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DISTRIBUTION AND ABUNDANCE OF FORAMINIFERA AND THECAMOEBINA IN MIRAMICHI RIVER AND BAY

by

GRANT A. BARTLETT

REPORT BIO 66-2

FEBRUARY 1966

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B E D F O R D   I N S T I T U T E   O F   O C E A N O G R A P H Y

D A R T M O U T H, N. S. - C A N A D A

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ABSTRACT

The Miramichi River and Bay form an estuary, approximately forty miles long, emptying into the Gulf of St. Lawrence on the eastern shore of New Brunswick. The eastern boundary of the bay is characterized by a string of islands and sandbars that partially block the exchange of river water with those of the Gulf of St. Lawrence system. The bay is comparatively shallow with depths not exceeding fifteen metres. Seventy-nine bottom samples were collected with bottom grab samplers and by means of SCUBA. These samples were analyzed for their foraminiferal and sediment characteristics as part of a detailed study of the distribution and abundance of Foraminifera in the Atlantic Provinces.

Shallow water regions in Miramichi River and Bay undergo extreme fluctuations in temperature and salinity. Sediments with a median diameter in the fine silt to clay size have the highest organic carbon content. Calcium carbonate percentages are variable and are apparently related to foraminiferal and molluscan content. Depth and substrate do not bear a direct relationship to the distribution of four diagnostic foraminiferal species. Consequently, a definite foraminiferal depth or substrate zonation cannot be determined in the Miramichi environment. However, two distinctive biofacies: 1) River and 2) Bay are apparent. Beach, nearshore, and tidal flat environments form biotopes within the Bay biofacies. These biotopes are characteristic of areas on and adjoining the

baymouth bars and islands.

The estuary is characterized by two foraminiferal faunas; a Miliammina fauna in association with Thecamoebina such as Centropyxis arenatus, Difflugia oblonga and Pontigulasia compressa, which inhabits waters with salinities less than 20.00°/oo, and an Elphidium fauna composed of Buccella frigida, Elphidium incertum "complex", Elphidium margaritaceum, Elphidium orbiculare, Elphidium subarcticum and other species in subordinate amounts which inhabit waters with salinities between 20.00°/oo and 29.00°/oo. Low river inflows in 1965 with attendant higher salinities enabled the Elphidium fauna to migrate further upstream than in 1964 when the season was characterized by higher than average river inflow.

Living and total population distributions show fairly good correlation for all species. Areas of maximum populations of living Foraminifera generally do not coincide with areas of maximum dead populations. Living-total ratios have been utilized to determine the approximate relative rates of sedimentation. Highest rates of sedimentation are recorded at the mouth of the estuary immediately outside the baymouth barriers. Living-total foraminiferal ratios support field observations that there is a progressive westward and southwestward migration of the baymouth barriers. The living-total ratio expressed as percent is figured for all species and compared with living-total ratios of diagnostic species in the Miramichi Estuary. The dominance of the Elphidium incertum "complex" is reflected in the similarity of the living-total patterms for this species and those of all species. The irregular living-total ratios of other component species are attributed to their irregular distribution patterns. These species have a negligible effect on values for relative sedimentation rates if a species such as E. incertum "complex" is so dominant throughout the environment.

Four of the thirty-five species of Foraminifera and Thecamoebina in the Miramichi Estuary dominate the faunal assemblage. Two are arenaceous - Miliammina fusca and Eggerella advena - and two are calcareous-hyaline - Elphidium incertum "complex" and E. orbiculare. The four species are major constituents of two well defined biofacies within the estuary.

The open-gulf environment, with greater depths and higher salinities maintains a larger population and is a dumping ground for assemblages transported from the estuary and from the shore and nearshore areas of the baymouth bars and islands. Total populations are highest, living-total ratios are lowest and assemblage variability is greatest in the more uniform open-gulf environment.

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INTRODUCTION

Miramichi River and Bay (Figs. 1, 2) form an estuary approximately forty miles long emptying into the Gulf of St. Lawrence on the eastern shore of New Brunswick. The bay is approximately fifteen miles across at its widest point. The eastern boundary of the bay is formed by a string of islands that obstruct exchange of bay and Gulf of St. Lawrence waters. The average depth of the Miramichi is 4 metres, with a maximum depth less than 15 metres.

This paper describes the distribution and abundance of Foraminifera in an estuarine environment of the Atlantic Provinces region. Faunal distribution and environmental parameters are discussed. The investigation forms part of a detailed study of foraminiferal ecology in waters adjoining the Atlantic Provinces of Canada.

Samples were collected during the period June to November in 1964 and 1965. The program was financed by the Marine Sciences Branch and staffed by the Geological Survey of Canada.

Method of Study

Seventy-nine samples collected by bottom grab samplers and by means of SCUBA have been analyzed for their foraminiferal content and sediment characteristics. If possible, a

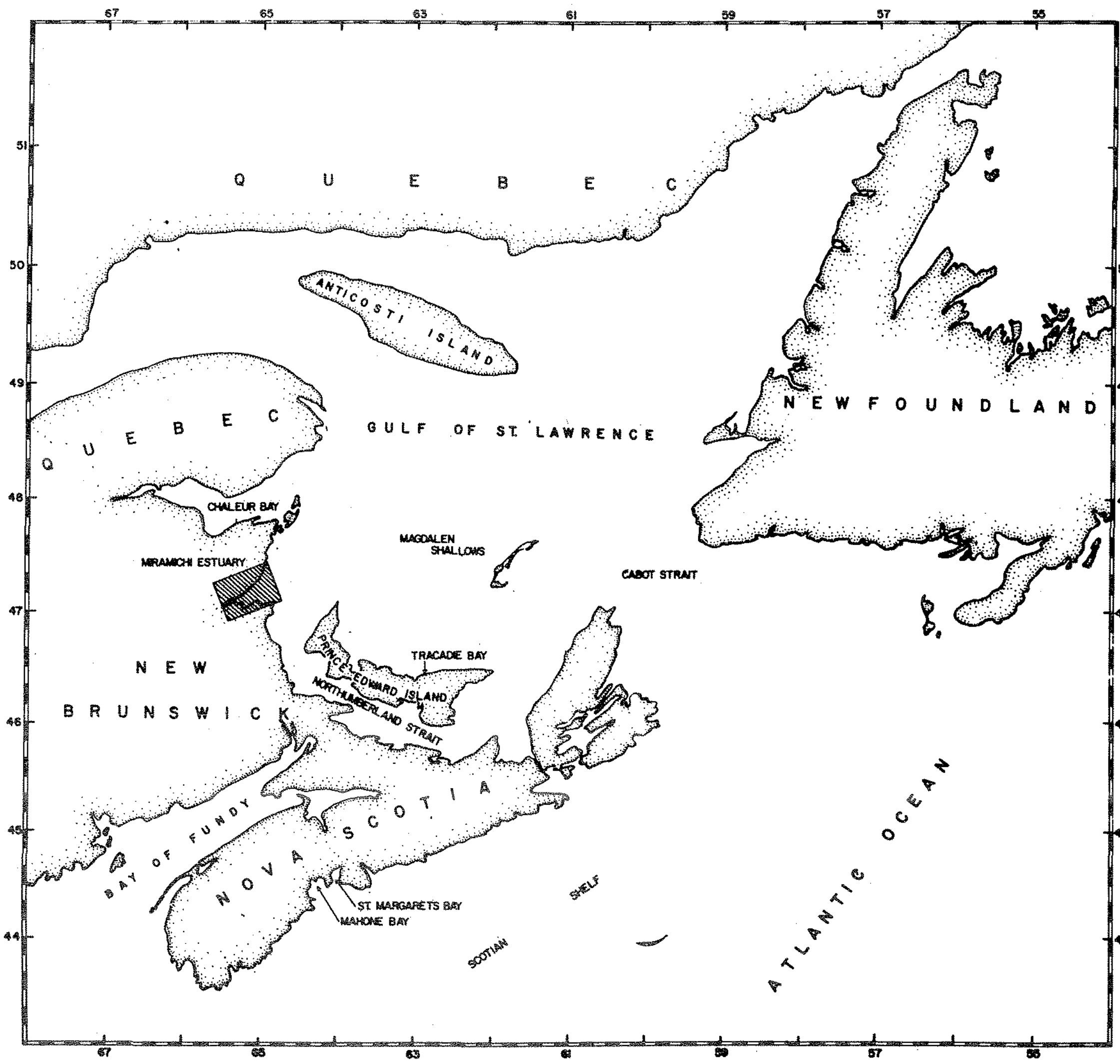

Fig. 1 Index Map of Study Area

given area of substrate (10 cm x 10 cm x 1 cm) was collected at each station. This enabled the natural measure of populations for comparative purposes. Sieve and pipette analyses are similar to those described by Krumbein and Pettijohn (1938). Statistical analyses were compiled from both sieve and pipette data. Faunal analyses are similar to those described by Bartlett (1964b).

Foraminiferal tests were concentrated by heavy liquid separation using either perchlorethylene or the four solutions described by Bartlett (1964b). Foraminiferal concentrates were split with an "OTTO" microsplitter and counted wet. A portion of each sample was used for size distribution, calcium carbonate content, organic carbon content and general mineralogy. Hydrogen-ion (pH) and oxidation reduction (Eh) measurements were made as soon as the sediment sample reached the surface.

Foraminifera were identified, counted, and each species was compared with the entire foraminiferal assemblage. Living-total ratios were calculated, as were the percentages of arenaceous, calcareous-hyaline and porcelaneous tests. Species collected at various seasonal intervals were measured and chambers counted to determine rate of growth.

Previous Investigations

This is the first detailed investigation of Foraminifera and sediments in the area. Sproule (1962) studied Foraminifera in a section from Gaspé to Anticosti, and Vilks (personal

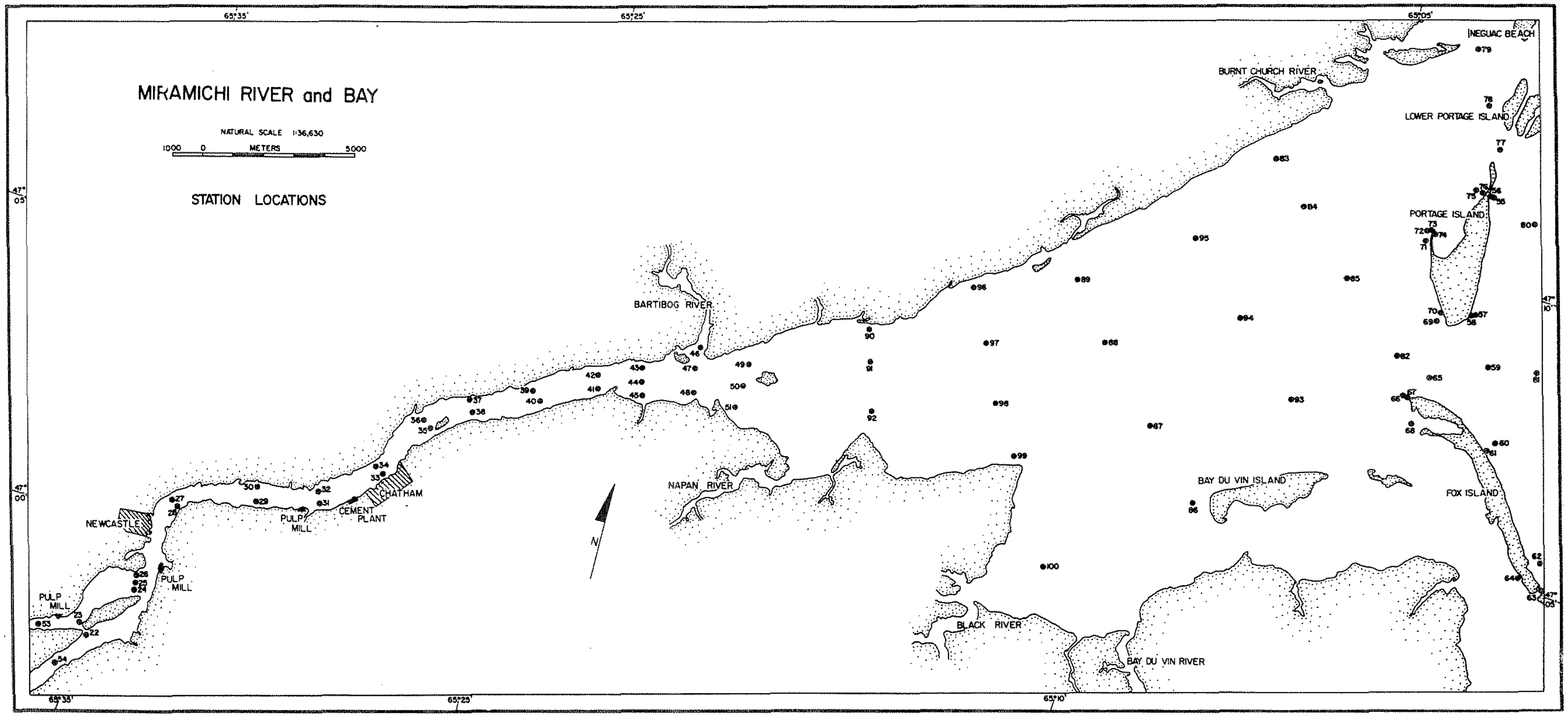

Fig. 2 Station Locations, Miramichi River and Bay

communication) has investigated foraminiferal distribution in waters adjoining the Magdalen Shallows. Bartlett (1965a) reported on a similar fauna from Tracadie Bay, Prince Edward Island. Cross (1951) carried out a general investigation of the hydrography of Miramichi Bay, which dealt mainly, in general terms, with erosion and sedimentation.

Acknowledgements

Dr. A. W. McCrone of New York University and Drs. D. G. Benson, B. R. Pelletier and F. J. E. Wagner, present colleagues of the writer, receive special thanks for critically reading the manuscript. Gratitude is expressed to T. Holler for extensive assistance in compilation of data and for drafting most of the illustrations. The writer is indebted to B. Bartlett, R. Cormier, N. Fowler, R. Herzer, D. Sarty and F. Schnare for able assistance in both field and laboratory investigations.

GEOLOGY

The study area lies at the edge of the northern part of a belt of deformed early Paleozoic sedimentary and volcanic rocks, cut by granite batholiths. This belt extends south-westerly to the Maine, U. S. A. border. The rocks of the district are divisible into three structural units.

1. Pre-Silurian sedimentary and volcanic beds that have undergone intense dynamic metamorphism.
2. Less deformed Silurian and Devonian strata that overlie these unconformably.
3. Flat-lying Upper Carboniferous sedimentary rocks that lie unconformably on 1 and 2.

The latter are sparsely scattered at the head of the river. These nearly flat-lying beds of Pennsylvanian age are grey and contain detrital plant remains. However, bedrock is obscured in most areas because of extensive covering by thick deposits of glacial debris.

OCEANOGRAPHY AND SEDIMENTOLOGY

Bottom Topography

The Miramichi River widens into Miramichi Bay and empties in the Gulf of St. Lawrence (Figs. 1, 2). The mouth of the bay is approximately 15 miles wide and is obstructed by islands and sand bars. Depths in the area under investigation are less than 15 metres, and the majority of the area is less than 5 metres at low tide.

A comparison of various hydrographic charts from 1885 to the present indicates large-scale changes in topography of both the estuary bottom and the adjoining land areas. Old channels have been closed and new ones opened. Islands and sand banks have been eroded or enlarged and rebuilt by sedimentation, especially through the action of longshore currents. Cross (1951) described three hydrographic surveys (1885, 1921, 1951) in detail.

Survey of 1885: At the time of the Admiralty survey in 1885, Portage Island, centrally located across the mouth of the bay, was a long, narrow, wedge-shaped island, with the southern end almost a mile wide and about sixty feet above high water level. The island became narrower in the central part, but it was still about sixty feet high. From here it extended northward as a long, low, slender peninsula, made up of sand dunes rising only a few feet above high water level. The total length of the island at this time was more than four

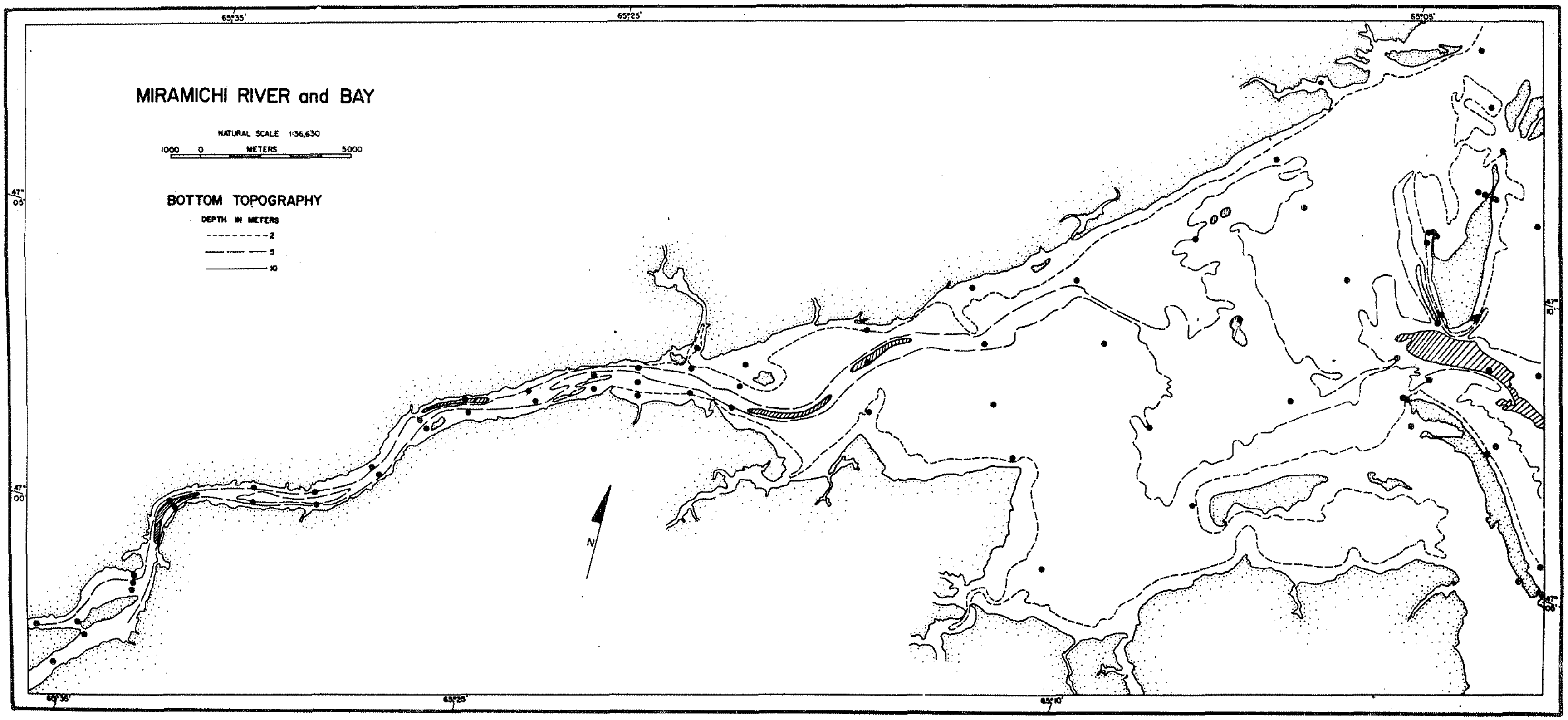

Fig. 3 Bottom Topography, Miramichi River and Bay

miles.

The southern and central parts of the island were covered with a stand of red pine. The sand dunes making up the long northern peninsula were sprinkled with saw grass. Between the northern tip of Portage Island and the southern end of Neguac Beach (the next island to the north) was a passage about a mile wide, partly obstructed by drying sandbanks, but with a depth of fifteen feet in the main channel called Neguac Gully. This gully lay just off the end of Neguac Beach.

Although complete data is lacking, there seems to have been eel grass in a broad area to the west of Portage Island and Neguac Beach, and in other patches in the inner bay.

<u>Survey of 1921-22:</u> Neguac Beach had extended southwestward a distance of over one-half mile. Neguac Gully had moved a similar distance, and lay where formerly there was a drying sandbank. The new gully was about five feet deeper than the old one. The general southward shifting resulted in the shortening of the northern tip of Portage Island.

The most dramatic change was the cutting of a new channel through the northern end of Portage Island that isolated a narrow sandy ridge about two-thirds of a mile long. The heights of the dunes on this new island, called Lower Portage Island, were up to fifteen feet above high water level. The new channel was poorly developed, being only a few feet deep at each end. Portage Island, proper, was less than three miles long.

Eel grass was still widespread throughout the shallow areas inside the islands and sandbanks. Portage Island was wooded with the exception of a coastal strip and the northern peninsula. The range of trees was therefore much the same as in 1885. The sand dunes carried a sparse cover of saw grass.

Survey of 1951: Because of obvious changes in the surface and bottom features, a survey of part of northeastern Miramichi Bay was made again in 1951.

Neguac Beach had extended southward a few hundred feet, and Neguac Gully was almost completely filled.

The sandy ridge that in 1885 had been the northern tip of Portage Island, and in 1921 had formed Lower Portage Island, fifteen feet high, was so greatly eroded that it was submerged at high tide. At low tide, however, the exposed sand dried sufficiently to be blown about by the wind.

The formerly unnavigable channel between Portage and Lower Portage Islands had deepened considerably, and served as the fishermen's main entrance into the northeastern part of the bay.

A comparison of the two latest charts shows how far the northern end of Portage Island had moved. Within thirty years the whole area above water had moved westward several hundred yards, a greater distance than the width of the island, and there had been an appreciable thickening of the tip and a narrowing of the neck of the peninsula about one-half mile to the south.

Cross (1951) noted that eel grass had disappeared from most of the bay. The absence of this prolific plant growth affects sediment movement so that sediment transport, rather than sediment entrapment, is the major physical environmental process.

