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PAPER 66-20

FORAMINIFERA DISTRIBUTION IN TRACADIE BAY, PRINCE EDWARD ISLAND

(Report and 14 figures)

G. A. Bartlett

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ABSTRACT

Tracadie Bay is characterized by a lagoonal environment. The bay is shallow (less than 20 feet), undergoes wide diurnal and seasonal temperature and pH changes, and is within the brackish water regime. Free circulation with the open Gulf of St. Lawrence is restricted by a baymouth bar. Sediments derived from the bar and surrounding coastal areas are filling the bay. Intertidal areas are prograding by means of filter trapping of sediment by plant growth. Bay bottom sediments grade from clay through sand. Sedimentation rates are highest adjacent the baymouth. Sediment sorting is normal. Deeper or central bay sampling stations generally yield finest sediment, and highest faunal content. Organic carbon and calcium carbonate content are highest in finer sediments.

The foraminiferal fauna is restricted to 11 genera and 23 species. This population is much smaller than those of bays having open circulation with the Gulf of St. Lawrence or Atlantic Ocean, but comparable to inner lagoon assemblages of southern latitudes. The fauna comprises over 50% calcareous hyaline tests at most stations. At some stations, arenaceous and porcelaneous tests are absent. This typical northern latitude lagoon lacks the miliolid fauna characteristic of southern areas (e.g. Gulf of Mexico). However, the _Elphidium_ and _Ammonia beccarii_ association resembles similar assemblages inhabiting inner lagoons of southern latitudes.

Total populations vary from 3,400 to 162,200 tests per square metre. The standing crop is lower, 1,400 to 72,000 per square metre, while the average standing crop for the entire bay is 20,180 per square metre. Per cent living varies from 9% to 64% with an average for the bay of 27%. Large populations of small tests of some species indicate optimum environmental

conditions. However, large size, distorted shape, and plastogamy of A. beccarii and Elphidium incertum tests indicate areas of marginal environments for these species.

The distribution of seven species, Ammonia beccarii, Eggerella advena, Elphidium incertum, E. margaritaceum, E. orbiculare, Miliammina fusca, and Trochammina lobata are distinctive in the bay environment. To the author's knowledge there is no previous record of the recent occurrence of A. beccarii this far north. Its absence along the Atlantic coastal areas north of Cape Cod suggests that it may be a local relict in this bay.

FORAMINIFERA DISTRIBUTION IN TRACADIE BAY, PRINCE EDWARD ISLAND

INTRODUCTION

This is a preliminary faunal and sedimentary investigation of Tracadie Bay, situated on the northeast coast of Prince Edward Island (Fig. 1). The purpose of this paper is to describe some of the sedimentary and faunal characteristics of a north temperate lagoonal environment and to compare them with lagoons of more southern latitudes.

This study is part of a long range detailed faunal and sedimentological study of various estuarine, lagoon, bay, and inner shelf environments adjoining the Atlantic Provinces of Canada. The lagoonal character of Tracadie Bay with its associated fauna containing foraminifera that are as yet unreported from southeast Nova Scotia, southern New Brunswick, or southeast Prince Edward Island prompted the present paper. In the present study only reconnaissance bottom sampling was undertaken by means of SCUBA and Dietz-Lafond during September 1965. Laboratory analyses of these samples were completed at the Bedford Institute of Oceanography, Dartmouth, Nova Scotia. Detailed sampling programs in lagoons adjacent northeast New Brunswick and Prince Edward Island will be undertaken in 1966.

Samples were obtained from depths of 3 to 15 feet. The shallower water stations (less than 4 feet) are located in tidal marshes at low tide (Fig. 3). A standard 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. Temperatures and pH of the sediments were recorded as soon as they reached the surface. Sediments were mixed with alcohol and Rose Bengal and set aside for faunal analyses. Field station positions were checked by triangulation, hydrographic charts, and aerial photographs.

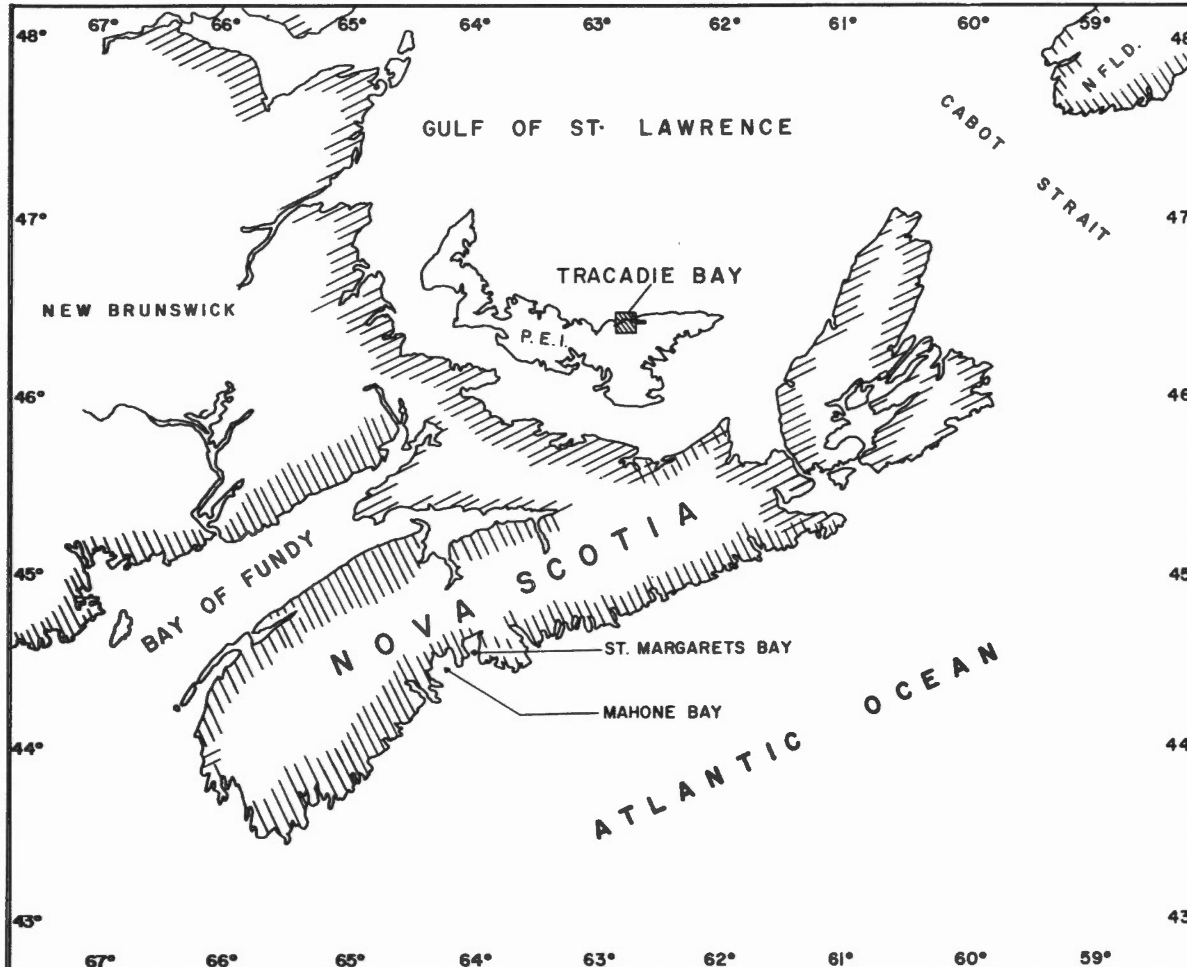


Figure 1 Index map of study area

Sieve and pipette analysis are similar to those described by Krumbein and Pettijohn (1938). Statistical analysis (Appendix B) were compiled from both sieve and pipette data. Faunal analyses are similar to those described by Bartlett (1964b).

Dr. B. R. Pelletier and Dr. R. J. Leslie of the Bedford Institute of Oceanography and Dr. B. F. Ellis and Dr. A. W. McCrone of New York University receive special thanks for critically reading the manuscript. The writer is indebted to B. F. Bartlett, D. D. Bishop, and F. M. Schnare for ably assisting in field investigations. R. Cormier and G. Duncan analyzed the sediments. S. Pitcher assisted in drafting many of the figures.

DESCRIPTION OF AREA

Tracadie Bay (Fig. 2), situated on the northeast coast of Prince Edward Island (Fig. 1), is approximately 2 miles wide and 5 miles long. The bay entrance is located at the western end of a range of sand hills 50 to 60 feet (15^m - 18^m) high. A shifting sand bar extends across the mouth of the bay, which is spacious within the sand bar and has a fairly consistent depth of 12 to 18 feet. Winter Creek (Fig. 2) is the major tributary of the bay.

Physiography and Geology

Temperatures, salinities, coastal configuration, and sediment movement in and adjacent Tracadie Bay are influenced by waters from the Gulf of St. Lawrence. Configuration of the bay is fairly regular with smoothed and rounded features attributable to weathering, erosion, and transport of loosely consolidated coastal sediments. General configuration, especially at the bay

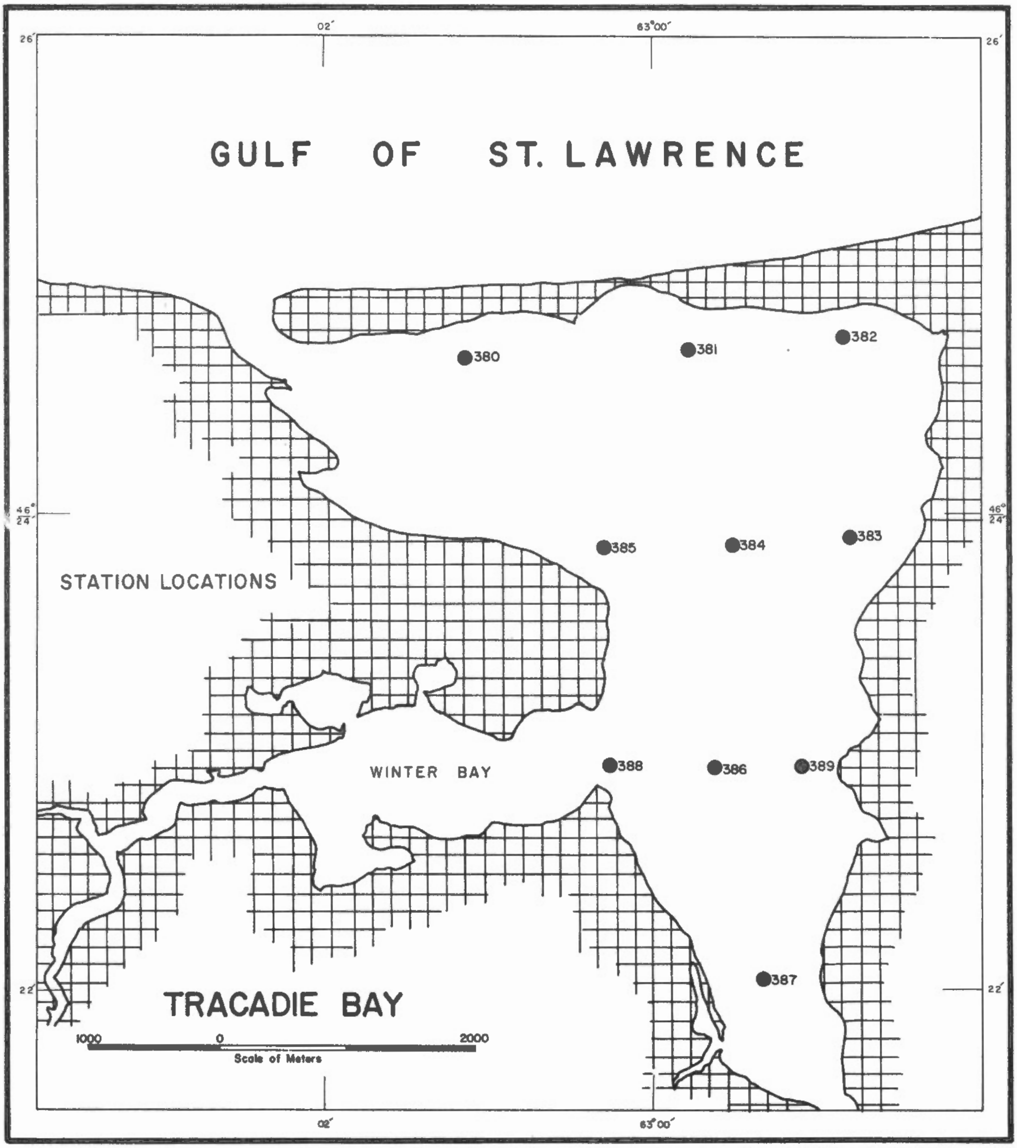


Figure 2 Station locations, Tracadie Bay

mouth, changes during highly turbulent conditions associated with seasonal storms.

