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POPULATION DYNAMICS AND FACIES ASSOCIATION OF RECENT FORAMINIFERA FROM A NEARSHORE MARGINAL MARINE ENVIRONMENT: PLYMOUTH SOUND

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POPULATION DYNAMICS AND FACIES ASSOCIATION OF RECENT FORAMINIFERA FROM A NEARSHORE MARGINAL MARINE ENVIRONMENT: PLYMOUTH SOUND

by

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Abstract

Population Dynamics and Facies Association of Recent Foraminifera from A Nearshore Marginal Marine Environment: Plymouth Sound

by

Paul Castignetti

Plymouth Sound is an area of shallow marine to marginal marine sea approximately 10km^2 in size. It is situated on the South coast of England and partially restricted from the open ocean by the Breakwater. Its shallow marine waters are diluted by the outflow from two significant rivers; the Tamar and the Plym. All of these factors combined with the partial restriction of the Breakwater and open channels adjacent the Breakwater have created many different sub-environments within this small region. Very low energy to very high energy conditions are present, which range from normal marine, slightly hyposaline to moderately hyposaline.

These varied sub-environments reflect many distinct foraminiferal assemblages, both living and dead. The live foraminiferal assemblages show great variation throughout the year in terms of abundance, diversity and number and style of reproductive events.

The dead assemblage is relatively stable throughout the year. The assemblages from the different sub-environments reflect varying degrees of post-mortem alteration.

A detailed study of the foraminiferal fauna reveals a complex interplay between energy conditions, sediment type, temperature and salinity which are reflected in the foraminiferal morphology, size and abundance. This is further complicated in the dead assemblages by post-mortem processes.

The live assemblages were dominated by *Ammonia beccarii batavus* (Linné) which reached a maximum abundance of 1200 individuals per 100 cm^3 and *Elphidium crispum* (Linné) which reached a maximum of 450 individuals per 100 cm^3, other species were locally important such as *Brizalina pseudopunctata* (Höglund) in the muds of the

Breakwater (Location 9), which reached a maximum of 1600 individuals per 100 cm^3. Production of species was very variable but production was highest during April/May, July and September/October.

The dead assemblages are dominated by *Cibicides lobatulus* (Walker and Jacob), an exotic species, which testifies to considerable post-mortem transport. This species accounts for up to 60% of some assemblages. *Ammonia beccarii batavus* which accounts for up to 50% of some assemblages and *Elphidium crispum* which accounts for up to 30% of some assemblages.

The vertical distribution of foraminifera within the various sedimentary facies and sub-environments was determined by the retrieval of nine sediment cores from six different facies over two years. The cores revealed that the greatest abundance of live foraminifera occurred in the uppermost centimeter/s of the sediment, particularly within muddy sediments.

Cores for isotopic analysis were collected from three areas of the Sound and used to determined the sediment accumulation rate and date sediments down to approximately 50 centimeters. Sedimentation has been dynamic and discontinuous. Sediment accumulation rates range from 0.19 cm/per year to 0.48 cm/per year.

In addition to the main foraminiferal study of the Sound the previously unstudied Plym Estuary was sampled. This revealed a typical low diversity calcareous fauna composed of *Haynesina germanica* (Ehrenberg) and *Elphidium williamsoni* Haynes which attained very high abundances of 4000 individuals per cm^3.

This study is the most recent of several spanning almost an entire century. Although the data from previous studies are limited, comparison of these previous studies with the present study indicate little change of foraminiferal species in recent time but potentially large changes, particularly in recent years, of foraminiferal abundance and biomass within the Sound.

Acknowledgments

This study was undertaken to develop and increase knowledge of recent foraminifera in nearshore shallow marine setting with particularly emphasis on the effects of sedimentary facies on the populations, assemblages and community.

Financial support was provided by a Higher Education Research Council grant

I am very grateful to Professor Malcolm Hart who gave me the chance to follow the research in which ever direction it went and the almost unlimited use of facilities, in particular the many weeks spent in the Scanning Electron Microscopy Unit and associated large film and paper bills. Also many thanks to Malcolm for reading through the not insubstantial thesis from its early stages to its end and particularly for communication and feed back in the last year at the Geological Society, London.

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I would like to thank my office colleagues, Cath Manley, Andy Henderson, Guy Oliver and Mike Carroll, who made the office a great place to work (?) in and who often had me rolling around in laughter, they are thanked for talking over ideas and problems, offering advice and constructive criticism of research, techniques, computing, etc..

Special thanks to Cath Manley for collecting August samples and taking temperature, salinity and depth data when the author was on field work elsewhere.

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Finally I would like to thank Rob my brother for help with computing and data input, Anna Bertorelli for help in preparation of plates and reading through manuscripts and very special thanks to my parents for allowing me the complete freedom of choice and for their unconditional support of all kinds.

Author's Declaration

The work submitted for the degree of Doctor of Philosophy under the title "*Population Dynamics and Facies Association of Recent Foraminifera from a Nearshore Marginal Marine Environment: Plymouth Sound*" is the result of original work. All authors and works consulted are fully acknowledged. At no time during the registration for the degree of Doctor of Philosophy has the author been registered for any other University award.

This study was financed with the aid of a Higher Education Funding Council grant.

During the period of this study a parallel study concerning the interactions of foraminifera with biotic variables from Plymouth Sound and utilizing wild foraminifera from Plymouth Sound for culturing was undertaken by Catherine J. Manley. Several samples were collected by the author and C. J. Manley for their respective research on the same occasion. The collection of sediment cores from Plymouth Sound was undertaken jointly and the data shared. However I must state that all of the opinions and interpretations in this thesis are entirely my own and my responsibility.

During the course of this research the following papers have been published or submitted on the results obtained:

Castignetti, P., 1993. Foraminiferal analysis of Boreholes from Plymouth Sound. *Proceedings of the Ussher Society*, **8**: 189-193.

Castignetti, P., 1996. A time series study of foraminiferal assemblages of the Plym Estuary, south-west England. *Journal of the Marine Biological Association of the U. K.*, **76**: 569-578.

Castignetti, P. and Manley, C. J., The Correlation of Energy Levels and Vertical Distribution of Foraminiferida from Plymouth Sound; A Preliminary Study. Submitted to *Terra Nova*.

Candidate

Signed...........................

Date....10th....October....1997

Research Supervisors

Prof. Malcolm B. Hart ....

Dr. Collin Williams...........................

Quotations

"*When the bear is crushing you between his arms, it is then most important to keep one eye on the bull, for it may get out of sight.*

Ralph Waldo Trine

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CHAPTER ONE

1.0. INTRODUCTON

1.1. Location of Plymouth Sound

Plymouth Sound is a shallow tidal embayment situated on the south coast of England between the border of Devon and Cornwall: it lies directly south of the city of Plymouth. The embayment is partially restricted from the open sea by an artificial breakwater which extends East-West for 1.7 km. Two rivers drain into Plymouth Sound, the largest (to the north-west) is the Tamar which, with its tributaries, drains the border of Devon and Cornwall for over 60 km and (to the north-east) the Plym which drains the southern slopes of Dartmoor.

Although Plymouth Sound is a relatively small body of water approximately 10 km^2 in area, with an average water depth of 6-10 m (although it reaches 40 m in depth in the palaeo-Tamar rock channel), a great range of sedimentological facies exist within the Sound.

1.1.1 The Geological History of the Area

During the Devonian Period many of the rocks which form and underlie the Plymouth Sound embayment were formed. The South Devon area was typified by a series of topographic highs and lows within a warm sub-tropical marine environment. In the lower energy environments, silts and clays were deposited. At the marine topographic highs, the Staddon Grits were deposited. Away from clastic sedimentation, calcareous muds, shelly debris, coral and stromatoporoids accumulated. During the Devonian and Permian periods tectonic instability resulted in the sedimentary sequence being punctuated by intrusive igneous rocks (Felsites and Granophyres) and extrusive volcanic rocks principally tuffs and lavas.

During the Variscan Orogeny which impressed an East-West foliation characteristic of many of the rocks in South West England, the sequence of rocks and sediments were gradually buried, lithified, then folded and metamorphosed. The Mesozoic and Cenozoic resulted in little sediment of that age being preserved within South Devon. Erosion has resulted in the modern day configuration of slates, grits, limestone and igneous rocks.
In the Pleistocene, Great Britain experience a period of glacial and interglacial stages. Evidence from the South West of England (principally a lack of glacial land forms and glacial deposits of tills and erratics restricted to the north of the peninsula) indicates that South Devon suffered mainly periglacial activity (although ice may have been present in the Wolstonian) which resulted in increased erosion and the formation of dry valleys, river sands and gravels and extensive head deposits (West, 1988). The end of the last glacial phase, the Devensian was followed by isostatic readjustment and ultimately sea level rise during the last 15000 years (Guilcher, 1969; Delibrias & Gullier, 1971). Sea level changes in the recent (Quaternary) past have been calculated using heights of marine cliffs, terraces, beaches and buried rock valleys; Cooper (1948), Fairbridge (1961), Delibrias & Gullier (1971), Durrance (1971, 1974), Donovan and Stride (1975), Codrington (1989), and Eddies and Reynolds (1989). The Plymouth region experienced a rise in sea level of 35 m from approximately 12000-14000 years to present resulting in the drowning of the river flood plains and the formation of estuaries. This event created the present day Plymouth Sound, bounded to the north by Devonian limestone and to the east and west by interbedded slates and grits punctuated by occasional igneous rocks such as those which form Drake's island.

1.1.2 The Physiography of Plymouth Sound

The shore of Plymouth Sound is characterised by steeply dipping slate and limestone rock with only occasional, small, gravelly or sandy coves. The exceptions to this are the estuaries, which are fringed with mud flats. The average water depth of the Sound is about 8 metres. The western side of the Sound is shallower particularly at the 'bridges' where it is less than 5 metres while the eastern and southern areas are 8-15 metres deep. At the northern end of the Sound the water depth increases to 40 m over the palaeo-Tamar rock channel. The tidal range for Plymouth Sound is 4.7 m for the Mean Spring tides and 2.2 m for the Mean Neap tides (courtesy of the Admiralty Hydrographic office)

Two rivers inflow into Plymouth Sound, the largest being the Tamar with a recorded maximum inflow of 321.56 m^3s. and minimum inflow of 0.58 m^3s. The Plym has a maximum recorded inflow of 31.01 m^3s and a minimum inflow of 0.12 m^3s (South West Water 1979 records). The Tamar contributes some fine sediment and minerals in solution (Butler and Tibbitts, 1972). No published information is available for the River Plym; its size, and the nature of the catchment area suggest that little natural sediment is associated with it but because it drains many of the china clay pits of south Dartmoor, (before the installation of sediment traps as part of the quarrying) considerable sedimentation of waste china clay has occurred both in the estuary and the adjacent part of the Sound. Whitepatch, an area on the eastern side of the Sound, takes its name from china clay waste often seen in suspension.

In 1812 because of the continual hazard to shipping the construction of the breakwater began and was completed in 1827. In subsequent years the lighthouses were built, concrete shields were added and gabbions were dropped to reinforce the Breakwater (Merratt, 1980). The 1.7 km Breakwater wall restricts the amount of energy received by the Sound particularly directly behind the Breakwater where muddy sediments have accumulated.

The salinity of the Sound exhibits a small amount of variation (a maximum of 5‰ or 6‰) both spatially (from the estuary mouths to the Breakwater) and temporally (as a result of seasonality). The lowest salinities are generally in the winter after heavy rain and particularly at stations closest to the estuaries: Barn Pool, near the mouth of the Tamar, recorded a salinity of 29.5‰ in November 1994. The average salinity for the Sound during 1994 was 34.50‰.

Sea temperature in Plymouth Sound lags behind that of the open sea (it warms and cools slightly after the open sea). Temperatures within the Sound have a slightly higher maximum and lower minimum during summer and winter (Lee and Ramster, 1976). The last recorded temperatures from Plymouth Sound in 1971 reached a maximum summer temperature in

July of 17°C and a minimum winter temperature of 8.7°C in February (Southward and Butler, 1972). During the present study temperatures varied little over the 12 stations within the Sound, reaching a peak at the end of July 1994 of 16.7°C and a low in February 1994 of 8.8°C. The Plymouth Sound temperature cycle exhibits a rapid period of warming and a slow period of cooling (Fig. 8.93, Chapter 8).

1.2 Location of Sample Sites and generalised substrate sediment map

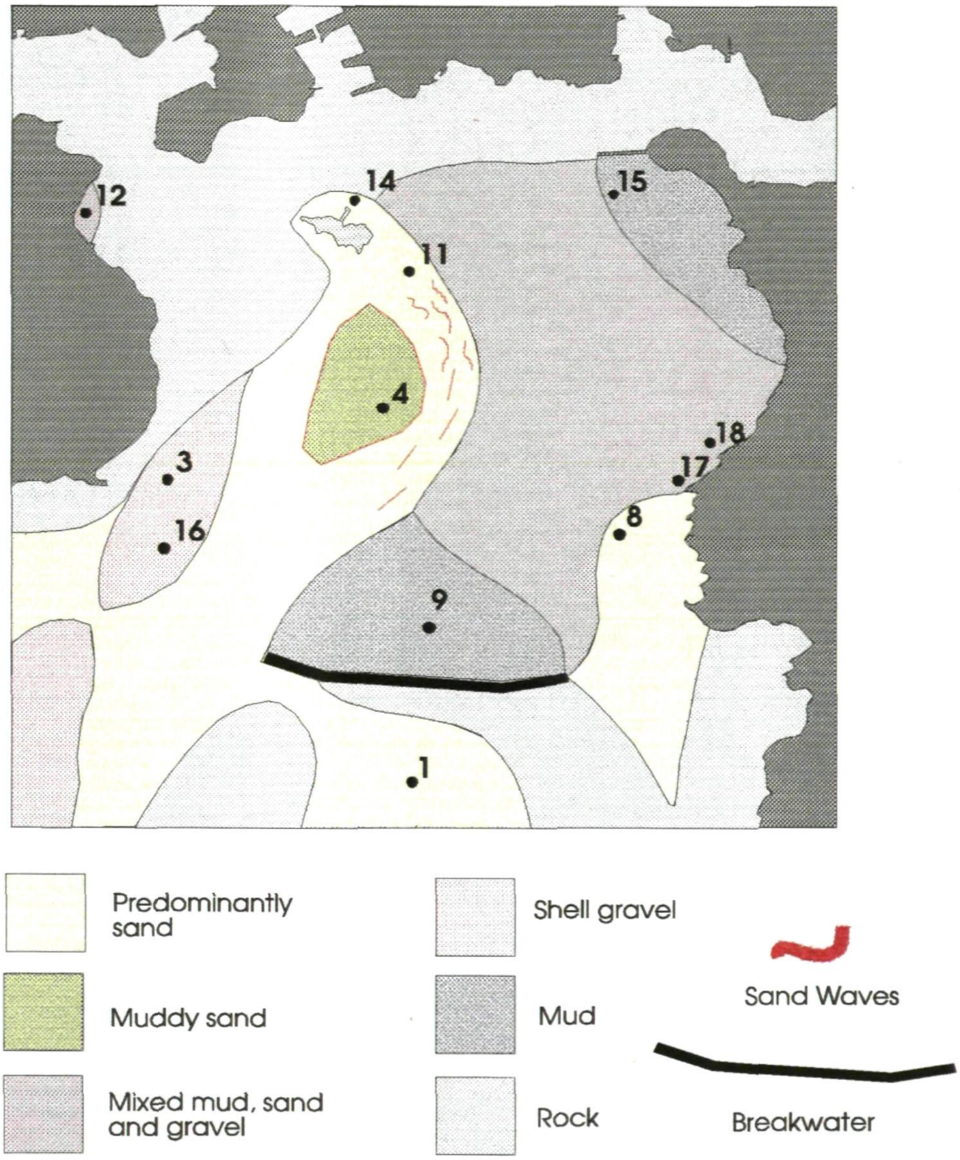

Figure. 1.1. Map of Plymouth Sound with station locations and idealised sediment type and distribution. Based on mapping carried out by Fiona Fitzpatrick (1991).

Thirteen stations are chosen within the Plymouth Sound region, eleven within the Sound, one outside the Breakwater (Location 1) and one within the Plym Estuary (referred to as 'Plym'). Stations 12; Barn Pool, 14; Drakes Island and 15; inside the Mountbatten Breakwater (formally known as Rum Bay), are situated in the north of the Sound. Stations 17; Anchorage Beacons and 18; Withyhedge Beacons are in the east of the Sound, Stations 11 and 8 occur within the central region, whilst stations 3, 4, 9 and 16 occur within the southern part of the Sound.

The sediment map (Figure 1.1) is adapted from sediment maps produced by Fitzpatrick for a Ph.D. thesis. The original maps were constructed by direct sampling (diving) and remote sensing of the substrate. The original map has been simplified and additional information added from observations made during the present study.

1.2.1 **Reasons for the locations**

The location of the sample sites fill several important criteria:-

1. The large range of different substrates that occur within the Sound should be adequately sampled. Hard rocky areas could not be sampled (as a grab cannot be used to retrieve foraminifera on such substrates). Sea-weeds were examined but did not prove worthwhile (they bore few foraminifera and were restricted in their distribution). This study is based on foraminifera from, on and within, the sediments. The sediments which occur within the Sound vary greatly, from areas of low energy where muds and silts occur, to areas of very poorly sorted sediments, sands of various grain size and gravels composed of shelly material. All of these general sediments can be subdivided into areas of different sub-facies: muddy sediments (dominated by silts, clays and to a lesser extent fine sands) can vary considerably. The muds which occur at Barn Pool are consolidated and composed of a high amount of silt and very fine sand, whilst those which occur inside the Breakwater are very soft and composed of predominantly silt and clay; both are sampled in a comprehensive programme.

The location of sample sites spatially within the Sound is a very important factor (in terms of environmental variables). In the previous example the similar sediments (in that they contain high proportions of silt and clay) of Barn Pool and the Breakwater (ignoring potentially major influential factors for foraminiferal abundance and species composition such as available food, competition, oxygen levels, particularly for the infauna) have different salinity regimes. Barn Pool is close to the mouth of the River Tamar and as a result is influenced both by lower general salinities and moderate salinity fluctuations whilst the Breakwater exhibits relatively constant normal salinity. Consequently the spatial location of sample sites within the Sound is very important as similar sediments may have quite different foraminiferal assemblages.

2. Plymouth Sound has previously been studied by several workers who have conducted foraminiferal investigations. A priority of this study was to sample as accurately as possible those areas studied by previous workers, in order to allow direct comparisons. Six of the eight stations sampled by previous workers (details of previous studies are mentioned later within this chapter) are incorporated into the present sample programme whilst keeping to its main aims of sampling as many sedimentary facies and sub-facies within the Sound as possible.

Heron-Allen and Earland, sampled Drake's Island and Rum Bay (the area south of the Mountbatten Breakwater) in 1916 which correlate to the present Loc 14 (Drake's Island) and Loc 15 (Mount Batten Breakwater). Mr E. C. Manley's two main stations in the eastern Sound near Jennycliff were sampled in 1973 and 1974, they correlate with Loc 17; Anchorage Beacons and 18; Withyhedge Beacon. J. W. Murray sampled five stations within Plymouth Sound, two of which were very rocky and deemed to be unsuitable for sampling with a sediment grab (off the West Hoe and off the western part of the breakwater). The three other stations correlate with Loc 11 (Melampus Beacon), Loc 12 (Barn Pool) and Loc 14 (Drakes Island)

3. The Plym Estuary is chosen as a sample location because it provides information on foraminiferal assemblages and populations dynamics within an adjacent estuary, whilst foraminiferal data were available for the Tamar Estuary (Ellison, 1981, Murray, 1965). No previous data are available on the foraminifera of the Plym Estuary. For these reasons the Plym estuary is incorporated into the sample programme.

4. Originally 18 sample sites were chosen within the Sound together with an additional site within the Plym Estuary. A test sampling run was carried out in June 1993 which showed that several sites were unsuitable for sampling because of an almost entire lack of sediment in the site areas. Two sites near Plymouth Hoe (one close to a main sewer outlet), two more close to the breakwater and another within the palaeo Tamar rock channel, were rejected because of lack of sediment. A revised sample suite of 12 sites within the Sound and 1 within the Plym Estuary was selected.

Of the 12 stations within the Sound, four are within muddy facies, three are poorly sorted mixed sediments, four stations within sands of various grain size and two are shell gravels.

5 The size of the sample programme was influenced by two factors. Firstly boat time on board the Plymouth Marine Laboratories boat ***Sepia*** was limited to one morning per month shared with other researchers. This allowed in the region of 10 sites to be sampled at a monthly frequency depending on weather and sea state (including duplicate samples, resampling due to poor retrieval and measurements of salinity, temperature and depth). Secondly processing 12 samples per month for all live and 301 dead foraminifera represents the upper limit in terms of work time, especially because of the relatively late commencement of the sampling programme (within the second year or research). The duration of the sample programme was originally planned for between 13 to 14 months, it was however cut short to 12 months because of the unavailability of a boat.

1.3. History of Foraminiferal Research within Plymouth Sound

J. J. Lister collected specimens of *Polystomella crispa* (now *Elphidium crispum*) from Plymouth Sound, in an attempt to study the life history of this species. This was published in 1895 in *Contributions to the life history of Foraminifera*.

R. H. Worth undertook a brief examination of the invertebrate fauna of "The Plymouth Region", resulting in a scientific paper published in 1904 entitled *Plymouth Marine Invertebrate Fauna*. The paper is principally a species list dealing with 116 species of foraminifera, and 7 species of sponges. No information is provided on materials and methods. Abundance is referred to in a qualitative fashion and there is no information on the living foraminifera. The areas sampled were Rame, Eddystone, Looe, Hand Deeps, Cawsand and Drake's Island. The latter falls into the present area of study.

Heron-Allen and Earland studied the near shore and littoral foraminiferal fauna of the Cornwall and Plymouth Region. Very few data are available for the live foraminifera as the study deals principally with the dead assemblage. Their work, undertaken in 1916, was the first comprehensive study of foraminifera from Plymouth Sound and it resulted in a scientific paper, published in two parts in 1930, entitled *The foraminifera of the Plymouth District*. A type slide collection of the foraminifera is now housed in the Natural History Museum. Three stations examined by Heron-Allen and Earland fall within the present area of study.

M. W. Jepps made detailed studies on cultures of *Elphidium crispum* based on material originally collected from Plymouth Sound. His findings, entitled *Studies on Polystomeller Lamark (Foraminifera)*, were published in 1942

E. H. Myers carried out detailed studies and cultures of *Elphidium crispum* from Plymouth Sound. The findings were published as series of scientific papers during 1937, 1942a-b.

J. R. Buchanan and R. H. Hedley (1960) studied the life processes and biology of *Astrorhiza limicola*

J. W. Murray's was the first study to examine both the live and dead foraminiferal fauna of the Sound. Samples were taken along a transect from the River Tamar, through Plymouth Sound to the Eddystone lighthouse. A total of 80 stations were sampled during the winter, spring and summer of 1962, although some stations in the Sound and outside the breakwater could not be sampled due to bad weather. Bottom water samples were also taken to determine the physical and chemical characteristics of the environments. Nine stations along the transect fall inside the present study area.

E. C. Manley principally examined two sites on the eastern side of Plymouth Sound during 1973-74 Both the live and dead foraminiferal assemblages were examined. Samples were collected from these two main sites at a fortnightly frequency for a period of 14 months.

R. L. Ellison analysed the meiofauna of an intertidal mudflat at the mouth of the River Tamar, resulting in the publication of a scientific paper entitled *Foraminifera and Meiofauna on an intertidal mudflat, Cornwall England; Populations; respiration and secondary production; and energy budget* in 1984. The study revealed a low diversity foraminiferal assemblage of testate and naked forms.

