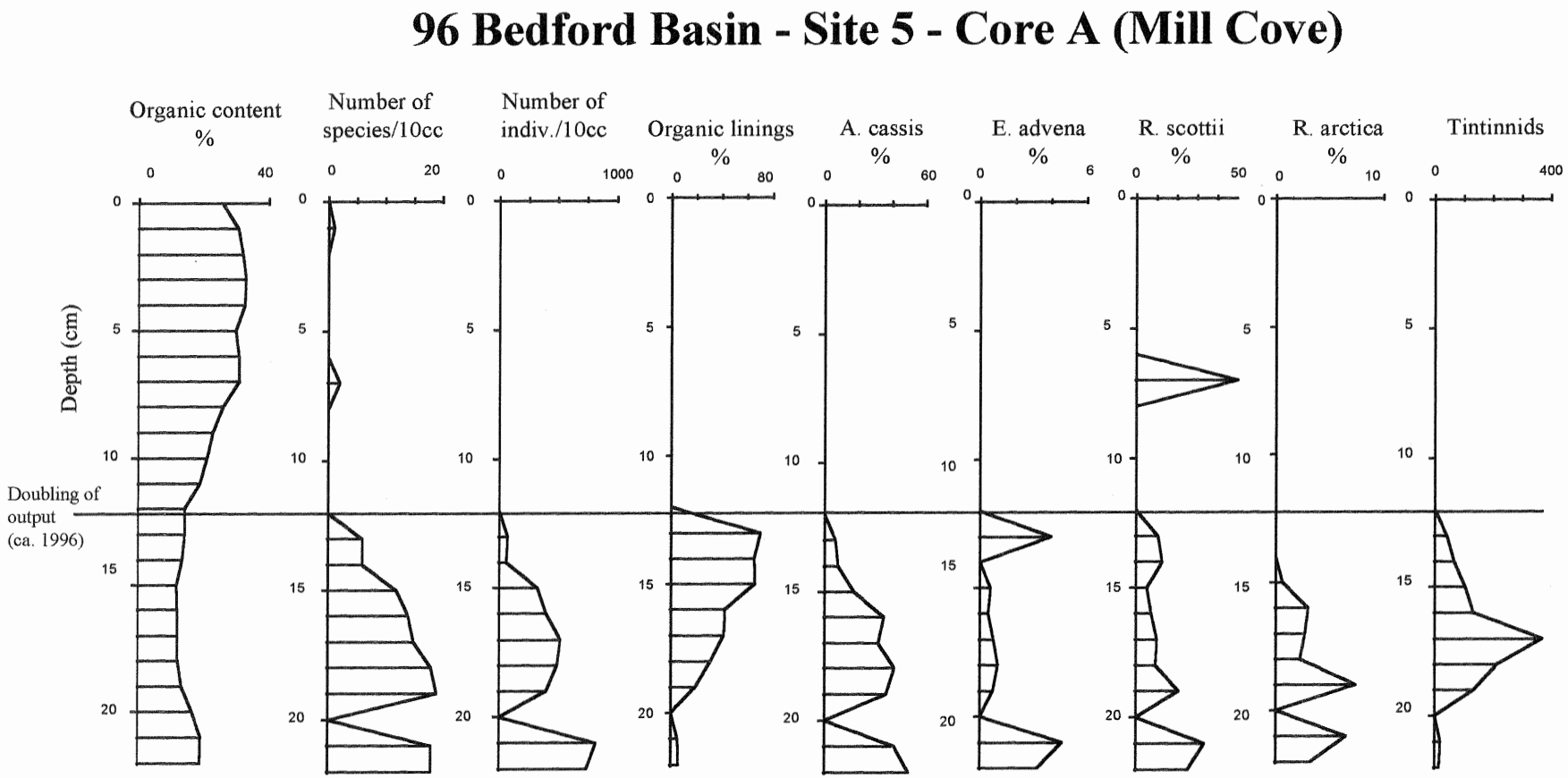


Figure 3.1 Distribution of foraminifera in a core near a domestic sewage outfall in Bedford Basin, Nova Scotia. Note that at the 12-14 cm mark the sewage output doubled resulting in an increased sedimentation rate causing dilution of foraminiferal abundances. The onset of pollution is signaled by tintinnids and *Ammotium cassis* (at 20 cm depth) which indicate high suspended particulate matter (SPM) (after Asioli, unpubl. data in Scott et al. 1998).

and *R. arctica* appears in small amounts at 15 cm depth. The organic content also decreases in this interval.

From 15-20 cm depth the number of species and individuals increases. *Ammotium cassis* and organic linings are dominant, but organic linings decrease in abundance down the core. *Eggerella advena, R. scottii* and *R. arctica* are uncommon and the number of tintinnids increases, peaking at 17 cm depth and then decreases. The organic content slowly increases up to 20 cm depth. Another barren zone occurs at 20 cm depth where no foraminifera are noted. From 20-22 cm the number of species and individuals increases significantly. *Ammotium cassis* and *R. scottii* are dominant while *E. advena* and *R. arctica* also have high percent abundance. The number of tintinnids and percent organic linings is low in this interval. Organic matter slightly increases in abundance at the bottom of the core.

The increase in organic matter above 12 cm depth is inferred to correlate with the doubling of sewage output from the outfall in 1996 (Scott pers. comm). This increase in organic matter resulted in an increased sedimentation rate, which was inferred to cause dilution of foraminiferal abundance. Species diversity is high near the bottom of the core and may indicate a pre-impact environment.

3.3 Estuarine Studies

Foraminiferal distribution patterns and responses to marine pollution have been studied in many estuarine environments. Scott et al. (1980) developed an estuarine classification based on foraminiferal distributions of three type estuaries: Miramichi River, New Brunswick; Restigouche Estuary, New Brunswick; and Chezzetcook Inlet,

Nova Scotia. Some estuarine studies also look at the impacts of pollution on the benthic community (e. g., Schafer 1970, 1973; Schafer and Cole 1974) as well as the impact of aquaculture effluent (Clark 1971; Schafer et al. 1995; Scott et al. 1995).

Scott et al. (1980) compared the previous studies in Restigouche estuary (e. g., Schafer 1970, 1971, Schafer and Cole 1978), Miramichi estuary (Scott et al. 1977) and Chezzetcook Inlet (Scott et al. 1980) to devise two classification schemes based on foraminiferal distributions in these estuaries. The first scheme, based on depth, has four divisions: intertidal, intermediate (between intertidal and shallow subtidal), shallow subtidal (<5 m water depth) and deep subtidal (> 5 m water depth). Table 5 in Scott et al. (1980) lists these divisions along with the distinguishing foraminiferal species for each. The second scheme, based on circulation, discusses four zones in relation to foraminiferal distribution. The upper estuarine zone occurs where a river comes into contact with the marine environment. It is characterized by low (<20 ‰) but variable salinities and high organic content. The transition zone is a mixing zone between the marine and river influences and is controlled by the strength of the river and tidal currents. The marginal marine zone is the most seaward and is characterized by near normal salinities and decreasing organic content. The near shore zone is a highly turbulent zone with near normal salinities.

The foraminiferal species found in the transition assemblage zone are dependent on depth (Table 1). Intertidal estuaries are characterized by the absence of *A. cassis*, due to the high temperature and salinity. The presence of *Ammonia beccarii* and *Elphidium williamsoni* are also typical in these conditions, and are indicative of intertidal or intermediate estuaries. Large abundances of *Haynesina orbiculare* and

Depth Type	Upper estuary	Transitional	Marginal marine
		ASSEMBLAGE ZONE	
Intertidal (from Chezzetcook)	*M. fusca* *A. salsum* *A. dilatatus* Thecamoebians	*M. fusca* *E. williamsoni* *H. orbiculare* *A. salsum* *H. bradyi* *A. becarrii*	*E. advena* *M. fusca* *H. orbiculare* *E. williamsoni* *E. excavatum* *A. becarrii*
Intermediate (from Prince Edward Island)	*M. fusca* Thecamoebians		*Elphidium* spp. *E. advena* *H. orbiculare* *A. becarrii* *A. cassis*
Shallow subtidal (from Miramichi)	*M. fusca* Thecamoebians *A. salsum*	*A. cassis* *E. advena* *H. bradyi* *M. fusca*	*E. excavatum* *H. orbiculare* *E. advena* *B. frigida*
Deep subtidal (from Restigouche and Halifax Harbour)	*M. fusca* Thecamoebians	*E. advena* *A. cassis* *R. arctica* *R. fusiformis* plus an array of others	*E. excavatum* *E. advena* *B. frigida* plus many more oceanic forms

Table 1 Species composition of estuarine zones for each depth type. Species listed (top to bottom) in rank order (combination of commonality and mean %) (after Scott et al. 1980).