According to Crowl (1961) the surrounding topography is largely bedrock-controlled. Exposed bedrock, mostly red sandstone, around the bay is sparse. Glacial drift cover is commonly 5 to 10 feet thick. Ablation moraine, with local relief of a few feet is developed on loose sandy till in small isolated areas. Salt marshes together with beaches, bars, spits, and dunes are scattered along the shore.

Climate

The climate is tempered by the Gulf of St. Lawrence. Easterly winds prevail in the spring. Westerly winds become more frequent towards summer, but southwesterly winds prevail during the summer season. Light southerly winds blow occasionally, but northerly winds are uncommon during the summer. In October and November northwesterly winds are frequently violent in heavy squalls. Fogs of a few days duration are common during much of the spring and fall. High winds and associated waves create turbulent conditions within the bay, which alter substrate configuration and breach the baymouth bar. Land temperatures range as high as 80°F during the summer, but fall below 0°F during the winter.

PHYSICAL SETTING

Bathymetry

Depths in Tracadie Bay (Fig. 3) range from 0 to 18 feet. The central bay areas are deepest, whereas areas inside the 6 foot depth contour are largely intertidal marshes. The main tidal channel is approximately 8 feet deep, whereas

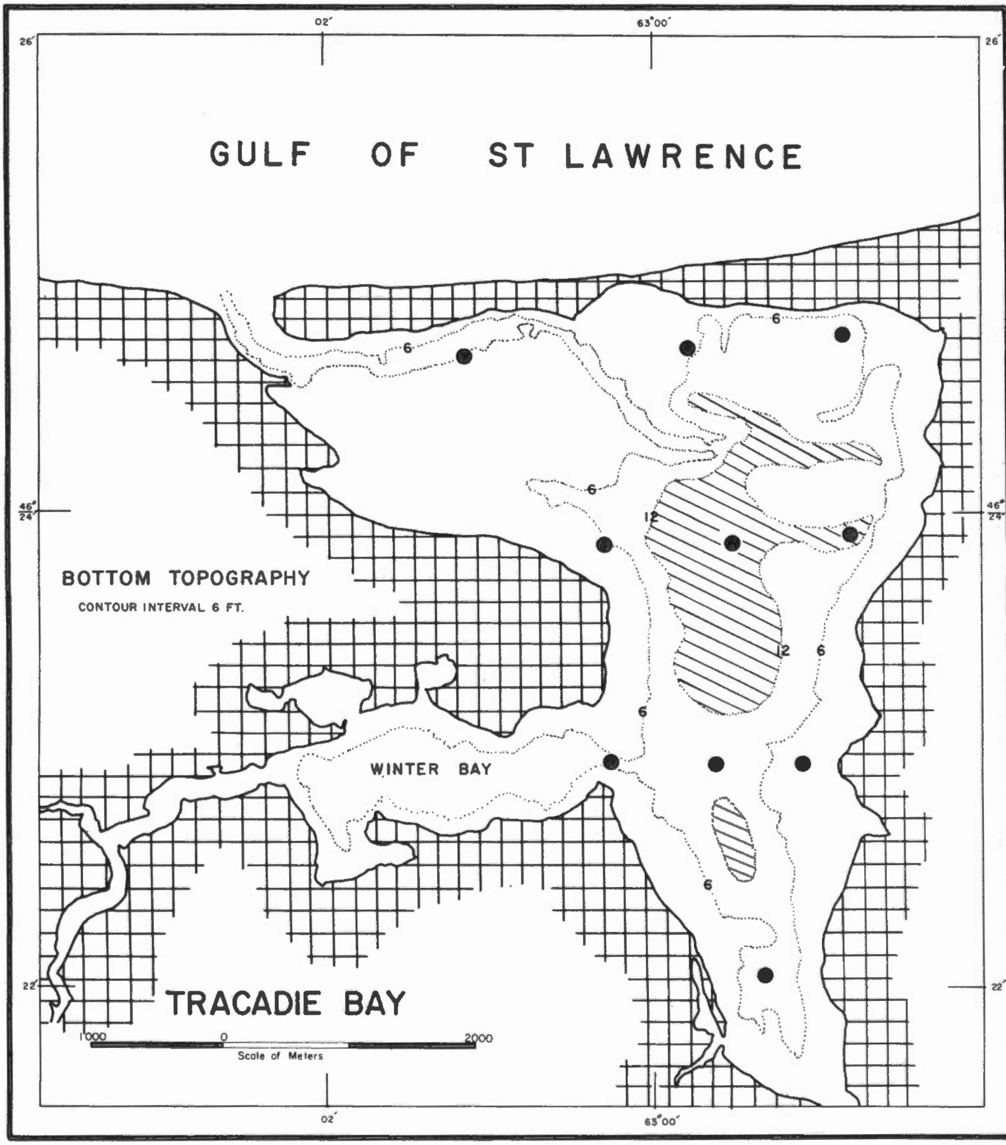


Figure 3 Bottom topography

the remainder of the bay has a smooth shallow U-shaped profile ranging from 0 to 18 feet throughout.

Oceanography

Longshore current velocities at the mouth of the bay are approximately 2 knots, while currents within the bay are less than ½ knot. These longshore currents are responsible for formation and maintenance of the baymouth bar, while onshore currents keep the channel clear of sediments. According to Emery and Stevenson (1957) the tidal inlet through an offshore bar is generally formed by storm waves, is kept open by tidal currents, and moved or closed by longshore currents. Similarly, local inhabitants relate many instances of bar breaching and channel shifting in Tracadie Bay, a fact compatible with changes noted in a comparison of hydrographic charts of the northern coast of Prince Edward Island.

Tides raise the level of Tracadie Bay 3 to 4 feet. Bar breaching increases in salinity, decreases in temperature, and introduction of sediment into the bay are associated with tidal influxes. These events are also related to turbulent weather conditions.

According to Lauzier (1957) the most striking feature of year to year differences in Gulf of St. Lawrence waters adjacent Tracadie Bay is the wide range of variations in temperature from July to October. Since the St. Lawrence waters move in and out of Tracadie Bay similar temperature patterns can be expected for similar periods. Highest temperatures can be expected from June through October and coldest readings from November through February. Mean temperatures recorded during the period in which the samples were collected are as follows: $7^{A.M.}$, 8°C - 10°C; $2^{P.M.}$, 16°C - 18°C; $7^{P.M.}$, 10°C - 14°C.

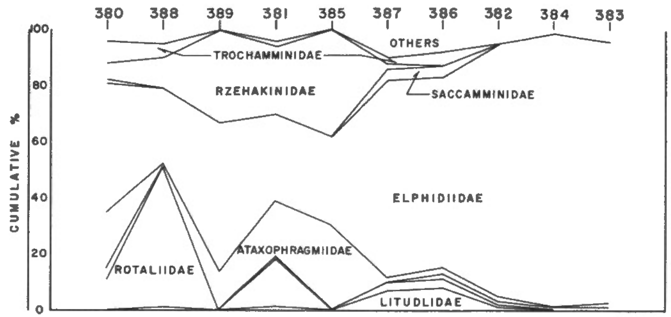
Maximum recorded summer temperature is 26°C, and minima during winter freeze-up are known to approach - 1°C.

During periods of tidal influx salinities at the mouth of Tracadie Bay approximate those of the open Gulf. Noticeably lower salinities are encountered only near the head of the bay. Tracadie Bay water is brackish, with maximum salinity of 28.39°/oo at station 380 and minimum of 27.84°/oo at stations 387, 388. Except for periods of abnormal tidal incursion, the salinity throughout the bay is relatively uniform.

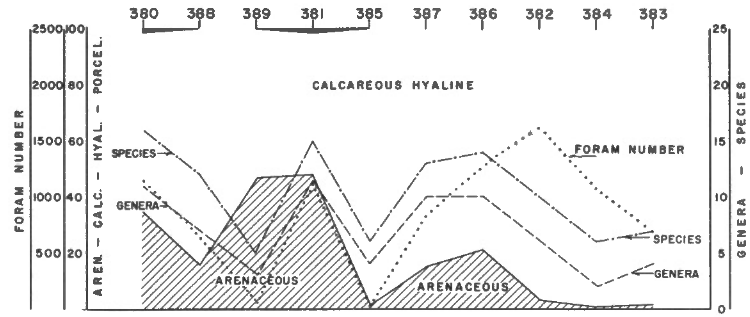
pH readings indicate that bottom surface sediments are alkaline (pH 7.2 - 7.8). However, immediately below the surface, especially in black, fetid oozes, pH values generally decrease to 6.8. Furthermore, sediments within 1-2 cm of the mud water interface are generally oxidized (+Eh), whereas deeper penetration generally indicates reducing (-Eh) conditions.

SEDIMENTS

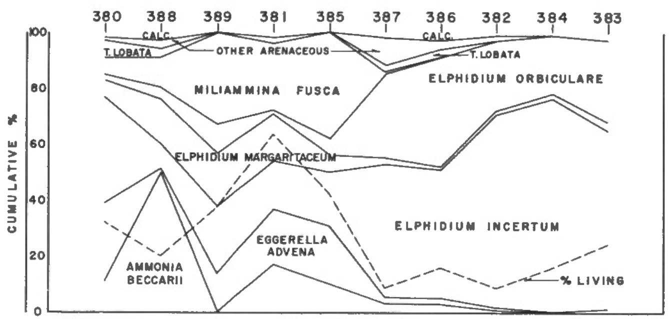
Bottom sediments (Fig. 4) grade from silty clays through coarse sand. Sand content (Appendix C) varies from 9% (Station 384) to 100% (Stations 385, 389) and is mainly derived from the offshore bar. Sand is carried into the bay by currents that are usually associated with turbulent weather conditions and onshore winds. The mouth of the bay is presently filling with sand from the baymouth side, and sand washed through the tidal inlet is forming a tidal delta (A, Fig. 3). Sand washed over the offshore bar by storm waves is forming a washover fan (B, Fig. 3). In addition to these processes tidal flats (C) are forming because of the entrapment of sediment by prolific plant



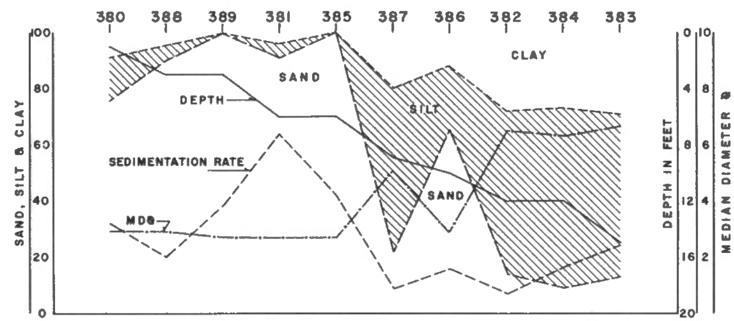
FORAMINIFERAL
FAMILY DISTRIBUTION



PERCENT - ARENACEOUS - CALCAREOUS
HYALINE AND PORCELANEOUS TESTS



FORAMINIFERAL
SPECIES DISTRIBUTION



D. SAND - SILT - CLAY DISTRIBUTION
WITH MDØ AND SEDIMENTATION RATE

FIGURE 4- SEDIMENTOLOGICAL AND FAUNAL CHARACTERISTICS IN TRACADIE BAY

growth.

Silt and clay content increases in central bay stations where most of this fine sediment is below the 6 foot contour interval. This indicates the effectiveness of the baymouth bar in inhibiting strong offshore Gulf currents from penetrating the bay. The organic carbon content is highest in silts and clays. The content ranges from .02 to 5.30 per cent with a mean of .78 per cent. Highest values are recorded in the central bay, whereas lowest values are recorded outside the baymouth barrier. Calcium carbonate content varies from .83 to 11.38 per cent with a mean of 4.14 per cent. Distribution patterns of $CaCO_3$ are comparable to the distribution patterns of organic carbon.