A. P. Eddles and **M. B. Hart** carried out a preliminary investigation into the foraminiferal assemblages of a borehole from the palaeo-Tamar sediment infill. Three foraminiferal assemblages were identified varying in age from 12000-4000 years old. The preliminary results were published in a paper entitled *Late Quaternary Foraminifera from Plymouth Sound; preliminary investigation* in 1989.

J. J. Lee and **R. E. Lee** collected specimens of *Elphidium crispum* from Drake's Island in Plymouth Sound to test the effects of chloroplast retention in various environments. The results were published in a paper entitled *Chloroplast retention in Elphidiids (foraminifera)* in 1989.

P. Castignetti studied the foraminiferal assemblages of two boreholes drilled into the palaeo-Tamar rock channel in Plymouth Sound after a preliminary investigation by Eddles and Hart (1989). The subsequent assemblages were correlated in both cores to seismic reflectors. The results were published in 1993 entitled *Foraminiferal Analysis of Boreholes from Plymouth Sound.*

P. Castignetti analysed the relations of live and dead foraminiferal fauna of the Plym Estuary, the results published in 1996, entitled *A time series study of foraminiferal assemblages of the Plym Estuary, South West England.*

1.4. The History of some relevant (non-foraminiferal) research in Plymouth Sound

L. Maddock and C. L. Swan carried out a statistical analysis of sea temperatures, air temperatures, rainfall and westerly weather to delineate long term trends in temperature which may be important biologically (influencing the composition of phytoplankton and fish). This work was published as *A statistical analysis of some trends in sea temperature and climate in the Plymouth area in the last 70 years.* in 1977.

A. J. Southward (1983) examined the distributional changes of various organisms in the Western Channel. The results were published in *Fluctuations in the ecosystem of the Western Channel: a summary of studies in progress.*

A. J. Southward, G. T. Boalch and L. Maddock studied data on fish species for the last 100 years and historical records from the 16th century to present for the coast of Devon and Cornwall. Their findings, published in 1988, entitled *Fluctuations in the Herring and Pilchard fisheries of Devon and Cornwall linked to change in climate since the 16th Century*, revealed that principal factors in the fluctuation of fish species was climate and temperature change.

R. D. Eddies and **J. M. Reynolds** surveyed the buried rock valleys of Plymouth Sound using a high resolution seismic surveys. Their study revealed an extensive system of rock channels filled with sediment. Their findings were published in 1988 entitled *Seismic characteristics of buried rock valleys in Plymouth Sound and the River Tamar.*

F. Fitzpatrick published a scientific paper on *the Remotely sensed sedimentology of Plymouth Sound* (1990) discussing sediment distribution, thermal structure and tidal bodies within the Sound.

F. Fitzpatrick's unpublished Ph.D. thesis provides a detailed series of substrate maps both remotely sensed and directly sampled, overflight results and magnetic measurements. It is based directly on Plymouth Sound and the adjacent estuaries and is entitled *Studies of Sediments in a Tidal Environment.* 1991.

A. J. Southward's study of intertidal population density of barnacles on a rocky shore near Plymouth; the study highlights the possible effect of climate and temperature on barnacle populations. The results were published in 1991 entitled *Forty years of changes in species composition and population density of barnacles on a rocky shore near Plymouth.*

1.5 A review of other major foraminiferal studies of marginal marine environments in Britain

J W. Murray's Ph.D. thesis entitled *The Ecology and Systematics of the Benthonic foraminifera of Christchurch Harbour, Hampshire* 1961 and subsequently published in several parts.

Christchurch Harbour is small, approximately 2 km^2, shallow (between 0-5 m), generally sand/mud mix substrate and fresh to brackish (0‰-30‰). The live and dead assemblages from 60 stations were examined for spring, summer, autumn and winter, at each season the temperature, salinity, chlorinity, dissolved oxygen content and calcium carbonate content of bottom waters was determined.

1.5.1. A brief summary of the Results from J. W. Murray's Papers on Christchurch Harbour.

Forty four species of living foraminifera were observed. They were placed into 4 groups based on their ecological requirements (the species listed were sufficiently abundant for ecological interpretations during each season):-

Group 1, stenohaline; these species typically lived outside the harbour, they were washed in but never successfully colonised the area. These species include:-

> *Textularia* sp, *Clavulina obscura* Chaster, *Cribrostomoides jeffreysii* (Williamson), *Cyclogyra involvens* (Reuss), *Massilina secans* (d'Orbigny), *Quinqueloculina seminulum* (Linné), *Miliolinella subrotunda* (Montagu), *Fissurina lucida* (Williamson), *Oolina melo* d'Orbigny, *Oolina williamsoni* (Alcock), *Bulimina marginata* d'Orbigny, *Buliminella elegantissima* (d'Orbigny), *Brizalina spathulata* (Williamson), *Rosalina globularis* d'Orbigny, *Elphidium macellum* (Fitchel and

Moll), *Cibicides lobatulus* (Walker and Jacob), *Fursenkoina fusiformis* (Williamson).

Group 2; comprises species which show a slight tolerance for variable salinities, they are sub-divided into successful colonisers and unsuccessful colonisers of the harbour during favourable conditions:-

Successful colonisers
Eggerella scabra (Williamson) and *Quinqueloculina dimidiata* Terquem.

Unsuccessful colonisers
Bolivina psuedoplicata Heron-Allen and Earland, *Brizalina* aff. *B. variabilis, Nonion depressulus* (Walker and Jacob), *Buccella frigida,* (Cushman), and *Elphidium incertum* (Williamson).

Group 3 is composed of moderately euryhaline species, although they show a preference for higher salinities:-
Reophax moniliformis Siddall, *Ammonia* (Linné) *beccarii batavus* Hofker and *Elphidium excavatum* (Terquem)

Group 4 is made up of highly tolerant euryhaline forms:-
Miliammina fusca (Brady), *Haynesina germanica* (Ehrenberg), *Elphidium oceanensis* (d'Orbigny) and *Elphidium* sp.

The foraminifera of groups 1-3 increased in distributions during the autumn when salinities within the harbour were highest. Foraminifera of group 4 showed little correlation with environmental variables.

Haynesina germanica was the most dominant species forming up to 70% of the assemblage, *R. moniliformis* formed up to 15% and *Q. dimidiata* formed up to 20% of the foraminiferal assemblage. Thecomoebians were abundant in the river and estuary during the winter, spring and summer.

All foraminifera showed little correlation with the substrate type; they generally lived on the muddy sand (20% mud and 80% sand) substrate, because this was the only substrate available. The temperature of Christchurch harbour varied from 15-20°C. Species often reproduced according to temperature and become dormant in low winter temperatures. The amount of calcium carbonate present in the water proved to be an important factor as thecomoebians preferred low levels whilst foraminifera needed higher levels. Where the calcium carbonate content was low the tests of foraminifera were often small and thin.

1.5.2. **Cardigan Bay Recent Foraminifera** by **J. Haynes 1973**.

Over 600 samples were collected between 1962-64 and supplemented with additional samples from the littoral zone during 1962-67. Most of the samples were taken from the inner bay at a depth of about 30 m with more scattered samples from the outer bay at a depth of 80 m. In addition, the Dovey Estuary was also sampled. The wide range of environments and the size of the programme resulted in the recognition of some 200 foraminiferal taxa, 165 of which were illustrated and described.

The foraminifera of the Dovey estuary fall into four groups:-
The high marsh which is rarely inundated by marine waters. The live foraminiferal assemblage was composed of a small number of agglutinated forms including:-

> *Haplophragmoides subinvolutum* Cushman and McCullock, *Jadammina macresens* (Brady), *M. fusca* and *Trochammina inflata* (Montagu).

The low marsh is inundated by most tides and composed of soft muds. Foraminifera reach their greatest abundance, the most common species were :-

> *H. germanica, E. excavatum, M. fusca, A. beccarii*, and *Elphidium selseyense* Heron-Allen and Earland.

The open sand flats are covered by all tides except the lowest neaps. The flats are well drained and often dry, and therefore no live foraminiferal were present. The main channel was sandy and permanently submerged. A meagre foraminiferal fauna was dominated by:- *Q. seminulum* and *M. subrotunda*.

Minor channels and tributaries in the high marsh are sandy, they bear a sparse fauna of *E. excavatum* and *H. germanica*.

1.5.3. **The foraminifera of the Exe Estuary** by **J. W. Murray 1980**

The Exe Estuary is located on the south coast of England approximately 60 kilometres east-north-east of Plymouth Sound. Samples were collected from the Exe estuary for a period of 31 months (1979-81). The sediment was dominated by mud with some sand. The salinity within the estuary varied greatly from near normal salinity (25‰ to 34‰) at high tide to brackish/fresh water (31‰-1‰) at low tide. The living assemblage within the main part of the estuary was composed entirely of hyaline forms: *N. depressulus* was dominant, *H. germanica* and *Elphidium williamsoni* Haynes form the next most abundant, *A. beccarii* was not common. The foraminiferal blooms occurred in the spring and autumn and were linked to temperature and possibly diatom abundance.

1.6. **International foraminiferal studies of marginal marine environments**

Jade Bay on the coast of Germany has almost normal to brackish salinity which varies from 32‰ in the outer bay to 24‰ in the inner bay. The sediments are muddy with some sand. In the high water zone *H. germanica* is dominant with a lower abundance of *E. williamsoni*. In the low water zone and channels *H. germanica* is associated with *E. excavatum*. For a full discussion see Richter 1964a, 1964b and 1965.

Arcachon Lagoon in France has normal marine salinities but in the inner parts salinities fall to 29‰. The bay is shallow with large areas exposed at low tide. Le Campion (1970) distinguished three sub-environments therein:-

1: subtidal sands with living *Planorbulina mediterranensis* d'Orbigny and dead *E. scabrus*

2 intertidal with living and dead *E. williamsoni, A. beccarii, E. scabrus, Ammoscalaria pseudospiralis* Williamson, *H. germanica* and *R. monoliformis*

3 *Scrobicularia* mud with *A. pseudospiralis* and dead *E. scabrus, M. fusca* and *T. inflata*.

Buzzards Bay, Massachusetts, USA, is a marginal marine environment with a variation in salinities of 29.5‰ to 32.5‰. The temperature ranges from 2°C to 22°C (Sanders, 1960). The sediments of mainly silt, with lesser amounts of sand and gravels are described by Moore (1963). The depth ranges from 4 m to 39 m with an average of 15 m. Fifty nine live species were observed, the most important were *Trochammina compacta, Eggerella advena* Cushman, *M. subrotunda, F. fusiformis, B. frigida, A. beccarii, Elphidium clavatum* Cushman and *Elphidium. subarcticum* Cushman. For a complete summary see Murray, 1968.

Tampa-Sarasota Bay, Florida, USA, was studied by Walton (1964). It is a marginal marine bay 400 km^2 in area, with a depth of 0-10 m. The temperature was 21-23°C with salinities near normal between 23.6‰ at the head of the bay, 32.1‰ at the mouth and 34‰ in Sarasota Bay. The sediment was oxidised very fine sand and silt. The major species present were *Ammotium salsus* Cushman and Bronnimann, *A. beccarii, Elphidium spp, Elphidium matogordanum* (Walker and Jacob) and *Quinqueloculina poeyana* d'Orbigny.

Tracadie Bay, Prince Edward, Island, Canada. The sediment ranges from silty clays to coarse sands. The salinity in the bay varies from 27.8‰ to 28.4‰ and the temperature ranges from 1°C-26°C The bay is 15 km^2 with an average depth of 3 m. The live foraminiferal assemblage was composed of *E. incertum, Elphidium orbiculare, Ammotium crassis* (Parker), *E. advena* and *M. fusca.* For a full review see Bartlett (1965).

The Russian River Estuary, California. A total of 50 stations were sampled four times from the summer of 1969 to the winter of 1969 for foraminifera. The river, estuary and adjacent offshore area were sampled. The temperature of bottom water varied from 10°C to 22°C. Salinity was between 20‰-26‰ in the estuary and channel and an average of 32‰ offshore. Live and dead foraminifera were not differentiated, a total of 29 species were identified from 12 000 specimens: 11 species occurred exclusively offshore; 15 occurred both offshore and within the estuary and; 3 species only within the river and estuary. For a detailed account of the distribution of foraminifera in the Russian River Estuary see Erskian and Lipps (1977).

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The **Gulf Coast of Texas**. A total of 40 surface samples were collected from three areas; Aransas River and Marsh Estuary, Mustang Island Marsh and Port Bay Marsh. Ten species were identified. The lower elevations of brackish areas were dominated by *A. beccarii*. Areas of higher although variable salinities were dominated by *Q. seminulum* and *Quinqueloculina costata* d'Orbigny, a full account of which is provided by Williams (1994).

A review of the brackish foraminifera of **New Zealand** (Haywood and Hollis, 1994) is a detailed examination of foraminiferal assemblages and associations from New Zealand's estuaries, harbours, inlets and lagoons. Taxonomy, ecology and environmental variables are discussed in detail resulting in a general trend of increasing salinity typified by the following species; *Trochamminita-Haplophragmoides-Miliammina-Ammonia/Miliammina-Elphidium/Ammonia.*

1.4 Aims and Objectives

Data Base

The first priority was the creation of a detailed and worthwhile data base. Most studies are not sufficiently large, accurate and of adequate duration to be considered adequate for meaningful research. It is hoped that this study (data base), incorporating over 150 surface samples throughout one year, in a range of sediment substrates and examining both the live and dead assemblages will prove sufficiently robust for future work.

- By providing time-series data which allow the quantification of the input of foraminiferal tests to the sediment and the assessment of post-mortem processes

- Providing new data of the modern foraminifera of the Plymouth area.

Faunal Change

Plymouth Sound has been the focus of several foraminiferal studies (and many non-foraminiferal studies). Some of the aims of this study were to examine, and review, previous research and where possible, re-sample areas previously sampled by other researchers. This should result in an appraisal of these studies and possibly highlight faunal changes in the assemblages of Plymouth Sound.

Facies Association

To observe how live and dead foraminifera are associated with sedimentary facies and how this association varies from live to dead assemblages. Ultimately this may be used to help understand fossil assemblages in nearshore environments.

CHAPTER TWO

2. MATERIALS AND METHODS

2.1. Sample collection

An important factor when collecting regular periodic foraminiferal samples is that they should be consistently obtained from the same position within the substrate both horizontally and vertically, that they are of similar size, as undisturbed as possible and no part or fraction of the sample is lost (e. g. by winnowing or washing) on retrieval.

Remote methods (grabs, corers, dredges, etc.) were preferred as these are invariably cheaper, quicker and can be used in a range of different sea states (including moderate to rough conditions) There is no limit apart from time, as to the number of times they can be used in the same day. A variety of grabs and corers were tested, but corers were in general unsuitable for the range of substrates to be sampled (being particularly poor in clean sands and gravels). Grabs are more suitable for a range of substrates and because they are generally smaller, more suitable for the research vessel used (some corers would have needed a larger research boat to deploy, in the interests of safety). Grabs are prone to losing sediment on retrieval through the water and often failed to retrieve a sample (this was particularly so with the shipeck grab). A grab designed and tested by W.G and J.W Murray (1987) was selected, as this consistently sampled the substrate irrespective of sediment type and sea state.

A "Murray grab" was constructed from designs of the original by the University Technical Services department at the beginning of 1993. It was completed and tested in Plymouth Sound by June 1993, but unfortunately delays in negotiating a contract for the use of the PML boat set back the sampling programme until December 1993.

The "Murray grab" was designed for the collection of benthonic Foraminiferida from subtidal sites. It weighs approximately 70 kg and is 76 cm wide by 100 cm high. It is superior to other comparable grabs in that it collects only the upper 1 cm from the sediment surface for a defined surface area of 100 cm^2 , (yielding a volume of 100 cm^3) and allows no winnowing of fine sediment because the scoop bucket is closed against a rubber faced plate creating a water-tight rubber seal. The grab is triggered by the cable becoming slack once the grab has settled on the sea bed. It collects the upper 1 cm of the sea bed in most sedimentary facies, although in soft muddy sediments a deeper section is removed due to the entire grab sinking into the substrate, and on irregular substrates larger or smaller samples may be retrieved depending on if the scoop bucket is directly over a high (ripple top) or trough within the substrate.

The Marine Biological Association Research Vessel ***Sepia*** was used to deploy the grab. Once the samples were retrieved they were transferred to sealed plastic containers and sea water added, no preservatives were used as shortly after collection the samples were taken to the laboratory and processed (within the same day).

Sample sites were located using a two fold method for maximum accuracy. Firstly a Decca navigational system was used to locate the area of the site (this was reasonably accurate to about 30 metres). Secondly the ship's skipper would align the boat using two sets of two markers (there were many potential markers e.g. tall buildings, beacons, headlands, etc.) to pinpoint the exact location.

Sampling began in December 1993 and continued to November 1994. Sampling had been planned to continue to at least December 1994 but this proved impossible due to an engine refit for ***Sepia*** at the end of November 1994 and the unavailability of other suitable boats.

In order to be consistent all samples were collected on high spring tides.

In total 13 foraminiferal samples were retrieved each month for 12 months, apart from December 1993 and January 1994 where 12 samples were retrieved due to bad weather. One sample was accidentally thrown away by laboratory staff from February's set, resulting in a total of 153 foraminiferal grab samples. Additional samples (duplicates) were retrieved from some stations for grain size analysis.

2.1.2. Grab size standardisation

The "Murray grab" was designed to obtain a standard sample size (100 cm^3), but sample size varied considerably. Sample size is the most important abiotic factor affecting abundance of live foraminifera. The dead assemblage is not measured in absolute numbers per sample but percentage amount, so is relatively unaffected by changes in sample size or volume. Depending on the nature of the substrate, grab sample sizes varied greatly, in very soft muds the grab tended to sink into the sediment surface resulting in a much larger sample being obtained (as much as 500 cm^3). Two wooden slats (2.5 cm thick) were lashed onto the base of the grab frame to compensate for the soft substrate but oversized samples were still collected (in the order of 200 cm^3). In shell gravels grab buckets were often retrieved empty, followed by samples of as much as 450 cm^3 because of this inconsistency, it was assumed that the substrate was very irregular, perhaps rippled at these locations (3 and 16).

The volume of each sample residue (sediment with <63μm fraction removed) was measured. This would reflect the original sample volume in sandy sediments as little if any significant material is lost during the wet sieving process. For samples which contained a significant amount of clay and silt, several duplicates samples were used to calculate the average amount of silt and clay at each of the locations. It is assumed that the proportion of silt and clay remained relatively constant at the muddy locations throughout the year, as they were less variable than other locations

Live foraminiferal absolute numbers were then treated with a technique which involved standardising foraminiferal numbers to the equivalent of a 100 cm^3 of sediment. For example if a sample had an original volume of 80 cm^3 (before sieving) the number of foraminifera would be multiplied by 1.25, and a sample of 125 cm^3 would be multiplied by 0.8. Thus both samples would be directly comparable.

This method is very useful for sandy sediments as foraminifera are distributed within the uppermost few centimetres (See Chapter 6), a larger, deeper sample would result in an over-estimation of live foraminifera within the standard 100 cm^3, (deeper samples may result in more infaunal forms being represented but core evidence suggests that few forms are restricted to particular levels or zones within the sediment). In muddy samples foraminifera are restricted to the top 1 cm or less (See Chapter 6), a larger and therefore deeper sample would not necessarily result in a proportional increase in the number of live foraminifera, hence compensating for larger mud samples may result in an under-estimation of live foraminifera, but in order to treat all samples in a similar and consistent manner, all samples have been adjusted to a standard 100 cm^3 as described above.

For smaller samples increasing the number of foraminifera by simple multiplication compensates for abundance but not for diversity, as no new species are added. Fortunately most samples were only slightly smaller (80 cm^3) or larger (120 cm^3) than the standard 100 cm^3. Standardisation of numbers of live foraminifera usually results in very small changes to the original number of live foraminifera.

The advantages of standardising samples is that all sample sites can be directly compared in terms of abundance and productivity. Spurious peaks or false trends in foraminiferal abundance produced by sample size variations (which do exist although usually small) are eliminated by the standardisation process.

2.2. Foraminiferal Cores from Plymouth Sound

Nine cores were taken from six sites, (Chapter 6, Figure 6.1.) three of which were not statistically valid due to very low living abundance of foraminifera. Four cores of 48 cm length and 4.4 cm diameter were taken by diver in June, 1994 in the areas of Withyhedge Beacon, Drake's Island, Barn Pool and Queen's Ground. Five cores of 48 cm long and 4.4 cm diameter were taken by diver in April, 1995, in the areas of Withyhedge Beacon, Drake's Island and Barn Pool, but due to weather conditions, the Queen's Ground sample could not be repeated, and was replaced by Melampus Beacon. An additional sample was taken inside the Breakwater. Cores were taken during different years to allow for inter annual variations within the foraminiferal assemblages. The core tubes were open at both ends and were pushed into the sediment (perpendicular to the sea bed). When the entire core tube had been pushed in or could not be pushed in any further, rubber or wooden spacers were used to fill the remaining space, in the tube (at the top of the core tube) before being sealed with a cap. A trowel was used to dig down to the base of the embedded tube. Once the base was sealed the core tube was removed from the sea bed. The tubes were kept in an upright position until freezing in the laboratory. Core recovery was variable, ranging between 18 cm and 48 cm of sediment. The cores were frozen because the exact date of collection was not known in advance. It depended on work load and availability of divers as well as weather conditions; as a result the author was not available to process the core material immediately hence they were frozen to preserve the foraminiferal protoplasm.

Because the core tubes were made from transparent plastic the frozen cores were examined whilst in their tubes, photographed and sketched, then sectioned. The topmost 1 cm of the core formed section 1; the next 2 cm, section 2; three further lengths, each of 5 cm, became sections 5a, 5b, and 5c; and the rest of the core was divided into 10 cm lengths, as sections 10a, 10b, and 10c. When the cores had thawed they were processed as described in Section *2.3*. All live and 301 dead specimens were picked from each sub-section of the cores where foraminifera were sufficient.

The upper 1 cm section in all cores provided a volume of 15.2 cm^3. Foraminiferal numbers in all sections of each core were divided by the length of the section (in centimetres) to standardise living abundance with volume i.e. a 5 cm long section of core (one sample) would be divided by 5 to give an average foraminiferal abundance per centimetre. This process is only necessary for the live assemblage where absolute numbers are used.

2.3. Sample preparation

Samples were wet sieved on a 63µm sieve with tap water to remove clay and silt. Once clean (this usually took just a few minutes) they were stained with a solution of rose Bengal (1 gram per litre) for 20 minutes (after Walton, 1952). After this time the samples were thoroughly rinsed in fresh water until all the excess stain was removed. The samples were then placed in aluminium or stainless steel containers in an oven at 60°C overnight.

Samples were in contact with tap water of 6.0-6.4 pH for approximately 30 minutes while processing (and perhaps 2-6 hours before dry)

When samples were completely dry and disaggregated they were poured into a beaker of heavy liquid (Carbon Tetrachloride) within a fume cupboard. The mixture was vigorously stirred. Mineral grains, disarticulated bivalves and gastropods all sank rapidly. Smaller-chambered organisms such as foraminifera, ostracods, crustaceans, and small gastropods readily floated to the surface forming a scum. The scum was gently decanted into a filter paper and the process repeated until little or no scum was produced. The float and residues were allowed to dry in a fume cupboard at normal room temperature before storage in glass bottles (float) and re-sealable plastic bags (residue).

Residues were examined carefully under the microscope. It was observed that foraminifera were present in very low numbers within the residue (predominantly representatives of the most abundant species, especially large broken forms such as *Massilina secans* and *Quinqueloculina* spp.). It is estimated that the foraminifera which remain within the residue probably represent less than 1 percent of the total sample foraminifera. In samples where the nature of the sediment hampers easy floatation (silts and very fine sands) or where there is an abundance of large robust foraminifera the amount of foraminifera that remained unfloated may rise to 3% or 4% of total sample foraminifera. Several sample residues from different stations were entirely scanned, producing a few to several tens of foraminifera.