Hemisphaerammina bradyi indicate intertidal or shallow subtidal conditions. *Ammotium cassis* is the transition zone indicator of high suspended particulate matter (SPM) concentrations in shallow and deep subtidal estuaries. Deep subtidal estuaries have high percentages of agglutinated forms such as *Reophax arctica* and *Cribrostomoides crassimargo*.

3.3.1 Impacts of Contamination

Foraminiferal distribution patterns are affected by changing environmental conditions, which are often a result of anthropogenic pollution. Studies have determined the effects of pollution on the benthic community (e. g., Schafer et al. 1991; Schafer and Cole 1974; Collins et al. 1995; Stott et al. 1996) and the sensitivity of foraminiferal species to pollution effluents (e. g., Schafer 1973). It has been found that an increase in

organic waste from sewage outfalls decreases foraminiferal diversity in the area. This relationship has been identified in Chaleur Bay, New Brunswick where pulp mill effluent is discharged into the bay (Schafer 1973). Foraminiferal distributions in the vicinity of the outfall give an indication of species sensitivities. For example, near the mouth of the outfall *E. advena* and *M. fusca* are dominant, implying these are pollution-tolerant forms while other species such as *A. cassis, R. arctica* and *R. scottii* occur in small abundance and appear to be pollution-sensitive (Schafer 1973). Spatial variation with distance from an outfall has also been studied and can be mapped using individual indicators such as *E. advena*, which usually decreases in abundance with distance from an outfall (Schafer and Cole 1974).

As a decrease in foraminiferal diversity near an outfall may imply negative pollution impacts, we may also determine positive effects using foraminiferal distributions. Recolonization of the benthic community in Saguenay Fiord, Quebec (Schafer et al. 1991) and Whites Point, California (Stott et al. 1996) can be related to improved waste disposal plans, and improved environmental conditions can be noted by an increase in foraminiferal diversity. Remediation of the benthic community is also being studied in New Bedford Harbour, Massachusetts (Scott et al. 1997) where the upper and lower estuarine faunas are being compared to the Apponagansett Bay fauna. A similarity between the two sites indicates that remediation has occurred within the last few years.

Studies have also been carried out on the impact of aquaculture operations on the benthic community. Fecal matter and unconsumed fish food are the major sources of organic matter, and the amount of organic matter is related to the production level of an

operation. Environmental stress on the benthic community increases as the production level increases, and foraminiferal abundance decreases (Clark 1971). Organic matter loading is generally high directly under these areas and can often lead to anaerobic conditions, resulting in barren zones in the foraminiferal distribution.

3.4 Pollution in Halifax Harbour

Since the establishment of Halifax in 1749, the harbour has been a major waste disposal site. Numerous outfalls empty into Halifax Harbour and Bedford Basin, discharging raw sewage, industrial and domestic wastes and surface drainage. The Mill Cove Sewage Treatment Plant has been in place since 1969 and provides secondary treatment to raw sewage. Prior to the placement of this treatment plant raw sewage entered the basin directly from a surface drainage outfall in Mill Cove and from surrounding outfalls.

Organic carbon concentrations are highest near major sewage outfalls and have high levels in Bedford Basin (6-7.3 %) (Buckley and Winters 1992). The concentrations of Cu, Zn, Pb and Hg in the surface sediments of Halifax Harbour have increased from 1890 to 1970. The levels of contaminants in Halifax Harbour are among the highest recorded levels in coastal estuarine systems in the world (Table 3 in Gearing et al. 1991).

CHAPTER 4 RESULTS

4.1 Core 1A, Site 5

Core 1A is a diver-collected core, which is 36 cm long and was collected in 15.2 m water depth. Samples were taken at 1 cm intervals for foraminiferal analysis and organic matter (OM) percentages. The lithology is predominantly a dark brown to black, organic rich mud which grades into black mud near the top of the core. Worm tubes are noted from 10 to 31 cm depth and small indeterminate shell fragments are noted at 33 cm depth.

4.1.1 Foraminiferal Analysis

Faunal distribution data have been calculated for core 1A and are shown in Table 2 (Appendix A). Figure 4.1 shows selected species distributions throughout the core, and includes the dominant species at the top of the core. The total number of individuals and number of species is low from 0-4 cm depth. The percent abundance of *Ammotium cassis* and *Saccammina difflugiformis* is low in this interval while the percent abundance of *Eggerella advena* and *Reophax scottii* are low at the top of the core but reach their peak abundance at 4 cm. Organic linings are abundant from 0-4 cm depth but show a decrease in abundance where *E. advena* and *R. scottii* increase. A clear pelagic hydrozoan that reflects water column conditions is very abundant in the surface layer of sediment, but are not recorded below 4 cm depth. *Tintinnopsis rioplatensis,* agglutinated tintinnids, are present in small numbers at 3-4 cm depth.

The total number of individuals slowly increases from 4 to 12 cm depth, as does the number of species and percent abundance of *A. cassis*. *Saccammina difflugiformis* is uncommon and *R. scottii* remains relatively constant at about 18 % abundance. Organic

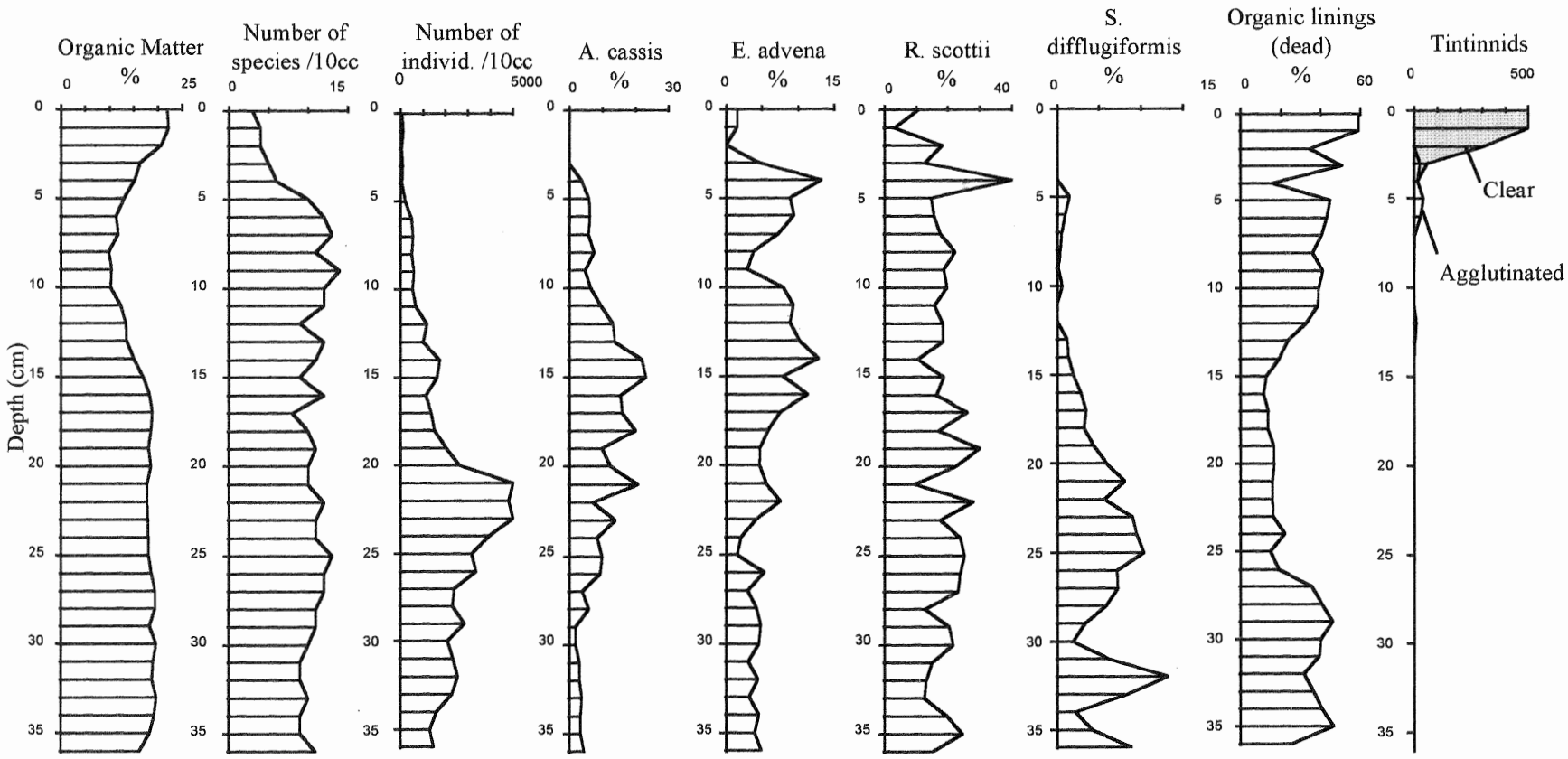


Figure 4.1 Percent organic matter, number of species, number of individuals and percent abundance of some common foraminiferal species selected from Table 2.

linings decrease in abundance in this interval. The percent abundance of *E. advena* decreases from 4-9 cm depth and then increases again. *Tintinnopsis rioplatensis* are present in small numbers, from 42 to 1 individual, and they are not recorded below 12 cm depth.