Median Diameter and Sorting

Median diameter decreases, (Fig. 4D), indicating an increase in fines (silt and clay) with increasing sediment depth. Median diameters for the entire bay fall within the fine silt to fine sand range. At station 382 correlation exists between maximum foraminifera per unit sample and lowest median diameter. However, similar correlation is not attained in other areas within the bay. Population-sediment relationship at station 382 may indicate that size, specific gravity, settling velocity etc. of the foraminiferal tests are similar to the associated sediments.

According to the Trask sorting coefficient, sediments in Tracadie Bay are well to normally sorted. Variations exist at both inner and outer bay stations (Appendix B). Fine sand at station 381 is approximately 4 times better sorted than fine to medium silt and fine sand at stations 384, 386, and 387. Sorting at stations 385 and 389 is identical, and shows better sorting than at other bay stations. Sediments adjacent the baymouth bar were probably partly sorted before being transported into the marine environment. Sorting is generally better in sand substrates (i.e. stations with high sand content), and decreases with increased silt and clay at slightly greater depths throughout the bay.

Sedimentation Rates

Relative rates of sedimentation (cm./year) are based on a formula proposed by Uchio (1960) as follows:

$1 \div R = T \div L/p$, where R = rate of sedimentation (cm./year); p = average reproductive period; T = total population; and L = living population

Sedimentation rates in Tracadie Bay (Fig. 5) are highest in sand substrates, as in areas adjacent the baymouth bar and shoreline of the bay. Station 381 has the highest rate (.64cm./year) compared with lowest rates of .09cm./year at stations 382, 387. Silt and sand characterize the substrate at station 381, whereas stations 382, 387 are characterized by black anaerobic silty clay.

In the Tracadie Bay study it was determined that the rate of sedimentation approximated the per cent of foraminifera living at each station. That is, a sedimentation rate of .64cm/year compares with 64% of the total population living at this station. As noted by Phleger (1955) the standing crop is generally indicative of the rate of foraminiferal production. Similarly, the present study indicates that most prolific growth is associated with highest rates of sedimentation. Rapid sedimentation buries empty tests and provides a large standing crop. Conversely, a small standing crop indicates a slow sediment supply rate. Furthermore, the present study supports the views of Phleger (1955) and Lankford (1959) that large living populations associated with increased sedimentation are probably indirectly related to the organic and inorganic nutrients associated with the sediments.

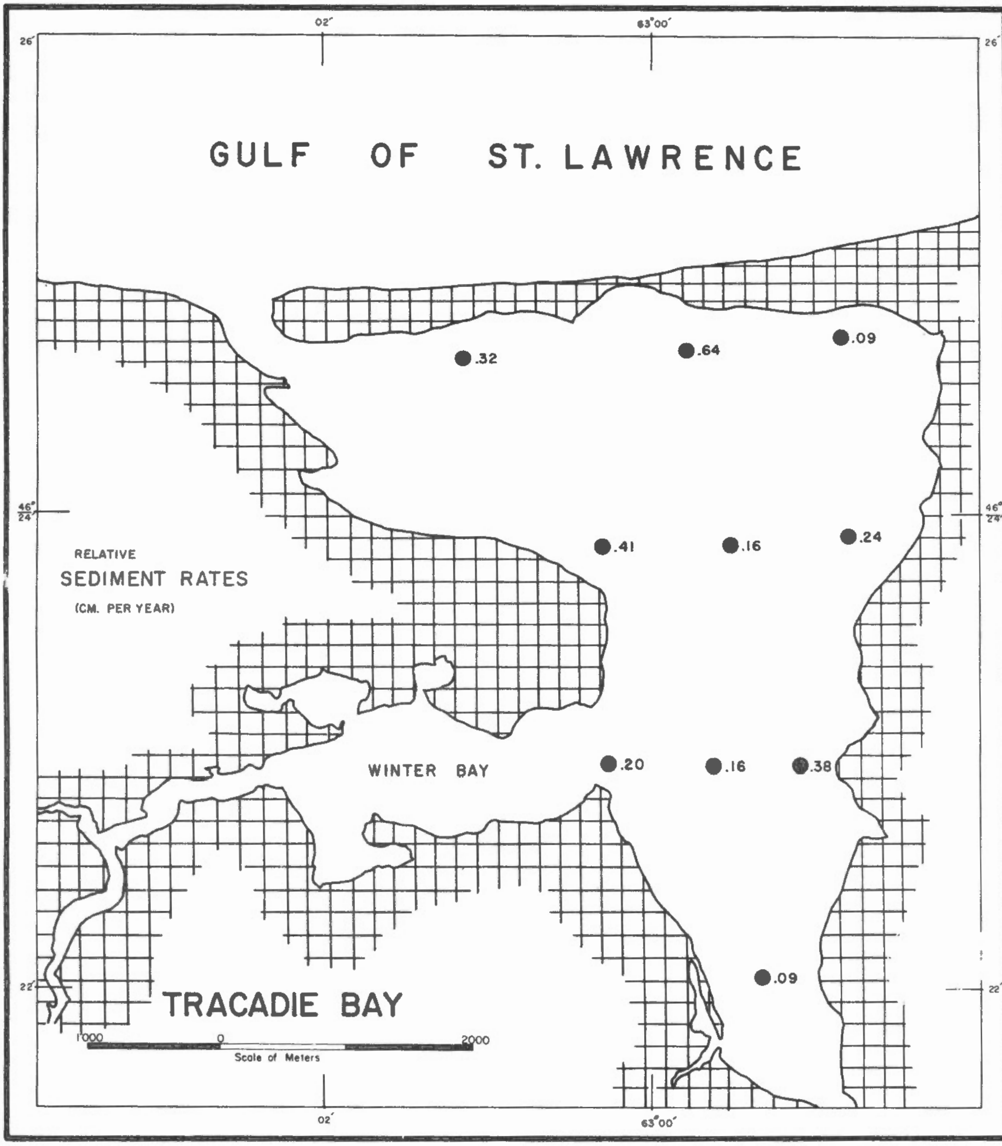


Figure 5 Relative rates of sedimentation

Fauna - Sediment Relationship

The following generalities regarding fauna - sediment relationship (Fig. 4) are apparent from this preliminary study. The most prolific foraminiferal growth is associated with highest rates of sedimentation, whereas the largest total population (living plus dead) is present in environments with lowest sedimentation rates. Furthermore, well aerated sand substrates with low organic carbon and calcium carbonate (e.g. station 381) contain the largest number of genera, species, per cent living and per cent arenaceous tests. Better sorted sediments generally contain a higher living foraminiferal population. However, total population distribution is more irregular and shows no relationship to sorting. Arenaceous tests are generally more abundant in substrates with highest sand content. Similarly, arenaceous genera and species are more common in substrates composed essentially of sand. On the other hand, calcareous hyaline tests, genera, and species, although characteristic throughout the bay, are most abundant in substrates containing higher percentages of silt and clay. These are also areas with higher organic carbon and calcium carbonate concentration in the sediments. Foraminiferal family distribution (Fig. 4) is comparable to distribution on a generic level.

FORAMINIFERAL DISTRIBUTION

The foraminiferal fauna of Tracadie Bay is typically lagoonal or inner bay. General similarities exist with lagoonal, inner bay, or deltaic faunas described by Phleger and Walton (1950), Parker (1952 a, b, 1954), Phleger (1952a, 1955), Ronai (1955), Lankford (1959), Parker and Athern (1959), Todd and Low (1961), Bandy (1963), and Bandy and Arnal (1957). Few sampling stations, and the rather uniform nature of the bay (in temperature, depth, substrate, salinity, and pH characteristics) does not warrant the establishment of distinctive biofacies in this preliminary investigation. It is sufficient to consider Tracadie Bay as a small lagoon, and therefore a biofacies within itself.

Ammonia beccarii and variants in the Atlantic Provinces region were first noted in the sediments of Tracadie Bay. Although of worldwide distribution this species had not been reported previously in sediments from southeastern Nova Scotia, southern New Brunswick, or southeastern Prince Edward Island. Specimens have been recorded by the writer in subsequent investigations along the north shore of New Brunswick and are described in another paper (Bartlett 1966). Parker (1952a) did not mention Ammonia beccarii in her study off Portsmouth, New Hampshire, but noted (1952b) its erratic distribution in the Long Island Sound - Buzzards Bay area. Ronai (1955) found it to be a prolific lagoonal form in sediments from New York Bight.

Elphidium incertum and E. orbiculare are the most prolific calcareous hyaline species, whereas Ammotium cassis, Eggerella advena, and Miliammina fusca represent the most characteristic arenaceous species in Tracadie Bay. There is a notable lack of porcelaneous tests in the bay environment.

The Tracadie Bay fauna is composed of 11 genera and 23 species (Appendix D). Calcareous hyaline tests and species predominate. Generically the fauna varies from 2 (Buccella, Elphidium) at station 384, to 11 (Ammodiscus, Ammonia, Buccella, Cibicides, Eggerella, Elphidium, Hemisphaerammina, Miliammina, Oolina, Quinqueloculina and Trochammina) at station 380. Similarly, there are six species at station 384 (Buccella frigida, Elphidium bartletti, Elphidium incertum, Elphidium margaritaceum, Elphidium orbiculare, and Elphidium subarcticum), compared with 16 species at station 380 (Ammodiscus minutissimus, Ammonia beccarii, Beccella frigida, Cibicides lobatulus, Eggerella advena, Elphidium frigidum, Elphidium incertum, Elphidium margaritaceum, Elphidium orbiculare, Elphidium subarcticum, Hemisphaerammina cf. bradyi, Miliammina fusca, Oolina borealis, Quinqueloculina seminulum, Trochammina lobata and Trochammina squamata).

Ammobaculites sp., Cibicides lobatulus, Elphidium bartletti, Elphidium frigidum, Hemisphaerammina cf. bradyi, and Oolina borealis were not found living during the present investigation; moreover, dead species are not represented by living individuals at all stations. Although the faunal content varies considerably at different stations it is unlikely that depth zonation in such shallow waters is a limiting factor in foraminiferal distribution. Indirectly depth may be a factor insofar as almost continuous bottom agitation is maintained by wind, waves, and tidal currents.

Wide temperature variations in Tracadie Bay necessitate the establishment of a eurythermal fauna to adjust to these. Moreover, foraminifera living in, and adjacent the intertidal marsh during the summer (e.g. Ammonia beccarii variants, Elphidium spp., Miliammina fusca and Trochammina lobata) must transfer below mean low water (M.L.W.) during the winter months to prevent protoplasmic destruction. Such movements may be associated with the reproductive cycle, or be in the form of mass migration. Means of survival during cold periods can be determined with the establishment of winter sampling stations.

Foraminifera living in the bay are known to inhabit environments with higher and lower salinities and temperatures than those recorded during the present study. Species such as Ammonia beccarii variants, Elphidium incertum, E. margaritaceum, E. orbiculare, Miliammina fusca, and Trochammina lobata are eurybathic forms well suited to such variable conditions. Furthermore, temperature and salinity changes associated with tidal incursions have little effect on the already established eurythermal and euryhaline fauna. However, the immediate effect of sediment influx is burial and probable annilhilation of the foraminiferal fauna in the area. The fauna survives only if it maintains or re-establishes its position at or near the sediment-water interface.

Tectinaceous linings of Ammonia beccarii, Elphidium incertum, E. margaritaceum, E. orbiculare, and Trochammina lobata, attest to the acidic, reducing nature of some substrates. This substantiates similar conclusions reached by Parker and Athern (1959) and Bartlett (1964b). It is apparent, therefore, that diagenetic processes are responsible for the removal of numerous tests from associated sediment. Such factors must be borne in mind in any paleoecological reconstruction. Furthermore, the large variations in plant growth and distribution in Tracadie Bay produce irregular pH patterns, while diurnal and seasonal changes in photosynthetic rates directly affect the pH, CO_2 nutrient concentration and therefore the associated fauna within the environment.