2.4. **Picking and the 301 count**

Float samples were sub-sampled using a small steel spatula-type device in order to obtain a representative sample. Mechanical sorting can cause segregation of grain sizes. The sub-sample was scattered onto a brass picking tray and 301 dead individuals were picked whenever possible. Picking 301 individuals results in many rarer species (5% of the total assemblage) being omitted. After the first 301, several trays of float were scanned for rarer species. This process was carried out for many of the samples, although these rarer individuals were recorded separately (with an asterisk in spread sheets e. g. *2).
The entire sample was scanned for live (stained) individuals. All of these were picked out and mounted on microfossil slides. Only specimens with a vivid red stain were identified as

living at the time of collection. This resulted in many specimens, with very minor red or pink flecks or general pink staining, being disregarded. Because of the range of differently stained tests this is a subjective selection and undoubtedly varies between workers (Reiter, 1959; Green, 1960; Boltovskoy, 1963, *pers. comm.* Catherine Manley). Different species often accept a stain in different ways. Some species, particularly miliolids, take on a strong surface stain which does not reflect that they were living at the time of collection (Martin and Steinker, 1973). Apart from the slightly subjective selection of stained foraminifera (hence live at the time of collection), rose Bengal is believed to result in a slight under estimate of live foraminifera (Walker *et al.*, 1974).

Once individuals had been picked they were subdivided into species and lightly glued (using gloy/water mixture to a ratio of approximately 1:10) to cells within microfossil slides

2.5. Fractions

Four sample stations which varied significantly sedimentologically (mud to shell gravel) were chosen as control samples. Every three months 301 individuals of the dead assemblage were picked from material retained on the 63µm, 125µm, 250µm, 500µm, and where appropriate 1000µm sieves. Periodically the <63µm fraction was scanned for foraminifera. Control samples were used to evaluate the validity of picking foraminifera from the entire sample without separating it into sieve fractions. The results of this method are discussed in Chapter 9, Section 9.13.

Duplicate sediment samples were collected several times during the study for sedimentological analysis. The samples were dried overnight at 60°C, weighed, soaked in white spirit and water added until they began to dissagregate. The samples were wet sieved on a 63µm sieve. The retained material was re-dried in an oven overnight at 60°C and weighed once more. The difference in weight represented the amount of silt and clay that had been present. This process was repeated for other samples from the same station allowing an average clay and silt content for that station to be calculated.
The exact distribution of silt and clay within the samples from muddy and mixed locations were calculated from a second set of duplicate (unprocessed) samples. Organic material was removed form the samples (as this may effect grainsize) by adding hydrogen peroxide

and heating until the solution bubbled gently. After several hours, the reaction (bubbling) stopped and the liquid and sediment mixture was allowed to cool. The samples were sieved on a 63µm sieve. The material which passed the sieve was collected, an anti flocculent (Calgon) was added until a low viscosity free flowing solution formed. The solution was analysed using the Mulvern Instrument Master Sizer, which gave a distributional curve and percentage amounts of the proportion of clay and silt ranging from 1µm-100µm.

2.6. Annual Productivity

Annual production of foraminifera is calculated using the following method:- Production = sum of values from the simplified population dynamics equation $N_{i+1} = N_i + B - D$ (where $N_{i+1} =$ the new population size, $N_i =$ the original population size, $B =$ births and $D =$ deaths) over a period of 1 year (after Murray, 1991).

2.6.1. Different rates of Production Determined from the Live and Dead Assemblages

If live and dead foraminiferal data are available for the same point the abundance of common species in both assemblages can be used to determine their production rates.

- Tabulate the abundance of live and dead forms for those species occurring >4% (to eliminate rare occurrences).
- For species having the smallest percentage of dead compared with the percentage of living, let the production rate be taken as x 1 (i. e. the annual production = standing crop).
- For this the number of individuals = 1% of the dead assemblage can be calculated because the percentage living = number of individuals equivalent to the percentage dead, e. g. living 50% dead 10%, therefore 50 individuals = 10% and 1% dead, = 5 individuals.
- Multiply the percentage dead of all other species by this amount.
- Finally divide the number of dead individuals by the living percentage for each species to give the rate of production (after Murray, 1991).

The criteria for establishing the base production rate of 1, from which all other production rates are based upon, is the smallest proportion of dead to live abundance e. g. in the case of 5% live & 2% dead, or 5% live and 4% dead, the former would be selected as having a production rate of one. In many samples small fractions occur such as 5.00% live and 0.02% dead. These numbers represent an extremely small percentage of dead and are liable to be inaccurate as the bases of species production. The use of such figures will also result in most other species having a calculated production rate of several hundred, obviously unrealistic. For these reasons only reasonably abundant species are used >4% live and at least >1% dead are used for production calculations

2.7. The Plym Estuary

Samples of 100 cm^2 and 1 cm deep (100 cm^3) were collected from an inter-tidal site in the Plym Estuary (Figure 2.1) by pressing a metal square 1 cm deep into the sediment. Sampling extended over 11 months from December 1993 to October 1994. The samples were put into a plastic container and processed immediately, as mentioned in Section ***2.3***.

A core was retrieved from the same location within the estuary to study taphonomic processes acting upon the foraminiferal tests. A core tube with the same specifications as those from Plymouth Sound (48 cm long and an internal diameter of 4.3 cm) was used to collect a sediment core on the 21st of February 1995. The core tube was sunk to a depth of 43 cm and a spade was used to excavate the core which was sealed at both ends. A sediment core of 39 cm was retrieved. This slightly shorter sediment core was due to compaction of clays during the coring process. The core was divided up into 5 cm sections, the last section being 7 cm in length, The sections were labelled A-G. Although the primary aims of the core were to evaluate the fossil potential of the assemblage, the sections of core were wet sieved and stained (for live foraminifera) as mentioned in Section ***2.3.*** but produced very few stained foraminifera.

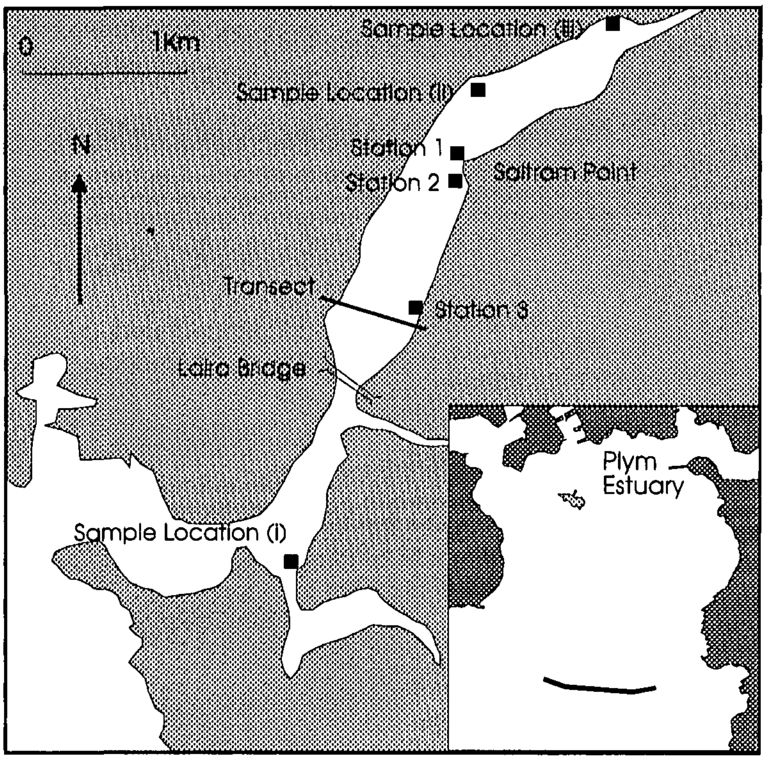


Figure 2.1. Map of the Plym Estuary and its relative position to Plymouth Sound.

A second core was taken from the same location within the Plym Estuary on the 27th of February 1995 to determine the vertical distribution of the live foraminifera (Figure 2.1). The core tube was 12 cm long and 7.6 cm internal diameter. The retrieved sediment core was 8 cm long. It was divided into 13 sections, the first 1 cm was divided in three 3 mm slices, the next 4.5 cm was divided into nine 5 mm thick slices and the final section was 25 mm thick (because the core was soft and had began to collapse, the last section could not be subdivided further). The samples were sieved and stained as mentioned in Section ***2.3***.

On the 17th March 1995 a transect across the Plym Estuary was taken (Figure 2.1). Seven samples were retrieved by inserting a plastic ring 11.2 cm in diameter and 1 cm deep resulting in a sample area of 98.5 cm^2 and a volume of 98.5 cm^3. The samples were processed as described in Section ***2.3***.

Plastic rings of the same dimensions as those for the transect were used to take spot samples at three other localities within the estuary. The samples were wet sieved, stained and floated as described in Section ***2.3***.

Samples to determine microlateral distribution were retrieved by inserting 7 plastic rings of 4.3 cm diameter and 1 cm deep (14.5 cm^3 in volume) in a Y shape (Chapter 4, figure 4.45). Two additional samples of the same size were retrieved from 1 m and 10 m distances.

2.8. Isotope cores

Three cores were collected from three sites in Plymouth Sound. These were located inside the Breakwater, Anchorage Beacons and Barn Pool. The cores tubes were 60 cm long with an internal diameter of 7.5 cm. Divers sunk the tubes into the sediment, dug down to the bottom and sealed both ends of the tubes. They were kept upright and taken to a veterinary surgery where they were X-rayed (to provide information about their internal structure). The sediment cores were forced out of the tubes, described and sliced with a spatula into 1 cm long sections. Each section was weighed and freeze dried. One hundred ml of material was placed into plastic containers from alternate samples such as 1, 3, 5 and so on, those samples were monitored for radio-isotope emissions of Caesium 137 (^{137}Cs), Lead 210 (^{210}Pb), Lead 214 (^{214}Pb), Cobalt 60 (^{60}Co), Beryllium 7 (^{7}Be) and Potassium 40 (^{40}K).

2.8.1. Lead 210 sediment accumulation rate

The Pb activity of sediments has two components, a supported component derived from the 222Rn decay within the sediment column and an unsupported component derived from the atmosphere. Subtracting the supported component from the unsupported component gives the true value of unsupported lead.

The unsupported lead 210 data plotted on a chart down the core. The data are regressed (i. e. a line of best fit is added by the computer). At this point a series of statistics are generated by Microsoft excel, including an R. square value which denotes the degree of fit of the regressed data. If the R. square value is low (i. e. a poor fit) spurious points in the lead 210 data may be removed to obtain a better fit and a higher R. square value. From the statistical data generated by regressing the lead 210 data an X variable coefficient is produced. This figure is divided by the half life of lead 210 (0.6931/22.3 years = 0.03108) resulting in a sediment accumulation rate (see Appendix 4)

CHAPTER THREE

3. SYSTEMATICS

3.1. Introduction

The taxonomy and systematics for this section is based upon Loeblich and Tappan, (1987), whilst identification of species was mainly carried out with reference to Murray (1971-"Atlas of British Recent Foraminiferids"), Haynes (1973-Cardigan Bay monograph), Heron-Allen and Earland (1930-monograph [and type slide collection held at the Natural History Museum] on "The foraminiferida of the Plymouth District"). Other references have been used, to a lesser extent, where relevant.

Species are set out in order of class, subclass, order, etc. and are arranged alphabetically within a genus, except where species are closely related (or very similar) and the remarks which follow one are pertinent to both species. In this case they follow each other, irrespective of alphabetical order.

A diagnosis is given where a species is well known and where there is no doubt about the identification. Where a species has been confused with others, unidentified or new, a full description is given.

After the species name, a reference to an illustration is given, either within the plates section of this work, or within another authors work when relevant .

The maximum occurrence of species is as follows:-

LIVE ASSEMBLAGE

Very common	Occurring in several hundreds or more; dominant or co-dominant
Common	Occurring in 50 to 100 individuals; numerically very important
Moderate	Occurring as 10 to 50 individuals; numerically important
Rare	Occurring as several specimens; accessory species
Extremely rare	Occurring once or twice

DEAD ASSEMBLAGE

Very common	Occurring as more than 25
Common	Occurring as 10 % - 25 %
Moderate	Occurring as 5% 9%
Rare	Occurring a few times in 301 (about 1% - 4% percent)
Extremely rare	Occurring once or twice (<1%) within a 301, or only in additional material scanned.

Species preference or occurrence with substrate is indicated as follows:-

Mud	Sediments with greater than 25% silt and clay
Sand	Sediments dominated by sands of various grain size
Gravel	Sediments consisting of greater than 50% >2 mm grain size
Mixed	Sediments with 10-20% silt and clay, 50%-90% sand, sometimes small amounts of gravel location 18, and sometimes locations 4 and 17.

Where a species is extremely rare a comment on its substrate preference may be omitted. Where a species occurs in several substrates they are listed in order of importance, a slash (/) between two of more substrate types signifies that they are of equal importance

3.2. SYSTEMATIC DESCRIPTION OF FAUNA

Phylum PROTOZOA
Subfamily SARCODINA
Class RHIZOPODEA
Subclass GRANULORETICULOSIA
Order FORAMINIFERIDA Eichwald, 1930

Suborder TEXTULARIINA Delage & Hérouard, 1896
Superfamily ASTRORHIZACEA Brady, 1881
Family PSAMMOSPHAERIDAE Haeckel, 1894
Subfamily PSAMMOSPHAERINAE Haeckel, 1894
Genus *PSAMMOSPHAERA* Schultze, 1875
Psammosphaera bowmani Heron-Allen and Earland
(Plate 4, Figs 8-12, Plate 5, Figs 1-6)

Psammosphaera bowmani Heron-Allen and Earland, 1912, pl. 5, figs 5-6.

Description

Test irregular sub-spherical to irregular, almost hemispherical; very coarsely agglutinated with micaceous fragments in excess of 500 microns in diameter set within a fine grey powdery cement/intergranular material. Unilocular, with a simple round aperture at the apex.

Remarks

Tests vary in shape markedly and fall into two broad groups; a roughly spherical to oval test composed of small windows of mica with an aperture at the apex, or an irregular hemispherical test composed of small fragments of mica and grey cement/intergranular material on one side and a large flake of mica on the other side. All specimens collected incorporate some translucent mica within their construction. The protoplasm is often green and the red stain of rose Bengal could be seen through the mica windows. The use of translucent mica windows and the strong green colouration of the protoplasm suggest that this species may have a possible symbiotic relationship.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare	Loc. 9	
Extremely rare	All other locations	All locations

Substrate type	All types	All types

Family SACCAMMINIDAE Brady, 1884

Subfamily SACCAMMININAE Brady, 1884

Genus *LAGENAMMINA* Rhumbler, 1911

Lagenammina arenulata (Skinner)

(Plate 6, Figs 1-2)

Reophax difflugiformis Brady, 1884, p. 289, pl. 30, fig. 5.

Reophax difflugiformis Brady subsp. *arenulata* Skinner, 1961, p. 1239

Proteonina difflugiformis (Brady) Cushman, 1918, p. 47, pl. 21, figs 1, 2.

Proteonina atlantica Parker, 1952a, p. 393, pl. 1, fig. 2

Reophax atlantica (Barker) 1960, p. 62, pl. 30, fig. 5

Lagenammina arenulata (Skinner) Haynes, 1973, p. 19, pl. 2, fig. 17; pl. 8, fig. 12; text-fig. 3, nos 1-3.

Diagnosis

A very coarsely agglutinated species of *Lagenammina,* roughly flask shaped with a slightly produced neck.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare		Locs 14,17

Substrate type		

Genus *TECHNITELLA* Norman, 1878

Technitella teivyense Haynes.

(Plate 6, Fig. 4)

Technitella teivyense Haynes 1973, p. 17. pl. 1, figs 1-4.

Diagnosis

Test unilocular, free, sponge spicules arranged at approximately 45 degrees to the growth axis; chamber appears to be cylindrical and slightly tapered away from the aperture. Aperture large and simple. Overall, test has a bushy appearance.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Locs 3, 4, 16	Locs 9, 11, 16

Substrate type	Gravel/Sand	All

Technitella legumen Haynes

Recommended source: Haynes 1973, pl. 9, fig. 2: 2.

(Plate 7, Figs 1-4)

Technitella legumen Haynes 1973, p.45, 84-85, pl. 9, fig. 2:2.

Description

Test agglutinated externally with simple sponge spicules; unilocular, curved and often elongate (adults) or fusiform (younger specimens), round in section. Spicules set within the wall and arranged longitudinally, often pointed but also occasionally blunt ends away from the aperture, walls thin and composed of an interwoven mesh of finer material and sponge spicules. Test often partially collapsed. Aperture round with a simple rounded lip of fine particulate material

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Locs 3, 4	Loc. 3

Substrate type	Gravel, Sand	Gravel

Technitella sp. (earbud form)

(Plate 6, Figs 5-6)

Description

Test agglutinated, composed of an almost spherical mass of sponge spicules with smooth rounded elongate bosses at either end; spicules arranged randomly, assumed to be unilocular.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Loc. 3	Locs 3, 14

Substrate type	Gravel	Gravel, Sand

Family HEMISPHAERAMMINIDAE Loeblich & Tappan, 1961

Subfamily HEMISPHAERAMMININAE Loeblich & Tappan, 1961

Genus *HEMISPHAERAMMINA* Loeblich & Tappan, 1957

Hemisphaerammina bradyi Loeblich & Tappan

(Plate 6, Fig. 3)

Webbina hemispherica Brady 1884, p. 350, pl. 41, fig. 11.

Hemisphaerammina bradyi Loeblich & Tappan 1957, p. 224, pl. 72, fig. 2a, b.

Hemisphaerammina bradyi (Loeblich & Tappan); Haynes 1973, p. 21, pl. 6, figs 1-2.

Diagnosis

A very smooth species of *Hemisphaerammina*, almost perfectly hemispherical; often occurs on relatively large flakes of rock or mineral.

Remarks

Haynes (1973) speculates as to whether this is a true foraminiferid as it resembles a gastropod egg case. These specimens are very similar to those figured by Haynes.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		

Moderate		
Rare		
Extremely rare	?	Locs 8, 9, 14, 18.

Substrate type		All

Superfamily RZEHAKINACEA Cushman, 1933

Family RZEHAKINIDAE Cushman, 1933

Genus *MILIAMMINA* Heron-Allen & Earland, 1930.

Miliammina fusca (Brady)

(Plate 1, Figs 11-12)

Quinqueloculina agglutinans Brady, 1867, p. 95.

Quinqueloculina fusca Brady, 1870, p.286, pl. 11, fig. 2a-c.

Miliolina fusca (Brady); Balkwill and Millett, 1884, p. 6.

Miliammina fusca (Brady); Rhumbler 1936, p. 209.

Diagnosis

An elongate ovate species of *Miliammina*, with a simple lunette aperture and a thick lip. The test is fragile, agglutinated with moderately size particles (silt) and is often a pale grey in colour.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Plym	Plym, Locs 9,12,15,17,18

Substrate type	Mud/Sand	Mud/Mixed

Superfamily HORMOSINACEA Haeckel, 1894
Family HORMOSINIDAE Haeckel, 1894
Subfamily REOPHACINAE Cushman, 1910.
Genus *REOPHAX* de Montfort, 1808
Reophax fusiformis (Williamson)
(Plate 1, Figs 1-2).

Proteonina fusiformis Williamson 1858, p. 1, pl. 1, fig. 1
Reophax fusiformis (Williamson); Siddall 1879, p. 4.

Diagnosis

An elongate fusiform species of *Reophax*; chambers only distinguishable by occasional external constrictions at the septal sutures, some specimens exhibit no evidence of septa and may be unilocular. The test is coarsely agglutinated with fine sand. The aperture is terminal, round and simple.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare	Loc. 9	
Extremely rare		Locs 1, 4, 9, 12, 15, 18

Substrate type	Mud	Mud, sand, mixed.

***Reophax* sp. 1**
(Plate 1, Fig. 3)

Description

This species superficially resembles *R fusiformis*, although it is slightly more flask shape. It is constructed externally from sponge spicules arranged parallel to the axis of growth. It may be unilocular or uniserial, the aperture is terminal round and simple.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare		Loc. 9

Substrate type		Mud

Reophax moniliformis (Siddall)
(Plate 1, Figs 4-5)

Reophax sp. Balkwill & Wright, 1885, p. 328, pl. 13, figs 9, 22-24.
Reophax moniliforme Siddall 1886, p. 54, pl. 1, fig. 2.

Diagnosis
A species of *Reophax* with a cylindrical, uniserial test, chambers do not increase much in size as they are added, sutures are slightly impressed, the test sometimes composed of a high proportion of sponge spicules (Pl. 1, Fig. 5).

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Locs 3, 9, 11, 16	Locs 3, 4, 8, 9, 11, 12, 16

Substrate type	Gravel, sand, mud	All

Reophax scottii Chaster
(Plate 1, Figs 6-7)

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

Diagnosis

A delicate and fragile species of *Reophax*, uniserial with up to 12 Swiss bell shaped chambers, composed of overlapping mica plates; often collapsed. Aperture terminal, small and often unclear.

	Live Occurrence	**Dead Occurrence**
Very common		
Common	Locs 9, 15	
Moderate	Loc. 12	
Rare	Loc. 18	
Extremely rare	Locs 4, 16, 17	Locs 3, 4, 9, 12, 15, 17, 18

Substrate type	Mainly Mud	All

Superfamily LITUOLACEA de Blainville, 1827
Family HAPLOPHRAGMOIDIDAE Maync, 1952
Genus *CRIBROSTOMOIDES* Cushman, 1910
Cribrostomoides jeffreysii (Williamson)
(Plate 2, Figs 1-2).

Nonionina jeffreysii Williamson, 1858, p, 34, pl. 3, figs 72-3.
Haplophragmium jeffreysii (Williamson); Berthelin, 1878, p. 24.
Haplophragmium canariense Brady 1884, p. 310, pl. 35, figs 1-3, 5.
Haplophragmoides canariense Cushman 1920, p. 38, pl. 8, fig. 1.
Haplophragmoides columbiensis Cushman 1944, p. 12, pl. 2, fig. 1.

Labrospira jeffreysi (Williamson); Hoglund, 1947, p. 146, pl. 11, fig. 3.

Alveophragmium jeffreysi (Williamson); Loeblich and Tappan, 1953, p. 31, pl. 3, figs 4-7.

Cribrostomoides jeffreysii (Williamson); Haynes, 1973, p. 29, pl. 2, figs 5-6; pl. 8, fig. 9; pl. 29, fig. 10; text-fig. 5, nos 8-10.

Diagnosis

A compressed species of *Cribrostomoides*, 6-7 chambers in final whorl, sutures are depressed and radial, test often brown in colour.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate	Locs 9, 16	Locs 9, 12, 16
Rare	Loc. 3	Locs 3, 15, 17
Extremely rare	Loc. 4	Locs 1, 4, 8, 11, 14, 18

Substrate type	Gravels, mud, sand	All

Family DISCAMMINIDAE Mikhalevich, 1980

Genus *AMMOSCALARIA* Höglund, 1947

Ammoscalaria pseudospiralis (Williamson)

(Plate 2, Figs 3-6)

Proteonina pseudospiralis Williamson 1858, p. 2, pl. 1, figs 2-3.

Ammoscalaria pseudospiralis (Williamson); Murray, 1971, p. 29, pl. 7, figs 1-5.

Diagnosis

Test planispiral in early stages, later uncoils, to become uniserial, flattened in cross section, and composed of large glassy grains (not always present) set in a matrix of small detrital grains. Aperture slit-like bearing a small knob, possibly a tooth (Pl. 2, Fig. 5).

	Live Occurrence	Dead Occurrence
Very common		
Common		
Moderate	Locs 4, 9, 18	
Rare	Loc. 15	
Extremely rare	Locs 12, 17	Locs 4, 9, 11, 12, 15, 17, 18

Substrate type	Mud, Mixed	All

Ammoscalaria runiana (Heron-Allen and Earland)

Recommended source for illustration: Murray, 1971, pl. 7, figs 6-8.