From 12-22 cm depth the number of individuals continues to increase and peaks with 6864 individuals at 21 cm depth. An average of 10 species occurs in this interval and percent abundance of *A. cassis*, *E. advena* and *R. scottii* varies. The percent abundance of *S. difflugiformis* increases progressively with depth while the percent abundance of organic linings decreases.

The number of individuals decreases from 22-27 cm while the number of species remains constant. The percent abundance of *A. cassis* and *E. advena* slowly decreases and the percent abundance of *R. scottii* remains fairly constant. *Saccammina difflugiformis* shows a slight increase, up to 25 cm depth, and then decreases, while organic linings increase in percent abundance.

From 27 cm depth to the bottom of the core, at 36 cm depth, the total number of individuals decreases slightly and the number of species remains fairly constant. The percent abundance of *A. cassis* and *E. advena* is low. *Reophax scottii* decreases in abundance from 27-33 cm depth and then increases to the bottom of the core. The percent abundance of *S. difflugiformis* varies in this interval, peaking at 32 cm depth. The percent abundance of organic linings is high in the bottom section, indicating a high percentage of calcareous species (probably *Elphidium excavatum*, where the test has dissolved).

4.1.2 Organic Matter

The percent organic matter is high at the top of the core (about 22 %) and decreases from 2-4 cm depth. From 4-8 cm depth the percent organic matter decreases to about 10 % and then increases from 8-12 cm depth. The percent organic matter continues to increase from 12-16 cm depth and then remains constant at an average of 18 % through to the bottom of the core.

4.1.3 Other Data

Other foraminiferal species, including *Reophax arctica, Reophax scorpiurus, Spiroplectammina biformis, Glomospira gordialis and Trochammina* spp. occur with varying abundances throughout the core. *Cribrostomoides crassimargo* increases intermittently from 0-21 cm depth and then decreases to the bottom of the core, at 36 cm depth. *Miliammina fusca* and *Reophax nodulosa* are uncommon. Two calcareous forms, *Elphidium barletti* and *Haynesina orbiculare* were noted in small abundance (0.1 and 2.0 %, respectively) at the bottom of the core. The thecamoebians *Centropyxis aculeata, Difflugia oblonga* and *Pontigulasia compressa* were present, but uncommon.

While Rose Bengal staining is traditionally used to distinguish living specimens from empty tests, in this study it was used to stain organic material. No living specimens were examined due to freezing of the cores. Some *E. advena* and *S. biformis* specimens were deformed but percentages were not calculated.

4.2 Core 1C, Site 5

Core 1C is a 61 cm long gravity core, taken in 15 m water depth. Samples were taken at 1 cm intervals up to 20 cm depth, after which every 5 cm was sampled. The

sediment is layered, with black, organic rich mud from 0 to 3 cm depth. From 3 to 9.5 cm depth this black mud is intermixed with lighter, less organically rich mud which is present to the bottom of the core. Indeterminate shell fragments were noted in the lower half of the core, from 32 to 60 cm depth and worm burrows were noted from 6.5 cm to 21 cm depth. The sediments in Core 1C may have been compacted due to the method of collection and this should be considered when comparing to other data.

4.2.1 Foraminiferal Analysis

Table 3a and 3b contain faunal distribution data (Appendix A) and Figure 4.2 shows some of the common species (in percent abundance) along with percent organic matter, the number of species and number of individuals per 10 cm^3 of sediment. In the 0-4 cm depth interval, the number of individuals is low, but increases slowly with depth. The number of species decreases from 0 to 3 cm depth and then increases. The percent abundance of *R. scottii* is high, increasing from 0 to 3 cm depth and then decreasing. *Ammotium cassis, S. difflugiformis* and organic linings decrease in abundance from 0 to 4 cm depth while *E. advena* decreases in percent abundance from 0 to 1 cm depth and then increases from 1 to 4 cm depth. The clear unidentified tintinnids are present in small numbers in the top layers of sediment. *Tintinnopsis rioplatensis* occurs in the top layers and peak at 2 cm depth with 247 individuals.

The number of individuals continues to increase from 4 to 8 cm depth while the number of species remains constant at 12 species/10 cm^3. The percent abundance of *A. cassis* increases from 4 to 8 cm depth and *E. advena* decreases in abundance. *Reophax scottii* and *S. difflugiformis* increase in abundance from 4 to 5 cm depth and then decrease

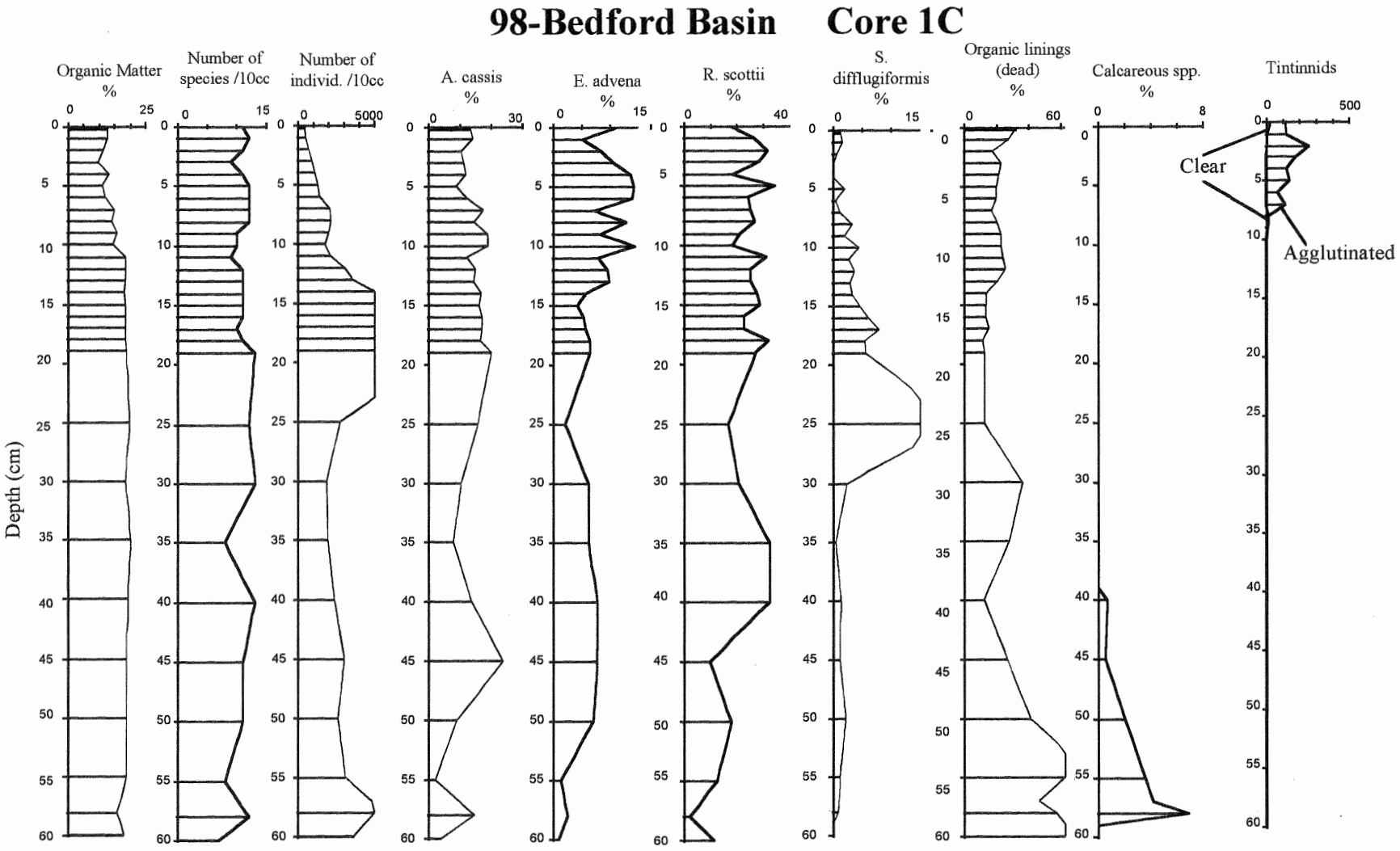


Figure 4.2 Percent organic matter, number of species, number of individuals and percent abundance of some common foraminiferal species from Table 3a and 3b.