The extent of the land vegetation had not changed appreciably. A scrubby growth of spruce covered Portage Island as far north as the narrow neck one-half mile from the tip. The tops of the sand dunes carried some saw grass and the tip of Portage Island and the sandbanks were bare.

The present investigation shows a continued westward movement of the northern tips of Portage Island and Fox Island. Sand bars and tidal flats are better developed between Portage Island and Neguac Island than those shown on the 1951 chart. The main channel between the two islands is being constricted. The channel between Portage Island and Fox Island is maintained by annual summer dredging. Inside the baymouth barriers the northern portion of the bay is relatively stable while the southern portion is silting up.

Currents and Tides

Observations of sediment movement during the present study support those of Cross (1951). Currents and wave action are the principal factors in erosion and sedimentation. Wind erosion and transport is significant in areas where sand dunes are barren of vegetation. Drifting and blowing sand is a common phenomenon in areas adjoining the islands at the mouth of the bay. The horizontal movement of water associated with tidal changes is probably the most significant current in the bay. However, the Miramichi River discharge gives a net seaward flow. Ebb tides have higher velocities and are of longer duration that flood tides. Consequently, there is a net seaward transport of sediment and associated fauna.

The tide in Miramichi Bay has a fortnightly cycle during which it varies from a regular semi-diurnal curve with two equal high waters and two equal low waters in each day, to an almost diurnal curve with only one clearly defined high water and a prolonged stand at low water. Cross (1951) stated that this current is a reversing one in the various openings from the Gulf into the bay, but of a rotary nature elsewhere. Semi-permanent currents are those with a general southward drift in the offshore area. This is part of the general counter-clockwise circulation in the Gulf of St. Lawrence. Miramichi River discharge is much larger during the freshet stage in spring and early summer, when penetration of a salt water wedge is at a minimum. The effect of waves, wind, and ice can only be surmised. Storm waves cause rapid erosion in shallow water areas. However, this material is generally redistributed during normal water conditions resulting in a net transport seaward or along shore. Ice must have a direct effect on sediment transport because of the lengthy period during which it covers the river and bay. During this period, wind, wave, and current action is greatly reduced.

Bottom Salinities and Temperatures

Waters of the Miramichi River and Bay are estuarine in character and are subject to tidal and seasonal variations. Salinities range from 7.86°/oo (Station 53) at the river head to 28.18°/oo (Station 81) in the open Gulf. These waters are polyhaline. Salinities in the river show a gradual increase from 7.86°/oo to 20.89°/oo (Stations 49, 50, 51), except in areas (e.g. Station 46) where tributaries dilute the water and salinities decrease to 16.00°/oo. Salinities in the bay range from 23.11°/oo (Station 91) to 27.44°/oo (Station 82). These salinities, especially in the river environment vary as much as 5°/oo depending upon the tidal state and season.

Salinities of 20.00°/oo to 21.00°/oo were recorded as far as Station 37 in 1965, whereas in 1964 during similar tidal conditions salinities were approximately 16.00°/oo. This is related to seasonal rainfall between 1964 and 1965, the latter being a year with low precipitation.

Water temperatures also undergo both diurnal and seasonal variations. During March and April temperatures are less than 6°C., but increase to a maximum of 20°C. during late August and early September. Temperatures in tidal and nearshore areas approach 0°C. in December and January. In June and July these shallow water estuarine areas may undergo a 15°C. change during a 24-hour period. Fauna in such an environment is restricted to hardy eurythermal and euryhaline species. Climatic conditions, water depth, and tidal cycle are controlling factors in temperature conditions in the Miramichi estuary.

Bottom Sediments

Bottom sediments in the Miramichi River are composed of sand, silty-sand, sandy-silt, and silty-clay. Sediment distribution is complex. Bottom sediments in Miramichi Bay are also variable in lateral extent and composition, and consist of sand or silty-sand. Extensive tidal flats in the central bay area are composed of well-sorted sand and poorly-sorted silt and clay. Coarsest sediments are deposited in channels on these flats, whereas silt and clay are deposited in areas between the channels. The coarsest sediments associated with the Miramichi estuary are located on and adjoining the baymouth barriers and islands. These sediments are coarse, well-sorted sands. Excellent sorting, and the absence of silt and clay in these areas may be attributed to the winnowing of fines by wave action and longshore currents.

Reworking of sediments, whether river-borne or derived from baymouth barriers, occurs in the Miramichi estuary. Sediments on shallow tidal flats undergo the most reworking since they are affected by two flood and two ebb tides daily. The turbid, brownish colour of the Miramichi River indicates that quantities of fine sediment and organic matter are being carried in suspension. Investigation of the substrate by means of SCUBA indicates that the river is also transporting sediment through traction and saltation processes. Frequent channel shifting attests to sediment reworking and migration on tidal flats and areas adjoining the baymouth barriers. Ebb currents carry sediment into the channels and seaward while flood currents have a tendency towards spreading sediment over tidal flats and shallow water areas.

Sediment colour varies from light grey to brown, on and adjoining baymouth bars, to light grey and olive green in the central bay. In the river, sediments are olive grey, reddish brown, and black. Colour depends on mineralogy of bottom sediments, depth of water, organic content and pollution by industrial sites situated in the immediate area. Darkest coloured sediments are usually silts and clays and have a higher organic carbon and higher total organic content than lighter coloured well-aerated sands. These dark sediments commonly smell of hydrogen sulphide.

The percentage of organic carbon (Fig. 4) (X1.7 $\simeq$ total organic content) varies from 0.16 to 4.60. This represents

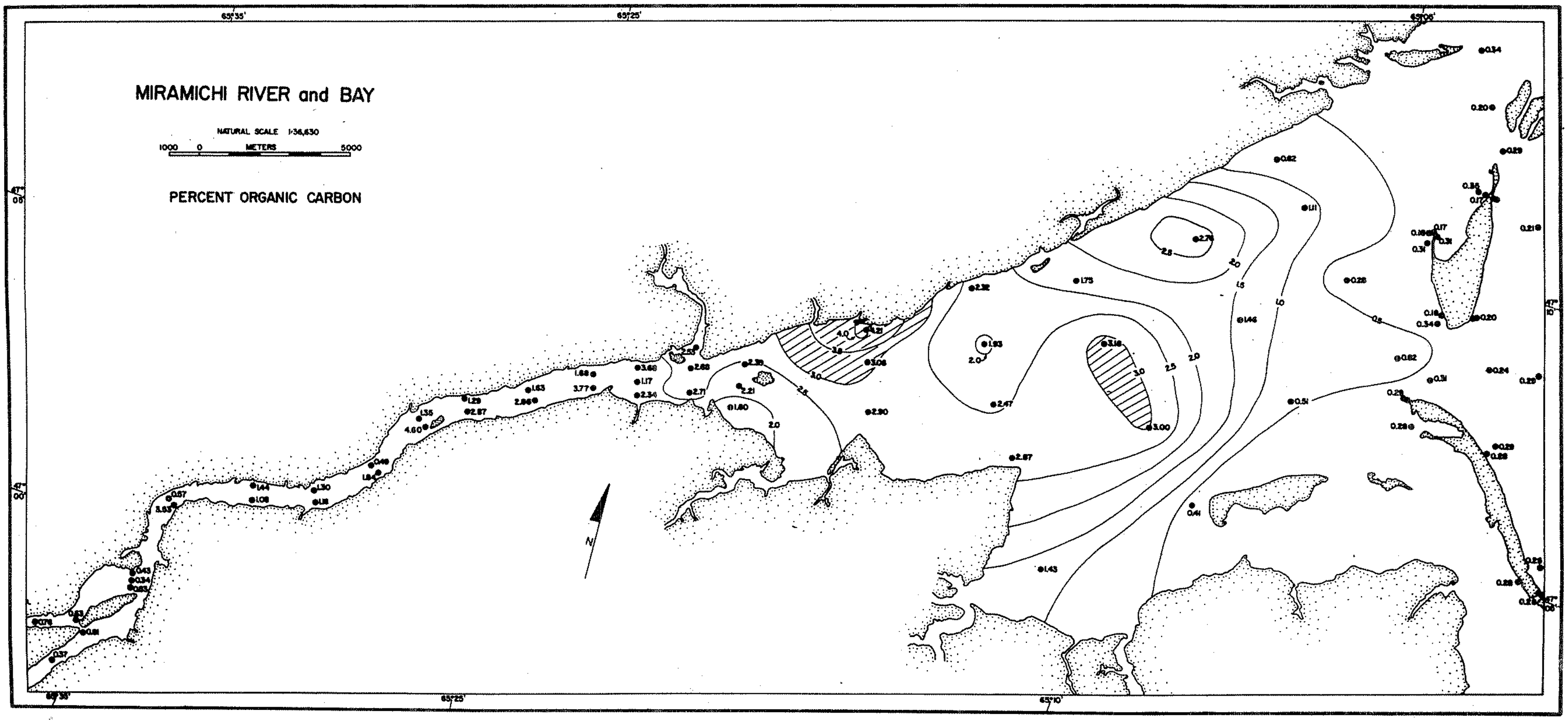

Fig. 4 Percent Organic Carbon, Miramichi River and Bay

a total organic content of 0.3 to 7.8 percent. The average organic carbon content is 1.31 percent and the average organic content is 2.2 percent. Highest organic carbon contents (to 4.60 percent) are present in river sediments of silty-clay or sandy-silt whereas lowest values are recorded in sediments associated with the baymouth barriers. This may be attributed to the winnowing of fines (silts and clays) from the baymouth environment. Values in the Miramichi estuary are comparable, on the average, to those in other positive or normal estuarine environments. Much of the organic material in the river is attributed to high concentrations of land and marine plant remains.

The calcium carbonate content (Fig. 5) in bottom sediments is also highly variable. Highest values are recorded in the river and central bay areas and lowest values are recorded in sediments on and adjoining the baymouth barriers. Highest calcium carbonate values are recorded in fine silty-clays or silty-sands with abundant whole shells, or shell debris. (e.g. 11.56 percent, Station 39, 32.03 percent, Station 90). The major portion of the river and inner bay area have calcium carbonate values greater than 3.00 percent whereas the outer bay and areas adjoining baymouth barriers are characterized by less than 2.00 percent calcium carbonate. Foraminifera are minor contributors to the total calcium carbonate content of the sediments. However, large aggregations of mussels (*Mytilus edulis*) are present in sediments with higher calcium

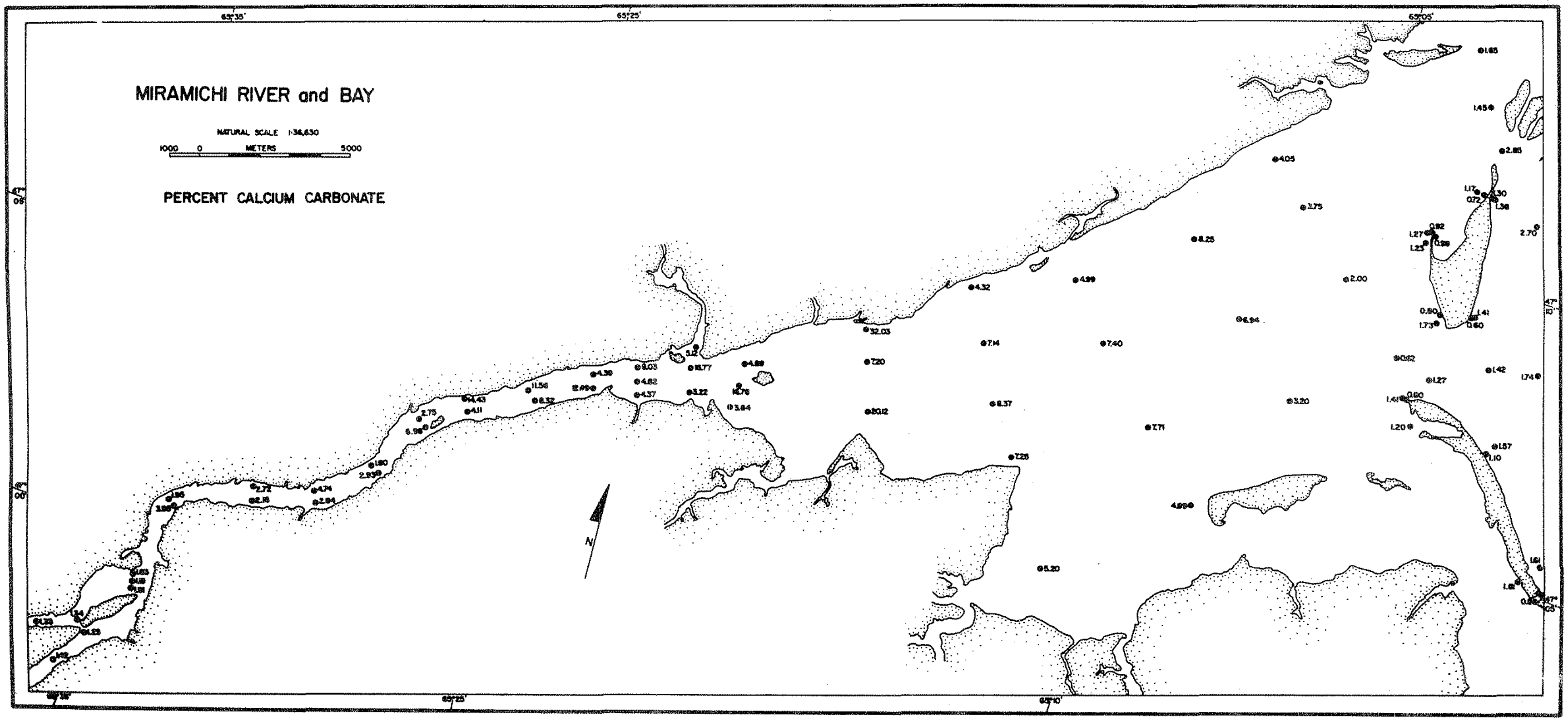

Fig. 5 Percent Calcium Carbonate, Miramichi River and Bay

carbonate content. These organisms are also responsible for alterations to sedimentation patterns in shallow waters and tidal flats in the Miramichi estuary.

The majority of the analyzed sediment samples have a Median Diameter expressed as ϕ units in the 1.2 to 3.0 range. These sediments are essentially fine to medium sands. The finest sediments (3.8 - 6.0) ϕ are found in deeper, quieter portions of the river channel or in protected, deeper water areas of the central bay. Cross-sections in the lower river and inner bay show highest MDϕ in the central areas away from the shore. Stations adjoining the barriers are much more variable but have higher MDϕ values in sediments adjoining the north shore than those on the south. MDϕ shows a progressive increase in sediment size from the headwaters of the river to the outer bay (Fig. 13). Sediments in a longitudinal profile in the southern area of the bay become progressively coarser (lower MDϕ values), towards the baymouth barriers; whereas, a more irregular pattern towards finer sediments (higher MDϕ values) develops in a northern longitudinal section (Fig. 15). These features are related to current patterns and sediment distribution in the respective areas.

Hydrogen-ion (pH) values within the sediments at the sediment-water interface ranged from 6.2 to 7.0 during the sampling period. These values vary both daily and seasonally. The hydrogen-ion concentration was highest during midday and lowest during dawn or dusk at the same station. However, recorded variations were less than 0.2 pH. Beckman pH readings as low as 5.0 have been recorded immediately below the surface sediment layer. The presence of tectinaceous or pseudochitinous inner linings of many calcareous Foraminifera attests to the acidic nature of sediments immediately below the surface "life zone". The top two centimetres, or less, of surface sediment is probably the only reasonable representative of the biocoenosis existing in a particular environment.

Oxidation-reduction (Eh) readings indicate oxidizing conditions at, and immediately above the sediment-water interface at most stations. Commonly, just below this horizon, reducing conditions persist. It is unlikely, therefore, that living Foraminifera can survive for long periods below the top few centimetres of surface material.

FORAMINIFERA

General

The foraminiferal fauna of the Miramichi estuary is eurybathic. It is composed of thirty-one foraminiferal species and four species of Thecamoebina. The latter are found in Miramichi River waters of low salinity. The estuary is characterized by two foraminiferal faunas: a _Miliammina_ fauna, prolific in the river, in association with Thecamoebina such as _Centropyxis arenatus_, _Difflugia oblonga_, _Difflugia capreolata_ and _Pontigulasia compressa_, which inhabits waters with salinities less than 20.00°/oo, and an _Elphidium_ fauna, prolific in the central bay and adjoining the baymouth barriers, composed of _Buccella frigida_, _Eggerella advena_, _Elphidium incertum_ "complex", _E. margaritaceum_, _E. orbiculare_, _E. subarcticum_ and other subordinate species which inhabits waters with salinities between 20.00°/oo and 29.00°/oo. Low river inflows in 1965 with attendant higher salinities enabled _Elphidium incertum_ and _E. orbiculare_ to migrate further upstream than in 1964 when the season was characterized by higher than average river inflow.

Population Distributions

Foraminiferal populations (Fig. 6) are variable both in total numbers and species composition throughout the estuary. Total populations are lowest in the river, and areas on and immediately adjoining the baymouth barriers.

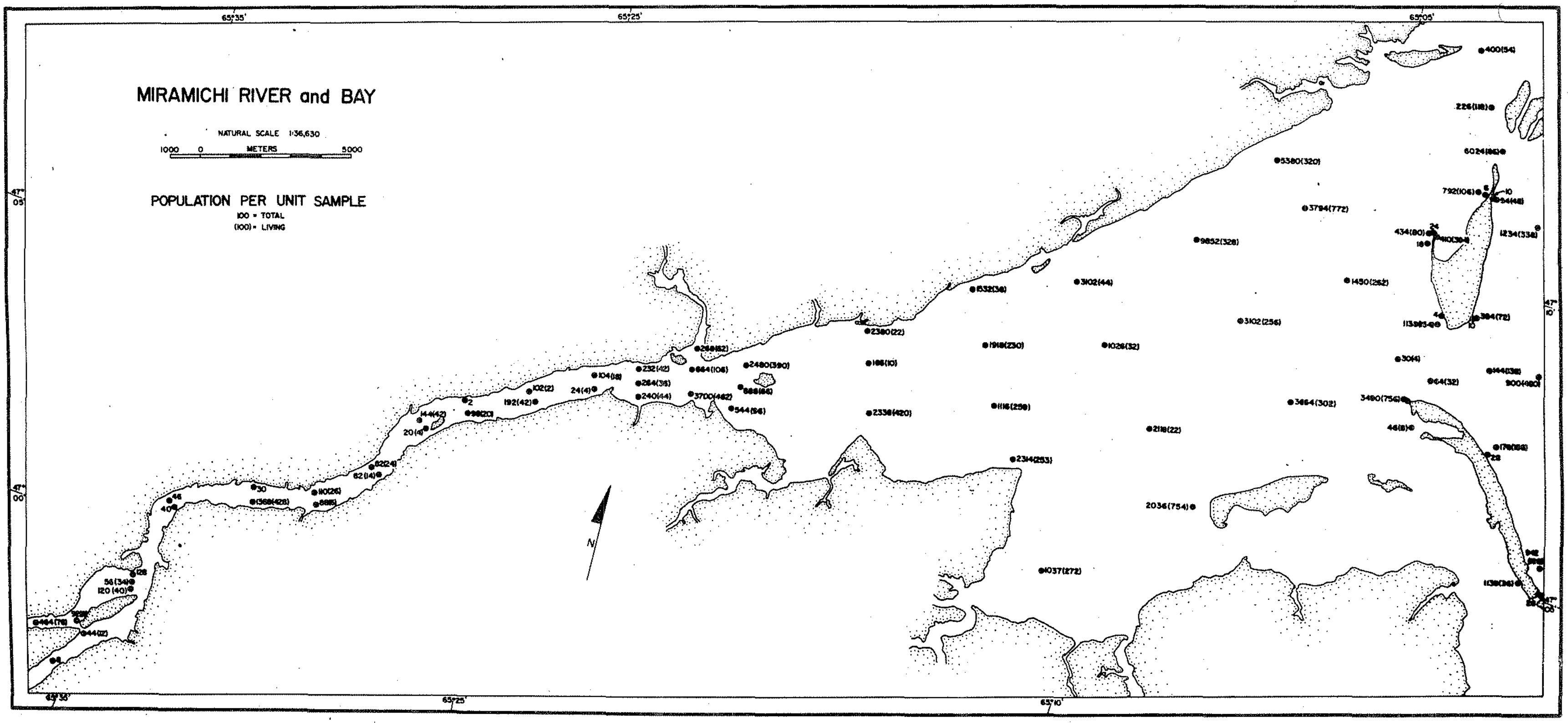

Fig. 6 Population Per Unit Sample, Miramichi River and Bay

Highest frequencies of species and specimens are located in central bay stations. Total populations vary from 2 per unit sample (10 cm x 10 cm x 1 cm), (200 per square metre) at Station 37 to 9,852 per unit sample (985,200 per square metre) at Station 95.

Living populations are fewer in both numbers and species than are dead populations. However, living species are represented by dead forms throughout the bay, an indication that dead populations are representative of living foraminiferal distribution. The foraminiferal populations have no living representatives at numerous stations (see Fig. 6). The living population varies from four specimens per unit sample (400 per square metre) at Station 82 to 772 specimens per unit sample (77,200 per square metre) at Station 84. Areas with large total populations are generally represented by largest living populations, however, some stations (e.g. 77, 87, 89, 90) with large total populations have few living Foraminifera.

Foraminiferal and Thecamoebina populations in Miramichi River are small compared to the central bay area. This assemblage is composed almost entirely of species characterized by arenaceous or pseudochitinous tests. Miliammina fusca dominates, and is commonly the only foraminiferal species present and Difflugia capreolata and D. oblonga are the most abundant species of Thecamoebina. Populations in the river average 160 specimens per unit sample.