Haplophragmium runianum Heron-Allen and Earland 1916, p. 224, figs 15-18.
Ammoscalaria runiana (Heron-Allen and Earland); Murray 1971, p. 29, pl. 7, figs 6-8.

Diagnosis

An *Ammoscalaria* with a coarsely agglutinated, entirely planispiral, compressed test. The chambers are not visible externally.

	Live Occurrence	Dead Occurrence
Very common		
Common		
Moderate		
Rare		
Extremely rare	Loc. 9	Locs 9, 15

Substrate type	Mud*	Mud

* One specimen

Superfamily SPIROPLECTAMMINACEA Cushman, 1927

Family SPIROPLECTAMMINIDAE Cushman, 1927

Subfamily SPIROPLECTAMMININAE Cushman, 1927

Genus *SPIROPLECTAMMINA* Cushman, 1927

Spiroplectammina wrightii (Silvestri)

(Plate 3, Figs 1-3)

Spiroplecta sagittula Wright 1891, p. 471.

Spiroplecta sagittula Wright; Wright 1902a, p. 211, pl. 3, figs 5-8.

Spiroplecta wrightii Silvestri 1903, p. 59, text figs 1-6.

Spiroplectammina wrightii (Silvestri); Cushman 1949, p. 6, pl. 1, figs 2-4.

Textularia sagittula Brady, 1884, p. 361, pl. 42, figs 17, 18.

Textularia cuneiformis Williamson 1858, p. 75, pl. 6, figs 158-9.

Textularia sagittula Defrance var. *cuneiformis* Goës, 1894, p. 36, pl. 7, figs 288-290.

Textularia Williamsoni Goës 1894, p. 36, pl. 7, figs 285-7.

Description

A relatively finely agglutinated tapered, biserial, compressed test, with a carinate lobate periphery. The chambers immediately after the proloculus are initially rounded planispiral, the next 3 or 4 pairs of chambers have a high angle of taper reducing (almost parallel) in adult section, 10-16 pairs of chambers in total, chambers twice as wide as long, sutures distinct, impressed and horizontal. Test has a sugary appearance, finer around sutures. Aperture small, narrow, slit-like at the basal suture.

Remarks

Often confused with *T. sagittula* which lacks the rounded planispiral early stage and is generally more inflated and oval in section.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare		Locs 1,3,4,8,9,11,14,16,17,18

Substrate type		All

Superfamily TROCHAMMINACEA Schwager, 1877

Family TROCHAMMINIDAE Schwager, 1877

Subfamily TROCHAMMININAE Schwager, 1877

Genus *PORTATROCHAMMINA* Echols, 1971

Portatrochammina murrayi Brönnimann and Zaninetti

Recommended source for illustration: Brönnimann & Whittaker, 1990, pl. 2, (not pl. 1 as stated), figs 1-8.

Lituola nautiloidea var. *globigeriniformis* Parker and Jones, 1965, p. 407, pl. 15, figs 46-47, pl. 17, figs 96-98.

Haplophragmium globigeriniforme (Parker and Jones); Heron-Allen and Earland, 1930, p.69.

Trochammina globigeriniformis (Parker and Jones) var. *pygmaea* Hoglund 1947, p. 200, pl. 17, fig. 3.

Portatrochammina murrayi Brönnimann and Zaninetti, 1984, pp. 72-74, pl. 5, figs 7, 12-15.

Diagnosis

A species of *Portatrochammina* reaching 0.25 mm in size. Four well inflated round chambers in final whorl.

	Live Occurrence	Dead Occurrence
Very common		
Common		
Moderate		
Rare		
Extremely rare	Loc. 4	Locs 4,9,12,16

Substrate type		All

Subfamily TROCHAMMINELLINAE Brönnimann, Zaninetti & Whittaker, 1983

Genus *JADAMMINA* Bartenstein & Brand, 1938

Jadammina macrescens (Brady)

(Plate 3, Figs 10-12).

Trochammina inflata (Montagu) var. *macrescens* Brady 1870, p. 290, pl. 11, fig. 5a-c.

Jadammina polystoma Barstenstein and Brand, 1938, p. 381, figs 1-3.

Trochammina macrescens (Brady); Phleger and Walton, 1950, p. 281, pl. 2, figs 6-9.

Trochammina macrescens (Brady); Parker and Athearn, 1959, p. 341, pl. 50, figs 23-25.

Jadammina macrescens (Brady); Adams and Haynes, 1965, p. 30.

Diagnosis

A species of *Jadammina* with a finely agglutinated test, often micaceous, moderately involute, inflated, although often collapsed; periphery rounded, up to eight chambers visible in the outer whorl.

Remarks

Taxonomically the only difference between *Trochammina macrescens* and *Jadammina polystoma* are the development of areal apertures. Parker and Athearn (1959) and Adams and Haynes (1965) all concluded that the areal apertures are not taxonomically significant and that the two species are virtually identical. Hence the widely accepted name of *Jadammina macrescens* is used here.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare		Locs Plym, 4, 9

Substrate type		Mud, Mixed

Subfamily POLYSTOMAMMININAE Brönnimann & Beurlen, 1977

Genus *DEUTERAMMINA* Brönnimann, 1976

Deuterammina (Lepidodeuterammina) ochracea (Williamson) ***sinuosa*** (Brönnimann)

(Plate 3, Figs 4-5)

Trochammina ochracea (Williamson); Heron-Allen & Earland, 1930, p. 71.

Asterotrochammina sinuosa Brönnimann, 1978, pp. 6-7, pl. 2, figs 1, 2, 6-8

Deuterammina (Lepidodeuterammina) ochracea sinuosa (Brönnimann); Brönnimann & Zaninetti, 1984, pp. 87-90, figs AD1, AE1-3, AF1-3.

Diagnosis

A species of *Deuterammina* with a test which is very compressed scale like, concave on ventral side convex on dorsal side. Two or more whorls visible on the dorsal side sutures almost indistinct, one whorl visible on the ventral side sutures distinct and arcuate. Umbilicus wide shallow and stellate, colour reddish brown.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		Loc. 9
Extremely rare	Locs 3,16	Locs 1,3,4,12,15,16,17,18

Substrate type	Gravel	Mud, all types

Deuterammina (Deuterammina) rotaliformis (Heron-Allen & Earland) Brönnimann & Whittaker

Recommended source for illustration: Brönnimann & Whittaker, 1990, pl. 2 (not pl. 1 as stated), figs 13-16

(Plate 3, Figs 6-7)

Trochammina inflata (Montagu) var. Balkwill & Wright, 1885, p. 331, pl. 13, figs 11a, 12b.

Trochammina rotaliformis (Wright); Heron-Allen & Earland, 1911, p. 309.

Trochammina rotaliformis (Wright); Heron-Allen & Earland, 1930, p. 71.

Deuterammina (Deuterammina) rotaliformis (Heron-Allen & Earland); Brönnimann & Whittaker, 1983b, pp. 349-352, figs 1-12, 25.

Diagnosis

A species of *Deuterammina* with a trochospirally coiled test, involute on the ventral side with 4-5 chambers in the final whorl, the sutures are impressed and curved on the convex dorsal side, but radial and straight on the concave ventral side.

	Live Occurrence	Dead Occurrence
Very common		
Common		
Moderate		
Rare		
Extremely rare		Locs 1,3,4,9,12,15,16,17

Substrate type		Mud. All

Family REMANEICIDAE Loeblich & Tappan, 1964

Subfamily REMANEICINAE Loeblich & Tappan, 1964

Genus *REMANEICA* Rhumbler, 1938

Remaneica helgolandica Rhumbler

(Plate 3, Figs 8-9).

Trochammina plicata (Terquem); Heron-Allen and Earland 1930, p. 71.

Remaneica helgolandica Rhumbler 1938, pp. 195-201, figs 38-45.

Diagnosis

A species of *Remaneica* that is wafer thin, concavo-convex, with plication on the ventral side and periphery and well developed lobes on the ventral chamber sutures.

	Live Occurrence	Dead Occurrence
Very common		
Common		
Moderate		
Rare		
Extremely rare		Locs 3,4,9,15,16,17

Substrate type		All

Superfamily VERNEUILINACEA Cushman, 1911
Family VERNEUILINOIDINAE Suleymanov, 1973
Subfamily VERNEUILININAE Cushman, 1911
Genus *GAUDRYINA* d'Orbigny, 1839
Gaudryina rudis Wright
Recommended source for illustration: Murray, 1971, pl. 14, figs 1-6

Gaudryina rudis Wright, 1900, p. 53, pl. 2, fig. 1a-b.

Diagnosis

A species of *Gaudryina* with a coarsely agglutinated, conical test. The apex of the cone is blunt and rounded, initially triserial, later biserial, simple interiomarginal aperture, through the median line.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare		Loc. 17*

Substrate type		Sand

* One occurrence.

Superfamily TEXTULARIACEA Ehrenberg, 1838
Family EGGERELLIDAE Cushman, 1937
Subfamily EGGERELLINAE Cushman, 1937
Genus *EGGERELLA* Cushman, 1935
Eggerella arctica Höglund
Source for illustration Sturrock 1982 (Ph.D. thesis, Unpublished) pl. 13, fig. 12.

Eggerella arctica Höglund 1947, p. 26, pl. 16, fig. 4.

Diagnosis

A species of *Eggerella* with globose well formed chambers, distinct depressed sutures, chambers increase regularly in size as added.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare		Loc. 14*

Substrate type		Sand

* One occurrence

Genus *EGGERELLOIDES* Haynes, 1973

Eggerelloides scabrum (Williamson)

(Plate 4, Figs 1-4)

Bulimina scabra Williamson, 1858, p. 65, pl. 5, figs 136-7.

Textularia scabra (Williamson); Fischer 1870, p. 393.

Verneuilina polystropha Brady 1884, p. 386, pl. 47, figs 15-17.

Verneuilina scabra (Williamson); Cushman 1922, p. 55, pl. 10, figs 5-6.

Eggerella scabra (Williamson); Cushman, 1937a, p. 50, pl. 5, figs 10-11.

Eggerelloides scabrum (Williamson); Haynes 1973, p. 44-46, pl. 2, figs 7-8; pl. 19, figs 10-11; text-fig. 8, nos 1-4.

Eggerelloides scabrus (Williamson); Loeblich and Tappan 1987, pl. 189, figs 5-7.

Diagnosis

Elongate species of *Eggerelloides*, initially trochospiral, later triserial, last one or two whorls often increasing rapidly in size

	Live Occurrence	**Dead Occurrence**
Very common	Locs 15, 17	
Common	Locs 1,9,12,18	Locs 1,4,9,12,14,15,
Moderate	Loc. 4	Locs 11,18
Rare		Locs 3,8,16,17
Extremely rare	Locs 3,8,14,16	

Substrate type	Mud/Mixed/Sand, Gravel	All

Family TEXTULARIIDAE Ehrenberg, 1838

Subfamily TEXTULARIINAE Ehrenberg, 1838

Genus *TEXTULARIA* Defrance, 1824

Textularia sagittula Defrance group

(Plate 2, Figs 7-10)

Textularia sagittula Defrance, 1824, p. 177, pl. 13, fig. 5-5a.

Description

Test biserial, sub-carinate in early stages becoming inflated and sub-rounded later, apical angle (40-50 degrees) becoming much lower in adult section. Test long often comprised of 8-10 pairs of chambers. Test coarsely agglutinated generally pale buff, often including a small amount of dark angular fragments; sutures slightly impressed but indistinct. The proloculus is sharp and pointed. Aperture short, narrow, slit-like at the basal suture of the final chamber.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare	Locs 4, 18	Locs 4,11
Extremely rare	Locs 1,9,15,17	Locs 1,3,8,9,12,14,15,16,17,18

Substrate type	Mixed, Mud, Sand	Sand, all types

Textularia truncata Höglund

Textularia truncata Höglund 1947, vol. 26, p. 175, pl. 12, figs 8-9.

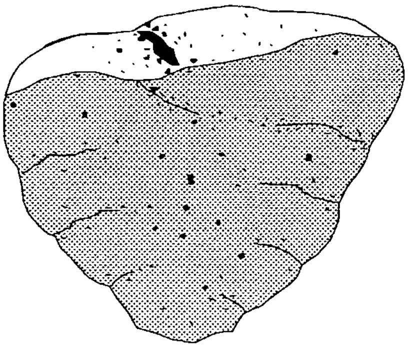


Figure 3.1. Line drawing of *Textularia truncata* Höglund, 150µm in diameter.

Diagnosis

Short, stout, wedge shaped species of *Textularia*, biserial, moderately compressed, apical angle 60 degrees, subsequent chambers increasing greatly in width, triangular (equilateral) in outline, generally 4-5 pairs of chambers..

	Live Occurrence	Dead Occurrence
Very common		
Common	Locs 3,16	Locs 1,3,16
Moderate		Locs 11,14
Rare		Locs 4,8,17,18
Extremely rare	Locs 1,4,8,11,12,14,15,17,18	Locs 9,12,15

Substrate type	Gravel, Sand, Mud, Mixed	Gravel, Sand, Mud, Mixed

Textularia earlandi Parker
(Plate 2, Figs 11-13).

Textularia elegans Lacroix, 1931, p. 65, pl. 14, figs 11.
Textularia tenuissima Earland 1933, p. 95, pl. 3, figs 21-40.
Textularia earlandi Parker, 1952, p. 458.
Spiroplectammina elegans (Lacroix); Norvang, 1966 pl. 1, fig. 24.

Diagnosis

An elongate species of *Textularia* with inflated, rounded chambers which increase very gradually in size. Sutures distinct, aperture is a small arch opening at the basal suture.

	Live Occurrence	Dead Occurrence
Very common		
Common		
Moderate	Loc. 9	
Rare		Loc. 9
Extremely rare	Locs 3,4,11,12,14,15,16,17,18	Locs 3,4,12,15,16,17,18

Substrate type	Mud, all types	Mud, all types

Family VALVULINIDAE Berthelin, 1880
Subfamily VALVULININAE Berthelin, 1880
Genus *CLAVULINA* d'Orbigny, 1826
Clavulina obscura Chaster
(Plate 4, Figs 5-6)

Clavulina obscura Chaster, 1892, p. 58, pl. 1. fig. 4

Diagnosis

A species of *Clavulina* with the initial part of the test triserial becoming uniserial, test elongate, straight or slightly curved, chambers are round in cross section, sutures impressed. Terminal aperture small, irregular and simple.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare	Loc. 16	Locs 9,12,15
Extremely rare	Locs 1,3,4,9,12,15,17	Locs 1,3,4,8,17,18

Substrate type	All	Mud, all types

The following are placed within this section because the unknown genera belongs within the suborder Textulariina.

Genus 1 unidentified
(Plate 1, Fig. 8)

Description

Test agglutinated, composed of overlapping mica plates very similar in construction to *Reophax scottii*. The test is elongate, pointed at the base, biserially arranged chambers are off set to each other, the periphery is sub-acute. The test is compressed, sutures are indistinct and the initial chamber arrangement is unclear, the apical angle is initially 30-40 degrees but diminishes within the adult section to become sub-parallel. The test is fragile and the aperture is on a very slightly produced neck.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare	Loc. 9	
Extremely rare		Locs 9,15

Substrate type	Mud	Mud

Genus 2 unidentified

(Pl. 1, Figs 9-10)

Description

Test coarsely agglutinated, very elongate and almost circular in cross-section. Chambers are round, inflated and give this species a slightly lobate outline. The proloculus is blunt. The test increases in size very gradually and remains constant in the adult section. The sutures are unclear and represented by slight constrictions, hence the chamber arrangement is possibly initially triserial ? becoming biserial ? in the adult section. The aperture is terminal. The test is composed of fine detrital material and includes a relatively large number of coccoliths.

Remarks

The chamber arrangement is unclear and because of its extreme rarity there were insufficient specimens to section and examine. For the same reason it is not known whether the coccoliths species utilised within its construction are characteristic of this species, i. e. it selects certain coccolith species

	Live Occurrence	Dead Occurrence
Very common		
Common		
Moderate		
Rare		
Extremely rare		Loc. 9*

Substrate type		Mud

* One occurrence

Genus 3 unidentified

Figured in Appendix 8.

Description

Test elongate, oval to fusisform, round in section, very finely agglutinated almost tectinous, with some larger, often brightly coloured angular glassy mineral grains, regularly distributed throughout the surface. The aperture is terminal, round and simple. The test is fragile often partially collapsed. The chamber arrangement is unclear and may be uniserial composed of one larger chamber or unilocular.

	Live Occurrence	Dead Occurrence
Very common		
Common		
Moderate		
Rare	Loc. 9	
Extremely rare		Locs 9,17

Substrate type	Mud	Mud Sand

Suborder SPIRILLININA Hohenegger & Piller, 1975
Family SPIRILLINIDAE Reuss & Fritsch, 1861
Genus *SPIRILLINA* Ehrenberg, 1843
Spirillina cf. ***vivipara*** Ehrenberg
(Plate 27, Figs 7-9)

Spirillina vivipara Ehrenberg, 1843, pp. 323, 422, pl. 3, fig. 41.

Very similar to those described and figured by Haynes (1973) pl. 16, figs 1-2, and Murray (1971) pl. 60, figs 1-2. It differs only in being a low trochospirally coil rather than planispiral.

Description

Test free, calcareous, very evolute, compressed, chambers slightly embracing in a very low trochospire; periphery with round outline, surface has a pitted appearance, but closer examination reveals pores at the bases of the pits; the chambers sub-quadrate in section. The aperture is simple.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Loc. 9*	Locs 4,9,15,16

Substrate type		All

* One occurrence

Spirillina vivipara Ehrenberg var. ***runiana*** Heron-Allen and Earland.

Source for illustration Murray 1971 pl. 60, figs 3-4

Spirillina vivipara Ehrenberg var. *runiana* Heron-Allen & Earland, 1930, p. 179, pl. 4, figs 51-53.

Diagnosis

This variety of *Spirillina vivipara*, is characterised by having short radial finger-like ribs connecting the whorls.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare		Loc. 9

Substrate type		Mud

Spirillina wrightii Heron-Allen and Earland

(Plate 27, Fig. 10)

Spirillina margaritifera Wright. 1877.p.321, pl. xxvi, fig. 12a-b.

Spirillina margaritifera Terquem, 1881, p. 110, pl. xiii, fig. 2a-d.

Spirillina margaritifera Halkyard. 1889. p. 69, pl. ii, fig. 7.

Spirillina wrightii Heron-Allen and Earland. 1930, p. 181, pl. 4, figs 54-58.

Description

Test calcareous, compressed, evolute, planispirally coiled, edge is flat to concave, bi-carinate, round in outline, chambers quadrate in section. The wall is white, opaque and relatively thick. The aperture is simple. The ventral and dorsal sides are either densely pitted and porous, or ornamented with irregular round flattened knobs/bosses.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare		Locs 4,12

Substrate type		Mud Sand

Subfamily PATELLININAE Rhumbler, 1906

Genus *PATELLINA* Williamson, 1858

Patellina corrugata Williamson

(Plate 27, Figs 11-12)

Patellina corrugata Williamson, 1858, p. 46, pl. 3, figs 86-89

Arpatellum dunst-corrugatum (Williamson); Rhumbler, 1913, p. 437, figs 134a-c, 136, pl. 5, figs 5-7, pl. 7, figs 11-15.

Discobolivina corrugata (Williamson); Hofker, 1951, p. 358.

Diagnosis

A typically limpet shaped species of *Patellina*, the dorsal side is porous, with several whorls (2-4) with two chambers in each. The dorsal side shows fine pitting and ornamentation. The periphery is acute, the ventral side is ornamented with a circular row of shallow pits.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare	Loc. 3	
Extremely rare	Locs12,16	Locs 1,3,4,9,12,14,15,16,17,18

Substrate type	Gravel, Mud	All

Patellina sp. 1

(Plate 27, Fig. 13)

Description

Test hyaline, attached, plano-convex, limpet shape, large and robust in appearance. The dorsal side has well developed, strong, protruding ribs which run in concentric rings initially from the apex to the periphery, these rings contain one whorl, composed of two chambers, which are strongly perforate. The periphery is acute.

Remarks

This form/species is similar to *P corrugata* but differs by being larger and having a more robust appearance and may represent large adults which have been abraded. Individuals are rare (no more than a dozen individual in total) and occurred exclusively in coarse sand to gravels. No living forms were recovered. Its absence from the live assemblage and rarity in the dead assemblage suggests it is unlikely to be common in any nice or sub-environment of the Sound.

	Live Occurrence	Dead Occurrence
Very common		
Common		
Moderate		
Rare		
Extremely rare		Locs 3,11,16

Substrate type		Gravel, Sand

Suborder MILIOLINA Delage & Hérouard, 1896

Superfamily CORNUSPIRACEA Schultze, 1854

Family CORNUSPIRIDAE Schultze, 1854

Subfamily CORNUSPIRINAE Schultze, 1854

Genus *CYCLOGYRA* Wood, 1842

Cyclogyra involvens (Reuss)

(Plate 7, Figs 6-7)

Operculina involvens Reuss, 1850, p. 370, pl. 46, fig. 20a-b.

Cyclogyra involvens (Reuss); Murray 1971, p. 53, pl. 18, figs 1-3.

Diagnosis

A species of *Cyclogyra* with a slightly raised proloculus is followed by a long, planispirally coiled, chamber, one to four whorls present. The periphery is round, the test is smooth, moderately inflated and round in outline, the aperture simple.

Remarks

Loeblich and Tappan (1987) have suppressed the genus *Cornuspira* for complex reasons. It is preferred to retain this species under the genus of *Cyclogyra*.

	Live Occurrence	Dead Occurrence
Very common		
Common		

Moderate		
Rare		Loc. 9
Extremely rare	Locs 3,4,9,12,14,15,18	Locs 1,3,4,8,12,14,15,16,17,18

Substrate type	Mud, all types	All

Subfamily CORNUSPIROIDINAE Saidova, 1981
Genus *CORNUSPIRELLA* Cushman, 1928
Cornuspirella diffusa (Heron-Allen and Earland)
(Plate 7, Figs 8-9)

Cornuspira diffusa Heron-Allen and Earland, 1913, pp. 272-6, pl. 12, all figs.
Cornuspirella diffusa (Heron-Allen and Earland); Murray 1971, p. 53, pl. 18, figs 4-8.

Diagnosis

This species of *Cornuspirella* has a flattened test which is fan shaped, sometimes branching, the fragile test is marked with many curved growth lines, the aperture/s are narrow, long, simple slits.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate	Loc. 9	
Rare	Locs 4,18	
Extremely rare	Locs 15,17	Locs 4,9,15,17,18

Substrate type	Mud, Mixed	Mud, Mixed, Sand

Family OPHTHALMIDIIDAE Wiesner, 1920

Genus *CORNULOCULINA* Burbach, 1886

Cornuloculina balkwilli (Macfadyen)

(Plate 8, Figs 1-2)

Ophthalmidium balkwilli Macfadyen, 1939, p.59, pl. 22, fig. 1.

Cornuloculina balkwilli (Macfadyen); Loeblich and Tappan 1987, p. 326.

Diagnosis

A species of *Cornuloculina* with an irregular test almost round in outline, compressed, chambers are coiled in a gyrospire in one plane, the chambers increase in length as they are added, the last chamber forms half to three quarters of the periphery, the periphery is acute. The aperture is simple.

Remarks

This genus was originally *Ophthalmidium*, Loeblich and Tappan have restricted *Ophthalmidium* to Triassic and Jurassic specimens. Therefore *Cornuloculina* is the appropriate extant genus.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare		Loc. 9

Substrate type		Mud

Superfamily MILIOLACEA Ehrenberg, 1839

Family SPIROLOCULINIDAE Wiesner, 1920

Genus *ADELOSINA* d'Orbigny, 1826

***Adelosina*? sp. 1**

(Plate 17, Figs 12-14)

Description

Test thick, porcellaneous, smooth, appears to be unilocular (?), globose-lenticular, one whorl coiled through 180° or more, 'comma' shaped in outline, slightly higher than wide, oval in section, periphery keeled, short tapering neck bearing approx. 8 short costae (four on each side), aperture terminal slightly produced, bearing a small bifid tooth.