from 5-8 cm depth. Organic linings decrease slightly from 21.8 to 16.2 % abundance. *Tintinnopsis rioplatensis* decrease from 4-8 cm depth and they are not recorded below 8 cm depth. *Eggerella advena* and *R. scottii* are the dominant species in this interval.

From 8-20 cm depth the number of individuals increases, reaching the maximum of 9760 individuals/10 cm^3 at 20 cm depth. The number of species declines slightly in this interval, with an average of 11 species/10 cm^3. *Saccammina difflugiformis* slightly increases in abundance while *E. advena* decreases. The percent abundance of *A. cassis* and *R. scottii* fluctuate in this interval and they are the dominant species. Organic linings decrease in percent abundance and *Tintinnopsis rioplatensis* occurs in small numbers from 8-10 cm depth, but is not recorded below this depth.

The number of individuals decreases in the 20-30 cm interval, while the number of species remains steady at an average of 13 species/10 cm^3. *Eggerella advena* and *R. scottii* decrease in abundance from 20-25 cm depth and then increase from 25-30 cm depth. *Saccammina difflugiformis* markedly increases in abundance from 20-25 cm depth and then decreases from 25-30 cm depth. The percent abundance of *A. cassis* decreases in this interval while organic linings increase in abundance. *Reophax scottii* and *S. difflugiformis* are the dominant species from 20-30 cm depth.

From 30-45 cm depth, the number of individuals remains constant while the number of species fluctuates. The percent abundance of *E. advena* remains constant in this interval while *A. cassis* increases in abundance. *Reophax scottii*, the dominant species in this interval, increases in abundance from 30-40 cm depth and then decreases in abundance from 40-45 cm depth. *Saccammina difflugiformis* has a low percent

abundance in this interval while organic linings decrease in abundance from 30-40 cm depth and then increase in abundance from 40-45 cm depth.

From 45-55 cm depth, the number of individuals remains fairly constant and the number of species decreases slightly. *Ammotium cassis* and *E. advena* decrease in abundance in this interval while organic linings increase in abundance. *Reophax scottii* and *S. difflugiformis* increase in abundance from 45-50 cm depth and then decrease in abundance from 50-55 cm depth. Organic linings are dominant in this interval.

At the bottom of the core, from 55-61 cm depth, the number of individuals and number of species increase slightly at 59 cm depth before decreasing. *Ammotium cassis* and *E. advena* increase in percent abundance from 55-59 cm depth and then decrease in abundance from 59-61 cm depth. The percent abundance of *R. scottii* and organic linings decreases from 55-59 cm depth and then increases from 59-61 cm depth. *Saccammina difflugiformis* decreases in percent abundance from 55-61 cm depth.

4.2.2 Organic Matter

The percent organic matter slightlydecreases from 0-4 cm depth and then increases from 4-8 cm depth. The percent organic matter continues to increase from 8-12 cm depth after which it remains steady, at an average of 18 %, through to the bottom of the core.

4.2.3 Other Data

Spiroplectammina biformis, R. arctica, R. scorpiurus, G. gordialis, M. fusca and *Trochammina* spp. are less abundant and vary throughout the core. *Cribrostomoides crassimargo* increases in abundance from 0-18 cm depth and then decreases to the bottom of the core, at 61 cm depth. The calcareous forms *E. barletti, E. excavatum,*

E. williamsoni and *H. orbiculare* occur in small abundances (<8 %) from 40-61 cm depth. No thecamoebians were noted in this core and, as with core 1A, no living specimens were examined. Deformed specimens included stunted *E. advena,* contorted *S. biformis* and *R. scottii* and *C. crassimargo* with inflated chambers.

CHAPTER 5 DISCUSSION

5.1 Introduction

To reconstruct the pollution history in Bedford Basin, a comparison must be made with other studies. As stated in Chapter 3, there are numerous studies of benthic foraminifera and their response to pollution and environmental change. While most of the studies serve as background information (e. g., Schafer 1970; Collins et al. 1995; Scott et al. 1980), major comparisons will be made with Gregory (1971), Haury (1996) and 1996 data from Asioli (unpubl. data).

The importance of pre-impact data in this study is immense, however such data are not available. The data obtained by Gregory in 1968 serve as a baseline for comparison. Gregory found the foraminiferal assemblages of Halifax Harbour to correspond to the assemblages found in St. Margaret's and Mahone Bays. This relationship indicates that there were no serious impacts on the benthic community as a result of pollution. However, Gregory did note some deterioration of the environment in Bedford Basin, most likely a result of continuous dispersal of raw sewage in the area. The Mill Cove Sewage Treatment Plant began operations in 1969. Before this time, raw sewage was pumped directly into the harbour through various outfalls. Since the emplacement of the sewage treatment plant occurred one year after Gregory's data was collected, it would be expected that the environmental conditions in 1968 would be worse than after placement of the treatment plant. However, as Haury (1996) determined, this is not the case. Even though the sewage is now treated, environmental degradation has taken place, and therefore we can assume that the environmental conditions in 1968 were somewhat natural.

5.2 Pollution

While most of the domestic sewage in the Bedford area is now routed to the treatment plant, there are times when raw sewage may overpass the treatment plant and go directly to the harbour. Although the amount of pollution from large industries has decreased, the overall waste discharge has increased as a result of an increasing population. This increase in urban development has led to an increase in sediment flux and effluent discharge, thus affecting the benthic community.

5.3 Comparison

According to the classification schemes set out in Scott et al. (1980), Bedford Basin is a transitional, deep subtidal estuarine environment which is defined by a series of deep water, agglutinated foraminiferal assemblages. Characteristic species of this zone include *E. advena, A. cassis* and *R. arctica.* As is observed in cores 1A and 1C, these species along with other agglutinated forms are present.

Figure 5.1 compares data from 1968 to the present. This illustration uses the surface sample data from Gregory (1971) and Haury (1996), and the top 1-2 cm of sediment in the Asioli cores and core 1A and 1C in this study. From this we can see that the percent organic matter increased from 1993 to 1996 and then decreased to the time of sampling for this study. Although there is no organic matter data for 1968, we can assume that the percent organic matter was low at this time because species diversity is high (Schafer 1973). The number of species decreases from 1968 to 1996, but then increases in 1998. An inverse relationship can, therefore, be inferred to exist between the amount of organic matter and species diversity.