Foraminiferal populations of the inner and central bay environment are composed almost entirely of calcareous specimens. Elphidium incertum "complex", Elphidium margaritaceum and Elphidium orbiculare represent up to 90 percent of the total population. Living populations are extremely variable in distribution. Total populations average 1,420 specimens per unit sample for the bay area. This represents almost ten times the populations occurring in the river environment. There are 172 specimens per unit sample living in the bay environment compared to 35 per unit sample living in the river. The Miramichi estuary supports an average living foraminiferal population of 127 per unit sample or 12,700 per square metre of bottom surface area.

Foraminiferal-Environmental Relationships

Foraminiferal distributions and their relationship to environmental parameters were studied in 5 major profiles across the bay and 3 major longitudinal profiles, one in the river and two in the bay. These are discussed systematically from the headwaters to the mouth of the estuary (Figs. 7-15).

Low salinity in the river (less than 20.00^{o}/oo) is probably one of the main factors in limiting the fauna to an arenaceous euryhaline assemblage of Miliammina fusca and various Thecamoebina. Salinities throughout the estuary are in the brackish water regime with polyhaline characteristics. The foraminiferal fauna is eurybathic and well suited to this

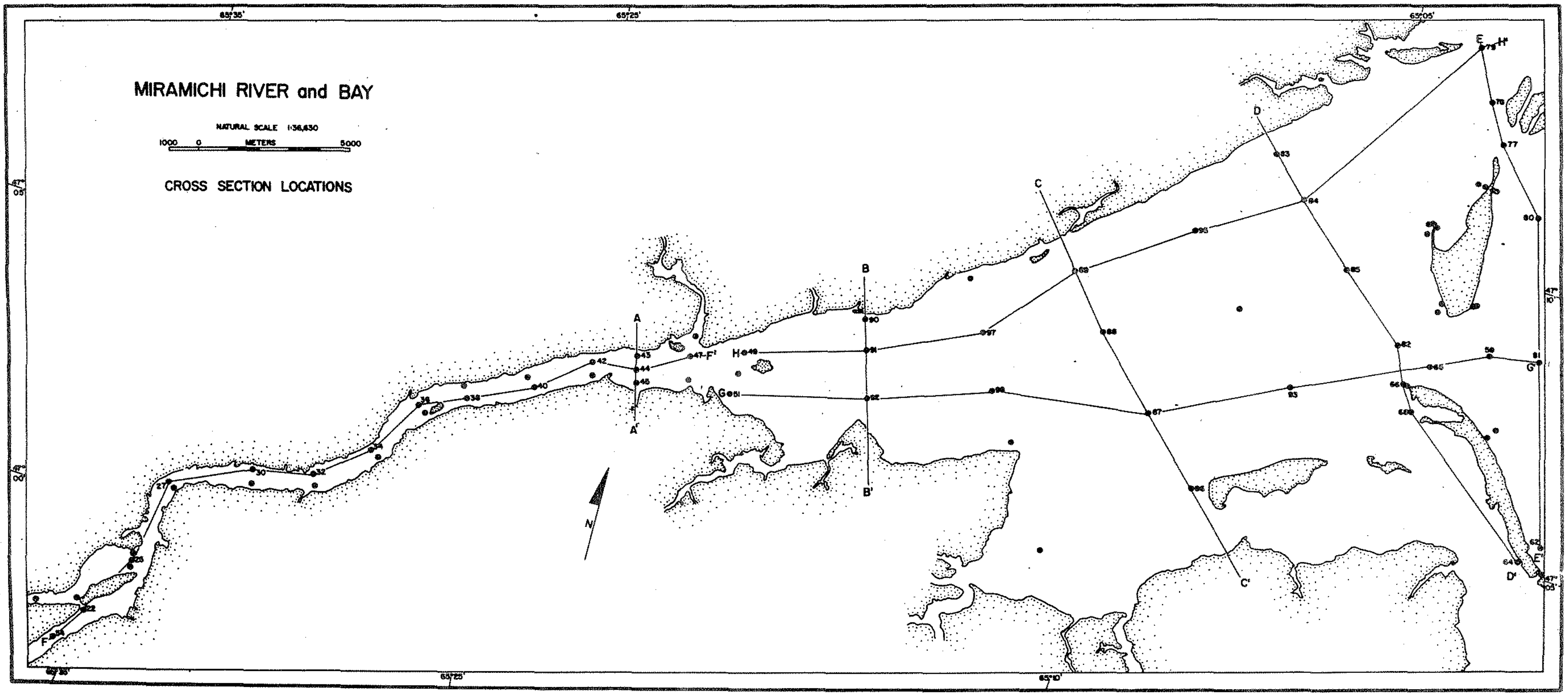

Fig. 7 Cross-Section Locations, Miramichi River and Bay

type of environment. All species present are capable of withstanding marked variations in temperature, salinity, depth, substrate and water turbidity. Foraminifera living in the estuary must be capable of withstanding both diurnal and seasonal temperature changes of 10^{o}C. to 15^{o}C. and be tolerant of temperatures as low as 0^{o}C. and as high as 20^{o}C.

Cross-section A-A' (Figs. 7, 8) is situated at the junction of the river mouth and inner bay. Salinities across the profile range from 20.62^{o}/oo - 20.89^{o}/oo. Temperatures recorded during the sampling program ranged from 8^{o}C. in early June and late October to 19^{o}C. in July and September. Station 43 is at 7 metres, Station 44 at 4 metres, and Station 45 at 1 metre depths. The environment supports approximately 20 percent of the total foraminiferal and Thecamoebina fauna.

The calcareous-hyaline fauna represented by Elphidium incertum "complex" dominates the assemblage at Station 43. This area is characterized by greatest depth, and highest organic carbon and calcium carbonate content in the profile.

The number of foraminiferal tests per unit area is consistent (232-264) throughout the environment. Genera and species vary, but are most abundant in the central area of the profile.

Arenaceous and pseudochitinous tests and species dominate the faunal assemblage at Station 44. Miliammina fusca,

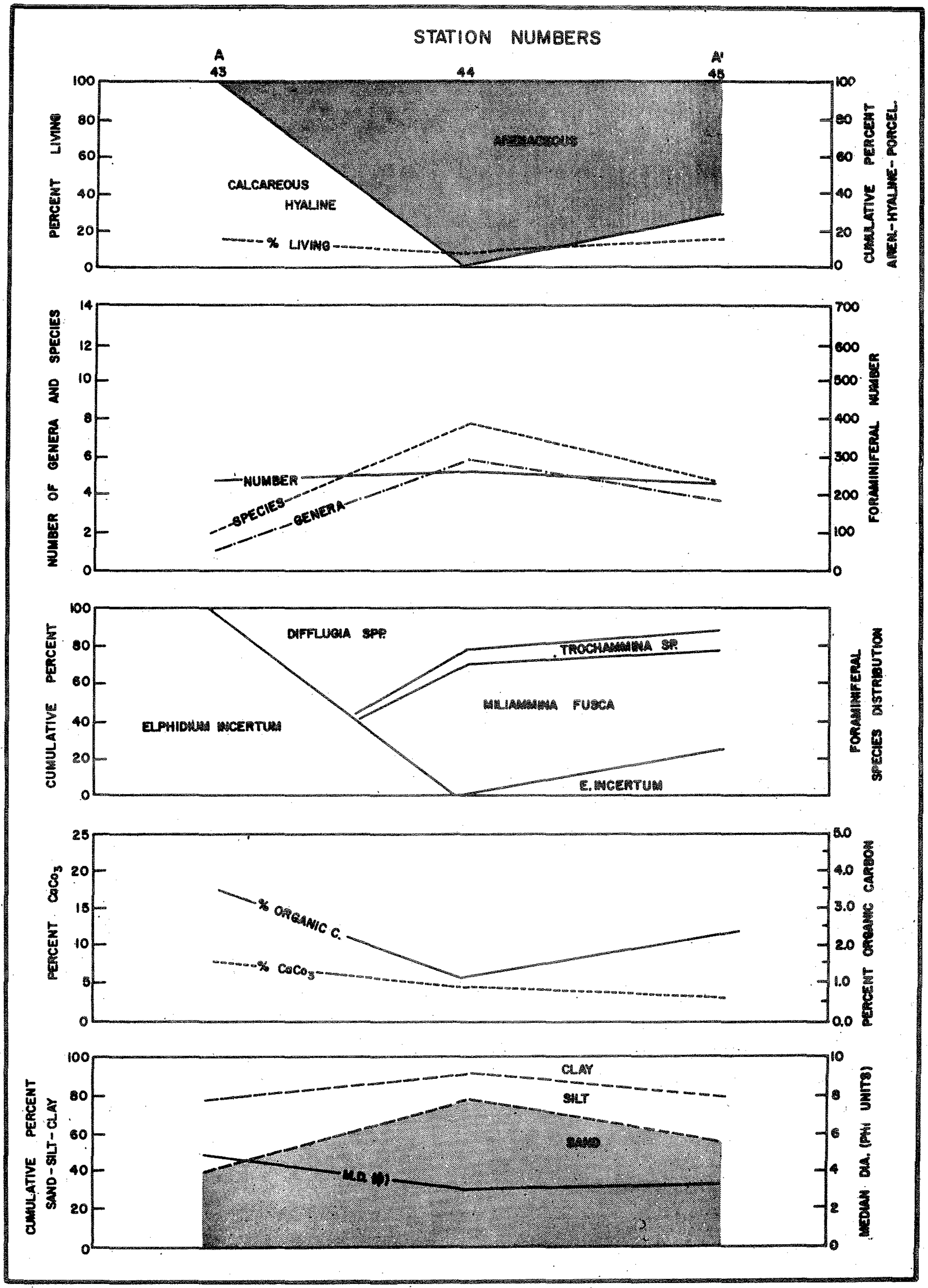

Fig. 8 Cross-Section A-A', Miramichi River

Difflugia capreolata, and D. oblonga are most abundant. Arenaceous tests are also most prolific at Station 45. However, calcareous tests are present, and species of Trochammina become more abundant. Organic carbon and silt-clay content increase at this station, but the calcium carbonate content decreases and does not reflect the calcareous foraminiferal content.

Calcareous-hyaline test distribution shows a relationship to silt-clay content and organic carbon content of the bottom sediment. Arenaceous and pseudochitinous tests predominate in sandy sediments with lower organic carbon content. The sediment textures are also reflected in the median diameter (ϕ), and there is an apparent relationship between high MDϕ and the distribution of Elphidium incertum "complex".

Cross-section B-B' is located in the inner bay (Figs. 7, 9). Salinities range from 22.62‰ to 22.89‰. Temperatures recorded during the sampling period varied from 11°C. to 19°C. Nearshore stations have average depths of 2 metres, whereas the central area has average depths of 7 metres. The environment supports from 1 percent to 18 percent of the total foraminiferal population.

A prolific calcareous-hyaline fauna is found at the nearshore stations, but these species occur in smaller numbers at the deeper central station. Highest numbers of foraminiferal tests are present at the shallower nearshore stations,

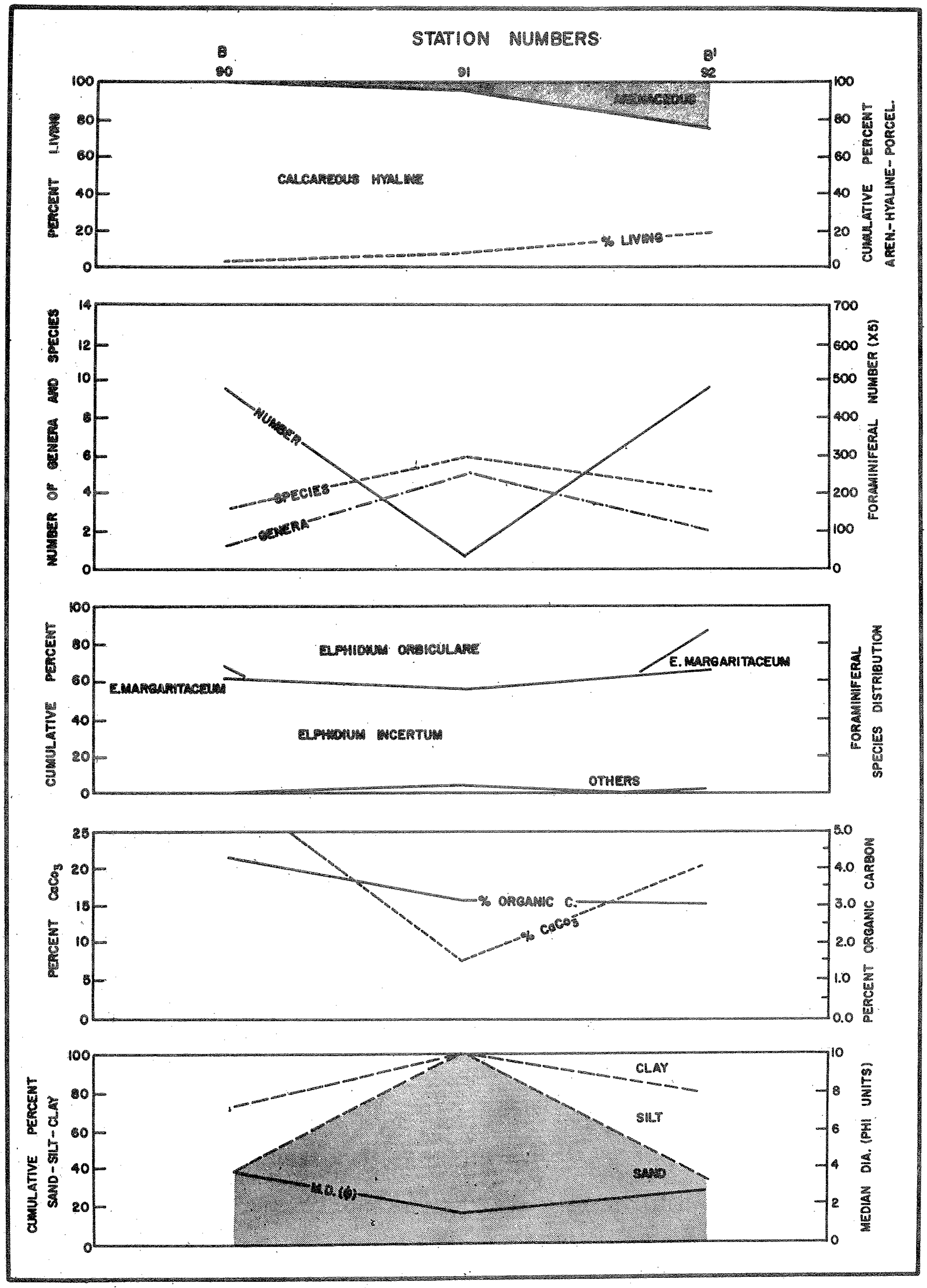

Fig. 9 Cross-Section B-B', Miramichi Bay

but the number of genera and species increase in the central area. Elphidium incertum "complex" and Elphidium orbiculare dominate the foraminiferal fauna throughout the section.

Calcareous-hyaline test distribution shows a relationship to calcium carbonate and silt-clay content of the bottom sediments. These values reach a maximum at the nearshore stations. The organic carbon content is greater than 3 percent and shows a decrease from north to south in the section. Increase in organic carbon is not related to an increase in silt-clay content or an increase in arenaceous tests. Sediment textures are reflected in MDϕ and there is an apparent relationship between high MDϕ and the distribution of Elphidium incertum "complex" and Elphidium orbiculare.

Cross-section C-C' (Figs. 7, 10) is located in the central bay area. Salinities from 24.10‰ to 25.14‰ and temperatures from 10°C. to 18°C. were recorded during the sampling program. They were dependent on depth of water, tidal cycle and season in which the values were recorded. Depths range from 2 metres to 7 metres. The percentage of the total fauna living decreases from south to north.

A prolific calcareous-hyaline fauna characterizes the environment. Arenaceous tests are present throughout, but in subordinate numbers. The number of foraminiferal tests shows a general increase towards the north (Station 89), whereas genera and species decrease in a similar manner.

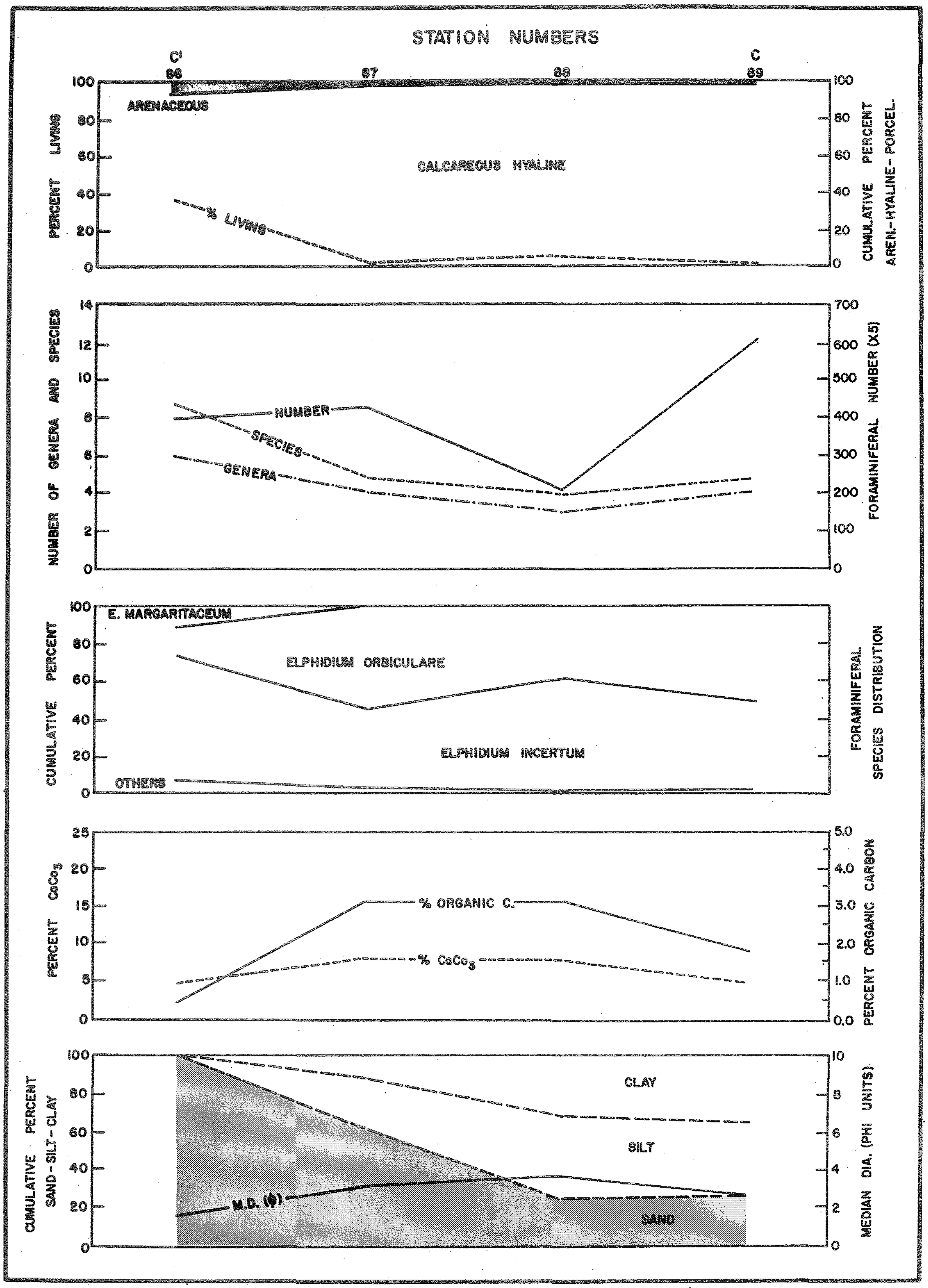

Fig. 10 Cross-Section C-C', Miramichi Bay

Elphidium incertum "complex" and E. orbiculare are dominant faunal constituents throughout the section.

Calcium carbonate and organic carbon content is highest in the deeper central bay stations. There is a general relationship between these values and higher silt-clay content in the bottom sediments. Sediments with higher sand content in shallow waters have lower organic carbon and calcium carbonate content. There is a general correlation between the calcium carbonate content in the sediment and the foraminiferal parameters. Regions of high foraminiferal number have high calcium carbonate contents. Foraminiferal assemblages are composed of calcareous specimens in these areas and are probably one of the reasons for the high calcium carbonate content rather than occurring as a result of it.

Sediment textures are reflected in MDϕ, but unlike the previous sections the relationship between high MDϕ and the distribution of Elphidium incertum "complex" and E. orbiculare is not apparent. The highest percentage of living Foraminifera occurs in a sandy substrate (low MDϕ). Arenaceous tests are also most abundant in this environment. Genera and species are most abundant in sand substrates, but the number of foraminiferal tests varies. High concentrations are present in both sand and silty-clay substrates.