Remarks

Some individuals are strongly carinate with several striations running parallel to the carina (Pl. 18, Figs 2-3), others have a rounded periphery and are densely costate (Pl. 18, Fig. 1).

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare		All Locations

Substrate type		All

***Adelosina* sp. 2**.

(Plate 18, Figs 1-3)

Diagnosis

Essentially the same form and construction as described above, specimens have a sub-acute to keeled periphery (the development of a keel may be an ontogenetic feature as some juveniles appear to lack a keel), the wall is ornamented with few, faint, longitudinal ribs or many prominent longitudinal costae, the neck is short, robust, the aperture is round and bears a small bifid tooth.

Remarks

The author regards these ornamented specimens as closely related to *Adelosina* sp. 1. It is possible that they may represent sexual dimorphs or ontogenetic stages but as they are rare the real relationship is not known.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare		Locs 1,3,9,12,14,17,18,

Substrate type		All

Genus *SPIROLOCULINA* d'Orbigny, 1826

Spiroloculina depressa d'Orbigny

(Plate 8, Figs 4-5)

Spiroloculina depressa d'Orbigny 1846, p. 271, pl. 16, figs 19-21.

Diagnosis

An elongate species of *Spiroloculina*, eye-shaped, chambers quadrangular in section, the edges of which are slightly rounded. The test is elongate, almost twice as long as it is wide. Bi-umbilicate, additional chambers are larger and hence stepped. Aperture almost square the corners rounded, the tooth is simple and tapered towards the rounded lip.

Remarks

This species is very similar to *S. excavata* d'Orbigny figured in Murray (1971, pl. 19, figs 1-3).

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Locs 4,9,15,17,18	All Locations

Substrate type	Mud, Mixed	All

Spiroloculina sp. cf. ***Spiroloculina rotunda*** d'Orbigny

(Plate 8, Figs 6-7)

Spiroloculina rotunda d'Orbigny, 1826, p 299.

Spiroloculina rotunda (d'Orbigny); Parker, Jones, and Brady, 1871, pp. 4-8, pl. 8, fig. 25.

Diagnosis

The chambers are sub-quadrate in section giving an almost round periphery, the test is oval in outline, it is only a little longer than it is wide. The arch-shaped aperture bears a 'toadstool' shaped tooth.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare		Locs 1,4, 8,9,11,14,15,16,17,18

Substrate type		All

Spiroloculina cf. ***Spiroloculina grata*** Terquem
(Plate 8, Fig. 11)

Spiroloculina grata Terquem, 1878, p. 55, pl. 5, figs 14a-b, 15a-b.

Description

Test porcellaneous, oval in outline, the final two chambers are slightly involute and obscure the initial chambers, ornamented with longitudinal coarse costae, periphery round, coiling may be quinqueloculine initially? later planispiral, The aperture is terminal and truncate.

Remarks

The type specimens of this species are from the Aegean Pliocene, although both Chapman (1915) and Cushman (1917) both recorded Recent varieties of this species. Heron-Allen and Earland also list this species from the south coast of England (1909) and the North Sea (1913).

	Live Occurrence	**Dead Occurrence**
Very common		
Common		

Moderate		
Rare		
Extremely rare		Locs 3,4,9

Substrate type		All

Spiroloculina **sp. 1**

(Plate 8, Figs 8-10)

Description

Test porcellaneous, white and appears agglutinated (sugary), it is oval to round in outline, chambers are arranged in a spiroloculine series, although coiling in the early chambers is unclear. The final two chambers are well inflated and increase greatly in size. They are round in section and have a rounded periphery. The aperture is sub-round and bears a complex plate-like tooth.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Locs 4,9,12	Locs 3,4,9,12,14,15,18

Substrate type	Mud, Mixed	Mud, Mixed, others.

Family HAUERINIDAE Schwager, 1876

Subfamily HAUERININAE Schwager, 1876

Genus *MASSILINA* Schlumberger, 1893

Massilina secans (d'Orbigny)

(Plate 15, Figs 8-10, Plate 16, Figs 1-3).

Quinqueloculina secans d'Orbigny, 1826, 1, 7, p. 303.

Quinqueloculina secans (d'Orbigny); Parker, Jones, and Brady, 1871, pp. 4, 8, pl. 8, fig. 14.

Miliolina secans Brady, 1884, 167, pl. 6, figs 1, 2.

Sigmoilina secans (d'Orbigny); Schlumberger, 1887, p. 118.

Massilina secans (d'Orbigny); Schlumberger, 1893, p. 218, pl. 4, figs 82, 83.

Miliolina secans (d'Orbigny); Mills, 1900, p. 143, pl. 10, fig. 18.

Description

Test thick imperforate and porcellaneous, early chambers exhibit quinqueloculine coiling, but the adult section becomes more planispiral (two chambers per whorl) as in *Spiroloculina*. Test compressed, chambers oval in section and the periphery is sub-angular. The aperture is truncate with a rounded lip, the aperture is large and almost quadrangular with a large robust tabular bifid tooth.

Remarks

Some of the final whorls are often deformed with constrictions and more commonly growth crenulations (rough bands across chambers). Very young juveniles are quinqueloculine like and difficult to distinguish as belonging to this species. Sub-adults are elongate to oval with a more rounded periphery, they may also bear one or more small short stout spines at the posterior pointing away from the test.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		Loc. 8
Rare	Locs 16,17	Locs 1,3,4,11,14,16,17
Extremely rare	Locs 1,3,4,8,9,11,14,18	Locs 9,12,15,18

Substrate type	Sand, Gravel, others	Sand, Gravel, Mixed, Mud

Massilina secans var. ***tenuistriata*** Earland

(Plate 16, Fig., 3)

Massilina secans var. *tenuistriata* Earland 1905, p. 198, pl. 11, fig. 6a-c.

Massilina secans var. *tenuistriata* Heron-Allen and Earland, 1914-15, p. 582, pl. xliv, figs 28-31.

Diagnosis

As above (*M. secans*) except the test surface is finely striated (longitudinally to obliquely) rather than smooth. This variety has not been treated separately and is included within as *M. secans*.

Remarks

The reason for treating this species as part of *M. secans* was because the fine striations which distinguish this variety were difficult to see at normal working magnification and it is believed that several individuals were not recognised as belonging to this variety and simply recorded as *M. secans*.

Genus *QUINQUELOCULINA* d'Orbigny, 1826

Quinqueloculina aspera d'Orbigny [forms 1, 2 & 3].

(Plate 9, Figs 1-9, Plate 10, Figs 1-5).

Quinqueloculina aspera d'Orbigny, 1826, p. 301.

Quinqueloculina aspera (d'Orbigny); Parker, Jones and Brady, 1871, p.301, pl. 8, fig.11.

Miliola (Quinqueloculina) agglutinans Parker & Jones, 1865, p.410, pl. 15, fig. 37a-b.

Miliolina sclerotica Balkwill & Millett, 1884, p. 24, pl. 1, fig. 2.

Quinqueloculina agglutinata Cushman, 1948, p. 33, pl. 3, fig. 13.

Quinqueloculina aspera form 1

(Plate 10, Figs 1-5)

Description

Test elongate to ovate, inflated, round in section, quinqueloculine coiled, exhibiting 5 chambers externally, test surface agglutinated with silt fragments and occasional larger angular dark minerals, chambers round and well inflated. Aperture round with a large rounded lip containing a strongly bifid tooth.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare	Locs 15,17,18	
Extremely rare	Locs 1,4,8,9,12,14,16,	Locs 4,8,9,11,14,15,16,17,18

Substrate type	Mud, Mixed, Sand	Sand, all others

Quinqueloculina aspera form 2

(Plate 9, Figs 1-3)

Description

Test elongate, quinqueloculine coiling, five chambers visible, chambers inflated, The final chamber has a well inflated base wrapped round the bottom of the test. The test surface has a finely agglutinated and often pitted appearance which resembles etching but is present on virtually all specimens of this variety. The aperture is round, lipped and containing a bifid tooth with widely divergent tines.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		Locs 16
Rare		Locs 1,4,18
Extremely rare	Locs 1,4,8,9,12,15,16,17,18	Locs 3,8,9,11,12,14,15,17

Substrate type	All	All

Quinqueloculina aspera var. 3

(Plate 9, Fig. 5-9)

Description

The test has a medium to coarsely agglutinated appearance, oval to elongate in outline. The chambers are quadrate in section, sub-angular to angular, between the chamber edges the chambers are flat to convex. The aperture is on a slightly produced neck, has a round lip and is round with some variation of tooth which is always present

Remarks

All of the forms of *Q. aspera* described above show a high variation in apertural tooth which ranges from (no stalk) bifurcating tines, tooth with bifurcating tines which are either slight or robust to a simple robust tabular tooth, the author speculates that these variations may be related to ontogenic stages, micro or megaloshperic individuals may bear different tooth types.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare	Locs 15,18	Locs 15,16,18
Extremely rare	Locs 4,9,17	Locs 1,3,4,8,9,11,12,14,17

Substrate type	Mud, Mixed	All

Quinqueloculina aspera var. 4 (Striated form)

(Plate 9, Fig. 4)

Description

Test elongate, quinqueloculine coiling, five chambers visible, chambers inflated. The final chamber has a well inflated base wrapped round the bottom of the test.. The test is ornamented with fine to moderate regular costae, distributed over all of the visible chambers. The test wall is rough with a pitted appearance.

Remarks

This variety is very similar in shape, form and size to *Q. aspera* var. 2 described previously. The test is slightly more inflated, the notable difference is the presence of fine to moderate regular costae, distributed over all of the visible chambers.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare		Locs 4,17

Substrate type		Sand

Quinqueloculina auberiana d'Orbigny

(Plate 17, Figs 4-6)

Quinqueloculina auberiana d'Orbigny 1846, p. 1-306, pls 1-21.

Miliolina auberiana (d'Orbigny); Brady 1884, p. 162, pl. v, figs 8-9

Description

Test free, porcellaneous, irregular heart shape, rounded triangular in polar view. Chambers are inflated, sub-angular to sub-rounded, rounded quadrangular in section and increase in size as added. The wall has very fine striations. The aperture is arch-shaped with a simple straight peg-shaped tooth.

Remarks

This species is very similar to *Q. lamarkiana*, which is distinguished by a produced aperture. Another similar species is *Q. vulgaris* which is distinguished in having a more slender bifid tooth.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		Locs 1,3,4,8,11,12,14,16,17
Extremely rare	Locs 4,9,11,12,14,16,17,18	Locs 9,15,18

Substrate type	All	All

Quinqueloculina bicornis (Walker and Jacob)

(Plate 17, Figs 6-7)

Serpula bicornis ventricosa Walker & Boys, 1784, p. 1, pl. 1, fig. 2.

Serpula bicornis Walker & Jacob, 1798, p. 633, pl. 14, fig. 2

Quinqueloculina bicornis (Walker & Jacob); Terquem, 1875, p. 443, pl. 6, fig. 6.

Diagnosis

A species of *Quinqueloculina* that is oval to sub-rounded in outline. Test well inflated and is ornamented with regular longitudinal costae The aperture is elongate rectangular, bearing a long straight tooth.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		Locs 8,16
Rare		Locs 3,11,
Extremely rare	Locs 4,8,9	Locs 1,4,9,14,15,17,18

Substrate type	Sand, Mud	Sand/Gravel, all others

Quinqueloculina cliarensis (Heron-Allen and Earland)

(Plate 15, Figs 4-7)

Miliolina stelligera Heron-Allen and Earland 1913, (non Schlumberger), p. 187, pl. 1, figs 14-15.

Miliolina stelligera Heron-Allen and Earland 1916, (non Schlumberger), p. 215, pl. 39, figs 28-31.

Miliolina cliarensis Heron-Allen and Earland 1930, p.58, pl. 3, figs 26-31.

Quinqueloculina cliarensis (Heron-Allen and Earland); Murray 1971, p. 61, pl. 22, figs 1-4.

Description

The test is porcellaneous, has a slightly rough appearance (due to its fine granular surface), particularly around the sutures. The test is very compressed, almost blade like. Chambers are arranged in a quinqueloculine series, they are carinate, angular, moderately embracing. The neck is well produced tabular and very compressed. Aperture is small, terminal, a compressed oval with a fine rounded lip and no tooth.

Remarks

This species resembles very well that figured by Heron-Allen and Earland 1930, and that illustrated in Ellis and Messina.

Heron-Allen and Earland revised there allocation of several specimens from Cliare Island to the species *Miliolina stelligera* (Schlumberger) after studying co-types of that species. The new species based on a specimen from Whitesand Bay, Cornwall is the same as the Cliare Island specimens from which it takes its name.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		Loc. 9
Extremely rare	Locs 9,17	Locs 1,4,11,15,17

Substrate type	Mud, Sand	Mud, Sand

Quinqueloculina* cf. *Q. cliarensis (Heron-Allen & Earland)
(Plate 13 Figs 1-4).

Quinqueloculina cf. *cliarensis* (Heron-Allen & Earland); Cushman, 1949, p. 9, pl. 1, fig. 10a-c.

Quinqueloculina cf. *cliarensis* (Heron-Allen & Earland); Haynes 1973, pp. 68-70, pl. 7, figs 8-9; text-fig. 17, nos 1-4.

Diagnosis

A species of *Quinqueloculina* in which the chambers are generally compressed and curved, the periphery is acute to round. The test may be 1.5 to 2.5 times as high as it is wide. The aperture is on a round neck and may or may not bear a bifid tooth

Remarks

This species may be made up of several species or varieties which graduate along a series. Because of their general similarity, but large variation of small features, the taxonomy has often been confused. This, coupled with their rarity (particularly live), in this study has resulted in these forms being regarded as one species. Some of the range in variability can be seen in Plate 14, Figures 1-4. For a full taxonomic discussion refer to Haynes (1973) pp. 68-70.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare	Loc. 9	Locs 4,9,14,16,18
Extremely rare	Locs 3,4,12,14,15,17,18	Locs 1,3,8,11,12,15,17,

Substrate type	All	All

Quinqueloculina lata Terquem

(Plate 11, Figs 1-4).

Quinqueloculina lata Terquem, 1876, p. 173, pl. 11, fig. 8a, b.

Miliolina oblonga var. *lata* (Terquem); Heron-Allen & Earland, 1930, p. 55, pl. 2, figs 12-15.

Diagnosis

A species of *Quinqueloculina* with an elongate oval to round, rectangular outline, sutures are slightly impressed. Rounded to slightly triangular in polar orientation, periphery rounded. The aperture is arch-shaped with a short, slender tooth (becoming almost bifid at the extremity).

Remarks

This species is very similar to *Q. seminulum*, which has a more oval, well inflated outline, a slightly narrower aperture and, importantly, a long slender simple tooth. The sutures of *Q seminulum* are less distinct. *Quinqueloculina lata* may often be coloured green or brown along the sutures and adjacent areas, whilst *Q seminulum* is almost always pure white. The juveniles of both species are virtually indistinguishable.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		Loc. 16
Moderate	Locs 8,17	Loc. 17
Rare		Locs 1,3,4,8,11,
Extremely rare	Locs 1,4,9,14,16,18	Locs 9,12,12,14,16,18

Substrate type	Sand, all others	Gravel, Sand, all others

Quinqueloculina lata var. 1 (Terquem)
(Plate 10, Figs 8-10)

Quinqueloculina lata Terquem 1875, p.82, pl. 11, fig. 8a-b.

Diagnosis

The test is smooth and rectangular in outline with rounded corners (similar to *Q. lata* which is more oval in outline and distinctly less rectangular in outline). The sutures are very slightly impressed and indistinct.

Remarks

This form belongs within the species *Q. lata* it forms a distinct and easily distinguishable variety, which may be the result of sexual dimorphism or eco-phenotypic variation.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Locs 4,9,11	All Locations

Substrate type	Mud/Sand/Mixed	All types

Quinqueloculina mediterranensis Group, Le Calvez & Le Calvez
(Plate 13, Figs 5-10)

Miliolina bicornis Sidebottom, 1904, p. 14, pl. 4, figs 13-14.

Quinqueloculina mediterranensis Le Calvez & Le Calvez, 1958, p. 177, pl. 4, figs 29-31.

Description

The test is porcellaneous, oval to irregular oval in outline, the chambers are arranged in the quinqueloculine series, the early chambers often develop carina or flaps. The test is compressed with an acute to carinate periphery, although in some individuals the periphery is rounded and bi-carinate. The surface has irregular parallel to sub-parallel costae near the periphery only, varying to regular, strong, longitudinal costae from aperture to apex over the entire test. The final chamber is slightly larger to much larger than the previous, it often partially embraces the bottom of the test, at the apex it produces a gently tapering cone-shaped neck, without a lip and often bearing a small bifid tooth.

Remarks

This group is morphologically diverse and contains a series of fine, sparsely ornamented to robust, bi-carinate, highly costate specimens. It may include several species such as *Q. colomi, Q. durthiersi* (Schlumberger), *Q. intricata* Terquem, *Q. granulocostata* Germaraad, and *Q. mediterranensis* (Haynes, 1973).
Quinqueloculina intricata is figured on Pl. 14, Fig. 1. It is distinguished by its oval outline and carinate periphery. This species was rare and identified rather late in the study, so is grouped within the *Q. mediterranensis* group. This group of costate, quinqueloculine species were not very common, and as a result of the gradation from one form to another are grouped as one.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare	Loc. 9	
Extremely rare	Locs 4,11,17,18	Locs 1,3,4,9,11,12,15,16,17,18

Substrate type	Mud, Sand, Mixed	All

Quinqueloculina oblonga (Montagu)

(Plate 12, Fig. 1)

Vermiculum oblongum Montagu, 1803, p. 522, pl. 14, fig. 9.

Quinqueloculina oblonga (Montagu); Murray 1971, p. 63, pl. 23, figs 4-8.

Diagnosis

A species of *Quinqueloculina* which is elongate and oval in section. The aperture is slightly produced, terminal and bears a small, simple tooth.

	Live Occurrence	**Dead Occurrence**
Very common	Locs 4,9	
Common	Locs 15,17,18	
Moderate	Loc. 12	
Rare	Loc. 14	Locs 4,9
Extremely rare	Locs 1,3,8,11,16	Locs 1,3,8,11,12,14,15,16,17,18

Substrate type	Mud, Mixed	All types

Quinqueloculina seminulum (Linné)

(Plate 11, Figs 4-8)

Serpula seminulum Linnaeus, 1767, p. 1264.

Miliolina seminulum (Linnaeus); Brady, 1884, p. 157, pl. 5, fig. 6a-c.

Quinqueloculina seminulum (Linnaeus); d'Orbigny, 1929, p. 24, pl. 2, fig. 2a-c.

Diagnosis

A species of *Quinqueloculina* with a particularly white lustrous test, oval in outline. Sutures are almost indistinct, test is rounded triangular in cross section. The aperture is oval with a long, slender, straight tooth.

Remarks

Very similar to *Q. lata*, it is distinguished in adult specimens by its larger size, more rounded and robust test and its long slender tooth. Also see remarks for *Q. lata*.

	Live Occurrence	**Dead Occurrence**
Very common		
Common	Locs16,17	Locs 3,4,16
Moderate	Locs 4,9,18	Loc. 1,
Rare	Locs 3,8,12,15	Locs 8,9,11,12,14,15,17,18
Extremely rare	Locs 1,11,14	

Substrate type	All	Gravel Sand all others

Quinqueloculina williamsoni (Terquem)

(Plate 12, Figs 2-6)

Triloculina williamsoni Terquem 1778, p. 58.

Triloculina williamsoni (Terquem); Williamson 1858, p. 86, pl. 7, figs 186-187.

Diagnosis

A species of *Quiqueloculina* whose test ranges in outline from elongate oval, to rounded rectangular, test slightly compressed, chambers inflated and round in section. The aperture is large, terminal with a rounded lip and bears a large very distinctive bifid tooth with widely divergent tines protruding above the aperture.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Locs 3,8,11,14,15,16,17,18	All Locations

Substrate type	Sand/Gravel, Mixed	All

Quinqueloculina horrida Cushman

(Plate 12, Fig. 7)

Quinqueloculina horrida Cushman, 1947, p. 88, pl. 19, fig. 1a-b.

Description

Test free, coarsely agglutinated appearance, compressed, oval to round in outline, almost as wide as high, chambers are curved and have a round periphery, chambers increase markedly in size as added, chamber arrangement based on the quinqueloculina plan. The aperture is terminal on a delicate cone-shaped neck, with a round everted lip and no tooth.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare		Loc. 9*

Substrate type		Mud

* One occurrence throughout study

Quinqueloculina spp. Group.

Remarks

This group is composed mainly of juveniles of common species (probably *Q. lata, Q. seminulum, Q. oblonga,* etc.) which cannot be identified with certainty, but may also include unidentified, usually juvenile specimens, of other rare quinqueloculine species.

	Live Occurrence	Dead Occurrence
Very common		
Common		
Moderate	Loc. 16	Loc. 3
Rare	Loc. 4	Locs 4,8,9,12,14,15,16
Extremely rare	Locs 8,9,11,12,15,17,18	Locs 1,11,17,18

Substrate type	Gravel, Sand, Others	Gravel, all others

Quinqueloculina sp. 1

(Pl. 14, Figs 4-8)

Description

The test is porcellaneous, irregular oval in outline, and coarsely costate. The test is round in section, the periphery is rounded. The chambers are arranged in an irregular quinqueloculine series, the last few chamber are twisted. The aperture is terminal on a slightly produced neck and bears a bifid tooth.

	Live Occurrence	Dead Occurrence
Very common		
Common		
Moderate		
Rare		
Extremely rare	Locs 4,9,16,17,18	Locs 4,9,11,14,15,17,18

Substrate type	All	All

***Quinqueloculina* sp. 2**

(Plate 14, Figs 7-8)

Description

The test is porcellaneous, irregular oval in outline, and coarsely costate. The test is round in section, the periphery is rounded. The chambers are arranged in an irregular quinqueloculine series, the last few chambers exhibit twisting. The aperture is large, terminal, everted, on a slightly produced neck and bears no tooth.

Remarks

This species is superficially very similar to *Quinqueloculina* sp. 1 described above, particularly because of its outline, chamber arrangement and ornament. This species differs significantly in having a relatively large, oval, aperture, with a slightly rolled back lip and no tooth. The costae are coarser, sparse and widely spaced. This species may be confused with species 1 above.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare		Locs 17,18

Substrate type		Mixed

***Quinqueloculina* sp. 3**

(Plate 14, Figs 7, 9)

Description

Test is free, porcellaneous, large (2000 microns in length), robust, quiqueloculine coiled, slightly compressed, periphery flat to bi-carinate, quadrate in polar orientation,. Test ornamented with fine, regular costae. The aperture is terminal, round, and bears a strongly bifid tooth.

Remarks

This species was very rare and is counted within the *Q. mediterranensis* plexus.

***Quinqueloculina* sp. 4**

(Plate 15, Figs 1-3)

Description

Test porcellaneous, robust, large, elongate, more than twice to 4 times as high than wide, the periphery is developed into one or more carina, the test may be ornamented with costae. Chambers are arrange in a quinqueloculine plan, test quadrate to sub-quadrate in section. The neck is well produced, aperture round, simple and bears a well developed bifid tooth.

Remarks

This distinctive species shows a high degree of variation in the development of ornament.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Locs 4,17,18	Locs 3,4,9,11,16,17,18

Substrate type	Mixed	Gravel, Mixed, Others

? ***Quinqueloculina*** **sp. 5**

(Plate 17, Figs 1-3)

Description

Test globose, porcellaneous, thin, chambers triloculine coiled, 4-5 chambers visible externally, well inflated, sub-round to round in section. Test is only a little higher than wide. The aperture is large, slightly produce, with a thin lip bearing a complex bifid tooth.