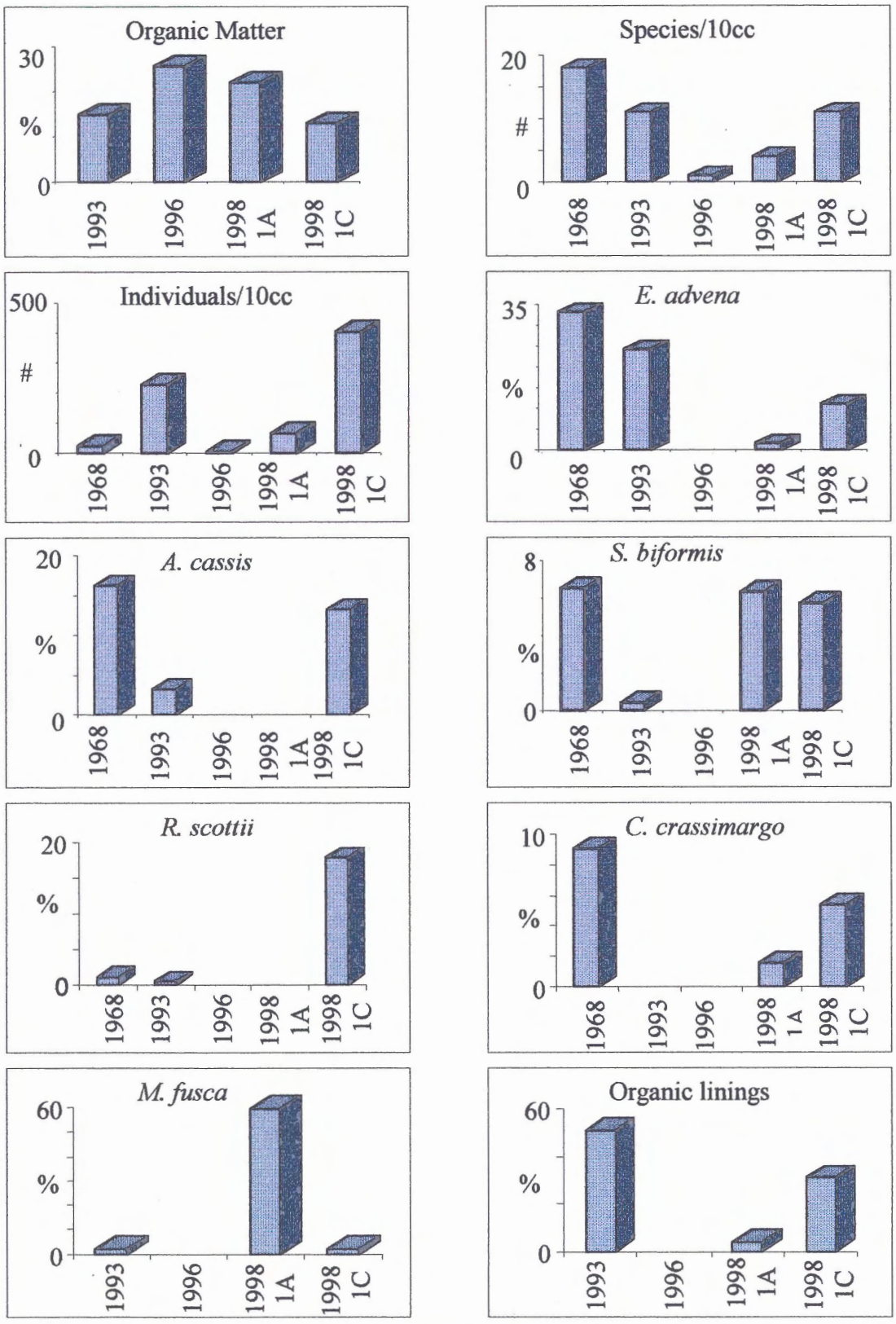


Figure 5.1 Comparison of data from 1968 to 1998 showing percent organic matter, number of species and individuals/10 cc and percent abundance of common foraminiferal species.

The abundance of *E. advena* is included because it is found to be tolerant to pollution. Aquaculture studies in Clam Bay, Nova Scotia (Clark 1971) and pollution studies in Restigouche estuary, New Brunswick (Schafer 1970) have determined that *E. advena* is a high nutrient demanding species and is commonly found in high abundance near sewage outfalls and aquaculture sites. While the abundance of *E. advena* decreases with an increase in organic matter it is still found to be a dominant species near the outfall in Mill Cove. A high abundance of *E. advena* can, therefore, imply that this is an opportunistic species, which utilizes the increased food availability resulting from an increase in organic matter concentrations.

Ammotium cassis is also a dominant species near the Mill Cove outfall. High abundances of this species have been associated with proximity to sewage outfalls (Gregory 1971) and are related to high concentrations of suspended particulate matter (SPM) (Scott et al. 1977). Although abundance of *A. cassis* has decreased with increased organic matter it shows a high abundance with respect to other species. A low percentage of *A. cassis* is found near the bottom of core 1A, possibly indicating low concentrations of SPM and, therefore, pre-impact conditions.

Gregory (1971) noted an abundance (26.7 %) of calcareous species at Mill Cove. In 1993 the abundance of calcareous species decreased to 0.4 % while abundance of organic linings was high (50.7 %). There were no occurrences of calcareous species in the surface samples of core 1A and 1C, however organic linings were abundant. This high percentage of organic linings indicates an increase in carbonate dissolution. An increase in organic matter is most likely responsible for increases in carbonate dissolution.

High numbers of *Tintinnopsis rioplatensis* were noted in 1993 by Haury as well as near an aquaculture site in Bliss Harbour, New Brunswick (Scott et al. 1995). They are found to occur in proximity to high organic matter outputs, such as sewage outfalls and aquaculture operations. Tintinnids occurred in high numbers in the top 7 cm of core 1A and 1C and appear to be indicative of high concentrations of suspended particulate matter (SPM) in the water column.

Environmental stress on the benthic community is often noted by test deformation. Deformed specimens of *S. biformis* and *R. scottii*, stunted *E. advena* and *C. crassimargo* with an irregular chamber size were noted in core 1A and 1C. The emphasis of this study, however, was placed on diversity and abundance. The presence of these deformed specimens, which indicate a stressed environment such as low oxygen conditions or increased pollution, are noted in the results (Chapt. 4), but are not drawn upon in any of the conclusions.

Increased fluxes of organic material can lead to anaerobic conditions if the oxygen consumption used in the decay of the organic material is high. This is reflected in the benthic community by barren zones, where foraminiferal abundances are drastically reduced (Schafer et al. 1995). Using 1993 samples, Haury (1996) noted barren zones near the mouth of the Sackville River and areas adjacent to sewage outfalls. The 1996 Asioli data shows a barren zone at Mill Cove, where the doubling of organic matter in the top 12 cm correlates with a drastically reduced foraminiferal abundance. This 12-15 cm mark in the Asioli data probably represents an increase in sewage output which is believed to have occurred in 1996 (Scott pers. comm.). This barren zone was not seen in the data for this study, implying that spatial variation may exist. Pollution

impact should decrease away from the source while the circulation patterns may produce a gradient around the outfall. Unfortunately, precise sample locations are unknown, but we do know, qualitatively, that the Asioli cores were collected right on the outfall and the cores for this study were collected at least 100 m away from that site.

Although precise correlation can not be made, relative time intervals can be obtained. Core 1A showed calcareous species at the bottom, but abundance was extremely low (2 %). This low abundance in core 1A and the absence of calcareous species in the 1996 cores indicates that these cores did not deeply penetrate the sediments. The presence of calcareous species at the bottom of core 1C, from 40 cm to 59 cm depths, shows that this core penetrated farther, indicating somewhat stable environmental conditions at this depth. Such conditions were only noted in surface samples by Gregory, therefore the bottom of core 1C can be inferred to occur prior to 1968, the time of Gregory's data collection.

The abundance of *E. advena* and organic linings at 12 cm depth in core 1A and 1C, along with the low abundance and decrease in species diversity can be related to a time of increased pollution. Haury (1996) noted a similar decrease in species diversity and abundance and a dominance of *E. advena* and organic linings. This interval is therefore believed to correspond to 1993, or earlier.

A decrease in species diversity and in the number of specimens present along with an increase in organic matter in core 1A and core 1C at 5 cm depth resembles the decrease in foraminiferal abundances noted by Asioli, and is therefore associated with the barren zone seen by Asioli. Since this barren zone was not noted in Mill Cove by Haury the onset of this increased pollution did not occur before 1993. The Asioli core indicates

an increase of organic matter as a result of a doubling of sewage output in 1996, therefore this 5 cm interval is allotted to the same time interval.

5.4 Implications

The overall findings of this study show that organic matter concentrations are lower and species diversity and number of individuals are higher in the 1998 samples than in 1993 and 1996. Other studies which show similar trends (e. g., Schafer et al. 1991; Scott et al. 1997; Stott et al. 1996) have indicated that recolonization has taken place. In California, at the Los Angeles County Whites Point sewage outfall, Stott et al. (1996) noticed a significant difference in foraminiferal populations compared to the Bandy et al. (1964) study 30 years earlier. In 1964 a barren, or "dead" zone occurred adjacent to the outfall, but in 1996 Stott found that benthic foraminifera have recovered in this area. Improvement of sewage treatment and a reduction in discharge have resulted in improved environmental conditions which is indicated by the benthic community.