Cross-section D-D' (Figs. 7, 11) is located just inside

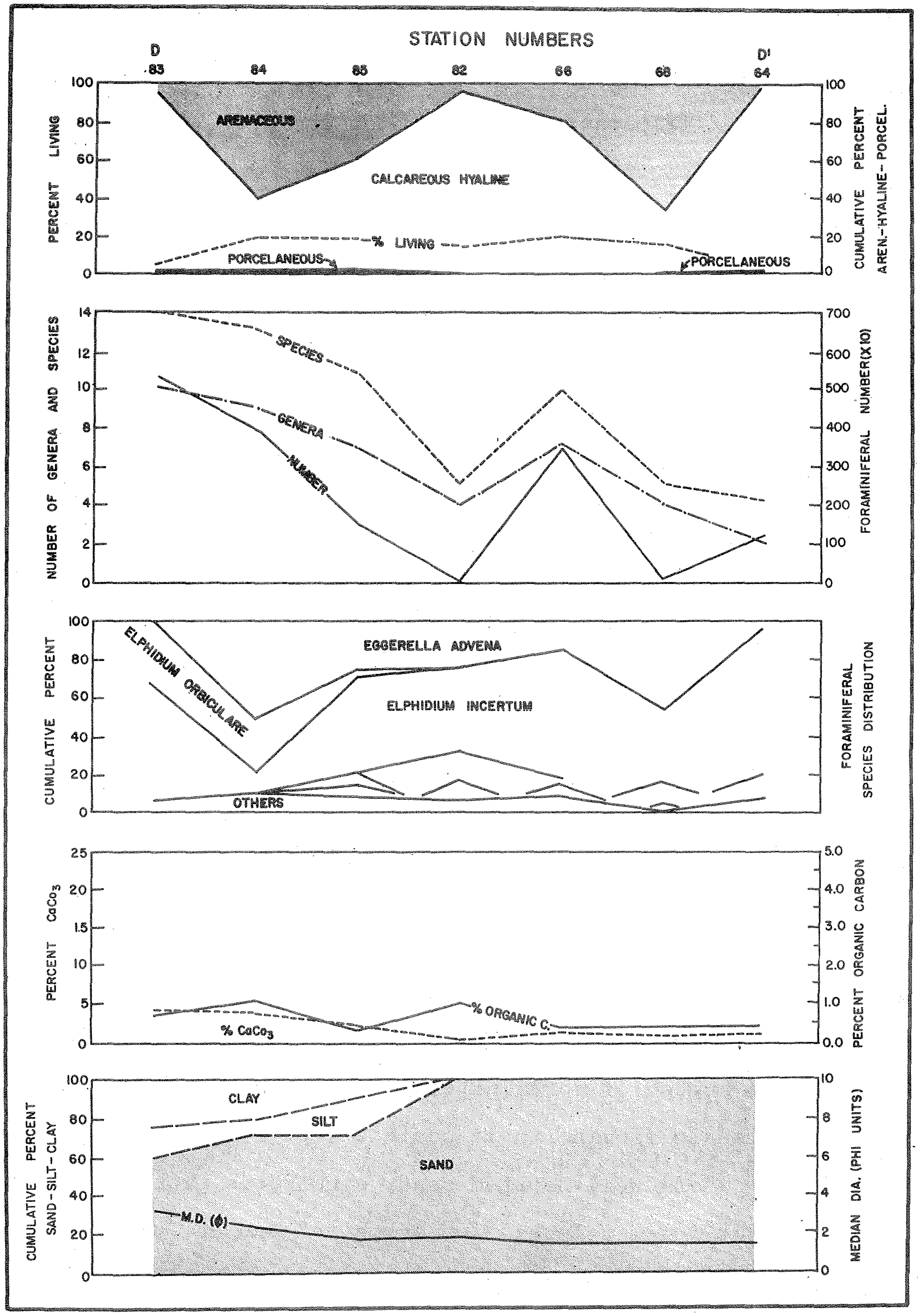

Fig. 11 Cross-Section D-D', Miramichi Bay

the barrier islands and sand dunes at the mouth of the bay. Salinities range from 27.17°/oo (Station 83) to 28.18°/oo (Station 64). Temperatures recorded during the sampling period ranged from 10°C. to 20°C. and were dependent on water, depth, tidal cycle and season. Depths vary from 4 metres (Station 83) to 8 metres (Station 82) in the northern and central bay areas, to 1 metre at the extreme south (Station 64).

Porcelaneous tests are significant in the estuary for the first time. In this section, arenaceous forms are most abundant in areas adjoining the baymouth barriers, and are significant throughout the section. Calcareous-hyaline tests are prolific at all stations, but more so in the main channel to the Gulf of St. Lawrence. Elphidium incertum "complex" remains a dominant member of the faunal assemblage but E. orbiculare is replaced by Eggerella advena at most stations. Highest Eggerella advena concentrations are also in areas with reduced numbers of Elphidium incertum "complex".

The environment supports from 1 percent to 20 percent of the total foraminiferal population. Larger living populations are found in the central stations, although there is a general decrease in living forms in the north and south. The number of foraminiferal tests, genera, and species decrease from north to south except at stations 66 and 64. These well-aerated sandy substrates probably contain large foraminiferal "lag deposits" and act as a dumping ground for specimens transported from shallower environments. The most diverse foraminiferal assemblages are found in sediments in the main channel of the estuary.

Organic carbon and calcium carbonate content is low and there is no apparent correlation between these and foraminiferal parameters. The sandy substrates at most stations are reflected in the low calcium carbonate and organic carbon content. These substrates show no particular relationship to foraminiferal distribution. MDϕ, although reflecting the sediment texture, shows no particular relationship to species distribution.

Cross-section E-E′ (Figs. 7, 12) is situated at the mouth of the bay, seaward from the baymouth barriers. Salinities are consistent at 28.11^{o}/oo to 28.18^{o}/oo. Temperatures recorded during the sampling period ranged from 10^{o}C. to 18^{o}C. Depths vary from 4 metres (Stations 79 and 62) to 14 metres (Station 77).

Porcelaneous tests are present through most of the section, but are most abundant in the southern half. Arenaceous tests are also significant and are most abundant at Stations 78 and 62. These areas are characterized by sandy substrates and low MDϕ. Calcareous hyaline tests are prolific at all stations. Elphidium incertum "complex" is the dominant member of the faunal assemblage, which is more diverse than assemblages at stations inside the baymouth barriers. Eggerella advena and Elphidium orbiculare are present as

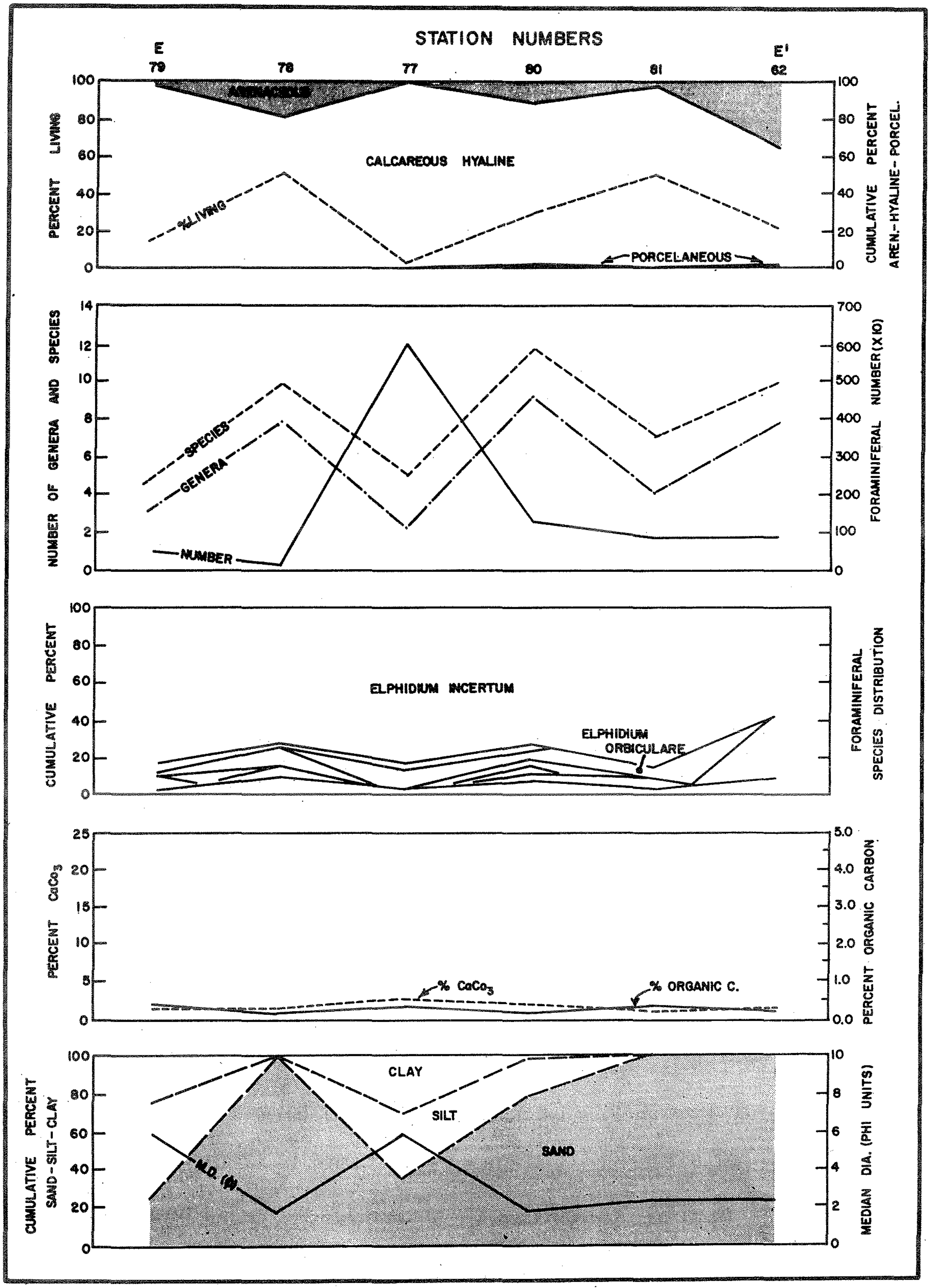

Fig. 12 Cross-Section E-E', Miramichi Bay

subordinate members of the assemblage.

The environment supports from 17 percent to 53 percent of the total foraminiferal populations. Largest living populations are present in the central area of the section, whereas percentage of Foraminifera living is more irregular. The largest total population (6,023 per unit sample) at Station 77 has few (86 per unit sample) living forms. The number of foraminiferal tests, genera, and species distribution is irregular. However, the largest number of tests, and fewest number of genera and species are in the deepest water in a silty-clay substrate (Station 77).

There is no apparent correlation between organic carbon and calcium carbonate content and foraminiferal patterns. Percentages of organic carbon and calcium carbonate are low, less than 5 percent calcium carbonate and less than 0.5 percent organic carbon, at all stations. Slight increases are noted in the finer textured silty-clay sediments. However, this is not uniform throughout the area. The variation in substrate texture is reflected in differences in sand-silt-clay ratios and MDϕ of the sediments. There is an apparent correlation between a high MDϕ and high silt-clay values and the large numbers of Elphidium incertum "complex" at Station 77. Although Elphidium incertum "complex" dominates the faunal assemblage in other areas, it is not as prolific as at Station 77. Large total populations and low numbers of living specimens may indicate that Station 77 is an area of deposition for tests transported from nearby shallow-water environments.

Longitudinal profile F-F′ (Figs. 7, 13) extends from the forks to the mouth of the Miramichi River. Salinities range from 7.86°/oo to 20.89°/oo. Temperature recorded during the sampling period ranged from 8°C. to 20°C. It is anticipated that temperatures in the river approach 0°C. during winter freeze-up. Depths are irregular along the profile, but range from 1 metre to 12 metres.

The Foraminifera and Thecamoebina faunas are almost entirely composed of arenaceous and pseudochitinous species. Calcareous-hyaline forms are more abundant as the river mouth is approached, but their regional distribution is complex. The percentage of the total populations living is high at Station 25 (65 percent), but shows a general decrease from Station 36 to the mouth of the river. Populations of both dead and living forms are low at all stations. Genera and species distributions are irregular but are generally low (less than 6). The number of foraminiferal tests increases sharply at the mouth of the river.

Miliammina fusca is the dominant foraminiferal species in most of the river. Centropyxis arenatus, Difflugia capreolata and D. oblonga are more abundant in sediments near the headwaters and become subordinate as the mouth of the river is approached. Elphidium incertum "complex" and

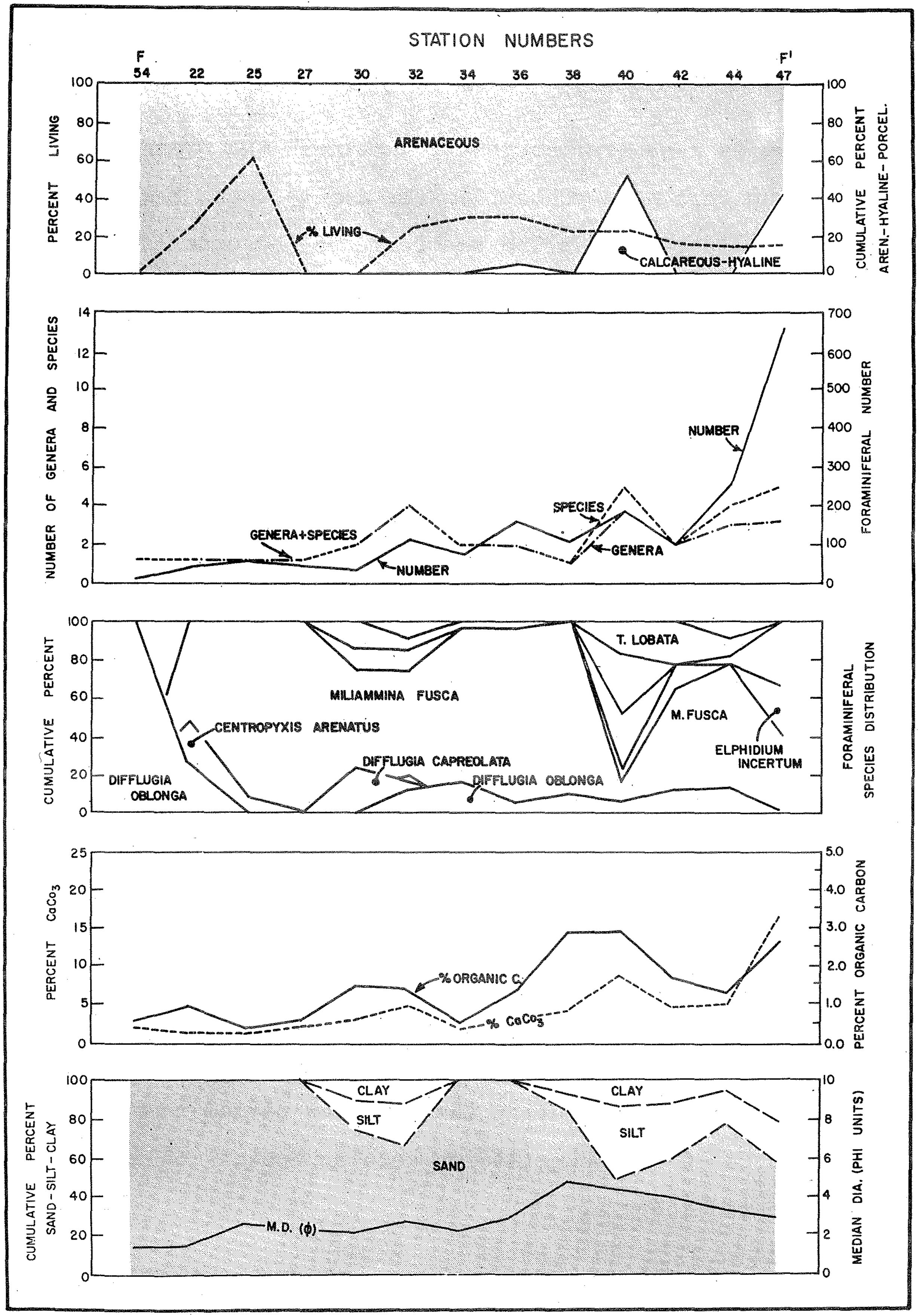

Fig. 13 Longitudinal Section F-F', Miramichi River

E. orbiculare are irregularly distributed at the mouth of the river.

There is a general correlation between the organic carbon and calcium carbonate content in the sediment and the distribution of calcareous-hyaline species. An increase in these parameters reflects the increase in the calcareous forms. Highest concentrations of organic carbon and calcium carbonate are also present in the finer textured silts and clays. The sedimentary texture is also reflected in the median diameter (ϕ) of the sediments. Regions with higher silt-clay, organic carbon and calcium carbonate content are also regions of high foraminiferal number.

These parameters are probably significant in limiting foraminiferal distribution in the river. However, salinity is probably the major factor in limiting penetration of the calcareous species farther up the river.

Longitudinal profile G-G' (Figs. 7, 14) is located in the southern half of the study area and extends from the inner bay to beyond the baymouth barriers. Salinities range from 20.89°/oo to 28.18°/oo. Depths are also variable ranging from 2 metres (Station 51) to 14 metres (Station 59). Temperatures recorded during the sampling period ranged from 9°C. to 19°C. Temperatures were dependent on water depth and tidal cycle.

Calcareous-hyaline Foraminifera are dominant throughout

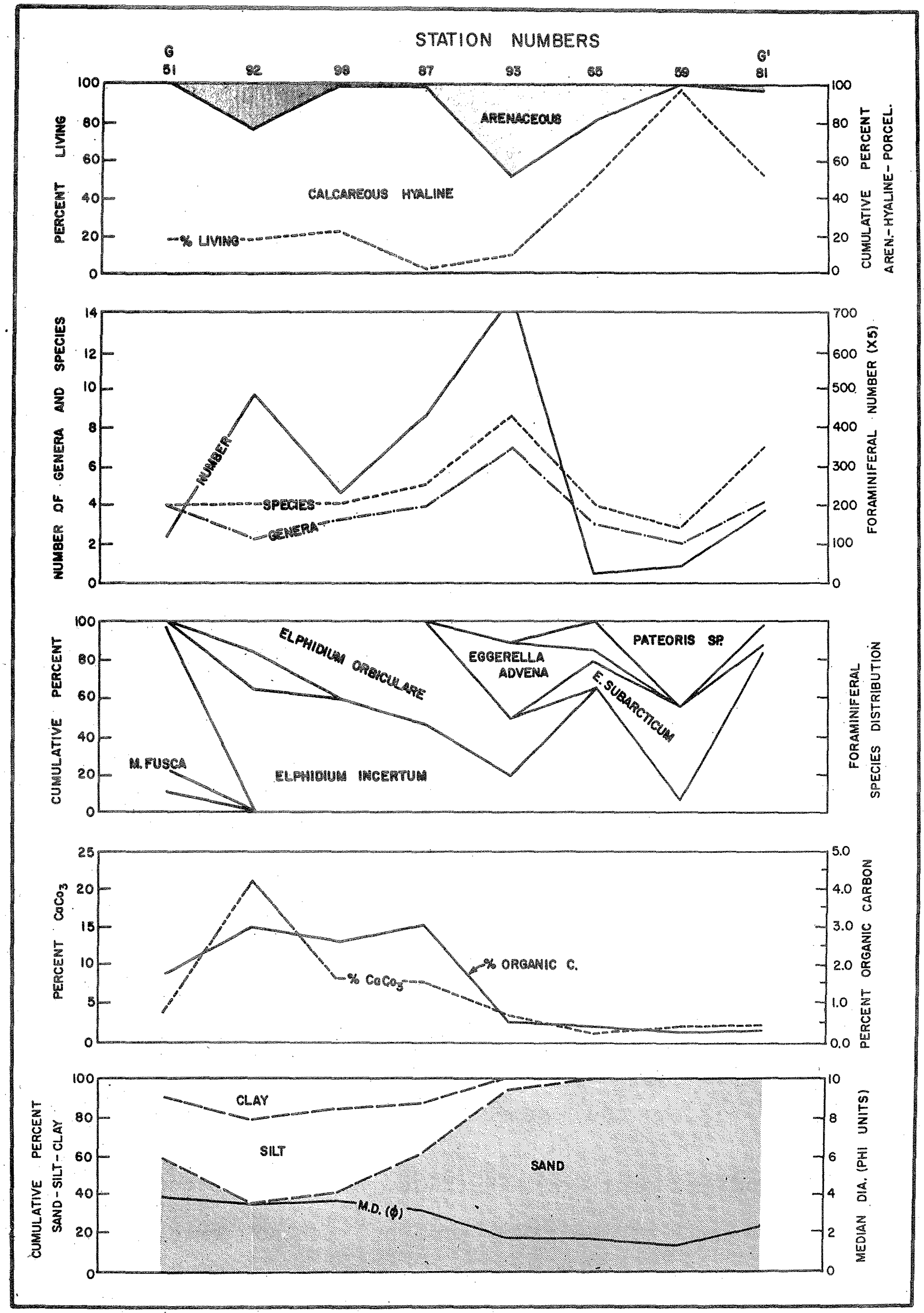

Fig. 14 Longitudinal Section G-G', Miramichi Bay

this profile. Increases in arenaceous tests result from an increase in specimens of *Eggerella advena*. Genera, species, and number of foraminiferal tests are highest at Station 93. Arenaceous tests are also most prolific at this station located in 7 metres of water on a predominantly sandy substrate. Station 59 has the largest percent of the total fauna living (98 percent) in the section. However, both total and living populations are low (144 and 138 respectively). *Elphidium incertum* "complex" and *E. orbiculare* are the most prolific species in the area. They dominate the fauna in the inner bay, but become less dominant as the baymouth barriers are approached. Here *E. orbiculare* is replaced by *E. subarcticum*.

Organic carbon and calcium carbonate content is highest in sediments with high percentages of silt and clay in the inner bay environment. The high calcium carbonate content is reflected in the high calcareous-hyaline test content in the silty-clays of the inner bay, but is more irregular and decreases in sands adjoining the baymouth barriers. Organic carbon content is also related to silt-clay content in this environment. High concentrations are found in silts and clays and low concentrations are found in sandy substrates. Substrate characteristics are also reflected in the Median Diameter (ϕ) of the sediments.