Total Populations

Total populations (Fig. 6) were counted from a unit sample of 10 centimetres square. These values are easily converted to population per square metre and compared with studies of Phleger (1951, 1952a, 1955),

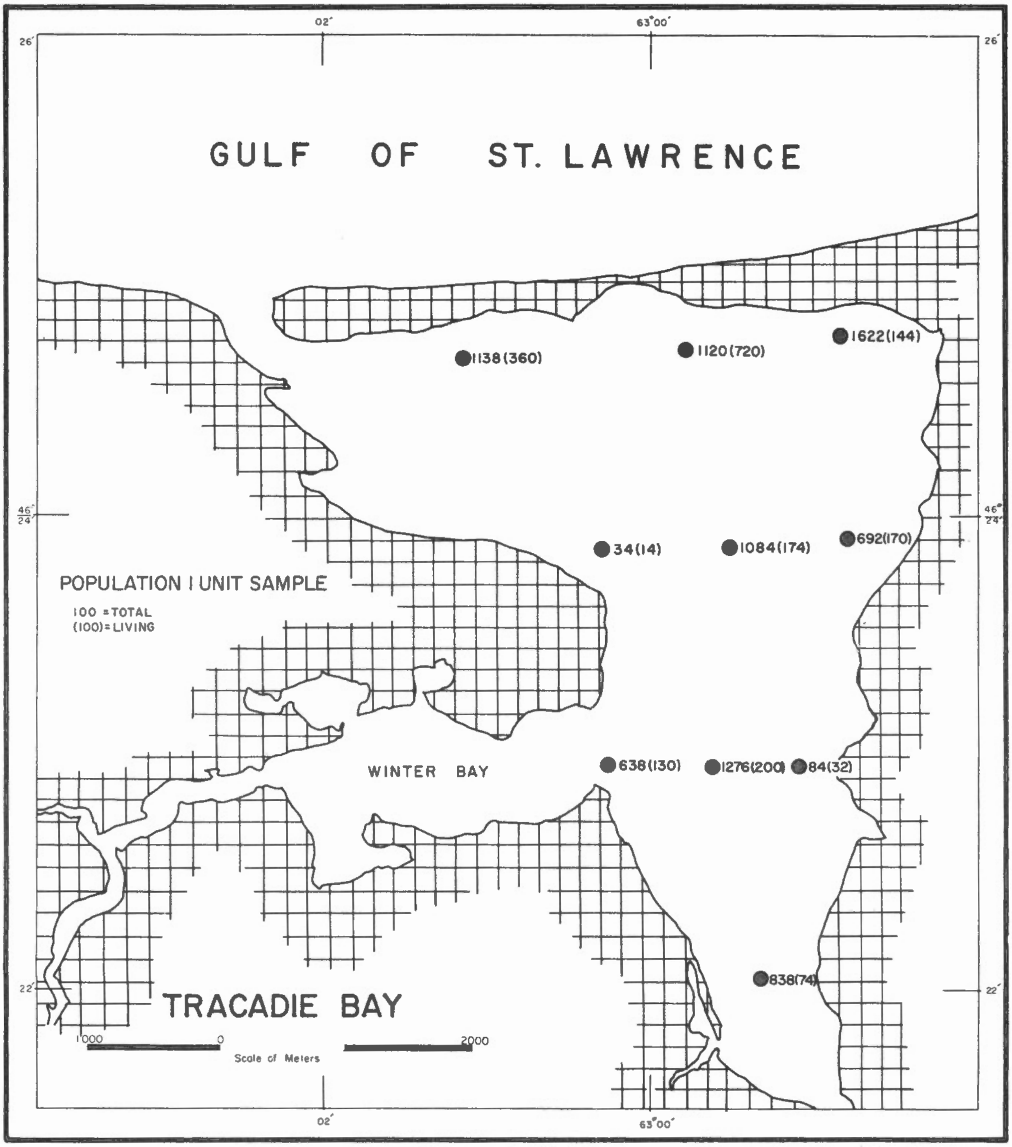


Figure 6 Foraminiferal population per unit sample

Lankford (1959) and Bartlett (1964b). Total populations vary from 3,400 to 162,000 tests per square metre of surface area. The largest populations, with most genera and species, adjoin the baymouth bar (stations 380, 381, 382) and the central bay (stations 384, 386). In each instance temperature, salinity, depth, and substrate are generally uniform. Populations with lowest foraminiferal, generic, and specific content are associated with coarser substrates on intertidal flats (stations 385, 389). These stations also contain more arenaceous than calcareous hyaline tests.

Living and total population distribution shows fairly good correlation for all species. As pointed out by Phleger (1955) this demonstrates either little post-mortem distribution of dead tests or that any transportation affects both living and dead populations. Total population counts are affected more by rates of sedimentation and diagenetic processes than by currents in Tracadie Bay. This is in direct contrast to bays along the southeast coast of Nova Scotia in which currents play a major role in the distribution of dead populations (Bartlett, 1964b). Station 381 is the only area containing more living than dead tests. This is also an area with highest sedimentation rate.

Living Populations

The patterns of density and areal occurrence of living foraminiferal species (Fig. 7) are irregular. The areas of maximum living foraminifera populations generally do not coincide with areas of maximum dead populations. This conforms with similar conclusions reached by Walton (1955) in a foraminiferal study at Baja, California. Standing crop per square metre of surface area varies from 1,400 to 72,000 tests. Living foraminifera are less

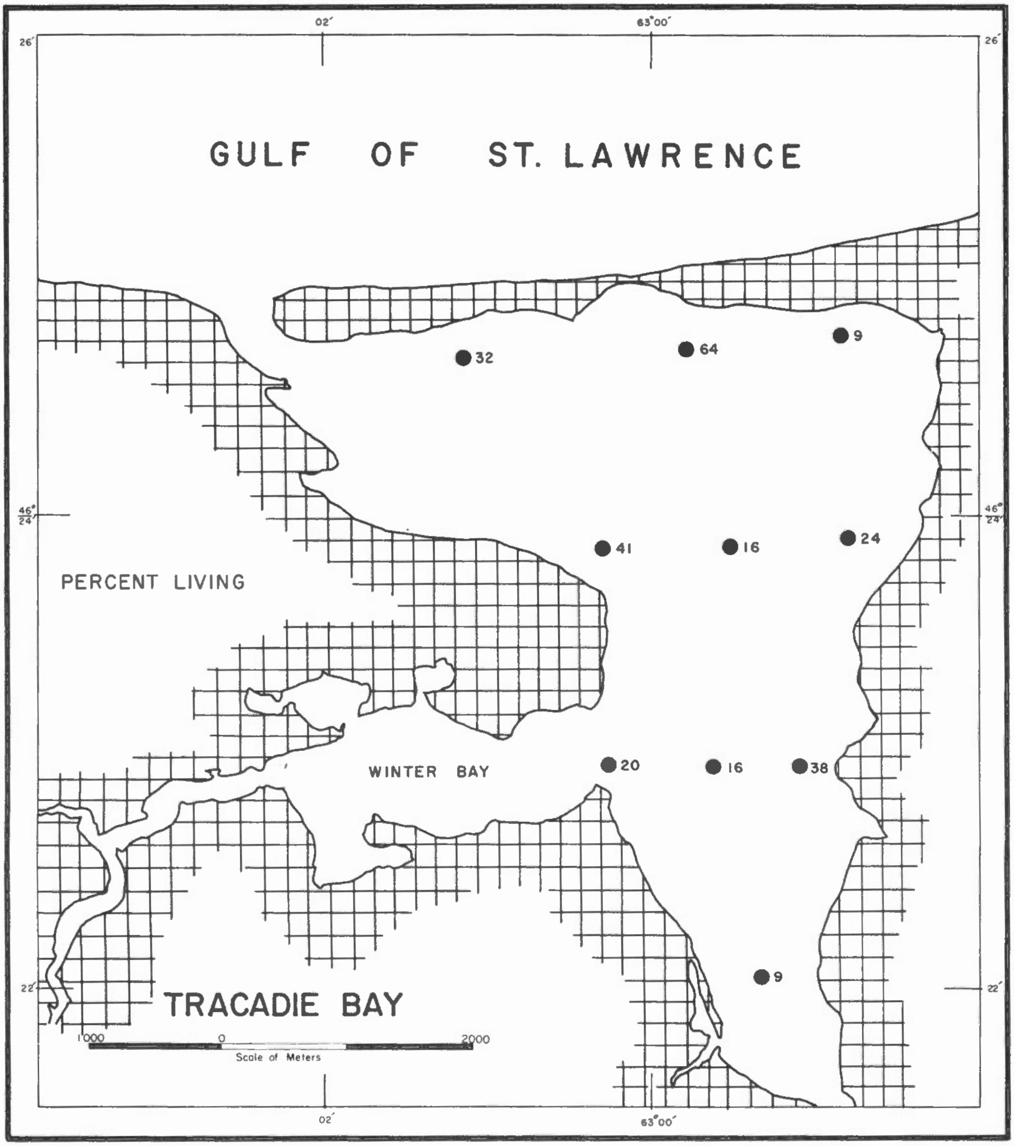


Figure 7 Per cent of total population living

numerous than dead tests. The average living population for the entire bay is 27% of the total population. Living foraminifera per unit sample are more prolific than similar species inhabiting bays along the Atlantic coast of Nova Scotia.

DISTINCTIVE SPECIES DISTRIBUTION

Variations in living and dead populations at stations apparently possessing similar substrates, depths, temperatures, pH, Eh, and salinity characteristics indicate that other factors, either alone or in combination, may be more important in the distribution of recent foraminifera. Species considered distinct enough to warrant separate consideration are: *Ammonia beccarii* and variants, *Eggerella advena*, *Elphidium incertum*, *E. margaritaceum*, *E. orbiculare*, *Miliammina fusca*, and *Trochammina lobata*.

Specimens resembling *A. beccarii* (Linné) and *A. beccarii tepida* (Cushman) are present in Tracadie Bay. Forms resembling *Helenia anderseni* (Warren) have not been distinguished. *A. beccarii tepida* is more characteristic of the inner bay, whereas the typical form frequents the outer bay environment. An apparent intergradation exists among many specimens, and the variety or subspecies *A. beccarii tepida* may be a minor variation of the typical form.

Ammonia beccarii

Ammonia beccarii (Fig. 8) is most abundant at station 388, but station 381 contains the largest number of living individuals. Dead and living specimens are absent from the central bay area (stations 383, 384, 385). Stations 383, 384, have approximately equal silt and clay content.