Remarks

This species is highly variable and may be composed of several species or varieties, all of which are rare or very rare. The aperture, lip, neck, and tooth plate show most variation. The paucity of this species within the study, and their similar appearance has meant that they have been place in one group. The group is unidentified but exhibits strong affinities to the *Quinqueloculina* genus.

? ***Quinqueloculina*** **sp. 6**

(Pl. 17, Fig. 3)

Description

Test sub-globose, porcellaneous, thin, chambers triloculine coiled ?, 3 visible on one side, 2 on the other (although sometimes only two chambers visible), well inflated, sub-round to round in section. Test is as high as is wide. The aperture is large, sub-quadrate, lip thick, well developed bearing a heavy, bifid tooth.

Superficially the test is very similar to *Quinqueloculina* sp. 5, but it differs significantly in having a thick lip around the sub-quadrate aperture and bearing a strongly bifid tooth.

Remarks

Due to its similarity to *Quinqueloculina* sp. 5 and its general rarity it was initially grouped within *Quinqueloculina* sp. 5 group. The two species are plotted together on the following table.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Locs 4,9,12,14,15,17,18	All Locations

Substrate type	Mud, All	

Subfamily MILIOLINELLINAE Vella, 1957

Genus *MILIOLINELLA* Wiesner, 1931

Miliolinella circularis (Bornemann) var. ***elongata*** Kruit

(Plate 17, Figs 7-8).

Miliolinella circularis (Bornemann) var. *elongata* Kruit, 1955, p. 110, pl. 1, fig. 15a-b.

Description

Test exhibits triloculine coiling, the wall is imperforate, thin, translucent and porcellaneous. Test is elongate, periphery rounded, chambers are inflated and round in section. The aperture is semicircular with an apertural flap resulting in a crescentic aperture.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate	Loc. 3	Loc. 16
Rare	Locs1,8,16	Loc. 3
Extremely rare	Locs 4,9,17,18	Locs 1,4,8,11,12,14,15,17,18

Substrate type	Gravel Sand, Mixed, Mud	Gravel, Sand, all others

***Miliolinella subrotunda* (Montagu)**

(Plate 17, Figs 9-10).

Serpula subrotunda dorso elevato Walker & Boys, 1784, p. 2, pl. 1, fig. 4.

Vermiculum subrotundum Montagu, 1803, p. 521.

Quinqueloculina subrotunda (Montagu); d'Orbigny, 1826, p. 302.

Miliolina subrotunda (Montagu); Parker & Jones, 1865, p. 411, pl. 15, fig. 38a-b.

Miliolina seminulum var. *disciformis* (Macgillivray); Williamson, 1858, p. 86, pl. 7, figs 188, 189.

Quinqueloculina subrotunda (Montagu); Brady, 1867, p. 94, pl. 12, fig. 2.

Miliolina subrotunda (Montagu); Fischer, 1870, p. 386.

Miliolinella subrotunda (Montagu); Weisner, 1931, p. 63.

Quinqueloculina disciformis (Macgillivray); Cushman, 1944, p. 15, pl. 2, figs 17, 18.

Triloculina subrotundum (Montagu); Boltovskoy, 1954, p. 127, pl. 1, figs 8, 9.

Miliolinella subrotunda (Montagu); Phleger, 1960, p. 77, pl. 5, fig. 19.

Miliolinella cf. *subrotundum* (Montagu); Feyling-Hanssen, 1964, p. 262, pl. 7, fig. 1.

Diagnosis

An oval to round species of *Miliolinella* with a translucent test. Chambers compressed but inflated, exhibiting quinqueloculine coiling but the last two chambers are added in one plane. Final chambers are often much larger than earlier chambers and may become irregular, corrugated and crenulated. Aperture lunate with a small round lip and a small flap.

Remarks

Juveniles of this species are very similar and hence difficult to distinguish from *M. circularis*. Many individuals appear to trend towards *Pateoris,* retaining the lip but losing the flap (Haynes, 1973). It is difficult to be certain as to how well these species can be separated because many individuals share important taxonomic features. The validity of such a separation is questioned.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate	Locs 3,16	Locs 3,9,16
Rare		Locs 1,8,12,14,18
Extremely rare	Locs 4,14,17	Locs 4,11,15,17

Substrate type	Gravel, Sand	All

Genus *PATEORIS* Loeblich and Tappan, 1953.

Pateoris hauerinoides (Rhumbler)

(Plate 17, Figs 11)

Quinqueloculina subrotunda (Montagu) forma *hauerinoides* Rhumbler, 1936, pp. 206, 217, 226.

Pateoris haunerinoides (Rhumbler); Loeblich and Tappan, 1953, p. 462, pl. 350, figs 4-6.

Description

The test is thin, imperforate, porcellaneous and translucent, chambers are initially coiled in a quinqueloculine fashion, but later become planispirally coiled.(two chambers per whorl). The last few chambers increase greatly in size, the aperture is crescentic to semi-circular without a flap.

Remarks

This species is often difficult to distinguish from *M. circularis*; remarks for *M. circularis*.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare		Loc. 4, 9, 18

Substrate type		Muds

Genus *PYRGO* Defrance, 1824

Pyrgo depressa (d'Orbigny)

(Plate 9, Figs 4-6)

Biloculina depressa d'Orbigny, 1826, p 298.

Biloculina depressa (d'Orbigny); Parker, Jones & Brady, 1871, p. 8, pl. 8, fig. 5.

Pyrgo depressa (d'Orbigny); Murray 1971, p. 71, pl. 27, figs 1-4.

Diagnosis

A species of *Pyrgo* with a thick porcellaneous test, only last two chambers visible externally, the chambers are round, the test is inflated, lenticular and have a thick wide prominent carina which may undulate slightly. The aperture is a long slit on the acute periphery.

Remarks

Loeblich and Tappan (1964) state that the genus *Biloculina* as described by d'Orbigny, is the same as that of *Pyrgo* Defrance.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate	Loc. 9	
Rare	Loc. 4	
Extremely rare	Loc. 14	Locs 1,3,4,9,11,12,14,15,16,17

Substrate type	Mud, Mixed	All

Pyrgo williamsoni (Silvestri)

(Plate, 16, Figs 7-8)

Biloculina ringens, typica Williamson, 1858, p. 79, pl. 6, figs 169, 170.

Biloculina williamsoni Silvestri, 1923, p. 73.

Pyrgo williamsoni (Silvestri); Loeblich & Tappan, 1953, p. 48, pl. 6, figs 1-4.

Diagnosis

A species of *Pyrgo* with a globose test, oval on outline, imperforate. Only the last two chambers are visible, the last embraces the penultimate, the suture is impressed and distinct, the periphery is rounded. The aperture is terminal with a large, thick, flat, bifid tooth.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		

Extremely rare	Loc. 18	Locs 4,8,9,11,15,18

Substrate type	Mixed	All types

Genus *SPIROPHTHALMIDIUM* Cushman, 1927

Spirophthalmidium acutimargo var. ***emaciatum*** Haynes

(Plate 18, Figs 5-6)

Spiroloculina acutimargo Brady 1884, p. 154: pl. 10, fig. 14.

Spirophthalmidium acutimargo (Brady); Cushman 1949. p. 16: pl. 2, figs 14-15.

Spirophthalmidium acutimargo (Brady); Cushman, var. *emaciatum* Haynes, 1973, p. 51-53, pl. 5, fig. 11, pl. 9, fig. 16.

Description

Test elongate-ovate, very compressed blade-like, up to 4 times as long as it is wide delicate, with considerable keels at the periphery. Test wall is imperforate porcellaneous, spiroloculine coiling with flaps along the sutures. 5 or more chambers visible. This species possesses a thin long tabular neck with a simple round aperture and a distinct phialine lip.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare		Locs 4,9,15,16

Substrate type		Mud, others

Suborder LAGENINA Delage and Hérouard, 1896
Superfamily NODOSARIACEA Ehrenberg, 1838
Family NODOSARIIDAE Ehrenberg, 1838
Subfamily NODOSARIINAE Ehrenberg, 1838
Genus *DENTALINA* Risso, 1826
***Dentalina* spp. Group**

Dentalina* cf. *trondheimensis Feying-Hanssen
(Plate 19, Fig. 1)

Dentalina trondheimensis Feying-Hanssen 1964. p. 275: pl. 9, figs 3-7.

Description

Test hyaline, elongate uniserial, slightly recurved, round to oval in section, 5 to 6 inflated chambers, impressed slightly oblique sutures. The periphery is lobate whilst the umbilical edge is straight and round. The early chambers show the partial development of ribs, the initial chamber has a thorn like spike. The aperture is produced and composed of a series of seven ridges with openings in-between

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare	Loc. 9	Loc. 9
Extremely rare	Loc. 4	Locs 4,12,15,17

Substrate type	Mud, Mixed/Sand	Mud, Mixed/Sand

***Dentalina* sp. 1**

(Plate 19, Fig. 2)

Description

Test calcareous, hyaline, perforate, elongate uniserial, chambers round to oval in section, peripheral and umbilical edges are lobate, sutures are strongly impressed, and oblique increasing in obliquity with additional chambers, which increase gradually and consistently also. The aperture is produced and composed of a radiate series of seven ridges with openings in-between.

***Dentalina* sp. 2**

(Plate 19, Fig. 3)

Description

Test calcareous, hyaline, perforate, uniserial, curved, sutural angle is oblique, initial chamber is larger and more inflated than following chambers. The chambers are finely costate, less so near sutures, The aperture is on a long tube like neck, and is composed of a basket (wider than the neck) constructed of 7 or more finger like ridges with a small elongate apertures between.

Remarks

This species is slightly more curved, has a sutural angle which is more oblique than *Dentalina* sp. 1. The forms/species mentioned (*Dentalina* cf. *trondheimensis*, *Dentalina* sp. 1 and *Dentalina* sp. 2) were very rare and are treated as one group for the purpose of this study

Genus *NODOSARIA*, Lamark, 1812.

Nodosaria pyrula d'Orbigny

(Plate 19, Fig. 5)

Nodosaria pyrula d'Orbigny 1826, p. 253, fig. 13.

Description

The test is extremely elongate, very slightly curved, and composed or divided up into seven initially elongate to round, ultimately globular chambers, separated by considerable septal waists. The test is fragile most of the occurrences are of broken tests or just two or three chambers, the basal chamber is elongate and pointed at the base, the aperture is terminal on a short slender neck, it consists of approx. 8 ridges, meeting at the apex between which the openings occur.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Loc. 9	Locs 4,9,12,15

Substrate type	Mud	Mud, Mixed

Family VAGINULINIDAE Reuss, 1860

Subfamily LENTICULININAE Chapman, Parr, & Collins, 1934

Genus *LENTICULINA* Lamarck, 1804

Lenticulina crepidula (Fichtel and Moll)

(Plate 31, Figs 6-8)

Nautilus crepidula Fichtel and Moll, 1798, p. 107, pl. xix, figs g-i

Cristellaria crepidula Heron-Allen and Earland, 1915, p. 47, pl. vii, figs 5-10: pl. viii, fig. 1

Description

The test is calcareous, smooth, slightly compressed, the periphery is round. The first chambers are arranged initially planispiral, but later added in an arc, becoming much larger and wider as added, although the sutures end at the umbilicus. The sutures are flush and hardly visible externally. Most specimens observed often had the last chamber/s broken off but the inter-chamber apertures consist of a radial set of ridges and openings

Remarks

The specimen on Plate 31, Fig. 8 is typical of this species. The specimen shown on Plate 31, Figs 6-7, may represent an unbroken juvenile. It may however be a closely related species; specimens of this latter form were extremely rare.

Loeblich and Tappan (1964, 1987) place *Cristellaria* within *Lenticulina* and *Astacolus*. The author uses *Lenticulina* for this species, although Loeblich and Tappan (1988) equate *Nautilus crepidula* Fichtel and Moll with *Astacolus crepidulatus* de Montfort, which may take priority.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		Loc. 9
Rare		
Extremely rare	Locs 3,4,9,16,18	Locs 1,3,4,8,11,12,14,15,16,17,18

Substrate type	All	All

Lenticulina orbiculatis (d'Orbigny)

(Plate 32, Figs 3-6)

Robulina orbiculatis d'Orbigny, 1826, p. 288, pl. xv, figs 8-9.

Cristellaria orbiculatis Cushman, 1910, 1913, p. 67, pl. xxxvi, figs 4-5

Description

The test is calcareous, planispiral, lenticular and round in outline, the periphery is sub-acute. The chambers are arranged planispirally, the sutures are flush, although internally they can be seen to be complex with an inflection. The aperture is at the tip of the last chamber, it protrudes from the test slightly and is composed of a basket of radial ridges and openings.

Remarks

The aperture in this species is extremely variable, sometimes represented by a single terminal slit, or several parallel slits, or a tramatophore aperture of many small radial openings. These apertures may represent an ontogenetic series, with juveniles possessing a single slit and mature adults a full tramatophore.

Loeblich and Tappan (1964, 1987) place *Cristellaria* with *Lenticulina,* and the author uses *Lenticulina* for this species.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate	Loc. 9	
Rare		
Extremely rare	Locs 4,12,15,16,18	Locs All

Substrate type	Mud, others	All

Subfamily MARGINULININAE Wedekind, 1937

Genus *AMPHICORYNA* Schlumberger, 1881

Amphicoryna cf. ***scalaris*** (Batsch)

(Plate 18, Figs 7-10)

Nautilus (Orthoceras) scalaris Batsch 1791, pp. 1, 4, pl. 2, fig. 4a, b.

Amphicoryna cf. *scalaris* (Batsch); Murray, 1971, p. 77, pl. 21, figs 1-4.

Diagnosis

A species of *Amphicoryna* that has 1 to 5 chambers, uniserial, regular costae which die out or become faint half way up the earliest chamber. The aperture is terminal and made from several tapered ridges which meet at the apex. Specimens usually have a small basal spine.

Remarks

The specimen figured (Pl. 18, Fig. 10) appears to be a deformed individual.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Locs 4,9,15	Locs 1,4,9,12,15,16,17,18

Substrate type	Mud	Mud, Mixed, others

Genus *ASTACOLUS* de Montfort, 1808

Astacolus crepidulus (Fichtel & Moll)

(Plate 18, Figs 11-12)

Nautilus crepidula Fichtel & Moll 1798, p. 107, pl. 19, figs g-i.

Astacolus crepidulus (Fichtel & Moll); Murray 1971, p. 77, pl. 29, figs 5-6.

Diagnosis

A species of *Astocolus* with a slightly compressed test, chambers oval becoming round in section as added. Chamber arrangement is initially unclear, but becomes uniserial added at a tangent , resulting in increasingly (highly) oblique impressed sutures. The aperture is composed of 12 or more flat narrow strips which meet at the apex with openings in-between.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare	Loc. 9	
Extremely rare	Loc. 4	Locs 9,15

Substrate type	Mud	Mud

Subfamily VAGINULININAE Reuss, 1860

Genus *VAGINULINA* d'Orbigny, 1826.

Vaginulina linearis (Montagu)

(Plate 32, Figs 1-2)

Nautilus linearis Montagu, 1803-8, p. 87, pl. xxx, fig. 9

Vaginulina linearis Brady 1884, p. 532, pl. xvii, figs 10-12

Diagnosis

A large species of *Vaginulina* (3000 microns in length), test elongate up to 8 times as long as wide, slightly compressed, sub-quadrate in section, base is round sometimes bearing a basal spine. The periphery is rounded and the sides parallel. The sutures are oblique and flush. Terminal chamber (s) are always broken, apertures from penultimate chambers are a raised tramatophore.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Loc. 3	Locs 1,3,4,8,11,16,

Substrate type	Gravel	Gravel, Sand

Family LAGENIDAE Reuss, 1862

Genus *LAGENA* Walker & Jacob, 1798

Lagena clavata (d'Orbigny)

(Plate 19, Figs 9-11)

Oolina clavata d'Orbigny, 1846, p. 24, pl. 1, figs 2-3.

Lagena laevis (Montagu) var. *amphora* Williamson, 1848, p. 12, pl. 1, figs 3-4.

Lagena vulgaris Williamson var. *clavata* (d'Orbigny); Williamson, 1858, p. 5, pl. 1, fig. 6

Lagena clavata (d'Orbigny); Goës, 1894, p. 75, pl. 13, figs 725-727.

Lagena gracillima (Seguenza); Mills, 1900, p. 146, pl. 10, fig. 19.

Diagnosis

A species of *Lagena* with a smooth and slender bomb-shaped test, acutimate, although occasionally highly inflated. The aperture, at the end of a long slender neck has an everted lip, the rounded basal mucro is often broken revealing that it is hollow.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Locs 4,9,12,15,16,18	All except Location 3

Substrate type	Mud, Mixed	All

Lagena gracilis Williamson

(Plate 19, Fig. 14)

Lagena gracilis Williamson, 1848, p. 13, pl. 1, fig. 5.

Diagnosis

A species of *Lagena* with a smooth and slender bomb-shaped test, acutimate, although occasionally highly inflated. The test has fine widely spaced regular costae which do not reach the neck. The aperture, at the end of a long slender neck has an everted lip. A basal point is present.

Remarks

Lagena gracilis is very similar in outline to *L. clavata*, although it is slightly more slender. It is generally a more delicate species but differs mainly in its fine widely spaced regular costae.

	Live Occurrence	Dead Occurrence
Very common		
Common		
Moderate		
Rare		
Extremely rare	Loc. 9	Loc. 9

Substrate type	Mud	Mud

Lagena laevis (Montagu)
(Plate 19, Figs 12-13)

Vermiculum laeve Montagu 1803, p. 524, pl. 1, fig. 9.
Lagena laevis (Montagu); Williamson, 1848, p. 12, pl. 1, figs 1-2.
Lagena vulgaris Williamson, 1858, p. 4, pl. 1, fig. 5-5a.
Lagena sulcata Walker & Jacob var. *laevis* (Montagu); Parker & Jones, 1865, p. 349, pl. 13, fig. 22.

Diagnosis
A species of *Lagena* in which the test is smooth, often irregularly curved, the greatest thickness is below the mid point. The aperture is simple, the neck long and slender, but often irregularly corrugated near the aperture. The base is round, smooth and lacks any mucro.

	Live Occurrence	Dead Occurrence
Very common		
Common		
Moderate		
Rare		
Extremely rare	Locs 9, 16, 18	Locs 1,3,4,9,12,15,16,17,18

Substrate type	Mud, Mixed, Gravel	Mud, Mixed, Gravel

Lagena lyellii (Sequenza)

(Plate 20, Figs 1-5)

Amphorina lyellii Seguenza, 1862, p. 59, pl. 1, fig. 40.

Lagena lyellii (Sequenza); Brady, 1870, p. 292, pl. 11, fig. 7.

Diagnosis

A species of *Lagena* in which the test is oval to round to pear-shaped (perri-form), covered in costae which increase in number at the maximum width of the test. The base has a tube like projection which presumably is a broken hollow spine. The aperture is variable and often quite different (see Plate 20, Figures 2, 4 & 6) sometimes being a simple round aperture with a flat truncate lip or being composed of several finger-like ridges which curve in from the outside wall of the aperture to the inside wall of the aperture, on a strong. The neck of adults may be smooth, finely costate or wear one or more distinct, irregular rings (similar to the rings present on some mushrooms), these rings may be only partially developed i.e. not entirely circling the neck.

Remarks

This species exhibits a high degree of variation in general form but also in the type of aperture and ornament of the neck. These variations may be related to ontogenetic stages.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Loc. 9	Locs 4,8,9,11,12;15,16,17,18

Substrate type	Mud	Mud, Mixed, Gravel, Sand

Lagena perlucida (Montagu)

(Plate 20, Figs 6-9)

Vermiculum perlucidum Montagu, 1803, p. 525, pl. 14, fig. 3.
Lagena perlucida (Montagu); Brown 1844, pl. 3, p. 56, fig. 29.
Lagena striata var. *perlucida* (Montagu); Williamson 1848, p. 15, pl. 1, fig. 11.
Lagena vulgaris Williamson var. *semistriata* Williamson 1858, p. 6, pl. 1, fig. 9.
Lagena semistriata (Williamson); Cushman 1923, p. 50, pl. 9, fig. 15.

Diagnosis

A species of *Lagena* which is perri-form, neck long ornamented with strong costae slightly spiralled, sometimes unornamented or just exhibiting irregular crenulation in the upper half of the neck. Test two to three times as high than as wide. Chamber has sparse, strong ribs which begin just above the base and terminate half way up the chamber.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Locs 4,9	Locs 1,4,9,11,12,15,16,17,18,

Substrate type	Mud, Mixed	Mud, Mixed, others

Lagena semistriata (Williamson)

(Plate 20, Figs 10-11)

Lagena striata (Montagu) var. *semistriata* Williamson 1848, p. 14, pl. 1, figs 9-10.

Lagena semistriata (Williamson); Goës, 1894, p. 76, pl. 13, fig. 737.

Lagena sulcata Mills, 1900, p. 146, pl. 10, fig. 22.

Lagena sulcata (Walker & Jacob) var. *semistriata* (Williamson);Voorthuysen, 1960, p. 246, pl. 10, fig. 13.

Diagnosis

A species of *Lagena* in which test is inflated, clavate in outline, the neck is about one third of the length of the chamber, uppermost part of the neck is ornamented with ribs. The aperture is simple with a phialine lip. The chamber has fine costae on its lower third and no basal mucro.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Locs 17,18	Locs 3,4,9,12,15,18

Substrate type	Mixed	Mud, Mixed, Gravel

Lagena substriata Williamson

(Plate 20, Figs 12-13)

Lagena substriata Williamson, 1848, p. 15, pl. 2, fig. 12.

Lagena vulgaris Williamson var. *substriata* (Williamson), 1858, p. 7, pl. 1, fig. 14.

Lagena sulcata Haake 1962, p. 32, pl. 1, figs 18-19.

Lagena striata (d'Orbigny) forma *substriata* (Williamson); Feyling-Hanssen, 1964, p. 294, pl. 12, fig. 6.

Diagnosis

A species of *Lagena* with an elongate oval test, round in section, covered with longitudinal striae (30 or more), neck is short, tabular and slightly twisted, few striae continue from the chamber along the neck. The aperture is simple.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Loc. 9	Locs 4,9,12,15,18

Substrate type	Mud	Mud, Mixed

Lagena sulcata (Walker & Jacob)

(Plate 21, Figs 1-3)

Serpula (*Lagena*) *striata sulcata rotunda* Walker & Boys, 1784, p. 2, pl. 1, fig. 6.

Serpula Lagena Sulcata Walker & Jacob, 1798, p. 634, pl. 14, fig. 5.

Vermiculum striatum Montagu, 1803, p. 523.

Lagena striata (Montagu); Brown, 1844, p. 3, pl. 56, fig. 36.

Lagena sulcata (Walker & Jacob); Parker & Jones, 1865, p. 351, pl. 13, figs 24, 28-32, pl. 16.

Diagnosis

The test of this *Lagena* species is globular oval, round in section, has a rough surface giving it a dusty appearance, ornamented with approx. 20 blade like costae, half a dozen of which run up the neck to the aperture, which is simple. The neck is stout and about one third of the length of the chamber.

Remarks

Some specimens of this species have straight slightly twisted necks. They do not show the high degree of spiralling observed in the specimen figured by Haynes (1973, pl. 12, fig. 14.) which was referred to as *L. sulcata* var. *torquiformis*. Because of this these specimens are included simply as *L. sulcata*.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare		All

Substrate type		All

Lagena cf. ***L. vulgaris*** Williamson

(Plate 21, Fig. 4)

Lagena vulgaris Williamson, 1858, p. 3.

Lagena vulgaris Williamson var. *helophoramarginata* Rymer Jones, 1874, p. 61.

Diagnosis

A species of *Lagena* in which the test is oval, teardrop shaped, inflated and carinate, the surface is rough and under high magnification is granular and irregular. The neck is slender, pipe-like, and of reasonable length, it is supported for the lower half by two struts which are the continuation of the carina, a thin flange fill the area between the struts and neck. The aperture is simple and surrounded by an irregular phialine lip.