Longitudinal profile H-H′ (Figs. 7, 15) is located in the northern half of the study area and extends from the inner bay to just inside the baymouth barriers. Salinities

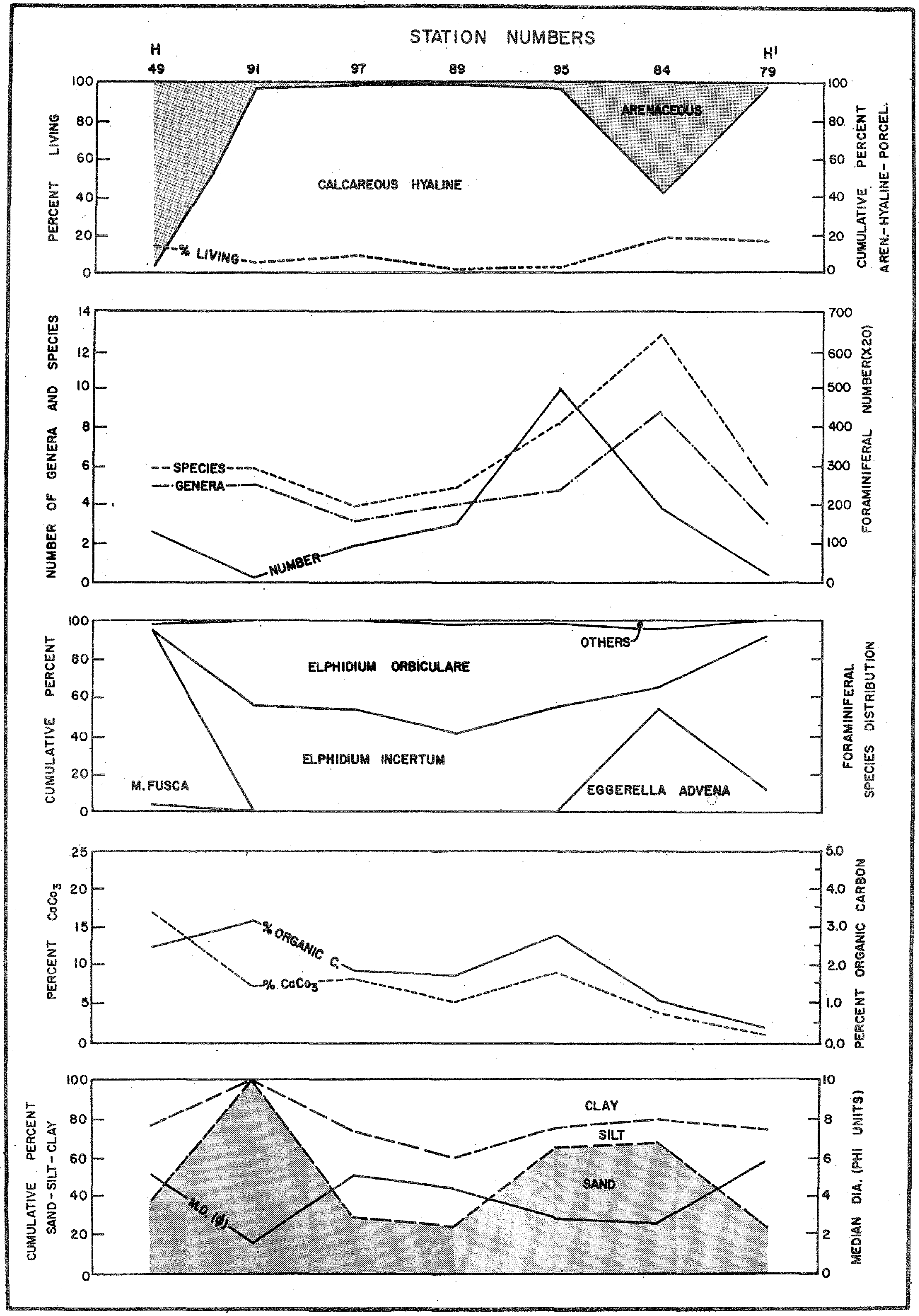

Fig. 15 Longitudinal Section H-H', Miramichi Bay

range from 20.24°/oo to 28.11°/oo. Depths range from less than 1 metre (Station 49) to 7 metres (Stations 89-91). Depths are relatively uniform, except Station 49, from 5 to 7 metres, throughout this section. Temperatures which were dependent on water depth and tidal cycle, ranged from 9°C. to 19°C. during the sampling period.

Calcareous-hyaline tests dominate the fauna except at two stations. Miliammina fusca represents 98 percent of the fauna at Station 49 and Eggerella advena represents 50 percent of the fauna at Station 84. Elphidium incertum "complex" and E. orbiculare dominate the fauna throughout the remainder of the section. Genera, species and number of foraminiferal tests increase from the inner bay (Station 91) towards the baymouth barriers (Station 84), but decrease in areas adjoining the barriers (Station 79). Station 95 has the largest total population (9,852) for the entire estuary. The fauna is composed almost entirely of Elphidium incertum "complex" and E. orbiculare, calcareous-hyaline species. This is reflected in the high calcium carbonate content in sediments at this station. However, highest calcium carbonate content is recorded at Station 49 in sediments with a high silt-clay ratio, but with a predominantly arenaceous fauna. Mytilus edulis, a common mussel, is prolific at this station and may explain the high calcium carbonate content in the bottom sediments.

Highest concentrations of foraminiferal specimens are found in sediments with higher sand and silt content, whereas lowest numbers are found in both sand and silty-clay substrates. Substrate characteristics are reflected in the Median Diameter (ϕ) of the sediments. Both organic carbon and calcium carbonate percentages are lowest in sediments adjoining the baymouth barriers and highest in the inner bay environment regardless of sediment type and water depths.

Cross-sectional and longitudinal profiles indicate the water chemistry, salinity in particular, is significant in limiting the Miramichi River bottom waters to an arenaceous and pseudochitinous fauna composed of *Miliammina fusca*, *Centrophyxis arenatus*, *Difflugia capreolata*, *D. oblonga* and *Pontigulasia compressa*. This is supported by the fact that species of *Elphidium* penetrated further upstream with attendant higher salinities during different years.

Depth control in this shallow water estuary is significant in that waters are continually agitated by winds, tides and currents. Water temperature is related to the climatic and tidal cycles. Depth, temperature and salinity are significant in that the foraminiferal fauna is limited to extremely tolerant eurybathic forms.

Calcium carbonate and organic carbon distribution is complex. They are usually highest in silts and clays with subordinate sand content. These areas are generally environments maintaining a large calcareous-hyaline fauna composed principally of Elphidium incertum "complex" and Elphidium orbiculare. Texture of bottom sediment, reflected in the median diameter is dependent on current patterns and bottom topography. Total populations of benthonic species are much larger than those of living benthonic species. However, living specimens present at each station show a distribution pattern similar to the dead populations.

Total populations are extremely variable between any given station. They are low in the river and areas on and adjoining the baymouth barriers. They are extremely high in the central bay area, with the northern portion having larger populations than the southern and centre sections respectively. Percentage of living populations and live-total ratios are highest immediately outside the baymouth barriers and in various sections of the river. However, the central bay area supports larger living populations which are masked by the large dead populations in this environment.

Living-Total Foraminiferal Ratios

The distribution of living and dead foraminiferal tests shows fairly good correlation for all species. As pointed out by Phleger (1955) this demonstrates either no post-mortem distribution of dead tests or that any transportation affects both living and dead populations. Total population counts are affected by rates of sedimentation and current rates and current patterns in the Miramichi estuary. The patterns for density and areal occurrence of living Foraminifera are irregular and complex. The areas of maximum populations of living Foraminifera generally do not coincide with areas of maximum dead populations. Commonly, it is just the opposite, large dead populations are represented by few living specimens. However, in the Miramichi estuary, the living specimens are similar to those in the dead assemblage. Walton's (1955) and Bartlett's (1965a) conclusions that maximum living populations generally do not coincide with areas of maximum dead populations is substantiated by the present study.

In the present study highest living-total ratios (Fig. 16) are present just outside the southern barrier and inside the barriers to the north. These ratios vary from .50 to .96. The entire southern section of Miramichi Bay and the northern section just inside the baymouth barriers are characterized by intermediate values, .17 to .37. The remainder of the bay, principally the northern half, is characterized by low values, .01 - .12. Values in the Miramichi River are irregular and their distribution is variable. However, highest values are recorded on the inner slope through the extent of the river. Values in the river are comparable with those in the southern section of the bay.

Walton (1955) in Baja, California, Phleger (1955) in Mississippi Delta, Uchio (1960) in San Diego, California, and Bartlett (1964b, 1965a) in Atlantic Provinces have used

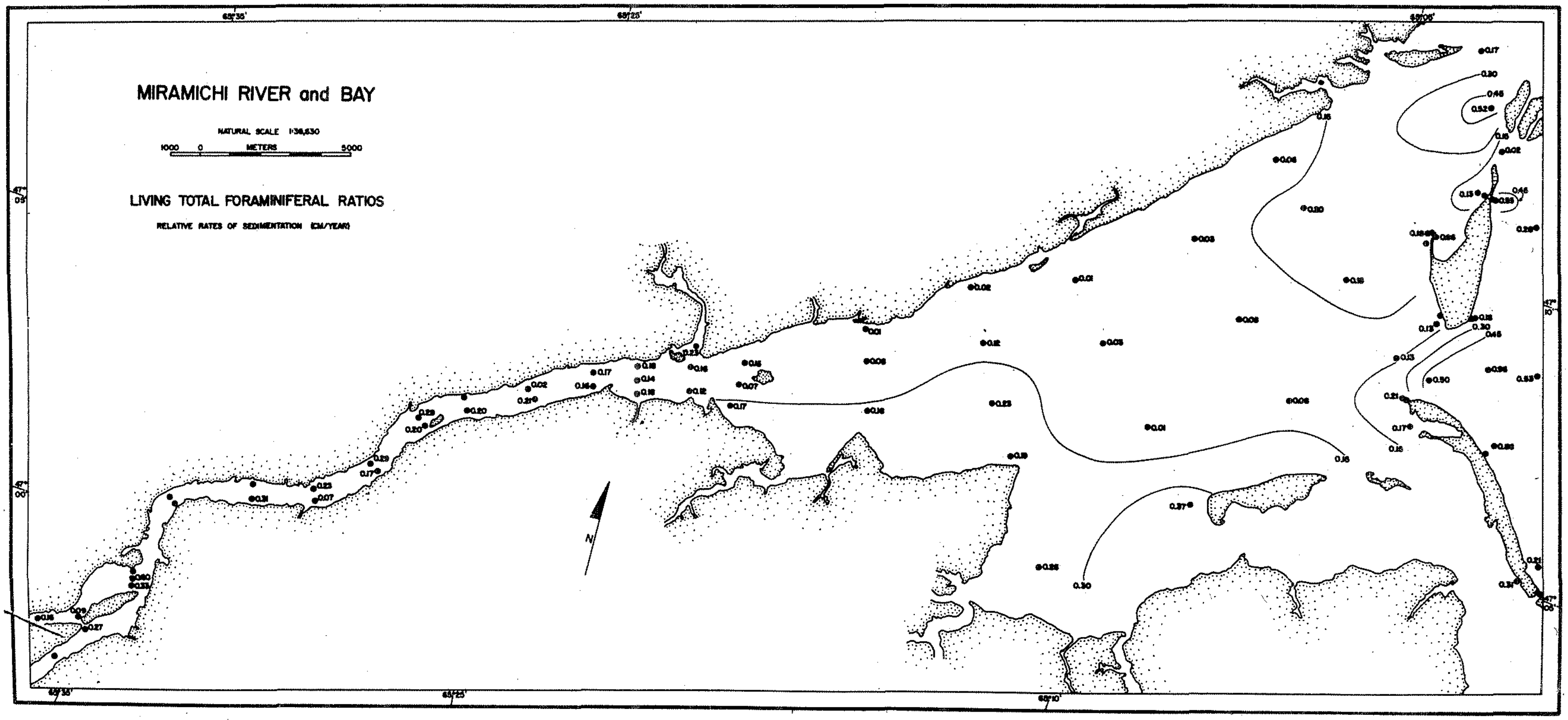

Fig. 16 Living-Total Foraminiferal Ratios

Foraminifera for the determination of relative rates of sedimentation. Abundant living specimens relative to the total population should indicate relatively rapid addition of sediment. Similarly, a small living population relative to the total population indicates a slow rate of sedimentation. It is assumed that the rate of production is uniform over a given period of time and that only the surface sediment is investigated. Bartlett (1964b) indicated that the observed displacement of foraminiferal faunas and the inadequate knowledge of foraminiferal life cycles masked the results. Also, in an environment such as the Miramichi estuary, some tests are lost after deposition because of solution. Large living populations ("standing crops") should, according to Phleger (1955) in Mississippi Delta, Walton (1955) in Baja, California, Lankford (1959) in Mississippi Delta, and Bartlett (1965a) in Prince Edward Island indicate rapid sedimentation. Bartlett (1964) found that large "standing crops" were frequently masked by large dead populations, and although an environment supported a prolific fauna a low living-total ratio was determined. Leslie (1965) found that areas of live foraminiferal abundance in Hudson Bay were areas of slow sedimentation, while areas with low living populations were regions of greater sedimentation.

Living-total ratios in the Miramichi estuary have been utilized to determine the approximate relative rates of sedimentation (Fig. 16). Highest values are recorded at the mouth of the estuary immediately outside the baymouth barriers. Substrates are composed mainly of sand in this environment. Relative-rates suggest that sediments being carried by the longshore currents are removed from Portage Island and environs to the north and deposited to the west and south in the main channel and on Fox Island. Sediments borne by currents in the estuary are probably deposited just outside the baymouth barriers and transported by these counter-clockwise longshore currents.

High living-total ratios at stations 74 and 78 support observations in the field that high sedimentation rates prevail in these areas. Sand-flats and dunes are prograding westward (towards the inner bay) at Station 78 whereas the area behind the western extension of Portage Island (Station 74) is rapidly silting up. High living-total ratios in the main channel (Stations 65, 59, 81) indicate rapid silting in this area. The necessity of annual dredging operations in the channel support these conclusions. The overall result is a progressive westward and southwestward migration of the baymouth barriers.

Values for living-total ratios indicate irregular sedimentation patterns for the Miramichi River. Values recorded were generally from .01 to .20 cm per year. Values at the mouth of the river are consistent at .12 to .18 cm per year. Much of this may be attributed to flocculation and deposition of fines at the fresh and salt water interface. Sands and silty-sands have the highest relative rates of sedimentation in the river.

Miramichi Bay is divisable, based on living-total foraminiferal ratios, into two sections of approximately equal proportions (Fig. 16). The northern section is characterized by low sedimentation rates (.01 - .12 cm per year), while the southern section is characterized by intermediate rates of sedimentation (.17 - .37 cm per year). This suggests that the northern area is relatively stable, while the southern area is actively silting up. This is substantiated by the relatively straight sandbar-free northern coastline as compared to the irregular southern area with numerous shallows and sandbars. Rivers such as the Black River and Bay du Vin River also contribute large quantities of sediment to the southern area.

Relative rates of sedimentation, based on living-total foraminiferal ratios, in the Miramichi estuary are comparable to those in Tracadie Bay, Prince Edward Island (Bartlett, 1965). Highest rates are in sand or silty-sand substrates in areas adjoining baymouth barriers. Lowest rates are recorded in silty-clays in the central bay areas.

The present study indicates that most prolific foraminiferal growth is not always associated with highest rates of sedimentation. Stations with small total and small living populations commonly have higher living-total ratios than stations with larger total populations and substantially higher living populations. However, the present investigation indicates that rapid sedimentation buries empty tests and provides a large "standing crop". Moreover, a small "standing crop" is indicative of a slow sediment supply rate. The limitations of living-total foraminiferal ratios in the approximation of relative rates of sedimentation are discussed in detail by Bartlett (1964b).

The living-total ratio expressed as percent (Fig. 17) has been figured for all species and compared with diagnostic species in Miramichi Bay. Eggerella advena, Elphidium incertum "complex", E. margaritaceum and E. orbiculare are the species considered separately. Miliammina fusca is not included in the present discussion, because it is restricted primarily to the river environment, and is the dominant foraminiferal species in the river. Consequently, the living-total ratio of this species reflects that of the total foraminiferal fauna in the river.

The living-total ratio of Eggerella advena is not expressed at inner bay stations because of its absence in this environment. Values are generally low (less than 30 percent and commonly less than 20 percent) in nearshore stations, but extremely high (40 percent to 91 percent) in the central bay and immediately outside the baymouth barriers. These values, except for high percentages at Stations 80 and 81 and low percentages at Stations 82 and 79 are comparable to values recorded for all species. High values within the bay are recorded in small populations, whereas high values outside the

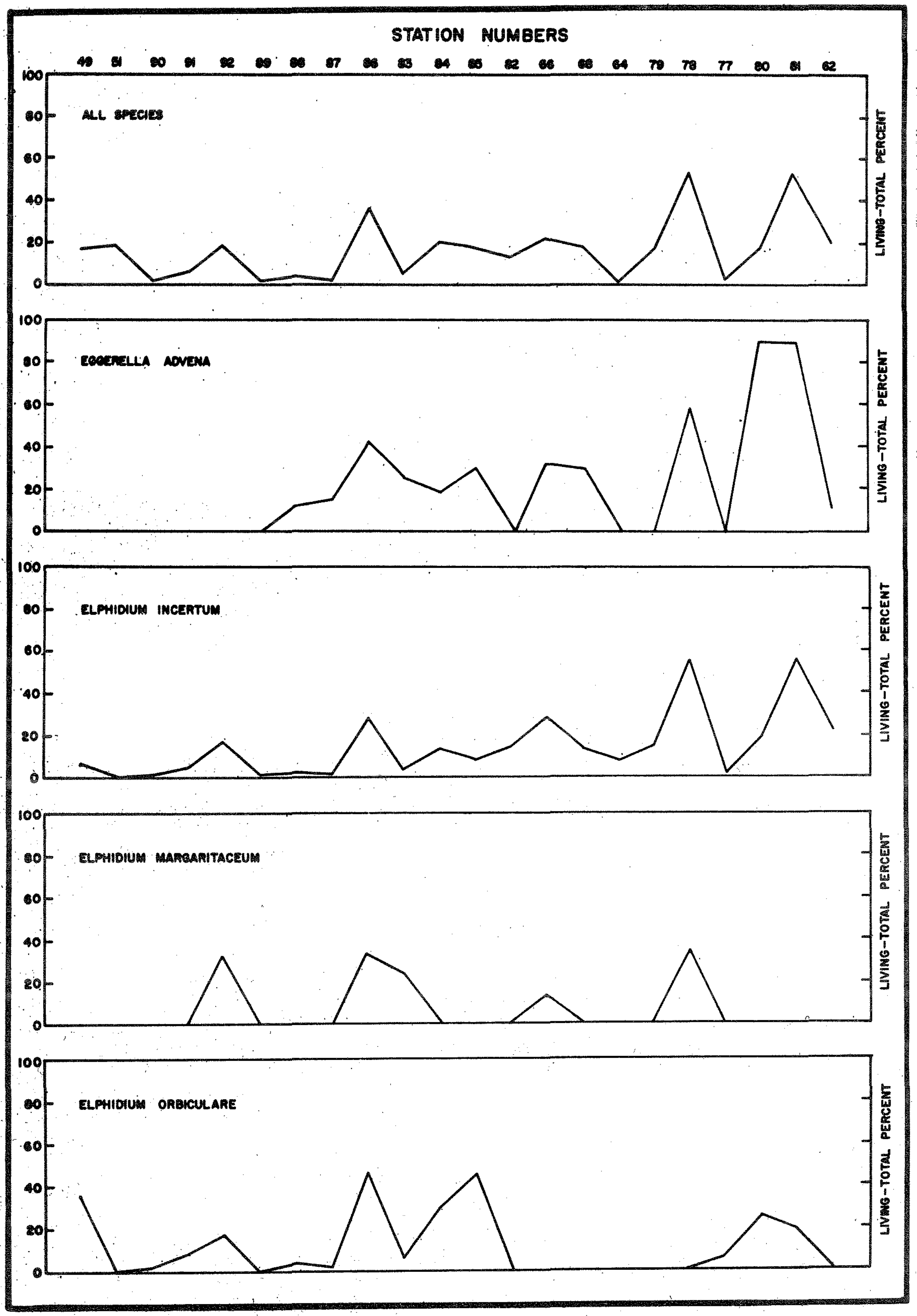

Fig. 17 Comparison of Living-Total Percents for all Species and Diagnostic Species in Miramichi Bay

barriers are located in areas continuing the largest populations of this species.

The living-total frequency of Elphidium incertum "complex" closely parallels the frequency for all species. This is attributable to the large populations and dominance of this form over the remainder of the foraminiferal assemblage in the Miramichi estuary. It is significant that relative rates of sedimentation in the Miramichi may be evaluated on this species alone.

There are few living Elphidium margaritaceum tests at stations chosen for this comparison. The living-total ratio shows no relationship to values determined for the entire fauna. It is apparent that most environments in the bay are unsuitable for growth and development of this species. Highest values are recorded (Appendix C) immediately inside the baymouth barriers at stations 72 and 74.

Stations with abundant Elphidium orbiculare show living-total ratios similar to those for all species. However, in areas with small populations these values are irregular. Some are high, some low, and at many stations no values are recorded because of the absence of living forms. Values for areas with large populations of both living and dead specimens are comparable to values determined for all species.

According to Buzas (1965a) if the living-total ratio of all species is an accurate indicator of relative rates of sedimentation, then the living-total ratio of component species must show similar patterns. Because of the dominance of Elphidium incertum "complex" in the Miramichi Estuary and because of the similarity of the living-total ratio of this species to that of the total fauna, it is assumed that the ratio for all species is correct. The faunal patterns in the Miramichi support the view that individual species, rather than entire assemblages, are more representative of sedimentation rates, especially in areas where transportation of these is common (Bartlett, 1964a).

Diagnostic Benthonic Foraminiferal Species

Four of the thirty-five species of Foraminifera and Thecamoebina in the Miramichi estuary dominate the faunal assemblage. Two are arenaceous, Miliammina fusca, and Eggerella advena, and two are calcareous-hyaline, Elphidium incertum "complex" and Elphidium orbiculare. These four species are major constituents of two well-defined biofacies, 1) river, 2) bay, within the estuary. The species are discussed individually with respect to total populations, living Foraminifera, percent living, and living-total ratios. Distribution of each of these species is presented and environmental factors affecting the distribution are discussed.