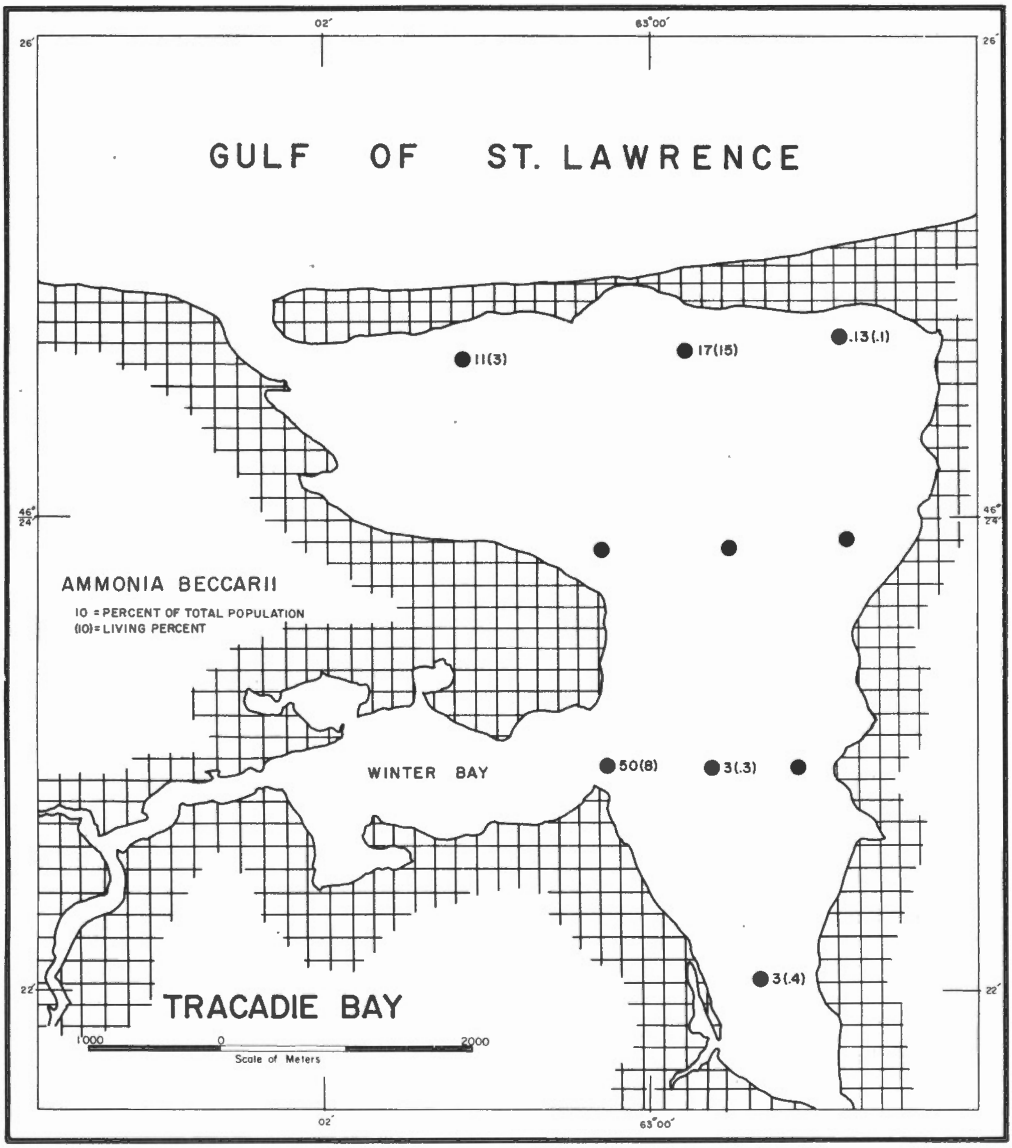


Figure 8 Distribution of <u>Ammonia beccarii</u>

whereas station 385 is predominantly sand. The occurrence of the highest value (15) of living per cent at station 381 may be attributed to the combined effects of the fauna having better access to Gulf of St. Lawrence water, a well aerated sand substrate, or nutrients associated with high rates of sedimentation. Tests of some specimens at stations 380, 381 are irregular and twisted or joined in plastogamy, indicating wide fluctuations in environmental conditions during growth.

Ammonia beccarii has world wide distribution, but is most prolific in warm Adriatic and West Indian waters. It has been reported by various authors from the coast of Western Europe, Southern California, Long Island Sound, Martha's Vineyard, the Mississippi Delta, Central America, and Gulf of Mexico. There is no previous record of this form in coastal waters of the Atlantic Provinces of Canada. At present there is an apparent correlation between the warm, brackish water of the Gulf of St. Lawrence estuary and the distribution of A. beccarii. Because of its apparent absence along the Atlantic coast of Nova Scotia and Bay of Fundy area A. beccarii is probably relict to areas adjoining the Gulf system. Ammonia beccarii must have originally inhabited waters adjoining the entire eastern Atlantic seaboard. Presumably it was annihilated in more northern areas, except the Gulf, because of the absence of environments suitable for growth, reproduction, and proliferation of the species. The numerous climatic, bathymetric, and oceanographic factors associated with the original migration or implacement of this species into the study area cannot be resolved with the findings of the present limited study. More detailed and refined sampling in this, and other Atlantic Provinces regions will help clarify existing problems.

Bradshaw (1957, 1961) successfully cultured *Ammonia beccarii tepida* under various conditions of temperature and salinity. Generally, specimens reached reproductive maturity most rapidly with minimum average size (small size, optimum conditions) at a salinity of 30.00% and temperatures of 24° - 30°C. Cultures grown under conditions of greater or less temperature and salinity values reproduced more slowly and attained a greater average size. The extremely low temperatures in Tracadie Bay during a greater part of the year are unfavorable for growth, reproduction, and proliferation of this species. Encystment or cessation of growth, particularly during cold winter months, is a plausible explanation. Tracadie Bay species are probably much hardier, with growth and reproductive cycles differing from the related southern forms. The occurrence of this species in this area, together with the large size and distorted nature of certain specimens is evidence of species adaptation and proliferation even under adverse environmental conditions.

Eggerella advena

Eggerella advena (Fig. 9) is most abundant at outer bay stations adjacent the tidal inlet and baymouth bar. These stations (380, 381) contain large total populations (113,800; 112,000) per square metre. Station 380 is characterized by a higher percentage of calcareous tests (64%), whereas the percentage of arenaceous to calcareous tests is approximately equal at station 381 (48% to 51%). *Eggerella advena* is absent from station 384, an area occupied almost entirely by species of *Elphidium*. High concentrations of *Elphidium incertum* are commonly marked by lower than usual concentrations of *Eggerella advena*. The largest populations of living and dead tests are associated with stations having higher than average fine

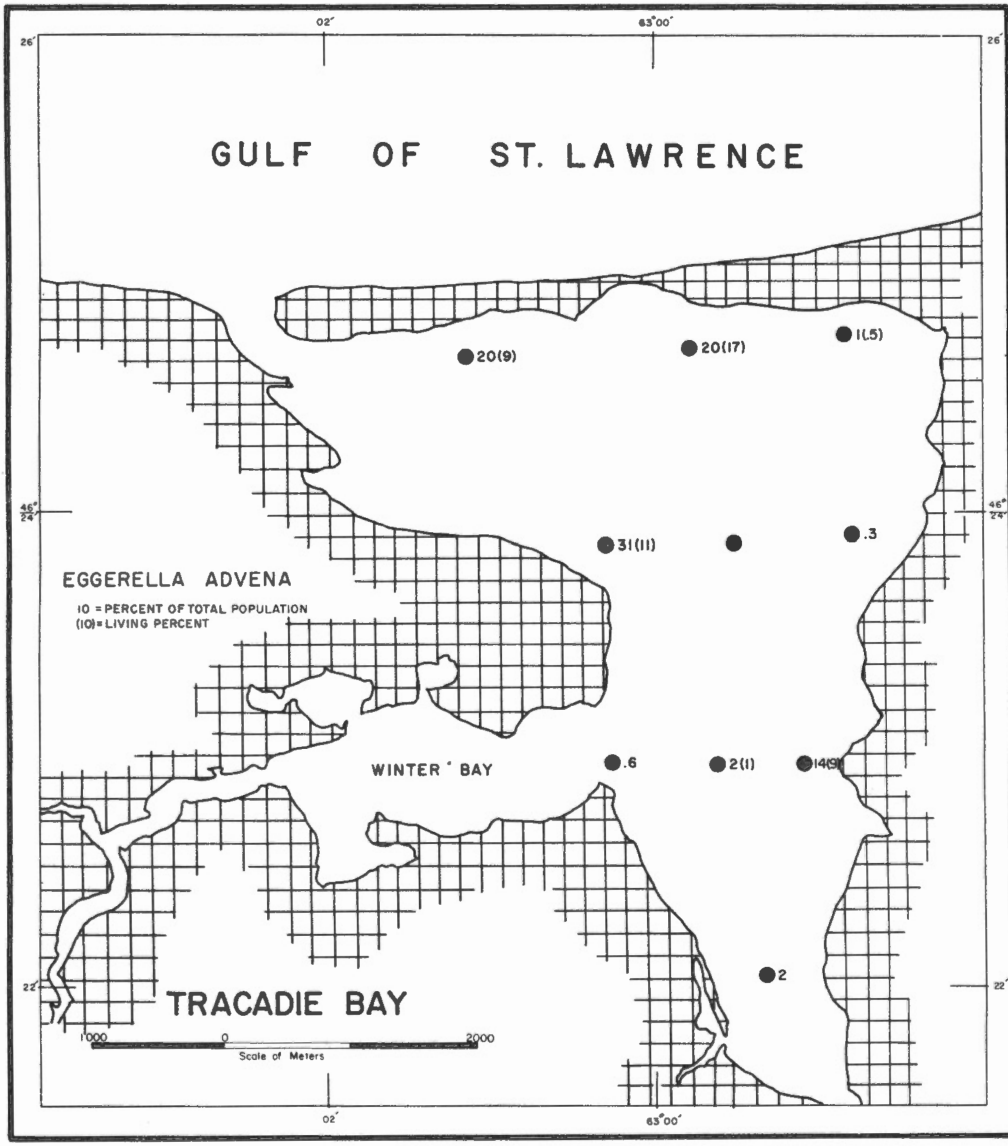


Figure 9 Distribution of Eggerella advena

sand content.

Eggerella advena is the most common arenaceous species in an area characterized by small numbers of arenaceous forms. Bartlett (1964 a, b) found this to be the most abundant arenaceous species on the Scotian Shelf. It is a prolific nearshore species in silty or silty sand substrates in bays of southeastern Nova Scotia. Leslie (1963) reported Eggerella advena to be dominant in depths from 33 to 52 metres in Hudson Bay. It is reported in depths less than 90 metres south of Cape Cod (Parker, 1952a), at Portsmouth, New Hampshire (Parker, 1952a), and from the Arctic (Phleger 1952a; Loeblich and Tappan, 1953; Cooper, 1964). Cooper (1961) reported it as a major constituent of stagnant, brackish waters off the California and Oregon Coast.

Specimens in Tracadie Bay are generally smaller and more loosely cemented than those from the Scotian Shelf and St. Margarets and Mahone Bays. Although possessing eurybathic qualities, growth and reproduction in Eggerella advena is apparently more prolific under more normal marine conditions than the brackish waters of Tracadie Bay.

Elphidium incertum

Elphidium incertum (Fig. 10) is represented by much larger dead than living populations, and is the major faunal constituent at all but stations 381 and 388. Substrate may be a factor in the distribution of this species because both of these stations (Appendix C) are characterized by similar substrates (predominantly sands), whereas largest populations (Appendix D) are associated with predominantly silt and clay substrates. However, the relationship may be indirect, because different substrates are also associated with differences in environmental conditions that may have a greater affect on species distribution. The living population is relatively uniform (96 to