A 30-year span also exists between the baseline data of Gregory (1971) and this study. While the foraminiferal assemblages in both studies are still quite different, remediation of the area seems to be occurring. The impact of organic pollution significantly decreased foraminiferal abundance from 1968 to 1993, and continued until 1996 when Asioli noted the barren zone at Mill Cove. Since 1996 foraminiferal abundances have increased indicating improved environmental conditions in Mill Cove.

CHAPTER 6 CONCLUSIONS

6.1 Conclusions

While still affected by anthropogenic pollution from the treatment plant, the foraminiferal abundance at Mill Cove has increased, indicating improved environmental conditions. As noted by Haury (1996), foraminiferal abundance declined since 1970 as a result of organic pollution. Degradation continued until at least 1996, when a dramatic increase in sewage disposal from the treatment plant resulted in complete annihilation of the benthic community at the outlet. Recolonization of the benthic community is still in the initial stages, but perhaps in another 30 years the foraminiferal assemblage at Mill Cove will resemble the assemblage noted by Gregory in 1971.

The transitional, deep subtidal environment in Bedford Basin is characterized by the abundance of agglutinated foraminifera. *Ammotium cassis* and *Eggerella advena* are dominant, and indicate high organic matter concentrations. The abundance of *Reophax scottii* and organic linings are indicative of low oxygen conditions, as a result of organic pollution. The high number of tintinnids in the top 7 cm of core 1A and 1C also reflect the high concentration of suspended particulate matter (SPM) in the water column.

By comparing the foraminiferal distribution seen in core 1A and 1C with the distributions noted in 1968, 1993 and 1996, relative time correlations have been determined. The presence of calcareous species in the bottom of core 1C, from 40 cm to 59 cm depths, implies a date of 1968 or older. At 12 cm depth, in both core 1A and 1C, species diversity and abundance show a significant decrease. This interval is inferred to represent 1993 or earlier. A further reduction in diversity and abundance occurs at 5 cm depth and represents 1996.

6.2 Recommendations

Time restrictions permitted only 2 of the 4 cores collected for this study to be examined. Further studies of the remaining cores to determine spatial variation, or to relate to the results found here, may be very useful.

Precision is very important when collecting samples for correlation. As spatial variation is found to exist around sewage outfalls, accurate sample locations are needed when trying to correlate data from various studies. The use of GPS to determine precise locations may eliminate any reservations about data correlation.

The time correlations determined from this study are only relative. Absolute dating would be useful to relate outfall discharges with core depth to determine sedimentation rates. Unfortunately Pb210 dating, which would calculate the age of the sediments, could not be done for this study.

Although there is an abundance of research on the impacts of pollution on the benthic environment, a full understanding of the dynamic processes and interactions is needed.

TAXONOMY

The classification of foraminiferal genera is in accordance with Loeblich and Tappan (1964) and Scott et al. (1977). The classification of thecamoebians is in accordance with Scott and Medioli (1983). This list includes species mentioned in figures and tables and is listed alphabetically by genus.

FORAMINIFERA

Ammobaculites dilatatus Cushman and Brönnimann
Ammobaculites dilatatus SCOTT and MEDIOLI 1980, p. 35, pl. 1, figs. 9, 10.

Ammonia beccarii (Linné)
Ammonia beccarri SCOTT and MEDIOLI 1980, p. 35, pl. 5, figs. 8,9.

Ammotium cassis (Parker)
Lituola cassis PARKER in Dawson 1870, p. 177, fig. 3.
Ammotium cassis (Parker). Loeblich and Tappan, 1953, p. 33, pl. 2, figs. 12-18.

Ammotium salsum (Cushman and Brönnimann)
Ammobaculites salsum CUSHMAN and BRONNIMANN 1948, p. 16, pl. 3, fig. 7-9.
Ammotium salsum (Cushman and Brönnimann) PARKER and ATHEARN 1959, p. 340, pl. 50, figs. 6, 13.

Buccella frigida (Cushman)
Pulvinulina frigida CUSHMAN 1921, p. 144.
Buccella frigida (Cushman) ANDERSON 1952, p. 144, fig. 4a-c, 5, 6a-c.

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.

Eggerella advena (Cushman)
Verneuilina advena CUSHMAN 1921, p. 141.
Eggerella advena (Cushman). Cushman, 1937, p. 51, pl. 5, figs, 12-15.

Elphidium barletti (Cushman)
Cribrononion barletti CUSHMAN, 1933, p. 4, pl. 1, fig. 9.
Elphidium barletti (Cushman)-GREGORY, 1971, p. 255, pl. 13, figs. 3-5. COLE and FERUSON, 1975, p. 34, pl. 7, figs. 3, 4. -SCHAFER and COLE, 1978, p. 27, pl. 10, fig. 4.

Elphidium excavatum (Terquem)
Polystomella excavatum TERQUEM, 1876, p. 429, pl. 2, figs. 2a-d.
Elphidium excavatum (Terquem)-CUSHMAN, 1944, p. 26, pl. 2, fig. 40.

Elphidium williamsoni (Haynes)
Polystomella umbilicatula WILLIAMSON, 1858, p. 42-44, figs. 81-82.
Elphidium excavatum (Terquem)-CUSHMAN, 1930, p. 21, pl. 8, figs. 4-7.
Cribrononion cf. *Alvarezianum* (d'Orbigny)-LUTZE, 1965, p. 101, pl. 15, fig. 46.
Elphidium umbilicatulum (Williamson)-LEVY *et* al., 1969, p. 96, pl. 1, fig 6a, b, pl. 2, figs. 1, 2.
Cribroelphidium excavatum (Terquem)-SCOTT *et* al., 1977, p. 1578, pl. 5, fig. 4.
–SCOTT, 1977, p. 169, pl. 6, fig 1.
Cribrononion umbilicatulum (Williamson)-SCOTT and MEDIOLI, 1980, p. 40, pl. 5, fig. 4.
Elphidium williamsoni HAYNES, 1973, p. 207-209, pl. 24, fig. 7, pl. 25, figs 6, 9, pl. 27, figs. 1-3.

Glomospira gordialis (Jones and Parker)
Trochammina squamata var. *gordialis* JONES and PARKER, 1860, p. 304.
Glomospira gordialis (Jones and Parker)-CUSHMAN and McCULLOCH, 1939, p. 70, pl. 5, fig. 5, 6.

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

Hemisphaerammina bradyi (Loeblich and Tappan)
Hemisphaerammina bradyi LOEBLICH and TAPPAN in LOEBLICH et al. 1957, p. 224, pl. 72, fig. 2.

Miliammina fusca (Brady)
Quinqueloculina fusca BRADY, 1870, p. 47, pl. 11, figs 2, 3.
Miliammina fusca (Brady)-PHLEGER and WALTON, 1950, p. 280, pl. 1, figs. 19a, b.

Recurvoides turbinatus (Brady)
Haplophragmium turbinatus BRADY, 1881, p. 50.
Recurvoides turbinsatus (Brady)-PARKER, 1952b, p. 402, pl. 2, fig. 23, 24.
GREGORY, 1971, p. 176, pl. 3, fig. 3, 4.

Reophax arctica (Brady)
Bigenerina arctica BRADY, 1881, p. 405, pl. 21, figs. 2a, b.
Reophax arctica (Brady)-PARKER, 1952a, p. 395, pl. 1, figs. 6, 7.

Reophax nodulosa Brady
Reophax nodulosa BRADY, 1879, p. 52, pl. 4, figs. 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 difflugiformis (Brady)
Reophax difflugiformis BRADY, 1879, p. 51, pl. 4, figs. 3a-b.

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

Tritaxis fusca (Williamson)
Rotalina fusca WIILLIAMSON, 1858, p. 55, pl. 5, figs. 114-115.
Tritaxis fusca (Williamson)-LOEBLICH and TAPPAN, 1955, p. 19.

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

Trochammina ochracea (Williamson)
Rotalina ochracea WILLIAMSON, 1858, pl. 4, fig. 112, pl. 5, fig. 113.
Trochammina ochracea (Williamson)-CUSHMAN, 1920, p. 75, pl. 15, fig. 3.
GREGORY, 1971, p. 182, pl. 4, figs. 8, 9.

ORGANIC LININGS – These are inner linings of various calcareous species, probably *Elphidium excavatum* here, but they are largely unidentifiable.