Eggerella advena

Eggerella advena (Fig. 18) is present in the outer bay and in areas adjoining the barriers at the baymouth. Largest

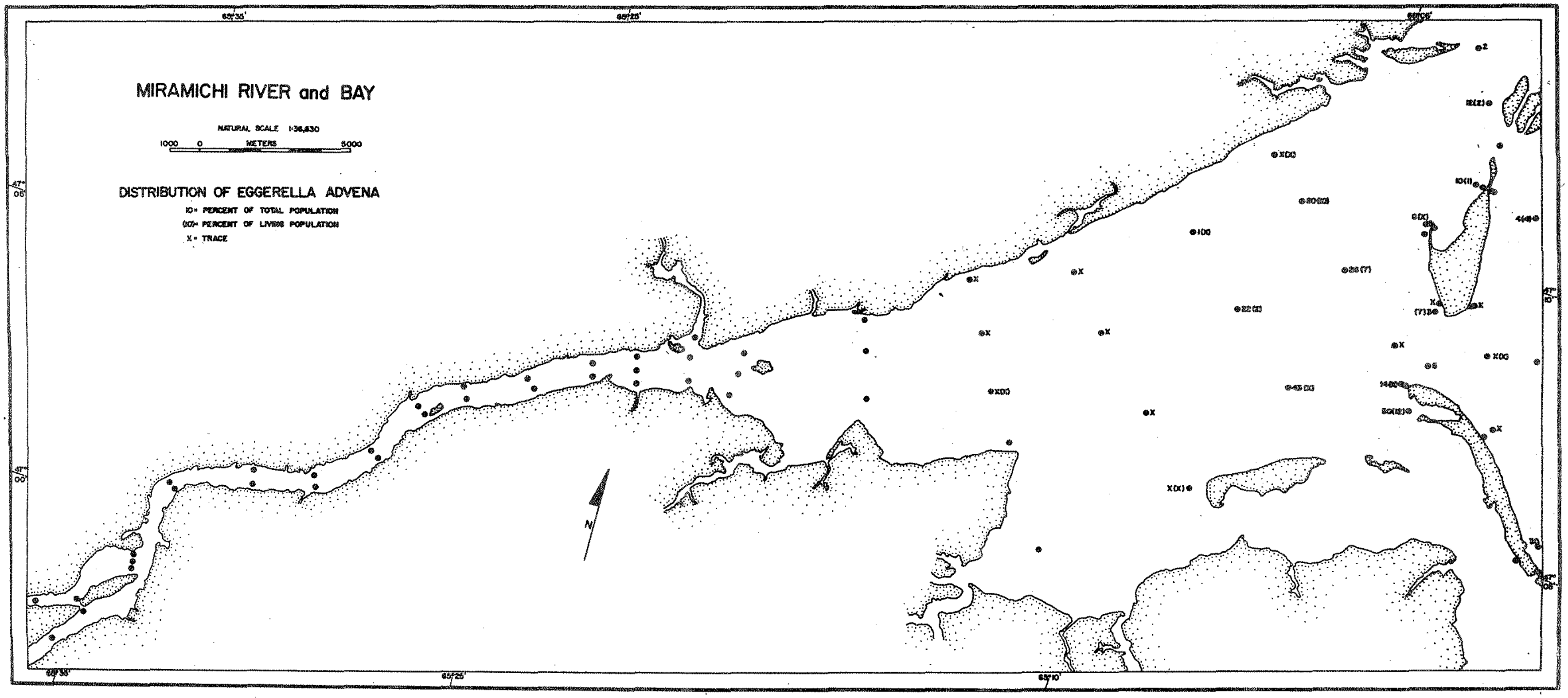

Fig. 18 Distribution of Living and Dead Tests of <u>Eggerella advena</u>

assemblages of both dead and living populations are found in areas just inside the baymouth barriers. It is the most common arenaceous species in the outer bay environment. *Eggerella advena* has not been found in areas with salinities less than 23.00°/oo. Substrates are variable and range through silty-clay, silty-sand, sandy-silt and sand. Depths are variable (0 to 7 metres) at stations with largest populations. However, substrates are commonly silty-sand or sand in areas with largest populations. These bottom sediments are well-sorted with low to medium calcium carbonate and organic carbon content for the estuary.

Bartlett (1964a, b) found *Eggerella advena* to be a prolific nearshore species in silty or silty-sand substrates in bays of southeastern Nova Scotia, and to be the most abundant arenaceous species on the Scotian Shelf and in Tracadie Bay, Prince Edward Island (Bartlett, 1965a). Forms in Tracadie Bay were also most prolific in silty-sand and sandy substrates in areas adjoining the baymouth bars. Leslie (1965) reported *Eggerella advena* in depths from 26 metres to 230 metres in silty-sand and sandy substrates in Hudson Bay. He believed that those depths and substrates were controlling factors in the distribution of this species. Substrate is probably significant, but because of its widespread occurrence, from shore, to the continental slope, it is questionable if depth within the above range, is a limiting factor. *Eggerella advena* is reported in depths less than 90 metres south of Cape Cod (Parker, 1952b), at Portsmouth, New Hampshire (Parker, 1952a), and from the Arctic (Phleger 1952, Loeblich and Tappan 1953, Cooper 1964 and Vilks 1964). Cooper (1961) reported it as a major constituent of stagnant, brackish waters off the California and Oregon coast.

In the Atlantic Provinces, Hudson Bay and Arctic environments the species prefers well-sorted silty-sand and sandy substrates. Although living in brackish water environments it has not been found in the Atlantic Provinces in areas with salinities less than 23.00^{o}/oo. In these same environments it is most commonly found in areas immediately inside baymouth barriers.

Elphidium incertum "complex"

Elphidium incertum "complex" (Fig. 19) is the most prolific species in Miramichi Bay, and in areas on and adjoining the baymouth barriers. It is recorded for the first time in beach environments in the Atlantic Provinces. Generally, the species is not found living in the Miramichi River. The species is represented by much larger dead than living populations, except in areas immediately inside and immediately outside the baymouth barriers. Here, from 14 percent to 96 percent of the total populations are represented by living *Elphidium incertum* "complex". It has not been found up river in sediments with bottom water salinities less than 16.00^{o}/oo and living forms have not been found in areas with salinities less

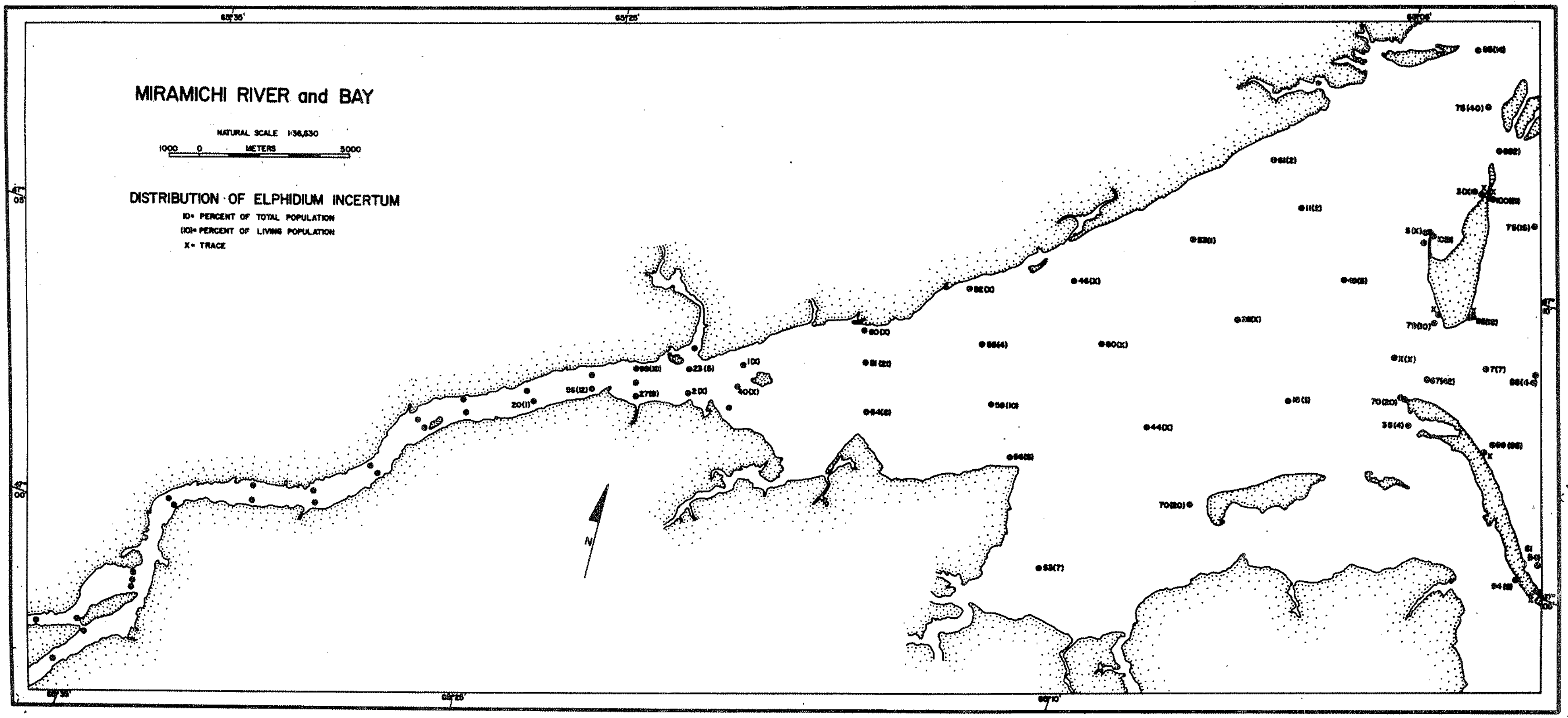

Fig. 19 Distribution of Living and Dead Tests of Elphidium incertum "complex"

than 20.00^{o}/oo. The species is common in Miramichi Bay at all depths recorded during the present study (0 - 15 metres), and in variable substrates from clayey-silt to sand. Largest populations of both living and dead specimens are commonly found in silt or silty-clay substrates. These sediments have a high MDϕ and larger concentrations of calcium carbonate and organic carbon. Large dead populations in sand substrates, with few living specimens, are probably transported lag deposits. Increased numbers of Elphidium incertum "complex" commonly correspond with decreased numbers of Eggerella advena in the outer bay. Similar circumstances are found in Tracadie Bay, Prince Edward Island (Bartlett, 1965a).

The living population is relatively uniform for the entire estuary. Large dead populations are commonly represented by smaller numbers of living forms. Living forms are prolific in well-aerated sand substrates with slight turbulence in the baymouth environment. However, largest numbers are also found in silts and silty-clays throughout the central bay environment.

This is an extremely variable species (Bartlett, 1964a, 1965a, b). A study of the literature reveals that many authors have different concepts of what actually constitutes this species. Variations among forms composing the Miramichi estuary fauna are similar to those recorded in other Atlantic Provinces regions (Bartlett 1964a, b, 1965a, b). Differences in external morphology of some of these specimens are apparently related to environmental parameters such as salinity and temperature.

Specimens have been found living in depths of 1 metre to 100 metres, substrates of clay, silt, and sand, and combinations of these, and salinities of 20.00°/oo to 32.00°/oo in the Scotian Shelf (Bartlett, 1964a). The "complex" has not been found living in waters with salinities less than 20.00°/oo. Similar forms have been reported in Western Long Island and New York Harbour (Shupack, 1934), Portsmouth, New Hampshire and the Long Island-Buzzard's Bay area (Parker, 1952a, b), Barnstable Harbour, Massachusetts (Phleger and Walton, 1950), the Arctic (Loeblich and Tappan, 1953), Hudson Bay (Leslie, 1965), and Martha's Vineyard (Todd and Low, 1961).

The presence of this species in widely separated areas and environmental conditions is indicative of its tolerance. Depths up to 230 metres do not appear to be a limiting factor in its distribution. Living specimens are more confined in aerial distribution, an indication of considerable transportation of dead tests. This accounts for rich foraminiferal "lag deposits" reported by Bartlett (1964b). Substrate may be a factor in distribution of this species because largest populations are found in finer textured sediments especially those in the silty-clay to silty-sand range. However, the relationship may be indirect, in that different substrates are also associated with differences in environmental conditions that may have a greater effect on the distribution of this species. In the Miramichi estuary bottom waters with salinities of less than 20.00°/oo have no living Elphidium incertum "complex". This may be the lower limit of tolerance for the species, and be the major reason for its absence in Miramichi River waters.

Elphidium orbiculare

Elphidium orbiculare (Fig. 20) is the second most abundant calcareous-hyaline species and the second most widely distributed foraminiferal species in the Miramichi estuary. Living forms are restricted to areas with salinities greater than 20.00°/oo. This prevents the species from migrating up river from inner Miramichi Bay. The species is confined almost entirely to Miramichi Bay, although small populations are found outside the baymouth barriers, but none are found in areas on, or immediately adjoining these features. Total populations are much larger than living populations and all stations, except Station 36, have living forms associated with the dead populations. The presence of this form at Station 40 is difficult to explain, as conditions do not warrant its presence in this area, over adjoining areas with similar environmental characteristics. Percentage of the total population living is relatively uniform for the entire bay. The absence of species at the baymouth may be attributed to coarse substrates and turbulent conditions associated with the interaction of tides and currents in these environments. Stations offshore and in the main channel (Fig. 20) are in

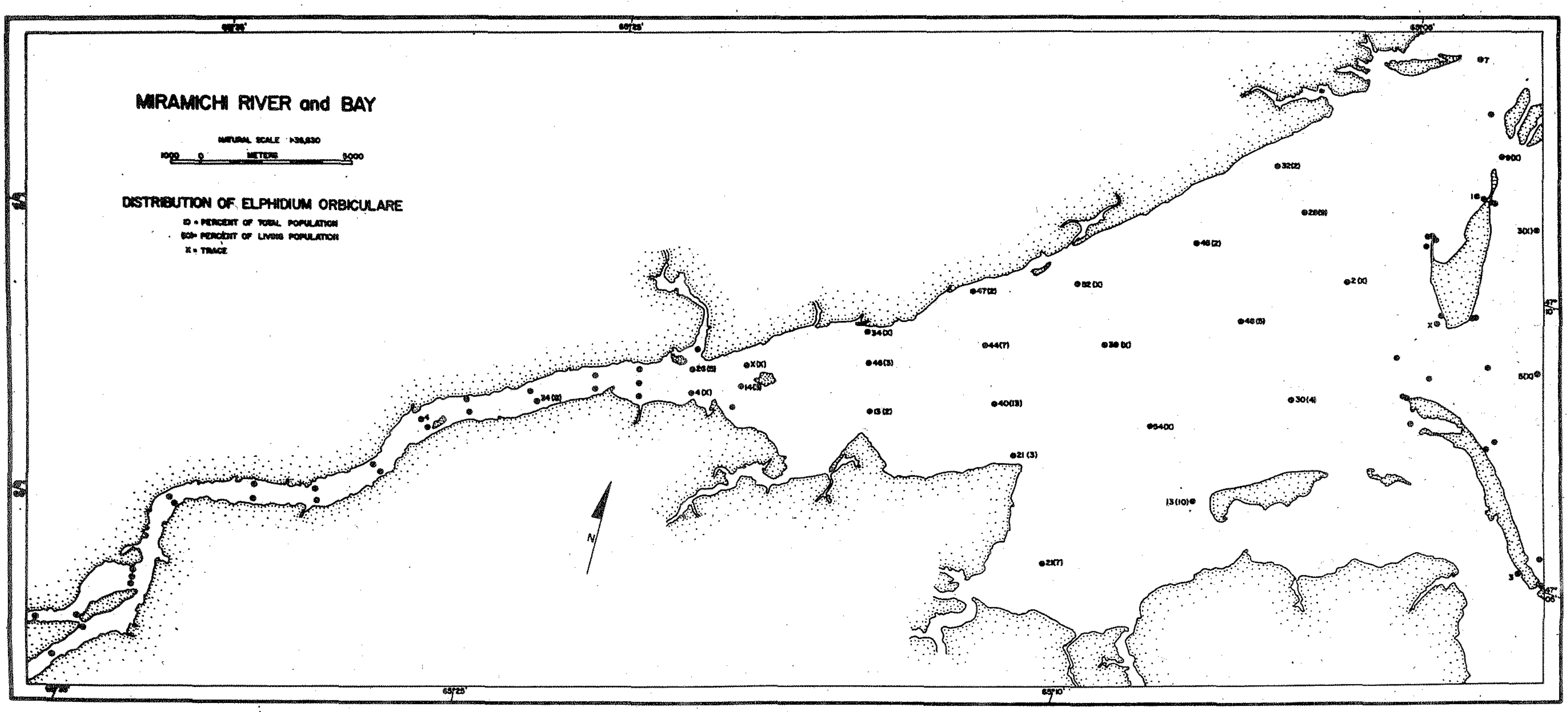

Fig. 20 Distribution of Living and Dead Tests of Elphidium orbiculare

coarse sands in depths from 5 metres to 7 metres. Currents are commonly 2 to 3 knots. All other baymouth stations with E. orbiculare absent are in beach sands at various levels in the intertidal zone.

Many Elphidium orbiculare tests inhabiting Miramichi Bay possess a surficial arenaceous "jacket" composed of silt and sand size quartz and mica grains. These grains are imbedded in an organic tectinaceous or pseudochitinous layer lying immediately against the calcareous test wall. All forms possessing the external arenaceous layer were living when collected.

E. orbiculare was reported as a distinctive species of the nearshore biofacies in St. Margaret's Bay and Mahone Bay, southeastern Nova Scotia (Bartlett, 1964b). Largest living populations inhabited shallow depths (3 metres - 13 metres), and the species replaced E. margaritaceum seaward from the intertidal zone. E. orbiculare is the second most abundant calcareous-hyaline species in Tracadie Bay, Prince Edward Island (Bartlett, 1965a), where distribution patterns resembled those of E. incertum "complex". Largest populations were recorded at inner bay stations where depths exceeded 2 metres and substrates were composed of silt and clay. E. orbiculare is stated to be the most abundant calcareous species in bays of the Arctic Islands (Vilks, 1964). E. orbiculare was found at all depths in Hudson Bay (Leslie, 1965) where distribution patterns resemble those of Eggerella advena. He concluded that E. orbiculare thrived best in a welloxygenated environment with the sand content approximately 40 percent.

E. orbiculare is widely distributed in Canadian Atlantic and Arctic waters. In the Miramichi estuary it is limited to environments with bottom water salinities greater than 20.00^{o}/oo. It prefers well-sorted sandy-silt to sandy environments at inner bay stations, and cannot survive in shallow nearshore or intertidal waters in the turbulent zone. Calcium carbonate and organic carbon content are low at stations with large living populations of *E. orbiculare*.

Miliammina fusca

Miliammina fusca (Fig. 21) is the most widely distributed arenaceous species in the Miramichi estuary. It is confined almost exclusively to the Miramichi River, and is the only species of Foraminifera able to survive in this environment. It is also found scattered in nearshore samples around the bay, and is quite prolific in nearshore waters and the intertidal area behind Portage Island. Substrates are commonly sandy-silts to sands in the bay environment and extremely variable in the river. The species is extremely tolerant of extremes in salinity (7.86^{o}/oo - 28.18^{o}/oo), depths (0 metres - 14 metres) and temperature (6^{o}C. - 20^{o}C.) in the Miramichi River. Sediment texture and calcium carbonate and organic carbon content of the sediments show no consistent relationship to the distribution of this species.

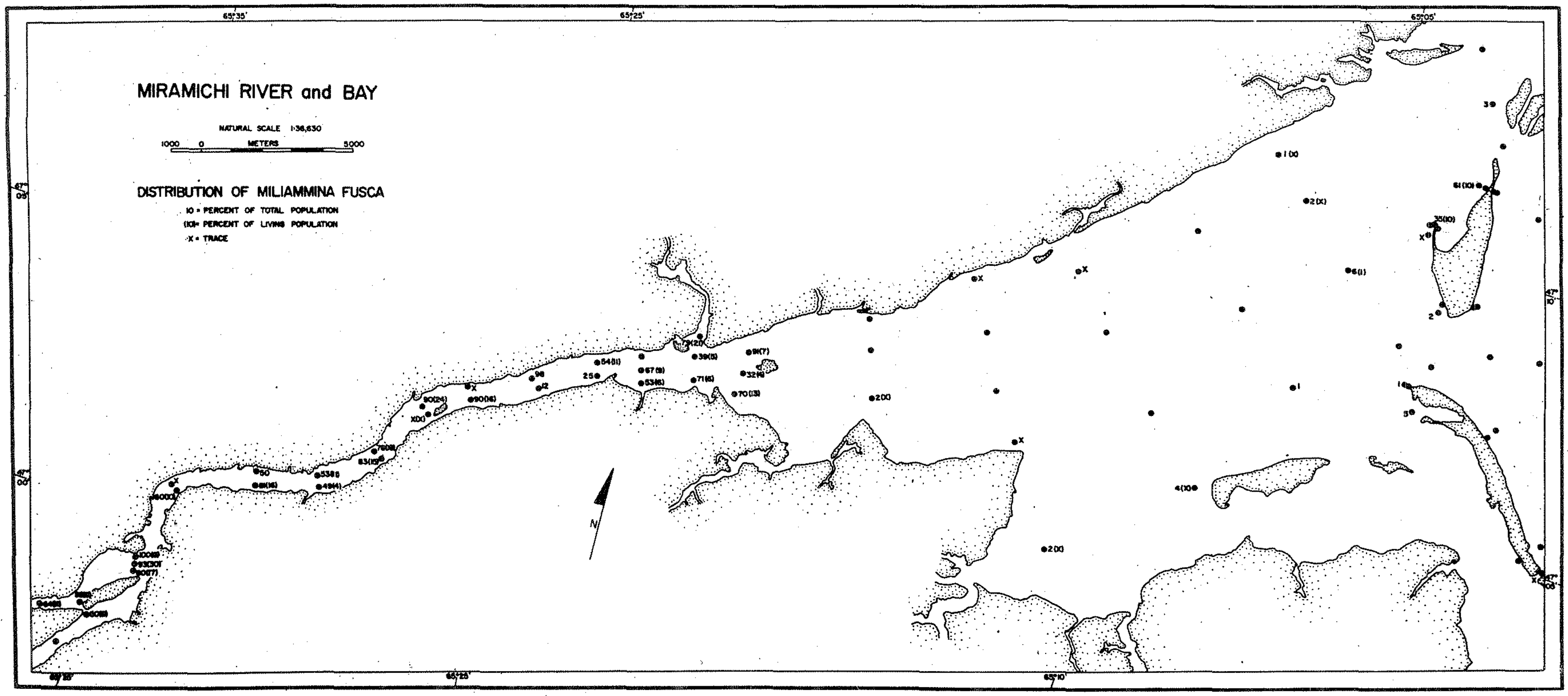

Fig. 21 Distribution of Living and Dead Tests of <u>Miliammina fusca</u>

This species occurs in association with *Trochammina lobata*, *Trochammina spp.* and *Elphidium margaritaceum*, distinctive intertidal species, in St. Margaret's Bay and Mahone Bay, southeastern Nova Scotia (Bartlett, 1964b). It is associated with various species of *Trochammina* near the mouth of Miramichi River and with *Elphidium margaritaceum* at the intertidal stations adjoining the baymouth barrier. *Miliammina fusca* was reported as the second most abundant arenaceous form in Tracadie Bay, Prince Edward Island (Bartlett, 1965) where largest populations are on tidal flats and in the intertidal zone. The latter supports a prolific growth of *Enteromorpha* and *Zostera* which provide a place of attachment for these species.