Remarks

Lagena vulgaris Williamson was subdivided by F. W. O. Rymer Jones (1874) into a number of varieties. At least two of which are described in the Treatise on Invertebrate Paleontology (1988) as *Cushmanina desmophora* Jones, 1984 and *Vasicostella* Patterson and Richardson, 1987 which have the greatest resemblance to the present specimens. Williamson's original species bears little resemblance to the present specimens, (although he records it from Plymouth Sound) hence the current specimens are placed with the species *Lagena* cf. *vulgaris*..

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare		Loc. 9

Substrate type		Mud

Lagena? Sp. 1

(Plate. 21, Fig. 5)

Description

Test free, hyaline, relatively small, oval to tear-drop shaped in outline, round in section. The surface is densely covered with irregular, coarse, longitudinal costae, the neck is very short and the aperture is only slightly produced. Aperture simple, lip constructed from a series of short ridges.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare		Loc. 9

Substrate type		Mud

Family POLYMORPHINIDAE d'Orbigny, 1839

Subfamily POLYMORPHININAE d'Orbigny, 1839

Genus *LARINGOSIGMA* Loeblich and Tappan, 1953

Laringosigma lactea var. ***concava*** Williamson

(Plate 31, Fig. 9)

Polymorphina lactea var. *concava* Williamson, 1858, p. 72, pl. 6, figs 151-152.

Polymorphina concava (Brady); Parker and Jones, 1870, p. 236, pl. 11, figs 22a-b

Polymorphina concava Heron-Allen and Earland, 1909, p.431, pl. xvii, fig. 6.

Guttulina lacteae (Walker and Jacob) var. *earlandi* Cushman and Ozawa, 1930, p. 45, pl. 10, fig. 5.

Sigmomorphina concava (Williamson); Cushman and Ozawa, 1930, p. 139, pl. 38, figs 5-7.

Laringosigma lactea var. *concava* (Williamson); Haynes 1973, pp. 104-105, text-fig. 21, nos 6-7.

Description

Test attached, hyaline, transparent to translucent, compressed, egg shaped with a irregular peripheral flange, dorsal side convex and smooth, ventral side concave and unusually attached to rock or shell fragments. Chambers arranged in a guttuline series, sutures flush. The aperture is located at the apex of the egg shaped test and composed of approximately 5 short radial slits.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Loc. 4*	Locs 1,4,8,9,14,16,18

Substrate type	Mixed	All

* One occurrence

Genus *GLOBULINA* d'Orbigny, 1839

Globulina gibba d'Orbigny

(Plate 23, Figs 5-10)

Polymorphina (Globuline) gibba d'Orbigny 1826, p. 266.

Polymorphina (Globuline) gibba (d'Orbigny); d'Orbigny 1846, pl. 13, figs 13-14.

Globulina gibba (d'Orbigny); Murray 1971, p.91, pl. 36, figs 1-3.

Globulina gibba (d'Orbigny); Loeblich and Tappan 1987, pl. 457, figs 6-7.

Diagnosis

A species of *Globulina* with a globular, sub-spherical test, smooth, attaining a large dimension (1000μm across). Sutures flush, test translucent, aperture is a series of radiate slits (20 or more).

Remarks

Some tests show two or three sub-spherical chambers joined together to form an irregular rounded sub-spherical test. Juveniles often exhibit a tear drop shaped test with a terminal aperture.

	Live Occurrence	Dead Occurrence
Very common		
Common		
Moderate		
Rare	Loc. 18	
Extremely rare	Locs 4,9,11,14,15,16,17	All Locations

Substrate type	All	All

Globulina gibba d'Orbigny var. ***myristiformis*** (Williamson)

(Plate 23, Figs 1-4)

Polymorphina myristiformis Williamson 1858, p. 73-74, pl. 6, figs 156, 157.

Globulina gibba d'Orbigny var. *myristiformis* (Williamson); Murray 1971, p. 91, pl. 36, figs 4-8.

Diagnosis

A species of *Globulina* with a globular oval to spherical test. Oval to round in outline, ornamented with coarse longitudinal ribs. The aperture is a series (often a ring) of small circular openings within a round imperforate area, at the apex.

	Live Occurrence	Dead Occurrence
Very common		
Common		
Moderate		
Rare		Loc. 11
Extremely rare		Locs 1,4,8,16,17,18

Substrate type		Sand, Gravel, Mixed

Genus *PSEUDOPOLYMORPHINA* Cushman & Ozawa, 1928

Pseudopolymorphina cf. ***novangliae*** (Cushman)

(Plate 31, Fig. 5)

Pseudopolymorphina cf. *novangliae* (Cushman) 1923, p. 1-228, pls 1-42.

Pseudopolymorphina cf. *novangliae* (Cushman); Haynes 1973, pp. 112-113, pl. 15, fig. 8, pl. 16, figs 10,17.

Diagnosis

Test elongate oval, compressed, oval in outline, sutures flush. Final two chambers account for half of the test. Aperture terminal, a series of radial slits.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Loc. 4	Locs all

Substrate type		

Genus *OOLINA* d'Orbigny, 1839

Oolina hexagona (Williamson)

(Plate 21, Figs 6-8)

Entosolenia squamosa (Montagu) var. *hexagona* Williamson 1848, p. 20, pl. 2, fig. 23.

Entosolenia globosa var. *squamosa* (Montagu) Parker & Jones 1857, p. 278, pl. 11, fig. 25.

Lagena favosa Reuss 1863, p. 334, pl. 5, figs 72-73.

Lagena sulcata Walker & Jacob var. (Entosalenia) *squamosa* Montagu, sp. Parker & Jones, 1865, p. 354, pl. 13, figs 40-41, pl. 16, fig. 11a-b.

Oolina hexagona (Williamson); Voorthuysen 1950, p. 56, pl. 1, fig. 12.

Diagnosis

A globular, sub-spherical, species of *Oolina,* with a raised network of ribs forming hexagonal areas. The neck is short, cylindrical, bearing a collar.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare	Loc. 9	
Extremely rare		Locs 1,9,12,14,15,16

Substrate type	Mud	Mud, Sand, Gravel

***Oolina melo* d'Orbigny**

(Plate 21, Fig. 12)

Oolina melo d'Orbigny 1839, p. 20, pl. 5, fig. 9.

Diagnosis

The test has longitudinal ribs and arching interconnections. The aperture is simple.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare		Locs 1,4,9,12,14,15,16

Substrate type		Mud, Sand, Gravel

Oolina squamosa (Montagu)

Recommended source for illustration: Murray, 1971, pl. 38, figs 1-3.

Vermiculum squamosum Montagu 1803, p. 526, pl. 14, fig. 2.
Oolina melo d'Orbigny 1839, p. 20, pl. 5, fig. 9.
Lagena squamosa (Montagu); Brown 1844, p. 3, pl. 56, fig. 32.
Entosolenia squamosa var. *catenulata* Williamson 1848, p. 19, pl. 2, fig. 20.
Entosolenia squamosa var. *scalariformis* Williamson 1848, p. 20, pl. 2, figs 21, 22.
Entosolenia globosa (Montagu) var. *catenulata* (Williamson); Parker & Jones 1857, p. 278, pl. 11, fig. 26.
Entosolenia squamosa (Montagu); Williamson 1858, p. 12, pl. 1, fig. 29.
Lagena catenulata (Williamson); Cushman 1923, p. 9, pl. 1, fig. 11.
Lagena melo (d'Orbigny); Cushman 1949, p. 21, pl. 4, fig. 6.
Oolina squamosa (Montagu); Van Voorthuysen 1951, p. 24, pl. 1, fig. 12.

Diagnosis

A species of *Oolina* with fine longitudinal ribs and arching interconnections. The aperture is simple.

Remarks

The differentiation (this species is distinguished from *O. melo* by its finer ornament) of these two species is based on the size of the ornament. The separation of the two species is therefore, somewhat subjective.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare		Locs 1,4,9,12,14,15,16,17

Substrate type		Mud, Sand, Others

Oolina williamsoni (Alcock)

(Plate 22, Figs 2-3)

Entosolenia williamsoni Alcock, 1865, p. 193.

Lagena williamsoni (Alcock); Wright, 1877, p. 104, pl. 4, fig. 14.

Oolina williamsoni (Alcock); Voorthuysen, 1951, p. 24, pl. 1, fig. 14.

Lagena alcocki White, 1956 p. 246, pl. 27, fig. 6.

Diagnosis

An *Oolina* with strong longitudinal costae, a flattened basal area and a network of ribs forming oval areas near the aperture in the top third of the test. The aperture is peristome.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare	Loc. 3	
Extremely rare	Locs 12,16	All Locations

Substrate type	Gravel, Mud	All

Oolina sp. 1

(Plate 21, Figs 10-11)

Description

Test free, hyaline calcareous, sub-spherical in shape, round in section, with broad ribs which create small deep round areas near the aperture, becoming shallow and oval in the mid region and rounded hexagonal near the base, no neck, aperture round, simple.

	Live Occurrence	Dead Occurrence
Very common		
Common		
Moderate		
Rare		
Extremely rare		Locs 4,9,18

Substrate type		Muds

Subfamily ELLIPSOLAGENINAEA. Silvestri, 1923

Genus *FISSURINA* Reuss, 1850

Fissurina lucida (Williamson)

(Plate 22, Figs 4-6)

Entosolenia marginata (Montagu) var. *lucida* Williamson 1848, p. 17, pl. 2, fig. 17.

Lagena lucida (Williamson) Reuss 1862, p. 324, pl. 2, figs 25-26.

Entosolenia lucida (Williamson) Cushman & Cole 1930, p. 98, pl. 13, figs 11-12.

Fissurina lucida (Williamson) Bandy 1950, p. 274, pl. 41, fig. 12a-b.

Diagnosis

An oval, slightly compressed, species of *Fissurina* with opaque areas of coarsely perforate test wall along the margin in the form of a horse shoe. The aperture is a terminal long slit.

Remarks

Several specimens, both dead and live, were recovered which were similar to *F. lucida*. Rather than being compressed, the test is rounded triangular from the polar view, with each of the rounded edges of the triangle having a broad band of coarsely perforate opaque wall, very similar to *F. lucida*. The aperture is a terminal slit. It is not known whether these specimens belong to another species of *Fissurina* or are a variety of *F. lucida* or whether they are aberrant forms of *F. lucida*. These forms were much rarer than *F lucida* and as result of their similarity to *F. lucida* have been grouped with this species.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate	Loc. 9	
Rare	Loc. 15	Locs 1,9,12,15,18
Extremely rare	Locs 4,12,16,17,18	Locs 3,4,8,11,14,16,17

Substrate type	Mud, Mixed, others	Mud, Mixed, others

Fissurina marginata (Walker & Boys)

(Plate 22, Figs 8-9)

Serpula (Lagena) marginata Walker & Boys 1748, p. 3, pl. 1, fig. 7.

Vermiculum marginatum Montagu 1803, p. 524

Lagena marginata (Walker & Boys); Brown 1844, p. 3, pl. 56, figs 30-31

Entosolenia marginata (Walker & Boys); Williamson 1858, 9, pl. 1, fig. 21.

Lagena sulcata Walker & Jacob var. (*Entosolenia*) *marginata* (Montagu); Parker & Jones 1865, p. 355, pl. 13, figs 42-43.

Fissurina marginata (Montagu); Loeblich & Tappan 1953, p. 77, pl. 14, figs 6-9.

Diagnosis

Test compressed, round in outline, coarsely porous, periphery keeled which becomes double keeled from between which a protruding compressed aperture is produced.

Remarks

This species matches Haynes (1973) description which is based on the specimens defined by Walker & Boys rather than Montagu.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		Locs 9,12
Extremely rare	Locs 3,9,15,16	Locs 1,3,4,8,15,16,17,18

Substrate type	Gravel/Mud	Mud, others

Fissurina orbignyana Seguenza

(Plate 22, Figs 10-12)

Fissurina orbignyana Seguenza 1862, p. 66, pl. 2, figs 19-20.

Fissurina orbignyana (Seguenza); Murray, 1971, p. 99, pl. 40, figs 1-5.

Lagena orbignyana (Sequenza) var. *elliptica* Cushman, 1924, pl. 6, figs 10-12.

Fissurina elliptica (Cushman); Haynes 1973, pp.94-95, pl. 14, fig. 5.

Diagnosis

A sub-globose and tricarinate species of *Fissurina*, the central keel runs round the compressed aperture which has an everted lip.

Remarks

This very distinctive species is very similar to that figured by Murray *(Fissurina orbignyana)*1971, pl. 40, figs 1-5 and Haynes (*Fissurina elliptica*) 1973, pl. 14, fig. 5, the author cannot distinguish between the mentioned species.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		

Rare		Loc. 9
Extremely rare	Loc. 9	Locs 1,3,4,8,12,14,15,16,17,18

Substrate type	Mud	All

Fissurina quadrata (Williamson)
(Plate 22, Fig. 13)

Endoselenia marginata (Walker and Boys) var. *quadrata* Williamson, 1858, p.35. pl. 4, fig. 1.

Fissurina quadrata (Williamson); Poignant, 1983, p. 501-509, pl. figs 14-15.

Description

The test is hyaline and porous, elongate to almost rectangular outline, very compressed, tricarinate. The central keel extends forwards at the anterior to produce shoulders bearing a short almost square neck with a narrow aperture with slightly everted lip.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Locs 3,9	Locs 1,4,9,12,17

Substrate type		Mud, Mixed/Sand

Fissurina sp. 1

(Plate 22, Fig. 14)

Description

Test free, hyaline, wall smooth unornamented, thin, bearing minute pores, test almost rectangular in outline with rounded corners, compressed, the periphery is rounded. The aperture is a terminal slit.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Loc. 9	Loc. 9

Substrate type	Mud	Mud

Subfamily PARAFISSURININAE R. W. Jones, 1984

Genus *PARAFISSURINA* Parr, 1947

Parafissurina malcolmsoni (Wright)

(Plate 22, Fig. 7)

Additional source for illustration: Murray, 1971, pl. 41, figs 1-4.

Lagena laevigata (Reuss) var. *malcomsoni* Wright 1911, p. 4, pl. 1, figs 1-2.

Parafissurina malcolmsoni (Wright); Murray 1971, p. 101, pl. 41, figs 1-4.

Diagnosis

As species of *Parafissurina* with a sub-round outline and a well developed flaring keel which includes a short stout rod-like thickening at the rear.

	Live Occurrence	Dead Occurrence
Very common		
Common		
Moderate		
Rare		
Extremely rare		Locs 4,9,18

Substrate type		Mud

Suborder ROBERTININA Loeblich & Tappan, 1984

Family CERATOBULIMINIDAE Cushman, 1927

Subfamily CERATOBULIMININAE Cushman, 1927

Genus *LAMARCKINA* Berthelin, 1881

Lamarckina haliotidea (Heron-Allen & Earland)

(Plate 26, Figs 7-8)

Additional source of illustration: Murray, 1971, pl. 86, figs 1-6.

Pulvinulina haliotidea Heron-Allen & Earland 1911, p. 338, pl. 11, figs 6-11.

Lamarckina haliotidea (Heron-Allen & Earland); Murray 1971, p. 205, pl. 86, figs 1-5.

Diagnosis

A species of *Lamarckina* with a compressed trochospiral test, oval in outline, the periphery is acute to keeled. The dorsal side shows approx. 6 chambers the sutures are impressed and radial. The umbilical side is flat, the sutures are impressed, the umbilicus is broad, open stepped in for this reason it is often obscured by detritus, but when clear exhibits the earliest formed chambers in a kidney or foetus.

	Live Occurrence	Dead Occurrence
Very common		
Common		
Moderate		
Rare		
Extremely rare		Loc. 9

Substrate type		Mud

Suborder ROTALIINA Delage & Hérouard, 1896

Superfamily BOLIVINACEA Glaessner, 1937

Family BOLIVINIDAE Glaessner, 1937

Genus *BOLIVINA* d'Orbigny, 1839

Bolivina pseudoplicata Heron-Allen & Earland

(Plate 23, Figs 11-12)

Bolivina plicata Brady 1870, p. 302, pl. 12, figs 7a-b. (non d'Orbigny 1839, p. 62, pl. 8, figs 4-7).

Bolivina pseudoplicata Heron-Allen & Earland 1930, p. 81, pl. 3, figs 36-40.

Diagnosis

A compressed *Bolivina*, sutures oblique, the surface is covered by folds which rise to form irregular processes, these form either a single or double row which run longitudinally along the test, laterally they form a reticulate surface.

Remarks

The original specimens described by d'Orbigny are of a deep water species found off Chile. Brady described a British species which has greater ornamentation, secondary plications often forming as the test broadens, and is larger in size which he incorrectly attributed to d'Orbigny's species. Heron-Allen and Earland later erected a new species for Brady's specimens and suggested that all British and possibly all European records of this species be change to *B. psuedoplicata*.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare	Loc. 4	Locs 9,12,15
Extremely rare	Locs 3,9,11,12,16	Locs 1,3,4,8,11,14,16,17,18

Substrate type	Mixed, Gravel, others	Mud, others

Genus *BRIZALINA* Costa, 1856

Brizalina pseudopunctata (Höglund)

(Plate 24, Fig. 1)

Bolivina punctata d'Orbigny, 1939, p. 63, pl. 8, figs 10-12.

Bolivina punctata Brady, 1884, p. 417, pl. 52, figs 18-19.

Bolivina punctata Goës 1894, p. 49, pl. 9, figs 478-480

Brizalina pseudopunctata Höglund 1947, pp. 273-4, pl. 24, fig. 5a-b, pl. 32, figs 23-24.

Diagnosis

A slender elongate *Brizalina*, slightly compressed, the periphery is straight and rounded, chambers biserially arranged with the upper half of each chamber being smooth non porous, the lower half porous. The aperture is a narrow terminal interiomaginal arch.

	Live Occurrence	Dead Occurrence
Very common	Loc. 9	
Common	Loc. 15	
Moderate	Locs 4,17,18	Locs 9,12
Rare	Locs 3,12,	Locs 3,15,18
Extremely rare	Locs 1,8,14,16	Locs 1,4,8,11,14,16,17
Substrate type	Mud, Mixed, others	Mud, others

Brizalina spathulata (Williamson)
(Plate 23, Figs 13-15)

Textularia variabilis Williamson, var. *spathulata* Williamson, 1858, p. 76, pl. 6, figs 164-165.

Bolivina dilatata Brady 1884, p. 418, pl. 52, figs 20-21.

Bolivina spathulata (Williamson); Macfadyen 1930, p. 57, pl. 4, fig. 20a-b.

Brizalina spathulata (Williamson); Hedley, Hurdle & Burdett 1965, p. 21, pl. 6, fig. 23.

Diagnosis

A compressed and arrowhead-shaped or blade-like species of *Brizalina*. The periphery is sub-acute to acute, the outline often has an irregular serrated edge, due to the formation of short, elongate, downwards curved points developed at the end of most chambers. Chambers are at least twice as wide as high, sutures are curved downwards. The test sometimes exhibits a slight twisting..

	Live Occurrence	**Dead Occurrence**
Very common	Loc. 9	
Common		
Moderate	Locs 4,15,18	Loc. 9
Rare	Locs 12,16,17	Locs 12,15,16
Extremely rare	Locs 3,14	Locs 1,3,4,8,11,14,17,18

Substrate type	Mud, Mixed, others	Mud, Others

Brizalina striatula Cushman

(Plate 24, Fig. 2)

Additional source for illustration: Haynes, 1973, pl. 10, fig. 1.1.

Bolivina striatula Cushman 1922, p, 27, pl. 3, fig. 10.

Bolivina (Brizalina) striatula (Cushman); Haynes 1973, pp. 137-138, pl. 10, fig. 1.1.

Brizalina striatula (Cushman); Murray, 1971, p. 113, pl. 46, figs 1-3.

Diagnosis

An elongate species of *Brizalina*, slightly tapered, periphery initially acute but becoming round as chambers are added, sutures oblique. The lower half of the test is covered by parallel longitudinal costae which may be regular or irregular.

Remarks

The specimen figured is atypical and develops a triangular outline, typically specimens develop sub-parallel sides. It illustrates the morphological variation observed in the species. This species is placed within the genus *Brizalina*

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate	Loc. 9	Loc. 9
Rare	Loc. 12	
Extremely rare	Locs 1,15,17	Locs 1,3,4,12,14,15,16,17,18

Substrate type	Mud, Sand	Mud, Mixed, others

Brizalina variabilis (Williamson)

(Plate 24, Figs 4-5)

Textularia variabilis Williamson 1858, p. 76, pl. 6, figs 162-163.

Bolivina variabilis (Williamson), Chaster, 1892, p.59.

Bolivina variabilis (Williamson), Cushman, 1922, p. 49, pl. 3, fig. 3a-b.

Brizalina variabilis (Williamson); Murray 1971, p. 113, pl. 46, figs 1-3.

Diagnosis

An elongate species of *Brizalina*, compressed, very porous, chambers high and narrow almost square, the sutures are impressed, periphery slightly lobate and round.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate	Locs 9,15	
Rare	Locs 12,18	
Extremely rare	Locs 4,16,17	Locs 1,3,4,9,12,15,16,17,18

Substrate type	Mud, Mixed, others	Mud, Mixed, others

Brizalina subaenariensis (Cushman)
(Plate 14, Fig. 3)

Brizalina subaenariensis (Cushman) 1922, p. 46, pl. 7, fig. 6.

Diagnosis

A species of *Brizalina* with an elongate, compressed test, arrowhead-shaped, with a marginal keel, downward curved sutures and is ornamented with prominent longitudinal costae which continue up as far as the ultimate or penultimate chambers.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Loc. 9	Loc. 9

Substrate type	Mud	Mud

Genus *STAINFORTHIA* Hofker, 1956

Stainforthia concava var. ***loeblichi*** (Feyling-Hanssen)
(Plate 25, Figs 1-4)

Virgulina loeblichi Feyling-Hanssen, 1954, p. 191, pl. 1, figs 14-18.

Stainforthia concava var. *loeblichi* (Feyling-Hanssen); Haynes, 1973, pp. 123-124, pl. 5 fig. 10.

Diagnosis

A large species of *Stainforthia* (up to 2000μm in length), test elongate, oval in section, chambers inflated, adults are usually four to six times as high than as wide, chambers arranged in a biserial gentle spiral, although some are simple biserial, the periphery is rounded, sides sub-parallel. The aperture is a broad interiomarginal arch, with a rounded lip

Remarks

Stainforthia concava var. *loeblichi* is distinguished from *S. concava* by the absence of a basal spine. *Stainforthia concava* var. *loeblichi* is easily confused with *S. fusiformis* and *Fursenkoinia fusiformis* because of their similar morphology and chamber arrangement.

	Live Occurrence	**Dead Occurrence**
Very common	Loc. 9	
Common		
Moderate		
Rare	Locs 4,15,18	Loc. 9
Extremely rare	Locs 1,3,12,17	Locs 1,3,4,8,12,14,15,16,17,18

Substrate type	Mud, Mixed, others	All

Superfamily BULIMINACEA Jones, 1875

Family SIPHOGENERINOIDIDAE Saidova, 1981

Subfamily SIPHOGENERINOIDINAE Saidova, 1981

Genus *SIPHOGENERINOIDES* Cushman, 1927

***Siphogenerinoides* sp.**

(Plate, 32, Figs 7-12)

Description

Test free, hyaline porous calcite, wall strongly perforate, chamber arrangement is uniserial with up to 12 or more chambers, sutures indistinct. Test is cylindrical, gently tapering with a rounded base, round in section, 3 to 5 times as high than as wide. Ornamented with approx. 10 strong, longitudinal ribs which begin from the base and become faint or stop on the last chamber. The ultimate chamber is smoother, slightly more inflated and represents the widest point of the test. The aperture is terminal, central, round, three quarters is bordered by a rounded, tapering at edges, crescentic C-shaped lip.