ARCELLACEANS

Centropyxis aculeata (Ehrenberg)
Arcella aculeata EHRENBERG, 1832, p. 91.
Centropyxis aculeata (Ehrenberg)-STEIN, 1859, p. 43. –MEDIOLI and SCOTT, 1983, p. 28, pl. 4, figs. 5-19.

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.

Pontigulasia compressa (Carter)
Pontigulasia compressa (Carter) TODD and BRONNIMANN, 1957, p. 21, pl. 1, fig. 5. – SCOTT et al. 1977, p. 1581, pl. 1, figs. 5,6.

TINTINNIDS

Tintinnopsis rioplatensis 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.

PLATE 1

Agglutinated foraminifera from the top 60 cm of the sediment column at site 5, Mill Cove, Bedford Basin. Scales are unknown because of the method used to create the plate.


Elphidium excavatum
Elphidium barletti
Elphidium williamsoni
Haynesina orbiculare
Glomospira gordialis
Cribrostomoides crassimargo
Saccammina difflugiformis
Spiroplectammina biformis
Ammotium cassis
Trochammina lobata (dorsal view)
Trochammina lobata (ventral view)
Trochammina ochracea
Miliammina fusca (5 chamber side)
Miliammina fusca (3 chamber side)
Reophax scottii
Reophax arctica
Reophax scorpiurus

Plate 1

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APPENDIX A

Faunal Distribution Data

Table 2 Faunal distribution data for core 1A showing core depth, percent organic matter, number of species and number of individuals per 10 cm^3 sample, percent abundance of foraminiferal species and thecameobians and number of tintinnids in the near surface samples.

Depth (cm)	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13
Pecent Organic matter	21.96	22.28	20.69	16.33	15.23	13.07	11.31	11.79	9.86	10.45	10.22	12.36	13.39
No. of Species/10cc	3	4	4	5	6	10	12	13	11	14	12	12	9
No. of Individuals/10cc	64	127	55	110	76	203	509	566	503	610	527	672	1176
Foraminifera													
Ammotium cassis					3.9	5.9	6.3	5.8	7.6	4.9	6.5	9.5	13.3
Cribrostomoides crasimargo		1.6	1.8	0.9		5.4	2.6	3.5	4.4	2.6	3.2	4.8	2.7
Eggerella advena	1.6	1.6		4.5	13.2	8.9	9.4	7.2	3.8	3.0	8.0	9.4	8.8
Elphidium barletti													
Glomospira gordialis							0.4	1.8	1.2	2.3	1.9	0.9	
Haynesina orbiculare													
Miliammina fusca					1.3	1.0		0.5	0.4	1.3	0.4	1.2	0.3
Organic linings (alive)	21.9	33.9	30.9		10.5	7.9	0.8	0.2	0.4	0.3	1.3	0.1	0.7
Organic linings (dead)	59.4	59.1	34.5	50.9	15.8	44.8	43.2	40.5	36.0	41.1	39.1	38.7	32.7
Recurvoides turbinatus				29.1			4.3						
Reophax Arctica			3.6		5.3	5.9		5.3	4.4	4.3	2.3	4.8	4.1
Reophax nodulosa							0.2					0.4	
Reophax scorpiurus						0.5	0.2		0.2	0.2			0.3
Reophax scottii	10.9	3.1	18.2	12.7	48.7	14.8	15.7	17.7	22.3	18.7	19.7	15.8	18.4
Saccammina diffugiformis						1.5	1.0	0.5	0.4	0.2	0.6		
Spiroplectammina biformis				1.8	1.3	1.5	6.5	6.9	6.0	8.7	2.5	6.3	4.1
Tritaxis fusca													
Trochammina lobata	6.3		10.9			0.5	1.4	0.4	0.6	0.3	5.9	0.6	0.3
Trochammina ochracea								0.5		0.7	0.4	0.6	
Agglutinated fragments						1.5	8.1	7.1	10.7	10.2	8.0	6.5	14.3
Thecameobains													
Centropyxis aculeata		0.787					0.196	1.767		0.328			
Difflugia oblonga								0.353	2.187	0.984	0.38	0.446	
Pontigulasia compressa													
Tintinnids													
Agglutinated				26	12	42	28	5	1				8
Clear	658	698	306	28									

Depth (cm)	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	24-25	25-26
Pecent Organic matter	13.6	15.18	16.96	18.23	18.81	18.61	18.06	18.55	17.78	17.72	17.91	18.07	18.09
No. of Species/10cc	12	11	9	12	8	10	11	10	10	12	11	11	13
No. of Individuals/10cc	1016	1752	1624	1128	1384	1512	2032	2592	6864	4816	5720	3952	3168
Foraminifera													
Ammotium cassis	13.8	21.9	23.2	15.6	16.2	20.1	9.8	12.3	20.6	7.1	14.0	8.5	9.8
Cribrostomoides crasimargo	2.4	2.7	8.4	6.4	5.2	7.9	7.5	11.4	13.1	8.0	10.9	6.7	5.1
Eggerella advena	10.2	12.8	7.9	11.3	7.5	5.8	4.7	4.6	5.6	7.5	4.2	2.0	1.5
Elphidium barletti													
Glomospira gordialis	0.4	0.5		1.4			0.4		0.7	1.3	0.8	2.4	1.5
Haynesina orbiculare													
Miliammina fusca	0.4	0.5								0.3			0.3
Organic linings (alive)	0.4												
Organic linings (dead)	23.6	19.2	12.8	11.3	13.9	13.8	16.5	16.7	15.7	15.8	16.2	22.1	14.6
Recurvoides turbinatus													
Reophax Arctica	3.9	8.2	4.9	5.7	2.3	3.2	1.2	1.5	2.1	2.7	2.5	0.8	1.5
Reophax nodulosa													0.3
Reophax scorpiurus		0.9	2.0	3.5	0.6	0.5	1.6	0.9	1.7	1.8	3.4	4.0	3.3
Reophax scottii	18.5	10.5	18.7	16.3	26.0	16.9	29.9	22.5	9.6	27.9	17.6	23.9	25.3
Saccammina diffugiformis	1.2	1.4	2.0	2.8	3.5	3.2	4.3	5.9	8.0	5.6	9.0	9.5	10.4
Spiroplectammina biformis	2.4	2.3	5.9	5.7	4.0	3.7	5.1	3.4	5.1	2.5	4.5	0.4	6.3
Tritaxis fusca													
Trochammina lobata	0.8	1.4	2.0	2.8		3.2	3.1	2.8	2.8	4.3	4.3	3.4	3.0
Trochammina ochracea	0.4			0.7		2.6	1.2	0.3		0.7	0.6	0.4	1.0
Agglutinated fragments	20.5	17.8	12.3	14.2	20.8	19.0	14.6	17.6	14.9	14.5	12.0	15.8	16.2
Thecameobains													
Centropyxis aculeata	1.18												
Difflugia oblonga													
Pontigulasia compressa				2.13									
Tintinnids													
Agglutinated													
Clear	4												

Depth (cm)	26-27	27-28	28-29	29-30	30-31	31-32	32-33	33-34	34-35	35-36	36-37
Pecent Organic matter	18.63	19.44	19.42	18.27	19.6	19.09	18.73	19.74	19.21	18.38	16.19
No. of Species/10cc	12	12	11	11	10	9	9	10	9	9	11
No. of Individuals/10cc	3352	2408	2304	2832	2112	2336	2552	2280	1608	1299	1473
Foraminifera											
Ammotium cassis	9.3	4.0	5.9	2.0	1.9	3.1	3.1	3.9	3.5	3.4	4.5
Cribrostomoides crasimargo	3.8	3.0	4.9	1.4		2.4	3.1	2.8	2.5	1.5	2.1
Eggerella advena	5.3	3.0	4.2	4.8	4.5	3.1	4.4	3.2	4.5	3.9	4.9
Elphidium barletti											0.1
Glomospira gordialis	3.1	2.3	1.0	1.4	3.0	0.3	1.6	0.7			
Haynesina orbiculare											2.0
Miliammina fusca											
Organic linings (alive)											
Organic linings (dead)	19.1	35.5	40.6	46.0	40.2	39.4	31.7	36.5	40.8	46.5	25.6
Recurvoides turbinatus											
Reophax Arctica	1.0	2.0	2.4	1.7	1.5	4.1	2.5	3.2	3.2	2.5	1.4
Reophax nodulosa											
Reophax scorpiurus	2.9	0.3	0.7	0.3							
Reophax scottii	23.9	23.1	12.8	20.3	21.6	15.1	13.2	12.6	19.7	24.6	15.2
Saccammina diffugiformis	7.2	7.3	5.9	3.4	1.9	6.2	13.2	8.4	2.2	4.2	8.9
Spiroplectammina biformis	5.0	3.3	2.4	3.7	5.3	2.7	2.5	0.7	2.5	1.3	3.3
Tritaxis fusca				1.1							
Trochammina lobata	3.8	3.0	3.5	2.5	4.2	2.7	3.4	3.9	2.2	7.3	13.0
Trochammina ochracea	1.4	1.3	1.7		0.4			0.7	0.7		
Agglutinated fragments	14.1	11.6	13.9	11.3	11.7	20.9	21.3	23.5	18.2	4.6	18.5
Thecameobains											
Centropyxis aculeata											
Difflugia oblonga	0.24	0.33			3.79					0.08	0.61
Pontigulasia compressa											
Tintinnids											
Agglutinated											
Clear											

Table 3a Faunal distribution data for core 1C showing core depth from 0 to 20 cm depth, at 1 cm intervals, percent organic matter, number of species and number of individuals per 10 cm^3 sample, percent abundance of foraminiferal species and number of tintinnids in the near surface samples.