Miliammina fusca is generally indicative of low salinity and intertidal environments in the Miramichi estuary. It is a significant biofacies indicator in that it is the only foraminiferal species living in the upper reaches of the river. Largest populations of *Miliammina fusca* in the river are present in environments with large numbers of diatoms. The presence of Thecamoebina in the Miramichi estuary in association with *Miliammina* suggests low salinity environments, while the presence of *Elphidium margaritaceum* suggests an intertidal environment.

The four diagnostic foraminiferal species described above are major contributors to the foraminiferal fauna in particular and the microfauna in general in the Miramichi estuary. Miliammina fusca and Eggerella advena are dominant arenaceous species and delineate the river and baymouth barrier environments respectively. Elphidium incertum "complex" and E. orbiculare - calcareous-hyaline species - dominate the entire microfauna assemblage in the bay. They are indicative of the central bay and nearshore environments when occurring together, but the presence of Elphidium incertum "complex" alone or in association with Eggerella advena or other forms characterizes areas on and adjoining the baymouth barriers. These factors are significant in the reconstruction of ancient environments and are discussed later in the paper.

Faunal Analysis and Comparison with Other Areas

Foraminiferal populations in Miramichi River and Miramichi Bay are dominated by arenaceous and calcareous-hyaline species respectively. Miliammina fusca characterizes the river, and Elphidium incertum "complex", E. orbiculare and Eggerella advena are characteristic bay forms. Most of the species present are eurybathic. They are universally distributed and have wide tolerances to fluctuating environments. The foraminiferal fauna of the Miramichi estuary is considered as typical of cool-temperate brackish water environments.

The foraminiferal fauna of the Miramichi estuary resembles the fauna in Tracadie Bay, Prince Edward Island, (Bartlett, 1965a). Both areas are characterized by abundant calcareous-hyaline assemblages and have similar forms dominating the assemblages (e.g. Eggerella advena, Elphidium incertum "complex", E. margaritaceum, E. orbiculare and Miliammina fusca). However, Ammonia beccarii, a common form in Tracadie Bay, is found at only two stations (72 and 78) and, furthermore, it is not found living in the Miramichi estuary. Strong currents, and temperatures too low for survival and reproduction may prevent this species from establishing in the Miramichi environment.

Arenaceous Foraminifera and Thecamoebina inhabit areas of lowest salinity. Miliammina fusca, an arenaceous form, is the only species able to survive in low salinity waters (less than 16.00°/oo) of the Miramichi River. Competing calcareous Foraminifera are eliminated in the river because of adverse ecological conditions, but are prolific in the bay where fluctuating conditions are less severe.

Most of the species described by Cooper (1964) from the Chukchi Sea, northern Alaska, are present in the Miramichi estuary. The predominance of Eggerella advena, Buccella frigida, Elphidium bartletti, E. incertum, E. orbiculare, E. subarcticum, Ammotium cassis and Trochammina lobata in the three faunal assemblages differentiated by Cooper (1964) is noteworthy. These forms are either the most characteristic or at least represented in Tracadie Bay, Prince Edward Island (Bartlett, 1965a). They are also the dominant forms in the Miramichi estuary. However, there is a significant difference in that Cooper's (1964) fauna was considered a meagre Arctic one consisting mostly of arenaceous forms, whereas the present fauna is characterized by a prolific calcareous-hyaline assemblage. Cooper (1964) found that depth, temperature and salinity changes restricted a few species but had only slight effects on faunal assemblages. She believed that bottom sediment had the greatest effect on distribution of the hardy Arctic fauna.

Leslie (1965) based his depth zonation in Hudson Bay on species that are also abundant in the Miramichi estuary. The Shallow Bay Fauna (26 - 130 m) was represented by Eggerella advena and Elphidium orbiculare, the Intermediate Bay Fauna (50 - 175 m) included Buccella frigida, and the Deep Bay Fauna had Buliminella elegantissima as one of the characteristic members. Leslie's (1965) Cosmopolitan Bay Fauna (26 - 230 m) was exemplified by Elphidium incertum. The three most prolific species in Hudson Bay are also the three most prolific species in Miramichi Bay (e.g. Eggerella advena, Elphidium incertum "complex", and E. orbiculare). Because of the extreme differences in depth between the two areas, it is questionable if depth is a limiting factor in the distribution of these species. Other environmental parameters such as substrate, salinity, and food supply are apparently more significant than depth in limiting the distribution of these species.

Forms common to the four established biofacies in

St. Margaret's Bay and Mahone Bay, Nova Scotia (Bartlett, 1964b) are also dominant forms in the Miramichi estuary. Miliammina fusca was a characteristic Intertidal form and was concentrated as dead tests in Back-Bay Lagoonal and Estuarine environments. Eggerella advena, Elphidium incertum and E. orbiculare were common forms in the Bay-Bay Lagoonal, Estuarine and Nearshore biofacies, and the Elphidium incertum "complex" was a common form in the Open Bay biofacies. These forms, in the presence of other foraminiferal assemblages, rather than individually, delineated the various biofacies. It is evident that these forms are extremely tolerant of variances in bathymetric conditions and are widely dispersed because of this tolerance to fluctuating conditions in the marine environment.

Species of Thecamoebina and Foraminifera in the Miramichi Estuary are similar to some of the forms reported by Todd and Bronnimann (1957) in the Tidal Zone of the Eastern Gulf of Paria, western Trinidad. Centropyxis arenatus, Difflugia capreolata and Pontigulasia compressa which are common Thecamoebina in the Miramichi River were present in the Tidal Zone of Todd and Bronnimann (1957). This Tidal Zone was represented by littoral areas, estuaries of rivers, and mangrove swamps and mudflats. Biotopes were developed in micro-environments characterized by special ecological conditions. Although most of the species in the Miramichi estuary were represented in the Gulf of Paria area, the fauna in the latter was much more prolific and diversified than that of the Miramichi. This is due to the presence of more normal marine conditions (variable fauna, uniform environment) investigated in the nearshore zone and offshore zone in the Gulf of Paria. Todd and Bronnimann (1957) considered the tidal zone fauna to be wholly indigenous and to be typical of other brackish water areas, such as those described from along the southwest coast of Texas (Parker, Phleger, Peirson, 1953), Mississippi Sound (Phleger, 1954), and New York Bight (Ronai, 1955).

Species able to make prompt readaptation to sudden changes in ecological conditions will thrive best in the Miramichi estuary. This ability is possessed by *Elphidium incertum* "complex", *E. margaritaceum*, *E. orbiculare*, and *Miliammina fusca* species that are found living in both the littoral and sub-littoral zones of the Miramichi estuary. Boltovskoy (1963) found that species of *Elphidium*, *Buliminella elegantissima*, and *Miliammina fusca* were tolerant of wide fluctuations in environmental conditions in Puerto Deseado, South America. The ability to make prompt readaptation is possessed by those species that are universally distributed.

Parker *et al* (1953) in an ecological study of Foraminifera from San Antonio Bay and environs believed that barrier islands were the principal factors in affecting foraminiferal distribution. These islands acted as effective barriers in inhibiting the exchange of waters between the open gulf and bay. Arenaceous species such as Ammobaculites dilatatus and Ammotium salsum were stated to be indigenous to the bay environment. Species of Elphidium and Ammonia beccarii, which occur in high frequencies in open gulf, bay, river and marsh facies were thought to be species that invaded the bay with open gulf water. A. salsum is restricted to the river, and various species of Elphidium to the bay and areas on and adjoining baymouth barriers in the Miramichi area. A. beccarii is a minor member of the fauna in the Miramichi probably being limited by temperature in the estuary. Elphidium is prevalent in the Gulf of St. Lawrence but A. beccarii is absent. It is present in lagoonal areas of Prince Edward Island (Bartlett, 1965b). It is apparent, that although various species of Elphidium may be open gulf forms as suggested by Parker et al (1953) that Ammonia has probably always been restricted to shallow water lagoons in temperate areas, such as those considered in the present investigation.

According to Bandy (1964) one of the most characteristic index species for euryhaline environments is Ammonia beccarii tepida, and marsh and estuarine populations are undoubtedly characterized by Miliammina fusca, Ammotium salsum and one or two other arenaceous Foraminifera. In the Gulf of Batabano, Cuba, Bandy (1964) concluded that two dominant inner and central bay indicators are Elphidium discoidale and E. poeyanum poeyanum. Miliolids were restricted to islands and shoals in the bay. There is an interesting parallel with faunal distribution in the Miramichi estuary. Ammonia beccarii tepida, because of temperature and current characteristics, is absent from the Miramichi. However, marsh and estuarine faunas are dominated by M. fusca, various Thecamoebina and subordinate numbers of Ammotium salsum. The inner and outer bay areas of the Miramichi are characterized by abundant specimens of Elphidium incertum "complex", E. orbiculare and E. margaritaceum. Miliolids, represented by Quinqueloculina seminulum, are sparsely distributed in areas adjoining the baymouth barriers. Depths in the Batabano and Miramichi are similar (0 - 14 metres), but other environmental characteristics in both areas are significantly different. Salinities (35.00°/oo - 36.00°/oo), temperatures (28.5 - 32.5°C.), pH values (8.1 - 8.7), and carbonate content in the Gulf of Batabano are much higher than those recorded in the Miramichi estuary. It is apparent that faunal assemblages of eurybathic species are common in widely separated areas and that these assemblages are comparable in content of prevalent species.

Twenty-three species and fifteen genera of Foraminifera were recorded in Long Island Sound by Buzas (1965a). He found that most of his species were common to Parker's (1952b) study in the Long Island Sound - Buzzards Bay area. Forms making up 90 percent of the Long Island Sound assemblage, Elphidium clavatum and E. varium (E. incertum "complex" of this study), E. pauciloculum (E. subarcticum of this study), Buccella frigida and Eggerella advena are, with the addition of Elphidium orbiculare the most common forms in Miramichi Bay. Three zones were established in Long Island Sound, 1) Elphidium clavatum which increases shoreward (depth range 3 - 23 metres), 2) Buccella frigida transition (15 - 33 metres), and 3) Eggerella advena (16 - 39 metres). The Elphidium incertum "complex" dominates the central bay and the Eggerella advena fauna is significant in the outer bay environments of the Miramichi. Buccella frigida, although present, is a subordinate species.

In conclusion, it is pertinent to compare the number of genera, species, and foraminiferal tests in related areas. Seventy-eight benthonic species were recorded by Phleger from the Gulf of Mexico where the approximate average "standing crop" was 10,000 per square metre. He recorded 73 species in the Portsmouth area and a "standing crop" of approximately 30,000 per square metre. Parker (1952b) reported 57 benthonic species in the Long Island Sound - Buzzards Bay area, but gave no values for total populations or "standing crop" of Foraminifera. Approximately 80 species were reported by Walton (1955) and a "standing crop" of approximately 193,000 per square metre in Todos Santos Bay, California. A study of a nearshore area of the southern Gulf of Maine showed a "standing crop" of 1,000 to 100,000 per square metre with an average of 30,000 per square metre (Phleger, 1952). He counted a "standing crop" of 1,000 to 1,000,000 per square metre, with an average of approximately 90,000 per square metre in the southeastern Mississippi Delta (Phleger, 1955). Eighty species and total populations of 300 to 362,800 per square metre of surface area and a "standing crop" of 300 to 92,700 per square metre were recorded in St. Margaret's and Mahone Bays, Nova Scotia by Bartlett (1964a). A "standing crop" of approximately 110,000 per square metre was reported in Long Island Sound by Buzas (1965a) and was composed of 15 genera and 23 species. A fauna composed of 11 genera and 23 species was found by Bartlett (1965a) in Tracadie Bay, Prince Edward Island. Total populations ranged from 3,400 to 162,000 tests per square metre, and the "standing crop" was represented by 1,400 to 72,000 tests per square metre of substrate surface area. In the present study there are 19 genera and 31 species of Foraminifera. Total populations vary from 200 to 985,200 tests per square metre. The "standing crop" is represented by 400 to 77,200 tests per square metre. It is evident from the above discussion that living populations are higher in the Mississippi Delta area than in other areas investigated. Moreover, "standing crops" are much lower in the Gulf of Maine than in other areas reported above. However, foraminiferal populations and production in the Atlantic Provinces regions are comparable to those in Long Island Sound. This suggests that although variations are extreme from station to station in any given area, that the rate of organic production, as indicated by foraminiferal populations, is relatively uniform in cool-temperate to temperate climates.

Furthermore, the stratigraphic occurrence of a eurybathic microfauna comparable to that in the Miramichi should indicate environmental characteristics similar to those in most shallow marine waters adjoining the Gulf of St. Lawrence. Numeric, generic, and specific increases in a comparable faunal suite will indicate the direction of more open marine conditions, and proximity to baymouth or offshore bars. Similarly, increases in comparable calcareous-hyaline species and specimens will indicate central bay areas within the estuarine complex. In addition, assemblages adjoining the up-river side of baymouth barriers will be larger and more diverse than those from the river, inner bay and shallow, nearshore areas immediately adjoining open, ocean facing environments. Moreover, the open-gulf environment, with greater depths and higher salinities maintains larger populations and is a dumping ground for assemblages transported from the estuary and from the shore and nearshore areas of baymouth bars and islands.

SUMMARY

1. Miramichi River and Bay form an estuary on the eastern shore of New Brunswick. The estuary is characterized by variability in environmental parameters. Landward erosion furnishes sediment for baymouth barriers that restrict circulation with Gulf of St. Lawrence waters and provide a quiet environment for deposition of finer sediments in the estuary.

A comparison of various hydrographic charts from 1885 to the present indicates large-scale changes in bottom topography. Old channels have been closed and new areas opened. Baymouth barriers have been eroded or enlarged and rebuilt chiefly through the action of longshore currents. Extensive tidal flats have been developed throughout the estuary.

Currents and wave action are principal factors in erosion and sedimentation. Waters are estuarine in character and are subject to diurnal and seasonal variations. They are polyhaline in both vertical and horizontal directions. Temperatures undergo both diurnal and seasonal variations. The wide range in temperature and salinity eliminates stenothermic and stenohaline Foraminifera in the Miramichi.

Bottom sediments are composed of sand, silty-sand, sandy-silt, and silty-clay. Sediment distribution is complex. Extensive tidal flats are composed of well-sorted sands and poorly-sorted silts and clays. Coarse, well-sorted sands

form in areas on and adjoining the baymouth barriers. Quantities of fine sediment and organic matter are carried in suspension, which imparts a turbid brown colour to the water. Sediment colour varies from light grey to brown on and adjoining baymouth barriers to live-grey, olive-green, and black in the central bay. Highest organic carbon contents are present in river sediments of silty-clay or sandy-silt and lowest values are recorded in sediments associated with baymouth barriers. Highest percentage of calcium carbonate are recorded in the river and central bay areas and lowest values are recorded in sediments on and adjoining the baymouth barriers. Foraminifera are minor contributors to the total calcium carbonate content of the sediments. Most of the analyzed sediment samples have a Median Diameter in the 1.2 ϕ to 3.0 ϕ range. Finest sediments MDϕ (3.8 - 6.0) are found in deeper quieter portions of the river channel or in protected deeper water areas of the central bay.

2. The foraminiferal fauna of the Miramichi estuary is eurybathic. A decrease in species indicates an increase in environmental variability, and an increase in species is indicative of a more uniform environment. These faunal characteristics represent the up-river and open-gulf environments respectively. This suggests that as marginal marine conditions are approached the environment becomes more variable and the number of species decrease. Moreover, the occurrence of the most common species in a foraminiferal

population (faunal dominance) is directly proportional to environmental variability. As the river is approached the environment becomes more variable and faunal dominance increases. This is exemplified by Miliammina fusca in the river and Elphidium incertum "complex" in the bay.

3. Foraminiferal populations are variable both in total numbers and species composition throughout the estuary. Living populations are fewer in numbers and species than corresponding dead populations. Areas with large total populations are generally represented by small living populations.

4. Cross-sectional and longitudinal profiles indicate that water chemistry, salinity in particular, is significant in limiting the Miramichi River bottom waters to arenaceous and pseudochitinous species, namely, Miliammina fusca, Centropyxis arenatus, Difflugia capreolata, D. oblonga and Pontigulosia compressa. This is supported by the fact that species of Elphidium penetrated further upstream with attendant higher salinities during different years. Calcium carbonate and organic carbon content are highest in silts and clays. These areas are generally environments maintaining a large calcareous-hyaline foraminferal fauna composed principally of Elphidium incertum and E. orbiculare.

5. Living-total foraminiferal ratios indicate irregular sedimentation patterns in the Miramichi estuary. Highest rates are recorded in sand or silty-sand substrates in areas

adjacent to baymouth barriers. Lowest rates are recorded in silty-clays in the central bay areas. The dominance of Elphidium incertum "complex" in Miramichi Bay is exemplified by the similarity in the living-total ratio pattern for this species and the pattern for all species in the bay.

6. The Miramichi River microfauna is composed almost entirely of arenaceous or pseudochitinous species. Miliammina fusca dominates and is commonly the only foraminiferal species present in the river environment. Foraminiferal populations in the inner and central Miramichi Bay environment are composed almost entirely of calcareous specimens. Elphidium incertum "complex", E. margaritaceum and E. orbiculare represent up to 90 percent of the total population.

Miliammina fusca and Eggerella advena are dominant arenaceous species and delineate the river and baymouth barrier environments respectively. Elphidium incertum and E. orbiculare, calcareous-hyaline species, dominate the entire microfauna. They are indicative of the central bay and nearshore environments when occurring together, whereas the presence of Elphidium incertum "complex" alone, or in association with Eggerella advena, characterizes areas on and adjoining baymouth barriers. This fauna is considered "typical" of cool-temperate brackish water environments. These factors are significant in the reconstruction of ancient environments.