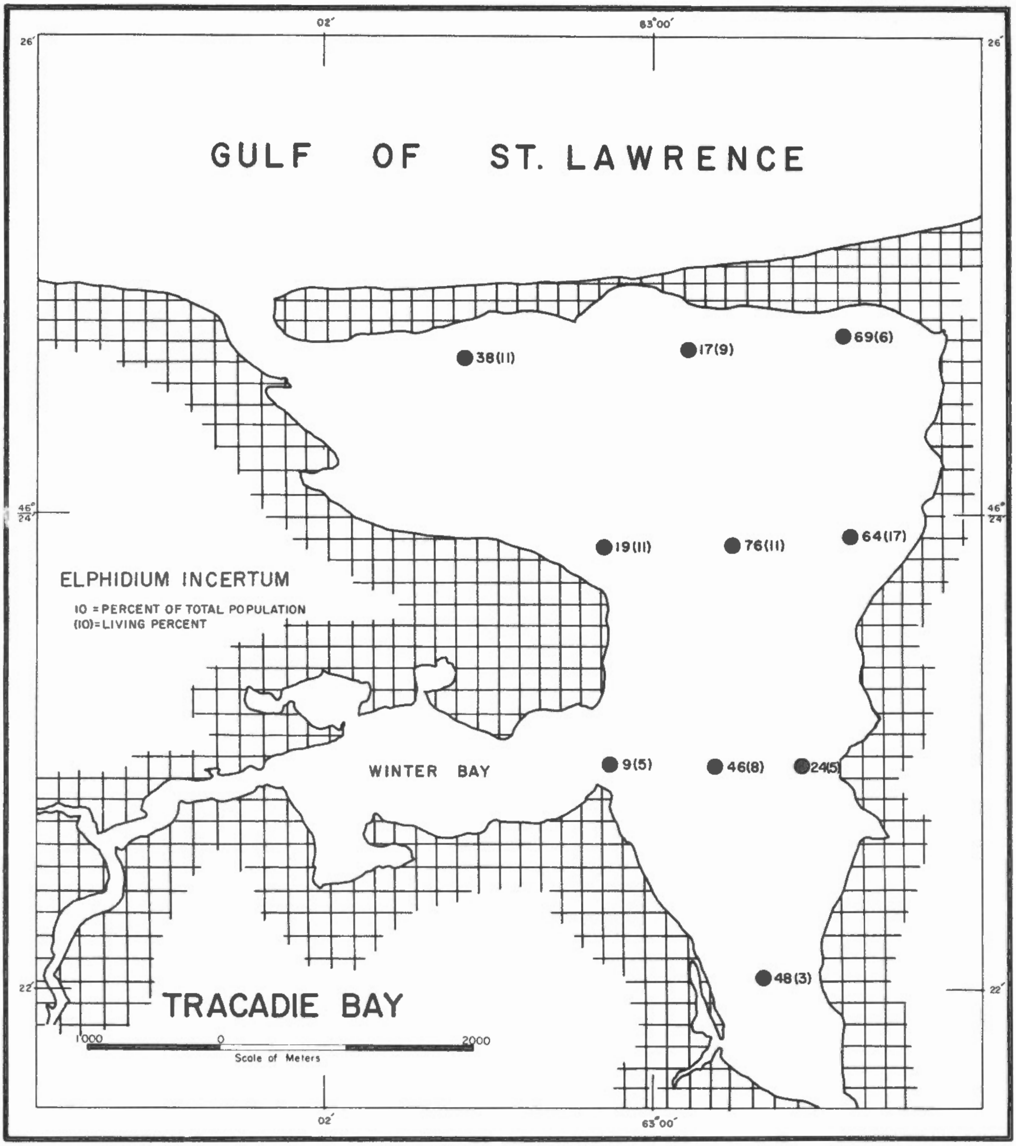


Figure 10 Distribution of Elphidium incertum

124 tests per unit sample) for the entire bay. However, stations 385, 387, and 388 contain only 4, 24,and 30 specimens respectively. These stations are located near the mouth of Winter Bay and are probably affected by a lowering of salinity because of freshwater runoff from Winter River. Small numbers of distorted Elphidium tests at station 388 indicate unfavorable conditions during certain periods of growth. E. incertum is replaced by A. beccarii as the most characteristic species at stations 385 and 388.

A study of the literature reveals that almost every author has a different idea of what actually constitutes Elphidium incertum. Subjective "species" separation on one occasion can be changed in subsequent determinations on additional material from other environments. Variations among forms composing the Tracadie Bay fauna are as follows: translucent with biumbonate knobs, or depressed umbilicus; translucent, umbilical slits with or without knobs; opaque tests with more pronounced umbilical slits and strong retral processes; opaque tests, biumbonate with one or more bosses confined to the umbilicus, or spread over the test well; specimens ranging from two chambered juveniles to fourteen chambered adults; maximum diameters 0.34 - 0.84 mm.; perforations distinct to faintly visible, indeterminate in most opaque forms unless test wetted; periphery sharp to broadly rounded.

Studies in Tracadie Bay and the Scotian Shelf (Bartlett 1964a,b) indicate that differences in external morphology of Elphidium incertum are apparently related to environmental parameters. Large, opaque forms are associated with turbulent nearshore environments or the outer shelf. Translucent, biumbonate forms with one or more umbilical bosses, together with translucent biumbilicate specimens, generally characterize more normal marine environments, such as inner shelves and open bays. Back-bay and lagoonal specimens are generally smaller, extremely variable in external morphology, and frequently possess pointed alar elongations that give the umbilicus a definite depressed silt-like appearance. Chamber overlap in the umbilical region is commonly broken into numerous knobs and slits that form either uniform or irregular patterns. Pores are larger and more distinct in translucent biumbonate or umbilicate forms associated with inner shelf assemblages. Retral processes are more strongly developed in opaque and umbilicate specimens. Retral processes are so strongly developed in some specimens that they approach Elphidium excavatum or E. margaritaceum in external appearance. Others with well developed bosses resemble E. gunteri, while others resemble forms described as E. incertum var. mexicanum, E. discoidale, and E. clavatum. Specimens having indistinct pores and lacking retral processes resemble E. orbiculare. Present investigations by the author also indicate that some specimens attributed to E. galvestonense and E. translucens may represent certain stages within this variable species. It is apparent that several "species" of Elphidium commonly associated with E. incertum in various marine environments are probably only variations within the species. These variations may be important environmental indicators that will aid in ecological and paleoecological interpretations.

Elphidium margaritaceum

Elphidium margaritaceum (Fig. 11) is the most abundant species at station 381, where the environment is characterized by a sandy substrate, high rate of sedimentation (.64 cm. per year), 11 genera, 15 species and 1120

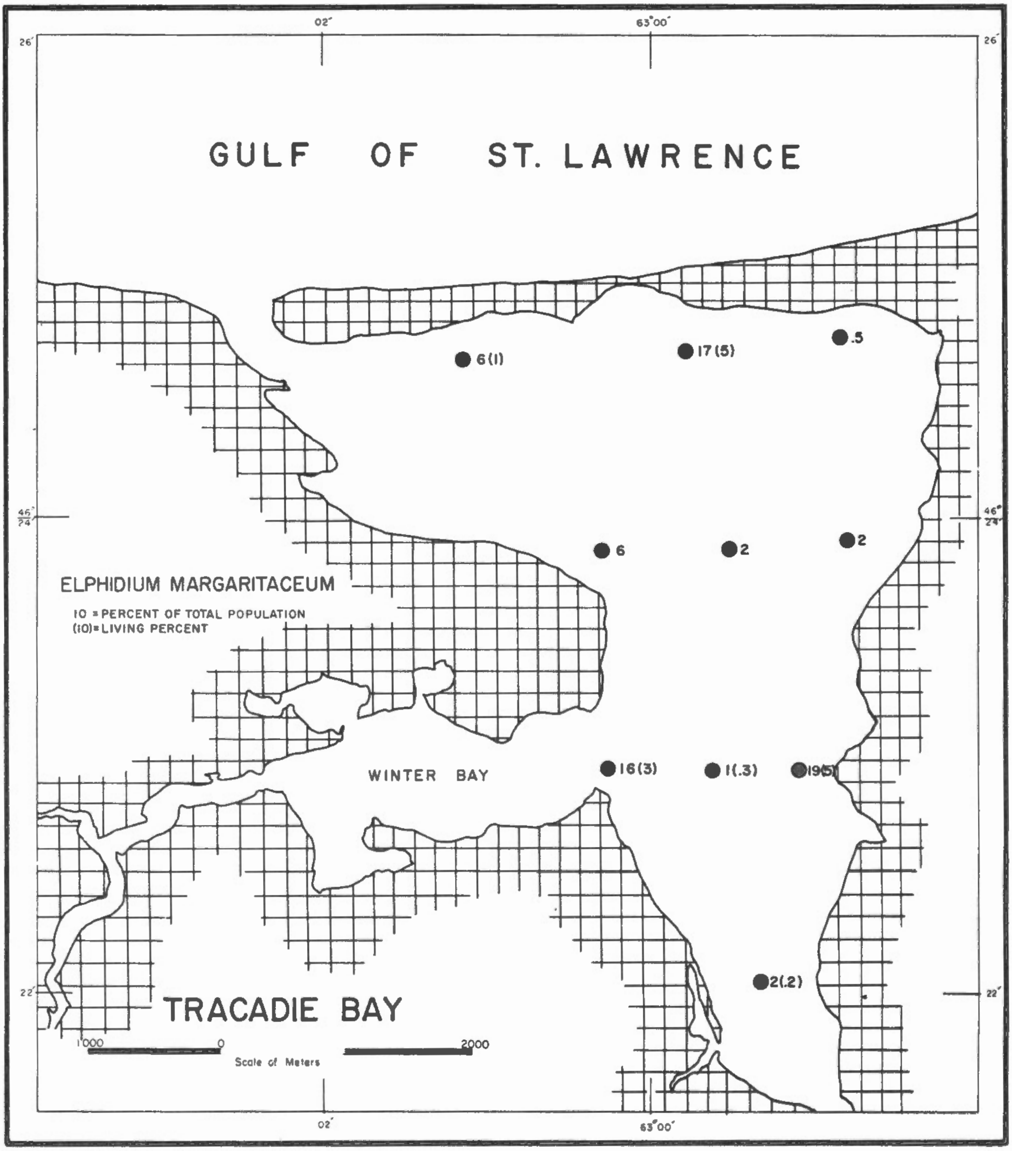


Figure 11 Distribution of Elphidium margaritaceum

tests per unit sample. In the remainder of the bay most stations are characterized by less than 50 specimens of E. margaritaceum per unit sample. The species is mainly confined, in association with Miliammina fusca, to intertidal flats at the baymouth and the shallow algal and seaweed covered entrance to Winter Bay. Bartlett (1964 a, b) found E. margaritaceum to be a distinctive member of the intertidal biofacies associated with Miliammina fusca, Trochammina lobata, and Trochammina spp. Largest living populations adjacent the Atlantic coast also inhabited brackish water environments characterized by little turbulence and substrates of silt, sand, and seaweed.

Elphidium orbiculare

Elphidium orbiculare (Fig. 12) is the second most abundant calcareous hyaline species in Tracadie Bay. The distribution patterns resemble those of E. incertum, and living representatives are found at all stations except 385. The largest populations of living and dead tests are recorded in the eastern and inner bay areas, where depths exceed 6 feet and substrates are composed almost entirely of silt and clay. These areas (Fig. 4) are also represented by the highest concentrations of calcareous tests; also the genera, species, and foraminiferal number are variable. Bartlett (1964b) reported E. orbiculare as a distinctive species of the nearshore biofacies in St. Margarets Bay and Mahone Bay, southeastern Nova Scotia, where largest living populations inhabited shallow depths (3m - 13 m), and the species replaced E. margaritaceum seaward from the intertidal zone.

Miliammina fusca

Miliammina fusca (Fig. 13) is the second most abundant arenaceous form in Tracadie Bay. However, it is absent from stations 382, 383, and 384. Silt and clay content is highest and algal and seaweed growth is lacking at these stations. The largest number of both dead tests and living specimens