Depth (cm)	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10
Pecent Organic matter	12.92	12.86	11.45	9.77	13.29	11	11.71	14.79	13.91	15.67
No. of Species/10cc	11	12	11	9	11	12	12	12	12	10
No. of Individuals/10cc	404	479	660	864	1084	1264	1376	2072	2152	2016
Foraminifera										
Ammotium cassis	13.1	14.0	10.3	11.1	11.8	8.9	12.2	17.4	14.5	18.7
Cribrostomoides crasimargo	5.4	4.0	2.1	4.2	2.6	2.8	3.8	2.7	2.6	3.6
Eggerella advena	11.1	5.2	8.5	10.6	13.7	14.2	14.0	7.3	13.0	8.3
Elphidium barletti										
Elphidium excavatum										
Elphidium williamsoni										
Glomospiral gordialis	2.0	3.8	3.2	1.9	1.8	1.3	0.6	1.5	2.2	1.6
Haynesina orbiculare										
Miliammina fusca	2.0	2.1	2.7		2.6	1.9	1.5	1.5	0.7	
Organic linings (alive)	0.5									
Organic linings (dead)	30.9	26.1	16.4	21.8	20.3	19.0	18.6	16.2	19.3	21.4
Recurvoides turbinatus										
Reophax Arctica	2.0	5.0	5.8	4.6	8.5	5.1	5.5	6.6	3.0	6.3
Reophax nodulosa	1.5	0.4	2.9	1.9	2.6	0.6	1.5	3.1	1.1	0.4
Reophax scorpiurus	0.5	0.2			1.5	0.3	0.3	0.4	0.4	
Reophax scottii	17.8	26.3	31.4	28.2	18.1	34.5	24.4	25.1	26.8	21.0
Saccammina diffugiformis	1.2	1.5	0.6			1.9	0.3	1.2	3.3	2.0
Spiroplectammina biformis	5.7	5.2	8.0	6.0	8.1	2.8	2.6	2.3	1.5	5.2
Trochammina lobata		0.6	0.8	0.9	0.4	1.6	0.3	0.4		2.4
Trochammina ochracea									1.5	
Agglutinated fragments	6.2	5.6	7.4	8.8	8.1	10.8	14.5	14.3	10.0	9.1
Tintinnids										
Agglutinated	88	108	247	176	120	136	64	112		
Clear	22	8	8						16	8

Depth (cm)	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20
Pecent Organic matter	14.69	18.63	18.33	18.44	17.86	18.32	18.62	18.57	18.46	18.78
No. of Species/10cc	10	9	11	11	11	11	11	10	11	13
No. of Individuals/10cc	1776	2112	3016	3560	5040	6224	5328	8360	8200	9760
Foraminifera										
Ammotium cassis	18.9	12.1	14.9	14.2	16.7	15.9	17.0	16.9	16.4	20.0
Cribrostomoides crasimargo	2.3	2.7	4.2	5.2	8.4	9.1	9.6	9.7	8.6	9.3
Eggerella advena	14.4	8.0	9.5	9.9	5.7	4.2	5.3	5.7	6.4	6.5
Elphidium barletti										
Elphidium excavatum										
Elphidium williamsoni										
Glomospiral gordialis	3.6		0.5	1.8	1.0	3.6	1.5	3.1	1.8	1.1
Haynesina orbiculare										
Miliammina fusca			0.3	0.9			0.3		0.2	0.1
Organic linings (alive)										
Organic linings (dead)	21.6	22.7	24.4	19.3	13.2	12.9	12.6	14.4	10.6	11.9
Recurvoides turbinatus					0.8					
Reophax Arctica	3.6	5.3	3.2	3.8	3.2	3.1	2.3	1.1	1.4	0.7
Reophax nodulosa	0.5	0.8		0.4		0.3				0.1
Reophax scorpiurus			0.3	0.9	1.4	1.4	1.7	2.0	1.9	1.9
Reophax scottii	18.0	31.1	24.9	25.2	27.6	28.5	22.5	22.8	32.0	27.2
Saccammina diffugiformis	4.5	2.7	3.7	2.9	3.3	4.6	6.0	7.8	5.5	5.7
Spiroplectammina biformis	6.3	4.2	3.4	5.8	9.4	7.1	7.2	5.0	5.3	7.5
Trochammina lobata	0.9	1.1	0.3	3.6	1.7	1.8	3.8	3.1	2.5	2.1
Trochammina ochracea										0.5
Agglutinated fragments	5.4	9.5	10.3	6.1	7.6	7.5	10.4	8.3	7.5	5.2
Tintinnids										
Agglutinated										
Clear										

Table 3b Faunal distribution data for core 1C showing core depth from 25-61 cm depth, at 5 cm intervals, percent organic matter, number of species and number of individuals per 10 cm^3 sample, percent abundance of foraminiferal species and number of tintinnids in the near surface samples.

Depth (cm)	25-26	30-31	35-36	40-41	45-46	50-51	55-56	58-59	60-61
Pecent Organic matter	19.86	18.44	20.22	19.28	18.79	18.82	18.85	15.95	18.07
No. of Species/10cc	12	13	8	13	11	11	8	12	7
No. of Individuals/10cc	2728	1860	1938	2360	3008	2592	3088	5680	3632
Foraminifera									
Ammotium cassis	15.5425	10.3226	7.73994	13.5593	23.6702	8.95062	2.07254	14.507	3.74449
Cribrostomoides crasimargo	5.57185	2.90323	3.40557	2.37288	2.65957	1.23457	0.51813	0.84507	0.44053
Eggerella advena	2.05279	6.12903	6.19195	7.79661	7.71277	7.09877	1.29534	2.53521	0.88106
Elphidium barletti								2.11268	
Elphidium excavatum				0.33898	0.26596			3.09859	
Elphidium williamsoni								0.28169	
Glomospira gordialis	2.93255	0.64516				0.61728		0.28169	
Haynesina orbiculare				0.33898	0.26596			1.40845	
Miliammina fusca				1.35593					
Organic linings (alive)									
Organic linings (dead)	11.7302	34.5161	26.6254	11.5254	25.266	39.5062	77.9793	54.7887	77.3128
Recurvoides turbinatus									
Reophax Arctica	1.17302	3.22581	4.95356	3.38983	1.06383	1.85185	0.51813	0.56338	0.88106
Reophax nodulosa	0.29326	0.64516		0.33898		0.61728	0.51813	0.28169	0.66079
Reophax scorpiurus	5.8651	0.96774		1.35593	0.26596	0.61728			
Reophax scottii	16.7155	20.6452	32.1981	32.2034	9.57447	17.9012	12.4352	1.97183	11.4537
Saccammina diffugiformis	21.4076	2.25806	0.3096	1.35593	1.06383	2.16049		0.70423	
Spiroplectammina biformis	4.10557	1.6129	3.09598	0.33898	0.53191	1.85185	0.51813		
Trochammina lobata	2.6393	1.93548	1.85759	1.35593	0.79787	2.77778	0.51813		0.44053
Trochammina ochracea	1.75953	0.32258							
Agglutinated fragments	8.21114	13.871	13.6223	22.3729	26.8617	14.8148	3.62694	16.6197	4.18502
Tintinnids									
Agglutinated									
Clear									