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APPENDIX A

FAUNAL REFERENCE LIST

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APPENDIX B

MEDIAN DIAMETERS IN PHI UNITS

MEDIAN DIAMETERS IN PHI UNITS

Station	Median Dia. ϕ
22	1.4
23	1.6
24	2.3
25	2.6
26	1.2
27	2.4
28	5.9
29	2.6
30	2.2
31	2.6
32	2.6
33	1.9
34	2.0
35	4.8
36	2.8
37	6.0
38	4.7
39	1.4
40	4.4
41	5.8
42	3.9
43	5.2
44	3.3
45	3.6
46	4.0
47	2.8
48	3.7
49	5.2
50	2.8
51	4.0
90	3.8
91	1.5
92	3.4
96	1.8
97	5.2
98	3.8
99	2.2
100	1.8
86	1.4
87	3.2
88	3.6
89	4.4
93	1.6
94	2.6
95	2.8
83	3.4
84	2.4
85	1.6
82	1.8

Station	Median Dia. ϕ
65	1.6
66	1.4
67	1.8
68	1.6
64	1.4
63	1.5
69	2.6
70	2.0
71	1.8
72	2.6
73	0.8
74	1.6
75	2.2
76	1.9
56	1.8
55	2.5
57	3.0
58	1.8
59	1.5
60	2.4
61	2.3
62	2.2
79	5.8
78	1.6
77	5.8
80	1.8
81	2.3
52	4.0
53	2.4
54	1.3

APPENDIX C

DISTRIBUTION CHART OF FORAMINIFERA AND THECAMOEBINA

DISTRIBUTION CHART OF FORAMINIFERA AND THECAMOEBINA IN RECENT SEDIMENTS OF MIRAMICHI RIVER AND BAY

10 - PERCENT OF TOTAL POPULATION (10) - PERCENT LIVING X - LESS THAN 1%

STATION NUMBER	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
TOTAL POPULATION	44	92	120	56	128	46	40	1368	32	88	110	82	82	20	144	2	98	102	192	24	104	232	262	240	268	664	3700	2480	888	544
LIVING POPULATION	12	8	40	34				428		6	26	14	24	4	42		20	2	42	4	18	42	36	44	62	106	462	390	66	96
LIVING - TOTAL RATIO	.27	.09	.33	.60				.31		.07	.23	.17	.29	.20	.29		.20	.02	.21	.16	.17	.18	.14	.18	.23	.16	.12	.16	.07	.17
1 AMMONIA BECCARI																														
2 AMMOSCALARIA FLUVIALIS											4																X	5		12
3 AMMOTIUM CASSIS																			7 (1)										3	
4 A.SALSUM								3		33	8		5 (5)														4	2		
5 ANGULOGERINA ANGULOSA																														
6 BUCCELLA FRIGIDA																										2				
7 BULIMINELLA ELEGANTISSIMA																														
8 CENTROPYXIS ARENATUS	23	17	5	7		X		1		18 (2)	4												1				2			
9 DIFFLUGIA CAPREOLATA	10	31	15 (5)		X			3 (3)			5 (2)	17											7 (2)				3 (2)			2 (X)
10 D.OBLONGA	7				X	X		7 (7)			11 (7)	17 (2)	17 (5)		6 (2)		10 (4)		6 (2)		12 (2)		5 (1)	7 (1)	3 (X)	3 (X)	2		4 (X)	12 (2)
11 EGGERELLA ADVENA																														
12 ELPHIDIUM BARTLETTI																														
13 E.INCERTUM																			20 (1)	56 (12)		98 (18)		27 (9)		23 (8)	2 (X)	1 (X)	40 (X)	
14 E.MARGARITACEUM																										6 (X)				
15 E.ORBICULARE															4				34 (8)							26 (5)	4 (X)	X (X)	14 (3)	
16 E.SUBARCTICUM																						2							6	
17 FISSURINA MARGINATA																														
18 GLOMOSPIRA GORDIALIS																														
19 HEMISPHAERAMMINA SP.																							3				2			2
20 MILIAMMINA FUSCA	50 (9)	52 (8)	60 (7)	93 (50)	100 (6)	X	60 (10)	61 (16)	50	49 (4)	53 (11)	83 (15)	78 (18)	X (X)	90 (24)	100	90 (16)	98	12	25	54 (11)		67 (9)	53 (6)	79 (21)	39 (5)	71 (6)	91 (7)	32 (4)	70 (13)
21 OOLINA BOREALIS																														
22 PATEORIS HAUERINOIDES																														
23 PONTIGULASIA COMPRESSA	10	2				X		3 (3)	12		11 (5)								5 (15)		11 (2)		5		7 (1)		2 (X)			
24 PSEUDOPOLYMORPHINA NOVANGLIAE																														
25 QUINQUELOCULINA SEMINULUM																														
26 REOPHAX ATLANTICA																														
27 R.CURTUS																														
28 R.PILULIFERA																														
29 R.SCORPIURUS																														
30 SPIROPLECTAMMINA BIFORMIS											4																			
31 TROCHAMMINA INFLATA																														
32 T.LOBATA							40											2 (1)			23 (2)		3	10 (1)			X		X	
33 T.MACRESCENS																		X	15 (4)								X (X)	X	X	2
34 T.OCHRACEA																														
35 T.SQUAMATA								1	12											24 (12)			9 (1)	3	11 (X)		6			
PERCENT LIVING	27	9	33	60				31		7	23	17	29	20	29		20	2	21	16	17	18	14	18	23	16	12	16	7	17
NUMBER OF GENERA	4	4	3	2	1	1	2	6	4	3	7	2	3	1	3	1	2	2	6	3	4	1	6	4	4	4	8	5	5	5
NUMBER OF SPECIES	5	4	3	2	1	1	2	7	4	3	8	2	3	1	3	1	2	3	7	3	4	2	8	5	4	6	13	6	8	6
% ARENACEOUS TESTS	100	100	100	100	100	100	100	100	100	100	100	100	100	100	96	100	100	100	46	44	100		100	73	100	58	94	97	40	100
% CALCAREOUS HYALINE TESTS															4				54	56		100		27		42	6	3	60	
% PORCELANEOUS TESTS																														

STATION NUMBER	90	91	92	96	97	98	99	100	86	87	88	89	93	94	95	83	84	85	82	65	66	67
TOTAL POPULATION	2380	166	2338	1532	1918	1116	2314	1037	2036	2118	1026	3102	3664	3102	9852	5380	3794	1450	30	64	3490	
LIVING POPULATION	22	10	420	38	230	259	253	272	754	22	32	44	302	256	328	320	772	262	4	32	756	
LIVING - TOTAL RATIO	.01	.06	.18	.02	.12	.23	.19	.26	.37	.01	.03	.01	.08	.08	.03	.06	.20	.18	.13	.50	.21	
1 AMMONIA BECCARI																						
2 AMMOSCALARIA FLUVIALIS																						
3 AMMOTIUM CASSIS		3							X (X)	X			X (X)	X (X)	X (X)	X (X)	5 (X)	1 (X)				
4 A.SALSUM																						
5 ANGULOGERINA ANGULOSA																X						
6 BUCCELLA FRIGIDA						X				X	X	X	1 (X)	X	X (X)	1 (X)	X	3 (X)				
7 BULIMINELLA ELEGANTISSIMA																						
8 CENTROPYXIS ARENATUS					X									X								
9 DIFFLUGIA CAPREOLATA																						
10 D.OBLONGA														X								
11 EGGERELLA ADVENA				X	X	X (X)			X (X)	X	X	X	43 (X)	22 (2)	1 (X)	X (X)	50 (10)	26 (7)	X	5	14 (X)	
12 ELPHIDIUM BARTLETTI													X		X	1 (X)		X				
13 E.INCERTUM	60 (X)	51 (21)	64 (8)	52 (X)	55 (4)	56 (10)	56 (5)	53 (7)	70 (20)	44 (X)	60 (X)	46 (X)	18 (2)	26 (X)	53 (1)	61 (2)	11 (2)	49 (5)	X (X)	67 (42)	70 (20)	
14 E.MARGARITACEUM	6		21 (7)				22 (7)	23 (9)	11 (3)							1 (X)		X			5 (X)	
15 E.ORBICULARE	34 (X)	46 (3)	13 (2)	47 (2)	44 (7)	40 (13)	21 (3)	21 (7)	13 (10)	54 (X)	39 (X)	52 (X)	30 (4)	48 (5)	45 (2)	32 (2)	28 (9)	2 (X)				
16 E.SUBARCTICUM															X	X		1 (X)	X (X)	14	6 (1)	
17 FISSURINA MARGINATA																			X			
18 GLOMOSPIRA GORDIALIS																					X	
19 HEMISPHAERAMMINA SP.																						
20 MILIAMMINA FUSCA			2 (X)	X			X	2 (X)	4 (X)			X	1			1 (X)	2 (X)	6 (1)			1	
21 OOLINA BOREALIS																					X	
22 PATEORIS HAUERINOIDES								X											X			
23 PONTIGULASIA COMPRESSA																						
24 PSEUDOPOLYMORPHINA NOVANGLIAE																					X	
25 QUINQUELOCULINA SEMINULUM																X	X	X				
26 REOPHAX ATLANTICA																	X					
27 R.CURTUS																	X					
28 R.PILULIFERA														X	X							
29 R.SCORPIURUS									X (X)				X	X			X (X)					
30 SPIROPLECTAMMINA BIFORMIS																	X					
31 TROCHAMMINA INFLATA																						
32 T.LOBATA									X				4 (X)	X (X)			1 (X)	6			1	
33 T.MACRESCENS									X (X)							X	X (X)				1	
34 T.OCHRACEA														X						14		
35 T.SQUAMATA																						
PERCENT LIVING	1	6	18	2	12	23	19	26	37	1	3	1	8	8	3	6	20	18	13	50	21	
NUMBER OF GENERA	1	5	2	3	3	3	2	3	6	4	3	4	7	8	5	10	9	7	4	3	7	
NUMBER OF SPECIES	3	6	4	4	4	4	4	5	9	5	4	5	9	11	8	14	13	11	5	4	10	
% ARENACEOUS TESTS		3	23	1	1	1	1	2	7	1	1	1	49	28	3	5	59	39	4	19	18	
% CALCAREOUS HYALINE TESTS	100	97	77	99	99	99	99	98	93	99	99	99	51	72	97	84	40	60	96	81	82	
% PORCELANEOUS TESTS																1	1	1				

STATION NUMBER	68	64	63	69	70	71	72	73	74	75	76	56	55	57	58	59	60	61	62	79	78	77	80	81	52	53	54
TOTAL POPULATION	46	1138	28	1136	4	16	434	24	410	792	6	10	94	384	10	144	176	28	942	400	226	6024	1234	900	292	464	6
LIVING POPULATION	8	36		154			80		394	106			48	72		138	156		198	54	118	86	338	480	116	76	
LIVING - TOTAL RATIO	.17	.31		.13			.18		.96	.13			.51	.18		.96	.88		.21	.17	.52	.02	.28	.53	.40	.16	
1 AMMONIA BECCARI							X														X						
2 AMMOSCALARIA FLUVIALIS																											
3 AMMOTIUM CASSIS										X									X		1						
4 A.SALSUM																											
5 ANGULOGERINA ANGULOSA																											
6 BUCCELLA FRIGIDA				2						X				X					X	5	1	3	3				
7 BULIMINELLA ELEGANTISSIMA																			X								
8 CENTROPYXIS ARENATUS																										16 (X)	
9 DIFFLUGIA CAPREOLATA																										10 (X)	
10 D.OBLONGA																											X
11 EGGERELLA ADVENA	50 (12)			7 (3)	X		8 (X)			10 (1)				X			X		30	2	12 (2)		4 (4)	X (X)			
12 ELPHIDIUM BARTLETTI				X										X								1	X	X			
13 E.INCERTUM	35 (4)	94 (9)	X	79 (10)	X	X	5 (X)	X	10 (9)	3 (X)	X	X	100 (X)	85 (18)	X	7 (7)	[illegible]	X	81 (14)	85 (14)	75 (40)	86 (8)	75 (15)	86 (44)	54 (21)		
14 E.MARGARITACEUM				3 (X)		X	50 (9)	X	90 (8)	14 (1)	X			X						1	5 (1)						
15 E.ORBICULARE		3		X						1										7		9 (X)	3 (X)	5 (X)	35		
16 E.SUBARCTICUM		X		4			X							4		30 (45)						X	4 (X)	6 (X)			
17 FISSURINA MARGINATA																							X				
18 GLOMOSPIRA GORDIALIS																											
19 HEMISPHAERAMMINA SP.																											
20 MILIAMMINA FUSCA	5		X	2		X	35 (10)	X		67 (10)											3				4 (16)	64 (10)	
21 OOLINA BOREALIS																			1								
22 PATEORIS HAUERINOIDES																43 (42)		X						X			
23 PONTIGULASIA COMPRESSA																										9 (X)	
24 PSEUDOPOLYMORPHINA NOVANGLIAE																							X				
25 QUINQUELOCULINA SEMINULUM			X	X										X				X	X				3 (X)				
26 REOPHAX ATLANTICA				X																			4 (4)				
27 R.CURTUS																							X				
28 R.PILULIFERA																											
29 R.SCORPIURUS																											
30 SPIROPLECTAMMINA BIFORMIS																					X						
31 TROCHAMMINA INFLATA										X																	
32 T.LOBATA	5			2			X	X						X					1				4 (4)	X (X)	7		
33 T.MACRESCENS	5																		X		1					X	
34 T.OCHRACEA																											
35 T.SQUAMATA						X				X									X		X						
PERCENT LIVING	17	31		13			18		96	13			51	18		96	88		21	17	52	2	28	53	40	16	
NUMBER OF GENERA	4	2	2	7	2	3	5	3	1	6	1	1	1	5	1	2	2	3	8	3	8	2	9	4	3	4	1
NUMBER OF SPECIES	5	4	2	11	2	4	7	4	2	9	2	1	1	6	1	3	2	3	10	5	10	5	12	7	4	5	1
% ARENACEOUS TESTS	65		20	12	50	22	44	75		89				1			1		35	2	18		13	2	11	100	100
% CALCAREOUS HYALINE TESTS	35	99	80	87	50	78	56	25	100	11	100	100	100	98	100	100	99	85	64	98	82	100	84	98	89		
% PORCELANEOUS TESTS		1		1										1				15	1				3				

PLATES

PLATE 1

Figure 1. Centropyxis arenatus (Cushman), X125, a) ventral view, b) edge view, Hypotype, G.S.C. No. 21121.

2. Difflugia oblonga Ehrenberg, X100, Hypotype, G.S.C. No. 21122.

3, 4. Miliammina fusca (Brady) X100, Hypotypes, 3, G.S.C. No. 21123, 4, G.S.C. No. 21124.

5, 6. Trochammina lobata Cushman, X100, Hypotypes, 5, G.S.C. No. 21125, 6, G.S.C. No. 21126.

7. Ammotium cassis (Parker), X25, Hypotype, G.S.C. No. 21127.

8, 9. Quinqueloculina seminulum (Linné) X60, Hypotypes, 8, G.S.C. No. 21128, 9, G.S.C. No. 21129.

10. Spiroplectammina biformis (Parker & Jones) X100, Hypotype, G.S.C. No. 21130.

11. Fissurina marginata (Montagu), X150, Hypotype, G.S.C. No. 21131.

12, 13. Pateoris hauerinoides (Rhumbler), X100, Hypotypes, 12, G.S.C. No. 21132, 13, G.S.C. No. 21133.

14. Eggerella advena (Cushman), X100, Hypotype, G.S.C. No. 21134.

15. Ammonia beccarii (Linné), X60, Hypotype, G.S.C. No. 21135.

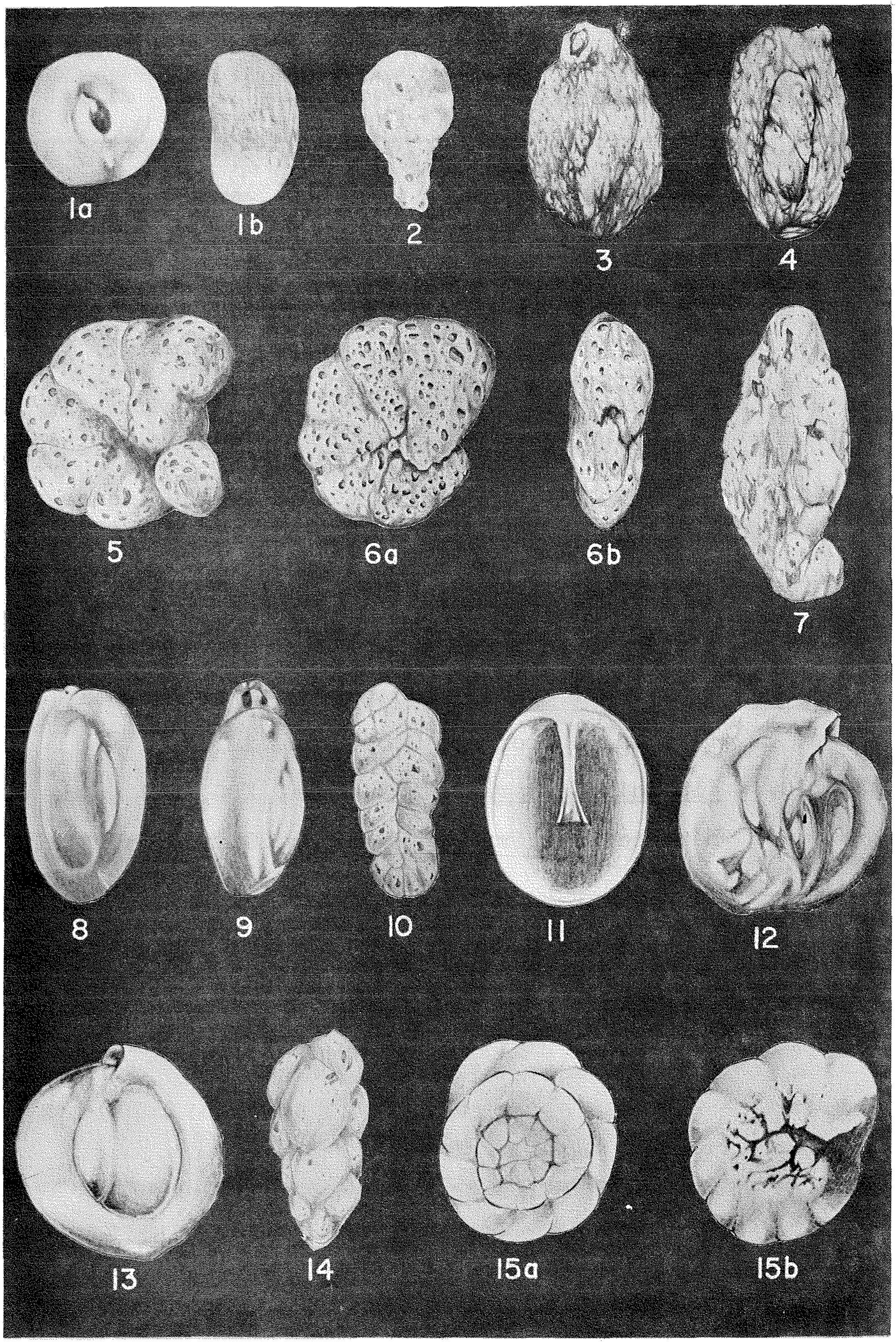

Plate 1

PLATE 2

Figure 1. Buccella frigida (Cushman), X100, a) dorsal view, b) ventral view, c) edge view, Hypotype, G.S.C. No. 21136.

2. Elphidium bartletti Cushman, X60, a) side view, b) apertural view, Hypotype, G.S.C. No. 21104.

3-7. Elphidium incertum (Williamson) "complex", 3-6, X120, 7, X100, 3a) side view, 3b) edge view, 4-7, side views, Hypotypes, G.S.C. Nos. 21108-21115.

8. Elphidium margaritaceum Cushman, X120, side view, Hypotype, G.S.C. No. 21116.

9. Elphidium orbiculare (Brady) X80, a) test with arenaceous "jacket" partially removed, Hypotype, G.S.C. No. 21117, b) test with arenaceous jacket removed, Hypotype, G.S.C. No. 21118.

10. Elphidium subarcticum Cushman, X80, a) side view, b) apertural view, Hypotype, G.S.C. No. 21119.

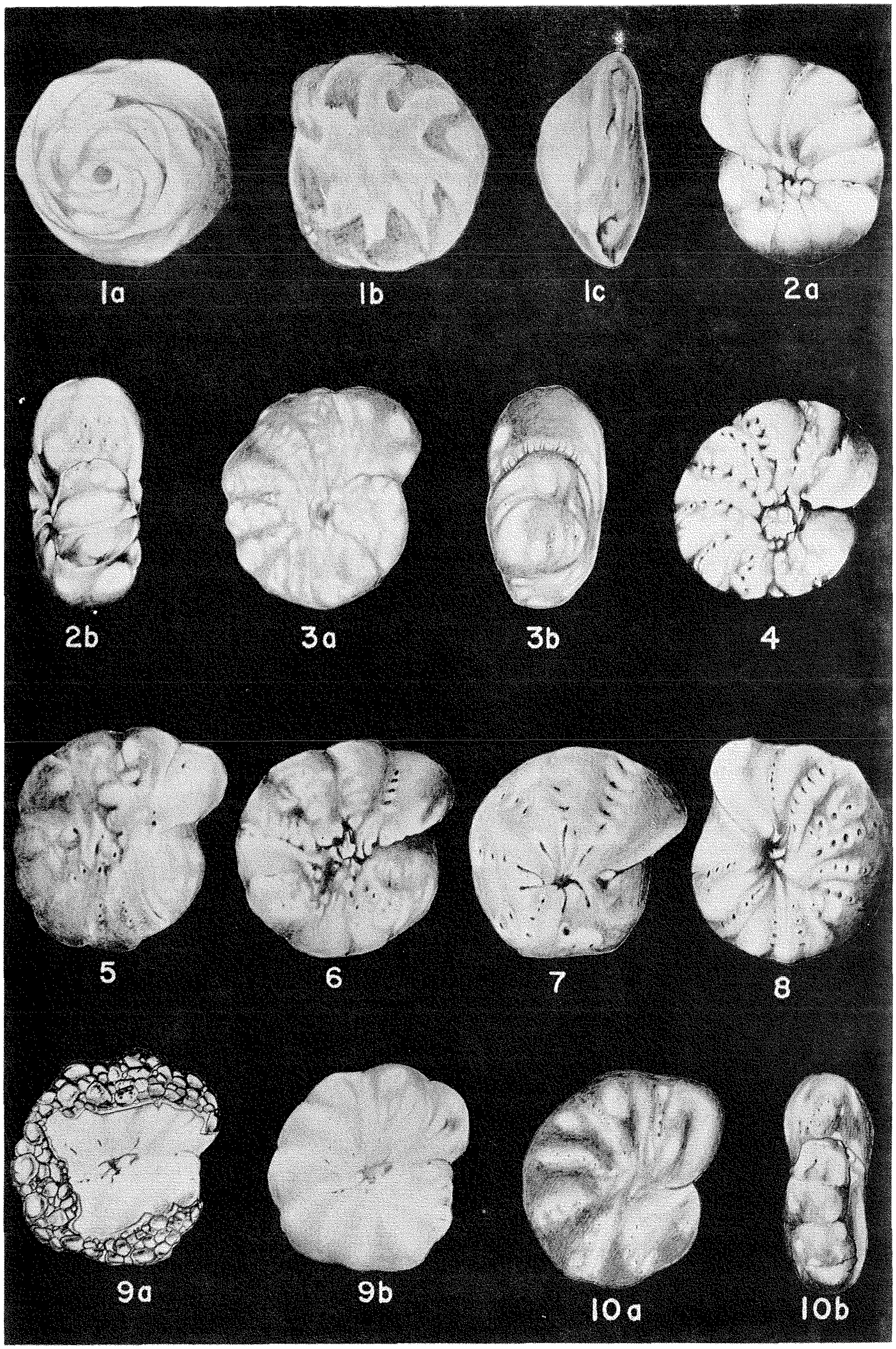

Plate 2