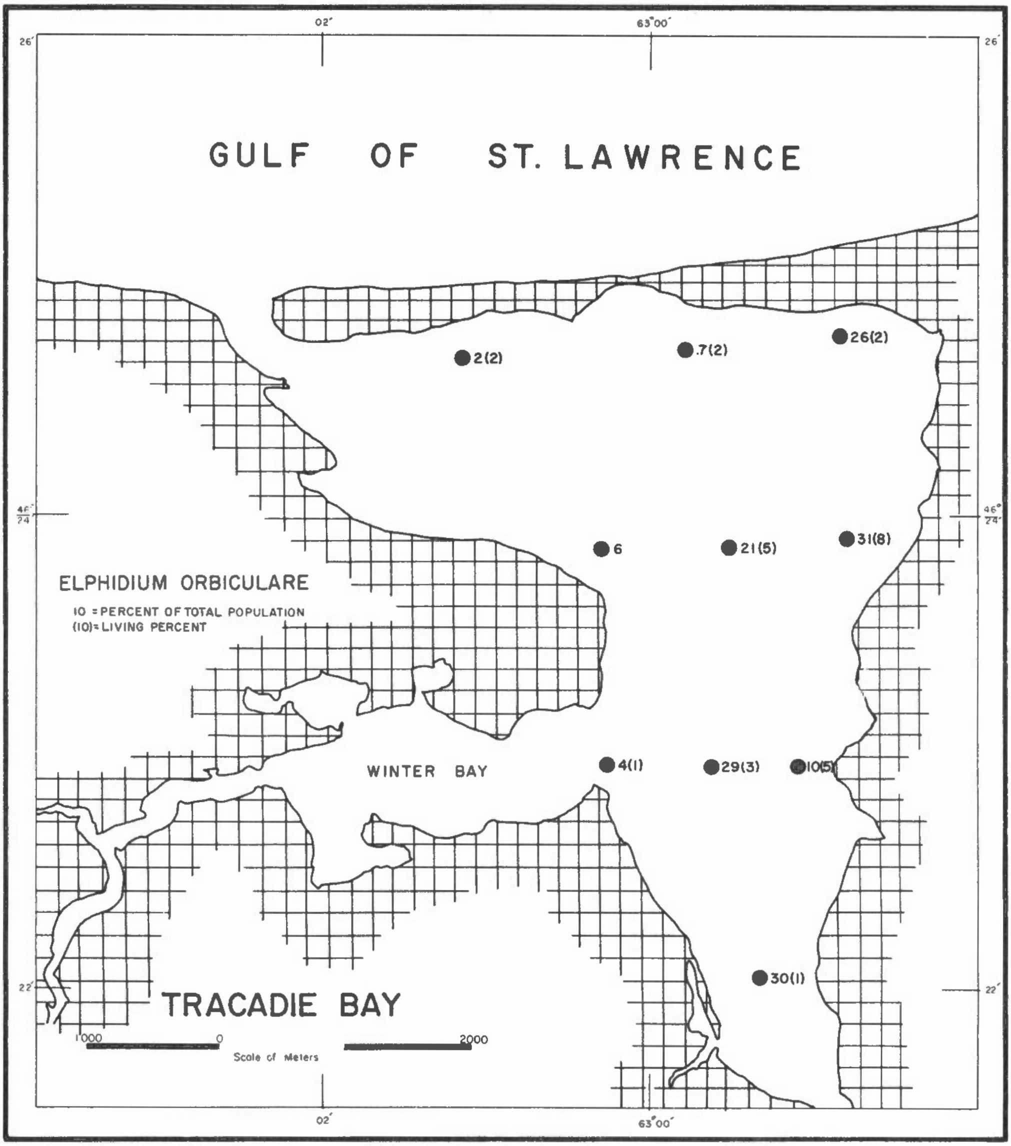


Figure 12 Distribution of Elphidium orbiculare

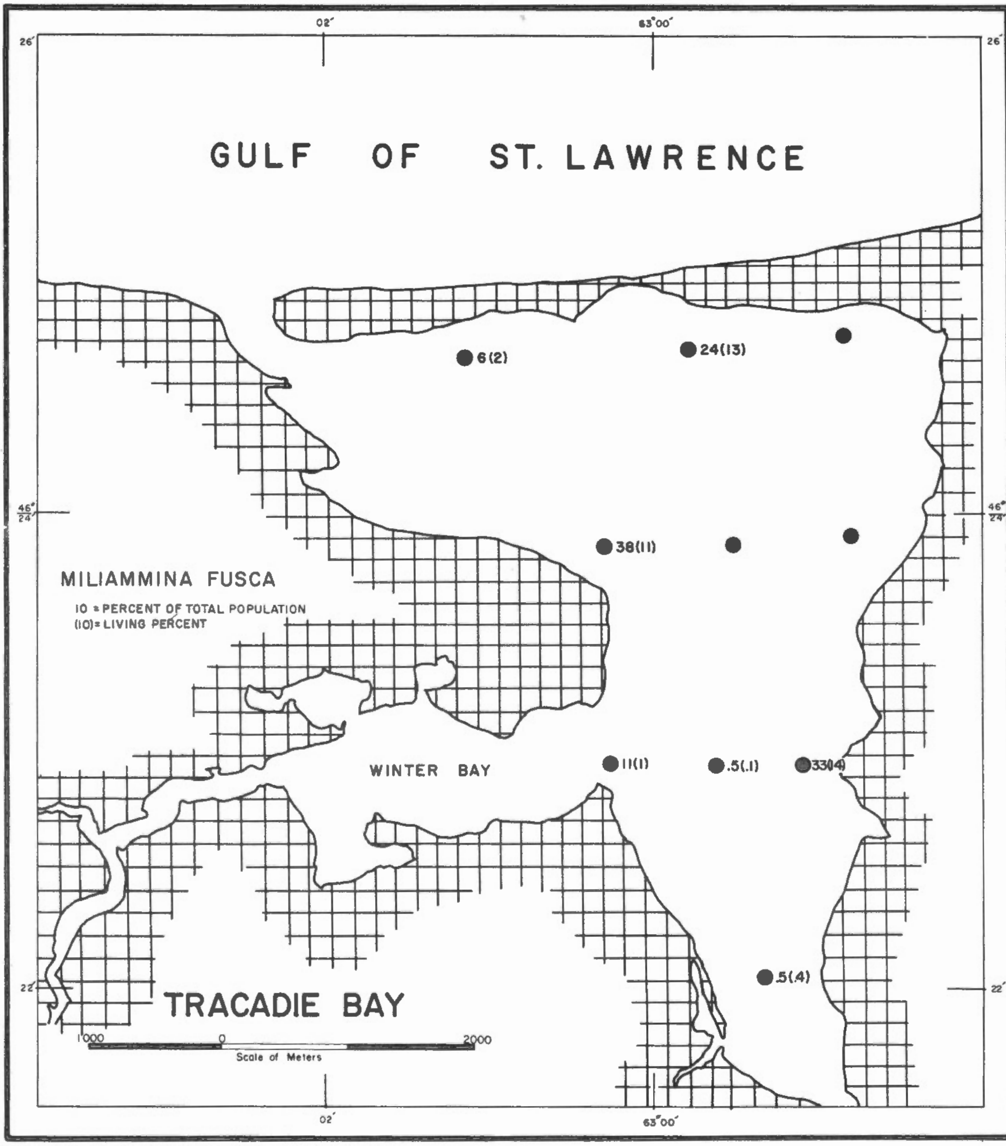


Figure 13 Distribution of Miliammina fusca

of M. fusca occurs at station 381 in an area forming the outer extremity of a broad tidal flat near a washover fan (Fig. 3). Furthermore, largest concentrations of living specimens throughout the bay are restricted to the intertidal zone, which generally supports a prolific growth of Enteromorpha and Zostera. Bartlett (1964b) found this species to occur in association with Trochammina lobata T. sp., and Elphidium margaritaceum, distinctive intertidal species in St. Margarets Bay and Mahone Bay, southeastern Nova Scotia.

Trochammina lobata

Trochammina lobata (Fig. 14) is a minor faunal constituent and is present at only half of the sample stations in Tracadie Bay. This is in contrast to more open bay environments where it is a prolific form inhabiting the intertidal zone (Bartlett, 1964b). The distribution of living specimens in Tracadie Bay compares favourably with the distribution of dead tests, and probably indicates little post-mortem transportation. Station 380 contains the highest number of both dead tests and living specimens in sediments from an algal and seaweed-covered intertidal flat adjacent the tidal channel. The present study supports views expressed by Bartlett (1964b), that this species is more characteristic of intertidal than nearshore environments. Generally, post-mortem transportation is responsible for its occurrence below the intertidal area.

FAUNAL ANALYSIS

Ammonia beccarii variants are typically warm water species. Environmental parameters in Tracadie Bay are unfavorable for their growth, reproduction, and proliferation during many months of the year. Bradshaw (1961) noted that

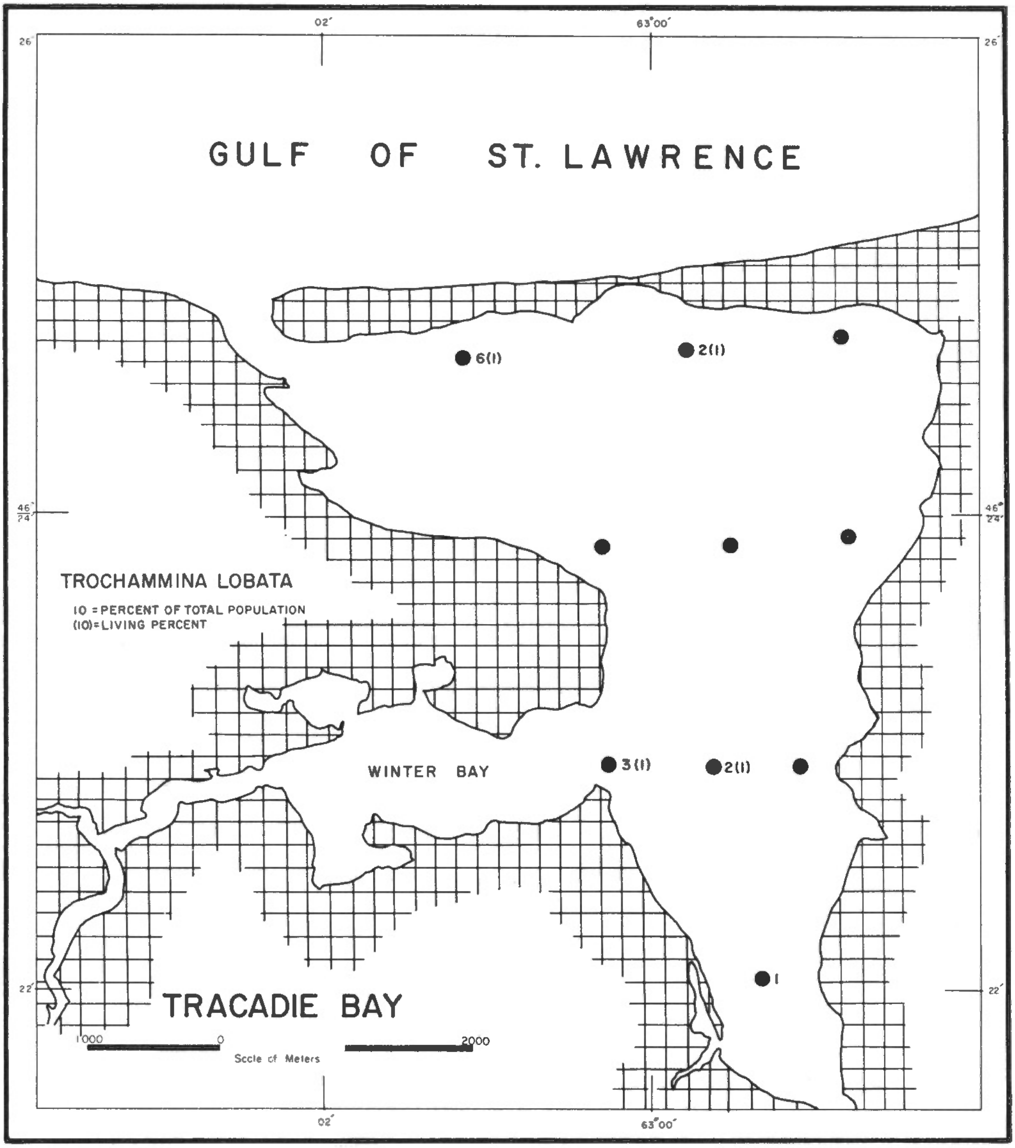


Figure 14 Distribution of Trochammina lobata

Ammonia beccarii tepida was confined to environments in which the temperature was above the lower reproductive limit for the species (18°C). The temperature of the lower limit of growth was approximately 10°C. Both temperatures are substantially higher than those encountered by *A. beccarii* and variants during the period November through March in Tracadie Bay. This suggests that (1) large numbers of *A. beccarii* are killed or remain dormant through the cold winter months, or (2) that this northern variety has adapted to more rigorous environmental conditions than its southern counterparts. Because Bradshaw (1961) found that reproduction occurred every 28 days under optimum conditions and took slightly longer as conditions deviated from the norm, it is apparent that growth rates and reproduction cycles of *A. beccarii* in northern latitudes are different from those of more southern environments. It follows, that the northern and southern forms may be physiologically, although not morphologically, distinct species. Larger than normal tests of *A. beccarii* suggest marginal growth conditions for many members of this species in Tracadie Bay.

Ammonia beccarii variants are the only species in Tracadie Bay that have not been recorded from the Arctic by Cushman (1948), Phleger (1952a), Loeblich and Tappan (1953), Anderson (1963), and Vilks (1964) or from Hudson Bay by Leslie (1963). Environmental parameters in the above-mentioned areas are different from those in the present study area. It is noteworthy that most of the species - except *A. beccarii* - in Tracadie Bay have been described by Cooper (1964) from the Chukchi Sea. Especially noteworthy is the predominance of *Eggerella advena*, *Buccella frigida*, *Elphidium bartletti*, *E. incertum*, *E. orbiculare*, *E. frigidum*, *E. subarcticum*, *Ammotium cassis*, and *Trochammina lobata* in the three faunal assemblages differentiated by Cooper (1964). Most of these forms are either the most characteristic species, or are at least represented, in Tracadie Bay. The fauna of the Chukchi Sea is considered by Cooper (1964) to be a meagre Arctic one consisting predominantly of arenaceous forms, whereas the foraminifera in Tracadie Bay are represented almost entirely by calcareous hyaline specimens.

Many foraminiferal tests in Tracadie Bay are represented by both calciferous and tectinaceous chambers in the single individual. Bradshaw (1961) found that below sublethal conditions, $CaCO_3$ tests could be dissolved without harm to the specimen, and later, normal test reconstruction and reproduction occurred. In the present study it is difficult to determine if any test is in a state of decalcification or reconstruction, although it is unlikely that decalcification takes place chamber by chamber. However, it is apparent that decalcification and recalcification are common phenomena in foraminifera that inhabit marsh, intertidal, lagoon, and shallow bay environments with wide diurnal and seasonal variations in pH.

Foraminiferal populations in Tracadie Bay are similar to those described by Phleger (1960b) adjacent the baymouth barrier (Padre Island) of Laguna Madre, Texas. However, populations at other Laguna Madre stations are much higher than those in Tracadie Bay. Furthermore, the Laguna Madre fauna is composed of 9 genera and 16 species as compared to 11 genera and 23 species in Tracadie Bay. The arenaceous fauna, significant in the present study, consisted of only one species in Laguna Madre. However, Tracadie Bay lacks the abundant miliolids of Laguna Madre. The _Elphidium_ fauna, although consisting of different species, is most characteristic of both areas, and indicates the tolerance of this genus to environmental extremes.

Phleger and Ewing (1962) noted similarities in the inner lagoon fauna of Laguna Ojo de Liebre (Elphidium spp., Ammonia beccarii variants, abundant miliolids) and that of San Antonio Bay, Texas, described by Phleger and Lankford (1957). Laguna Ojo de Liebre is characterized by hypersaline conditions, whereas San Antonio Bay is characterized by reduced salinity. Except for the abundant miliolid assemblage, the fauna in both of these Texas areas is comparable to Tracadie Bay. The presence throughout Tracadie Bay of the distinctive inner lagoon assemblage suggests that lower lagoon environmental conditions are non-existent in this area.

Phleger and Lankford (1957) interpret abundant miliolid distribution to be related to substrate in that miliolids prefer sand and shells, while silt and clay substrates are dominated by Elphidium and A. beccarii variants. Miliolids are insignificant in sand and shell substrates in Tracadie Bay, which suggests that salinity, temperature, depth, pH, or a combination of factors are as important as substrate in the distribution of such species. However, as indicated by Phleger and Lankford (1957), species of Elphidium are abundant in silt and clay substrates. Similarly, Phleger's (1960b) suggestion that living/total ratios indicate baymouth barriers as source of sediment for the bay is substantiated by the present study.

The Tracadie Bay fauna closely resembles Parker's (1952b) facies 2 off Long Island Sound and Buzzards Bay. Temperatures and salinities recorded by Parker are comparable to those in the present study area. Ammonia beccarii variants inhabit Parker's facies 2 and 3A, in which the most abundant constituents are Eggerella advena, Elphidium incertum variants, Elphidium subarcticum, and Buccella frigida, all characteristic forms in Tracadie Bay.

However, Parker's (1952b) fauna is more abundant in numbers of genera, species, and specimens than that of the present study. The fauna described by Parker is comparable with that of open bay and shelf environments adjoining the Atlantic Provinces (Bartlett 1964a, b).

Many authors have found, as the above discussion indicates, that Ammonia beccarii variants and Elphidium spp. are typical euryhaline and eurythermal environmental indicators. They have been placed in the marsh and sound facies (Phleger, 1955), shallow depths (Phleger, 1951), restricted to the bay environment (Moore, 1957), marginal marine environments, e.g. marsh, interdistributary bay, and fluvial marine (Lankford, 1959), general euryhaline environments (Bandy, 1953, 1957), protected bays and open beaches (Todd and Low, 1961), inner and lower lagoonal faunas (Phleger, 1960b) inner shelf (Bandy and Arnal, 1957) and marsh and lagoon (Ronai, 1955). The present study also indicates the much wider tolerance of A. beccarii and E. incertum for environmental variation than more restricted marine species. Moreover, the Tracadie Bay fauna cannot be differentiated into inner and lower lagoonal faunas; it is a composite of the two, with assemblages of both marsh and intertidal species predominant in nearshore localities.

The Tracadie Bay foraminiferal fauna is characterized by an abundant calcareous hyaline test assemblage. Most species are broadly distributed throughout the bay and have wide tolerances to fluctuating environmental condition. The miliolid fauna, characteristic of similar environments in warmer or more southern latitudes (e.g. Long Island Sound, Gulf of Mexico, Asiatic Coast, Central America, and Coast of California) is lacking, Specimens of arenaceous tests are less abundant in Tracadie Bay than in more northern latitudes, but more abundant than in southern areas previously discussed. It follows that cool temperate lagoonal environments such as Tracadie Bay can be differentiated from shallow bays of more northerly latitudes and lagoons of southern latitudes, as follows:

(1) Northern, subarctic to arctic environments - predominance of arenaceous tests.

(2) Temperate - cool temperate environments (Tracadie Bay) - predominance of calcareous hyaline tests; numerous species, but abundant specimens of only southern latitudes absent.

(3) Southern or warmer, more saline environments - prolific miliolid assemblage, numerous species, but fewer arenaceous specimens and a deficient calcareous hyaline fauna, compared to cooler temperate areas.

Furthermore, the stratigraphic occurrence of a eurybathic fauna similar to Tracadie Bay should indicate environmental characteristics similar to those in Tracadie Bay. 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 should indicate central areas within the lagoonal complex. In addition, assemblages adjacent the lagoonal side of baymouth bars or barriers will be larger and more diverse than those from areas immediately adjoining ocean-facing environments. Also, the increasing dominance of a particular species will indicate an increase in environmental variability.

SUMMARY

Sediments in Tracadie Bay are variable, grading from clay through fine silt and sand. Clay and silt content increases towards deeper water, whereas sand characterizes substrates adjacent the baymouth bar. Relative rates of sedimentation, based on living/total foraminiferal ratios, are highest adjacent the baymouth bar and the mouths of small streams. Distribution of certain foraminiferal assemblages is related to substrate characteristics. Arenaceous tests are most abundant in predominantly sand substrates, whereas calcareous tests are more abundant in substrates of silt and clay. Geographic positions of sampling stations have a direct bearing on both substrate and faunal analysis.

The foraminiferal fauna of Tracadie Bay is lagoonal in character and is composed of eurybathic species. Many of these have world wide distribution, (e.g. Eggerella advena, Elphidium spp., Miliammina fusca, Trochammina lobata, and T. squamata). Calcareous hyaline tests compose from 50% to 100% of the fauna. The Tracadie Bay assemblage is comparable to a depauperate composite of littoral and inner sublittoral faunas of open bays in the Atlantic Provinces and New England coastal regions. It also resembles the inner lagoonal fauna of the Gulf of Mexico, San Antonio Bay, Texas, and Laguna Ojo de Liebre, Baja California, Mexico, as described by Phleger (1955), Phleger and Lankford (1957), and Phleger and Ewing (1962) respectively. Distorted tests and forms joined in plastogamy indicate unfavorable environmental conditions during certain periods of test growth.

Cool-temperate lagoonal faunas lack the characteristic miliolid constituents of southern latitude and warmer water lagoons. However,

arenaceous populations in cool temperate areas are larger than their southern counterparts. On the other hand, lagoonal complexes of southern latitudes are represented by more genera and species than inner lagoons of cool-temperate areas.

Ammonia beccarii is recorded in recent sediments of the Atlantic Provinces region for the first time. To the author's knowledge there is no previous record of this species occurring in recent sediments of the Atlantic coastal area north of Cape Cod. At present, a general correlation exists between the distribution of this species and the warm brackish water associated with the Gulf of St. Lawrence system.

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APPENDIX A.

FAUNAL REFERENCE LIST

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APPENDIX B

STATISTICAL ANALYSIS FROM SIEVE AND PIPETTE DATA

PER CENT SAND - SILT - CLAY

STATISTICAL ANALYSIS - SIEVE AND PIPETTE DATA

STATION	MEDIAN (MM)	Q1 (MM)	Q3 (MM)	QDa	SO	Log 10 SO
380	0.150	0.070	0.210	.070	1.73	0.238
381	0.200	0.160	0.280	.060	1.32	0.121
382	0.011	0.003	0.035	.016	3.42	0.534
383	0.010	0.003	0.032	.015	3.27	0.515
384	0.012	0.003	0.035	.016	3.42	0.534
385	0.200	0.170	0.250	.040	1.21	0.083
386	0.140	0.020	0.200	.090	3.16	0.500
387	0.028	0.006	0.060	.027	3.16	0.500
388	0.150	0.100	0.200	.050	1.41	0.149
389	0.200	0.170	0.250	.040	1.21	0.083

SAND - SILT - CLAY RATIOS

STATION	% SAND	% SILT	% CLAY
380	76	15	9
381	91	5	4
382	14	58	28
383	13	58	29
384	9	64	27
385	100	—	—
386	65	23	12
387	22	58	20
388	90	5	5
389	100	—	—

A P P E N D I X C

FORAMINIFERAL DISTRIBUTION CHART

FORAMINIFERAL DISTRIBUTION CHART

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

	STATION NUMBER	380	388	389	381	385	387	386	382	384	383
	TOTAL POPULATION	1138	638	84	1120	34	838	1276	1622	1087	692
	LIVING POPULATION	360	132	32	720	14	74	200	144	174	170
	LIVING - TOTAL RATIO	.32	.20	.38	.64	.41	.09	.16	.09	.16	.24
1	AMMOBACULITES SP.						X	X			
2	AMMODISCUS MINUTISSIMUS	X			X						
3	AMMONIA BECCARII (VARIANTS)	11 (3)	50 (8)		17 (15)		3 (X)	3 (X)	1 (X)		
4	AMMOTIUM CASSIUS		2		1 (X)		8 (2)	8 (1)	X		
5	BUCCELLA FRIGIDA	4 (2)			X (X)		2	1	X (X)	X	X
6	CIBICIDES LOBATULUS	X									
7	EGGERELLA ADVENA	20 (9)	X	14 (9)	20 (17)	31 (11)	2	3 (1)	1 (X)		
8	ELPHIDIUM BARTLETTI						X			X	X
9	E. FRIGIDUM	1	X		X			X	X		
10	E. INCERTUM	38 (11)	9 (5)	23 (5)	16 (9)	19 (11)	48 (3)	46 (8)	69 (6)	76 (11)	64 (17)
11	E. MARGARITACEUM	6 (1)	16 (3)	19 (5)	17 (5)	6	1 (X)	1 (X)	X	2	2
12	E. ORBICULARE	3 (2)	4 (X)	10 (5)	X (X)	6	30 (1)	29 (3)	26 (2)	21 (5)	31 (8)
13	E. SUBARCTICUM	2 (X)	3 (1)		X				1 (X)	X	X
14	HEMISPHAERAMMINA CF. BRADYI	1					4	2			
15	MILIAMMINA FUSCA	6 (2)	11 (1)	33 (14)	23 (13)	37 (11)	X (X)	X (X)			
16	OOLINA COSTATA	X									
17	PATEORIS HAUERINOIDES		X (X)		X (X)				X (X)		
18	QUINQUELOCULINA SEMINULUM	X (X)			1 (X)						
19	REOPHAX ARCTICA							X (X)			
20	REOPHAX PILULIFER						X	2 (X)			
21	SCUTULORIS TEGMINIS				2 (1)	X					
22	TROCHAMMINA LOBATA	6 (1)	3 (1)		2 (1)		1	2 (1)			
23	TROCHAMMINA SQUAMATA (VARIANTS)	X (X)	X (X)		1		X	1 (X)			X
	PERCENT LIVING	32	20	38	64	41	9	16	9	16	24
	NUMBER OF GENERA	11	7	3	11	4	10	10	6	2	4
	NUMBER OF SPECIES	16	12	5	15	6	13	14	10	6	7
	% ARENACEOUS TESTS	35	17	48	48	1	15	20	1	–	1
	% CALCAREOUS HYALINE TESTS	64	83	52	51	99	85	80	99	100	99
	% PORCELANEOUS TESTS	1	–	–	1	–	–	–	–	–	–