Remarks

It is very similar to *Rectobolivina* with which it may be confused. *Rectobolivina* has a twisted internal tooth plate.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Locs 9,18	Locs 3,4,9,11,12,14,15,17,18

Substrate type	Mud, Mixed	All

Family BULIMINIDAE Jones, 1975

Genus *BULIMINA* d'Orbigny, 1826

Bulimina elongata d'Orbigny

(Plate 24, Figs 12-14)

Bulimina elongata d'Orbigny 1846, p. 187, pl. 11, figs 19-20.

Bulimina elegans Brady 1884, p. 398, pl. 50, figs 3-4.

Bulimina aculeata Cushman, 1944, p. 28, Pl. 3, fig. 47.

Bulimina aff. *aculeata* Parker 1952, p. 445, pl. 4, figs 7, 13.

Diagnosis

An elongate species of *Bulimina*, sub round in section, chambers inflated, round, two or more times as high than as wide, angel of taper approximately 30 degrees, sides sub-parallel sometimes becoming parallel.

Remarks

This species may includes very similar species and varieties such as *B. lesleyae* Atkinson and *B. elongata* var. *subulata* Cushman and Parker. Some specimens develop short stubby spikes of the lower edge of sutures, similar but more poorly developed than those seen in *B. marginata*. These specimens were rare but clearly form a separate variety or species (Plate 24, Figure 10) although for this study they have been group with *B. elongata*.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate	Locs 9,15,18	Loc. 15
Rare	Locs 4,12	Locs 1,12,18
Extremely rare	Locs 1,8,11,14,16,17	Locs 3,4,8,9,11,14,16,17

Substrate type	Mud, Mixed, others	Mud, Mixed,

Bulimina gibba Fornasini

(Plate 24, Fig. 11)

Bulimina elegans Brady 1884, p. 398, pl. 50, figs 1-2.
Bulimina gibba Fornasini 1902, p. 378, pl. 10, fig. 32.

Diagnosis

A species of *Bulimina* with an inflated cone shaped test, round in section, sutures impressed, chambers rounded, the angle of taper is approx. 50 degrees.

Remarks

Bulimina gibba and *B. elongata* are distinguished on the basis of their angle of taper. Specimens of both are seen to exhibit a range of angles of taper from very slender, almost parallel sided, forms (clearly *B. elongata*) to robust, globose forms which developed an angle of taper of up to 60 degrees (clearly *B. gibba*). Many specimens fall in between these two extremes and the allocation to *B. gibba* or *B. elongata* is sometimes rather subjective.

	Live Occurrence	**Dead Occurrence**
Very common		
Common	Loc. 9	
Moderate	Locs 15,18	
Rare	Locs 4,12	Locs 4,9,12,15
Extremely rare	Locs 1,3,16,17	Locs 1,3,8,11,14,16,17,18

Substrate type	Mud, Mixed, others	Mud others

Bulimina marginata d'Orbigny

(Plate 24, Figs 6-9)

Bulimina marginata d'Orbigny 1826, p. 269, pl. 12, figs 10-12.

Bulimina pupoides var. *marginata* Williamson 1858, p. 62, pl. 5, figs 126-127.

Bulimina marginata (d'Orbigny); Haynes 1973, pp. 122-123, pl. 10, fig. 10.

Diagnosis

A species of *Bulimina* with a high angle of taper (approx. 50 degrees) which gives it a cone shape identical to *B. gibba*. Widest at the ultimate whorl, the chamber edges develop into tuberculate or spinose overhangs on their lower edge.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate	Loc. 9	
Rare		
Extremely rare	Locs 4,12,15,16,17,18	All except Location 8

Substrate type	Mud, Mixed	All

Family BULIMINELLIDAE Hofker, 1951

Genus *BULIMINELLA* Cushman, 1911

Buliminella elegantissima (d'Orbigny)

Recommended source for illustration: Murray, 1971, pl. 42, figs 1-4.

Bulimina elegantissima Williamson, 1858, p. 64, pl. 5, figs 134-135.

Buliminella elegantissima Cushman, 1911, p. 88.

Bulimina elegantissima d'Orbigny, 1939, p. 51, pl. 7, figs 13-14.

Bulimina elegantissima (d'Orbigny); Murray 1971, p. 105, pl. 42, figs 1-4.

Diagnosis

Test elongate, trochospirally coiled, angle of sutures oblique, the final chamber wraps around the test, filling the umbilicus, to form a long basal suture.

Remarks

This species is very similar to *B. borealis* figured by Hayne's (1973, fig. 22, no 1-3) which is typified by a large final chamber forming most of the test. This species is most similar to those of d'Orbigny not those of Williamson or Cushman.

	Live Occurrence	**Dead Occurrence**
Very common		
Common	Locs 9,15	
Moderate		
Rare		Loc. 9
Extremely rare	Locs 12,16	Locs 12,15,16

Substrate type	Mud	Mud

Subfamily UVIGERININAE Haeckel, 1894

Genus *UVIGERINA* d'Orbigny, 1826

***Uvigerina* sp.**

(Plate 25, Figs 5-6)

Description

Test free, hyaline, triserial in early stages, but biserial there after, elongate oval to fusiform in outline with a round section, widest at the mid point, the chambers are round and inflated, sutures slightly impressed. The test is sometimes covered with fine striae. The aperture is terminal and slightly produced.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Locs 4,8,9,12,15,18	Locs 4,9,12,15,16,17

Substrate type	Mud, Mixed, Sand	Mud, others

Subfamily ANGULOGERININAE Galloway, 1933

Genus *TRIFARINA* Cushman, 1923

Trifarina angulosa (Williamson)

(Plate 25, Figs 7-8)

Uvigerina angulosa Williamson, 1858. p. 67, pl. 5, fig. 140.

Uvigerina pygmaea d'Orbigny, var. *angulosa* (Williamson); Parker & Jones, 1865, p. 364, pl. 13, fig. 58, pl. 17, fig. 66a-b.

Angulogerina angulosa (Williamson); Cushman, 1927, p. 69.

Trifarina angulosa (Williamson); Loeblich & Tappan, 1964 p. 571, fig. 450, 1-3.

Diagnosis

An elongate species of *Trifarina*, inflated, the test is strongly carinate in the lower chambers but final chambers have only three carina on the three corners which continue up to the terminal aperture which protrudes slightly, the aperture is round and simple.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		Locs 9,12,15,16
Extremely rare	Locs 9,15,16,17	Locs 1,3,4,8,11,14,17,18

Substrate type	Mud, Mixed, Gravel	Mud, others

Superfamily FURSENKOINACEA Loeblich & Tappan, 1961

Family FURSENKOINIDAE Loeblich & Tappan, 1961

Genus *FURSENKOINA* Loeblich & Tappan, 1961

Fursenkoina fusiformis (Williamson)

Recommended source for illustration: Murray, 1971, pl. 77, figs 1-5.

Bulimina pupoides d'Orbigny var. *fusiformis* Williamson 1858, p. 63, pl. 5, figs 129-130.

Bulimina fusiformis (Williamson); Brady, 1887, p. 897.

Fursenkoina fusiformis (Williamson); Murray, 1971, p. 185, pl. 77, figs 1-5.

Diagnosis

A slightly twisted species of *Fursenkoina*, fusiform in outline, adults are two to three times as high than wide chambers consistently increase in size as added. The aperture is terminal, arch shaped.

Remarks

This species may often be confused with sub-adults and juveniles of *Stainforthia concava* var. *loeblichi,* because of their similar size and chamber arrangement.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		Loc. 9
Extremely rare	Locs 4,9,15	Locs 1,3,4,12,15,16,17,18

Substrate type	Mud, Mixed	All

Superfamily DISCORBACEA Ehrenberg, 1838
Family ROSALINIDAE Reiss, 1963
Genus *GAVELINOPSIS* Hofker, 1951
Gavelinopsis praegeri (Heron-Allen & Earland)
(Plate 26, Fig. 3)

Discorbina praegeri Heron-Allen & Earland 1913, p. 122, pl. 10, figs 8-10.
Gavelinopsis praegeri (Heron-Allen & Earland); Murray 1971, p. 133, pl. 55, figs 1-5.
Gavelinopsis praegeri (Heron-Allen & Earland); Loeblich and Tappan 1987, pl. 608, figs 6-12.

Diagnosis

A species of *Gavelinopsis* that is trochospirally coiled, plano-convex, outline round , indented by the spiral sutures, the sutures are highly backwards curving, chambers are arranged in whorls of 5 or 6, the test is not highly perforate but the outer parts of the chambers of the last whorl are most perforate. The aperture is on the umbilical side at the base of the final chamber.

Remarks

Loeblich and Tappan (1964, 1987) have replaced the genus *Discorbina* with *Gavelinopsis* for this species.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Locs 3,16	Locs 1,3,4,9,12,15,16

Substrate type	Gravels	Mud, others

Genus *ROSALINA* d'Orbigny, 1826

Rosalina anomala Terquem

(Plate 25, Figs 12-14)

Rosalina globularis d'Orbigny, 1826, p. 271, pl. 13, figs 1-2.

Rosalina anomala Terquem 1875, p. 438, pl. 5, fig. 1.

Discorbina globularis var. *vesicularis* sub. var. *globularis.* Parker & Jones 1865, p. 386, pl. 14, figs 20-23.

Discorbina globularis Goës 1894, p. 94, pl. 15, fig. 793a-b.

Discorbis globularis (d'Orbigny); Cushman 1931, p. 22, pl. 4, figs 9a-c.

Discorbis globularis (d'Orbigny) var. *anglica* Cushman 1931, p. 23, pl. 4, fig. 10a-c.

Rosalina globularis (d'Orbigny); Voorthuysen 1958, p. 33, pl. 24, fig. 16.

Rosalina globularis d'Orbigny var. *anglica* Heron-Allen & Earland, Le Calvez & Boillot 1967, p. 397, pl. 1, figs 7-8.

Discopulvinulina globularis (d'Orbigny); Hofker 1951, p. 457, text-fig. 311.

Diagnosis

A species of *Rosalina* with a flattened plano-convex test, the dorsal side has 12 or more evolute chambers, 6 on the outer whorl. The test is round to oval in outline, the ventral side has no or few pores, sutures are impressed forming a wide, open, stellate umbilicus, The dorsal side is smooth and densely covered in large pores.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare		All locations

Substrate type		All

Rosalina cf. ***globularis*** d'Orbigny

(Plate 25, Figs 9-11)

Rosalina globularis d'Orbigny, 1826, p. 271, pl. 13, figs 1-2.

Diagnosis

A species of *Rosalina* with a compressed test, plano-convex, low trochospiral, the dorsal side is raised, highly perforate and has a distinctive imperforate proloculus. The sutures are impressed and backwards curving. The ventral side has distinct irregular sutures and is perforate. The aperture is ventral on the basal suture.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		Locs 1,8
Rare		Locs 3,4,9,12,17,18
Extremely rare		Loc. 11

Substrate type		All types

Rosalina williamsoni (Chapman and Parr)

(Plate 25, Fig. 15: Plate 26, Figs 1-2)

Rotalina nidita Williamsoni 1858 p. 54, pl. 4, figs 106-108.

Rotalina nidita (Williamson); Brady, 1864, p. 474.

Discorbina nidita(Williamson); Wright 1889: 449.

Discorbis nidita (Williamson); Cushman, 1931 : p. 26, pl. 6, fig. 1a-c.

Discorbis williamsoni Chapman and Parr, 1932 p. 226, pl. 21, fig. 25

Rosalina williamsoni (Chapman and Parr); Voorthuysen, 1958: p. 34, pl. 24, fig. 4

Diagnosis

A species of *Rosalina* with a plano-convex test, which is evolute and raised into a low cone on the dorsal side, involute and flat on the ventral side. The sutures are oblique and flush, periphery is acute. The test is sparsely or very sparsely perforate. The umbilicus has a central boss and radial sutures.

Remarks

This species is very similar to *Glabratella millettii*, which is distinguished by the distinct ventral side with tubercular ornament radiating from the umbilicus.

	Live Occurrence	**Dead Occurrence**
Very common		
Common	Loc. 16	
Moderate	Locs 3,4	Locs 3,16
Rare	Loc. 17	Locs 1,4,8,9,12
Extremely rare	Locs 1,8,9,12,15,18	Locs 11,14,15,17,18

Substrate type	Gravel, Sand, others	Gravel, others

Superfamily PLANORBULINACEA Schwager, 1877

Family CIBICIDIDAE Cushman, 1927

Subfamily CIBICIDINAE Cushman, 1927

Genus *CIBICIDES* de Montfort, 1808.

Cibicides lobatulus (Walker & Jacob)

(Plate 26, Figs 9-10)

Nautilus lobatulus Walker & Jacob, 1798, p. 642, pl. 14, fig. 36.

Truncatulina tuberculata (Walker & Jacob); d'Orbigny, 1826, p. 279.

Truncatulina lobatula (Walker & Jacob); d'Orbigny 1839, p. 134, pl. 2, figs 22-24.

Planorbulina lobatula (Walker & Jacob); Goës 1894, 88, pl. 15, fig. 774.

Lobatula vulgaris Fleming 1828, p. 232.

Cibicides lobatulus (Walker & Jacob); Cushman 1927, p. 93, pl. 20, fig. 4.

Heterolepa lobatula (Walker & Jacob) 1969, Gonzalez-Donoso, p. 6, pl. 2, fig. 1.

Diagnosis

A very porous species of *Cibicides*, sutures swept back on umbilical side, impressed on dorsal side. Initially compact and regular but may become twisted, uncoiled and sprawled, often becoming lobate, periphery may become keeled. Plano-convex, often heavily deformed to become irregular concavo-convex. Attaining large dimensions (over 3000μm in diameter).

	Live Occurrence	**Dead Occurrence**
Very common		Locs 1,8,11,14,17,18
Common		Locs 3,4,15,16
Moderate		Loc. 12
Rare		Loc. 9
Extremely rare	Locs 8,9,11,14	

Substrate type	Sand, Mud	Sand, Gravel, Mixed, Mud

Cibicides pseudoungerianus (Cushman)

(Plate 27, Fig. 1)

Truncatulina pseudoungeriana Cushman 1922, p. 97, pl. 20, fig. 9.

Cibicides pseudoungerianus (Cushman); Murray 1971, p. 177, pl. 74, figs 1-6.

Diagnosis

A species of *Cibicides* with a test that is compact plano-convex, round to sub-round in outline and has a prominent low imperforate umbilical boss on the dorsal surface. The dorsal side is coarsely perforate.

Remarks

During this study many specimens were recovered which are compact, regular, non porous or sparsely porous only in the last chamber of the dorsal side. The umbilicus on the dorsal side has a glassy calcite filling or low boss. These forms (Pl. 26, Fig. 11) may be juvenile *C. lobatulus*, or confused with them, but because of their umbilical boss are placed within the species *C. pseudoungerianus*.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		Locs 1,3,15
Rare		Locs 4,8,9,11,12,14,16,17,18
Extremely rare	Locs 3,16	

Substrate type	Gravel	All

Family PLANORBULINIDAE Schwager, 1877
Subfamily PLANORBULININAE Schwager, 1877
Genus *PLANORBULINA* d'Orbigny, 1826
Planorbulina mediterranensis d'Orbigny
(Plate 27, Figs 4-5)

Planorbulina mediterranensis d'Orbigny 1826, p. 280, pl. 14, figs 4-6.

Diagnosis

A species of *Planorbulina* with a test. The early part is trochospiral while later chambers are added in irregular whorls. Test quadrate to sub-round in outline, highly porous on dorsal side, each chamber bears one or more apertures on the ventral side.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate	Locs 3,16	Locs 3,16
Rare	Loc. 1	Locs 8,9,11,12,14,17
Extremely rare	Locs 4,8,11,12,15,18	Locs 1,4,15,18

Substrate type	Gravel, Sand, Mud/Mixed	Gravel, Sand, Mud/Mixed

Superfamily ACERVULINACEA Schultze, 1854
Family ACERVULINIDAE Schultze, 1954
Genus *ACERVULINA* Schultze, 1854
Acervulina inhaerens Schultze
(Plate 27, Figs 2-3 & 6)

Acervulina inhaerens Schultze 1854, p. 68, pl. 6, fig. 12.

Diagnosis
A species of *Acervulina* with irregularly arranged chambers. The test may be rounded plano-convex but its form is dictated by the surface on which it grows, sometimes the test is seen to be wrapped around detrital material (Pl. 27, Fig. 6, this specimen is wrapped around a Bryozoa stem). The test is coarsely perforate.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare		All Locations

Substrate type		All types

Superfamily ASTERIGERINACEA d'Orbigny, 1839

Family ASTERIGERINATIDAE Reiss, 1963.

Genus *ASTERIGERINATA* Bermúdez, 1949

Asterigerinata mamilla (Williamson)

(Plate 26, Figs 4-6)

Rotalina mamilla Williamson 1858, p. 54, pl. 4, figs 109-111.

Discorbina rosacea Brady 1864, p. 194.

Discorbina mamilla (Williamson); Heron-Allen & Earland 1913, p. 123, pl. 11, figs 4-6.

Discorbis planorbis Heron-Allen & Earland 1913, p. 124, pl. 11, figs 10-12.

Discorbis mamilla (Williamson); Cushman 1931, p. 23, pl. 5, figs 1a-c.

Asterigerinata mamilla (Williamson); Hofker 1951, p. 472, text-figs 322-326.

Heminwayina mamilla (Williamson); Troelsen 1954, p. 466

Rosalina mamilla (Williamson); Voorthuysen 1960, p. 251, pl. 11, fig. 17a-c.

Gavelinopsis mamilla (Williamson); Le Calvez & Boillot 1967, p. 394.

Discorbis? rosacea Cushman 1949, p. 44, pl. 8, fig. 6a-c.

Diagnosis

A robust species of Asteriginata with a high plano-convex test. The periphery is acute to sub-acute, the chambers are arranged trochospirally, sutures are flush but are marked with a row of pores. The aperture is a small arch with a semicircular round lip on the ventral side.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		Locs 1,3,4,9,11,14,16,17
Extremely rare	Locs 3,4,9,11,12,16	Locs 8,12,15,18

Substrate type	Gravel, Mud, Sand	All

Superfamily NONIONACEA Schultze, 1854
Family NONIONIDAE Schultze, 1854
Subfamily NONIONINAE Schultze, 1854
Genus *HAYNESINA* Banner & Culver, 1978
Haynesina germanica (Ehrenberg)
(Plate 30, Figs 7-8)

Nonionina germanica Ehrenberg 1840, p. 23.
Nonionina crassula Williamson 1858 p. 33, pl. 3, figs 70-71.
Nonionina depressula Brady 1867 p. 106.
Nonionina depressula (Brady); Walker and Jacob 1884, p. 725-6, pl. 109, fig. 6a-b.
Nonion depressulus Cushman 1930 p. 3, pl. 1, figs 3-6.
Protelphidium depressulum Adams and Haynes 1965 p. 36.
Protelphidium anglicum Murray 1965, p.149, pl. 25, figs 1-5, pl. 26, figs 1-6.
Nonion germanicum (Ehrenberg); Hofker, 1971, p.63, pl. 95, figs 14-15.
Haynesina germanica (Ehrenberg); Banner and Culver, 1978, p. 177-207.

Description

The test is hyaline, radial, perforate calcite, chambers are planispiral involute, inflated, the apertural face being no higher than wide, usually no more than 10 or 11 chambers, although often less. The umbilicus is open, impressed, lined with tubercles, which spread along the straight but later curved back, impressed sutures, not reaching the periphery. Aperture is a series of small, obscured (with tubercles) interiomarginal openings

	Live Occurrence	**Dead Occurrence**
Very common	Plym	Plym
Common		Loc. 12
Moderate		Locs 1,3,4,8,9,14,15,16
Rare		Locs 11,17,18,
Extremely rare	Locs 12,14,15,16,17,18	

Substrate type	Mud, All	Mud, All

Genus *NONION* de Montfort, 1808

Nonion depressulus (Walker & Jacob)

(Plate 30, Figs 9-10)

Nautilus spiralis utrinque subumbilicatus Walker & Boys 1784, p. 19, pl. 3, fig. 68.
Nautilus depressulus Walker & Jacob 1798, p. 641, pl. 14, fig. 33.
Nonion asterizans Heron-Allen & Earland 1913, p. 143, pl. 13, figs 12, 13.
Nonion depressulum (Walker & Jacob) Cushman 1930, p. 3, pl. 1, fig. 3.
Nonion depressulus (Walker & Jacob); Murray 1971, p. 195, pl. 82, figs 1-8.

Description

The test is perforate, granular, hyaline calcite (and so appears grey under ordinary light), compressed, apertural face visibly higher than wide, chambers are arranged in an involute planispire, the last few chambers become wider and tend to uncoil, the umbilicus is shallow, wide and off centre, lined with tubercles which continue along the backwards curved impressed sutures. The test is composed of up to 14 chambers. The aperture is a series of interiomarginal openings obscured by tubercles.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate	Locs 15,18	
Rare	Loc. 1	Locs 9,12,15,18
Extremely rare	Locs 3,4,9,12,14,16,17	Locs 1,3,4,8,11,14,16,17

Substrate type	Mud , Mixed, others	Mud Mixed, others

Genus NONIONELLA Cushman, 1926

Nonionella turgida (Williamson) var. ***digitata*** Norvang

Recommended source for illustration: Haynes, 1973, pl. 22, fig. 12.

(Plate 31 Figs 1-3)

Nonionina asterizans var. *turgida* (Williamson); Carpenter 1826, Parker & Jones, p. 311.

Rotalina turgida Williamson 1858, p. 50, pl. 4, figs 95-97.

Polystomella crispa sp., var. (Nonionina) *turgida* (Williamson); Parker & Jones 1865, p. 405, pl. 17, fig. 57a-c.

Nonionina turgida (Williamson); Brady 1884, p. 731, pl. 109, figs 17-19.

Nonionella turgida (Williamson); Cushman 1930, p. 15, pl. 6, figs 1-4.

Nonionella turgida (Williamson) var. *digitata* (Norvang); Haynes, 1973, p. 213, pl. 22, fig. 12

Diagnosis

A planispirally coiled species of *Nonionella* with chambers increasing rapidly in height, the final chambers extends a lobe across the umbilicus, the lobe has short finger like extensions pointing along the septa.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate	Loc. 9	
Rare		
Extremely rare	Locs 4,15,	Locs 1,4,9,17

Substrate type	Mud, Mixed	Mud, Mixed, Sand

Nonionella sp.

(Plate 30, Fig. 11-12)

Nonionella sp. Haynes, 1973, pp. 215-216, pl. 22, figs 17-18.

Description

Test free, hyaline, planispirally coiled, compressed, outline round to sub-round, test relatively large (up to 1000µm in diameter) the final chambers become almost uncoiled, the 10-12 chambers increase rapidly in height becoming 4 or 5 times as high than as wide, the final chamber extends across the previous few chambers to the umbilicus, the periphery is sub-round, the sutures are gently backward curving and impressed. The umbilicus is broad and shallow filled with granules which extend up the sutures for a small distance, the aperture is a series of small interiomarginal openings.

Remarks

This species is very similar to the *Nonionella* sp. figured by Haynes (1973) pl. 22, figs 17-18.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare	Loc. 18	
Extremely rare	Locs 4,9,15	Locs 4,9,15,18

Substrate type	Mixed, Mud	Mud, Mixed

Superfamily CHILOSTOMELLACEA Brady, 1881

Family TRICHOHYALIDAE Saidova, 1981

Genus *BUCCELLA* Andersen, 1952

Buccella frigida (Cushman)

Recommended source for illustration: Murray, 1971, pl. 53, figs 1-5.

Pulvinulina frigida Cushman 1922, p. 12.

Eponides frigida (Cushman); Cushman 1931, p. 45.

Buccella frigida (Cushman); Anderson 1952, p. 144, figs 4a-c, 5, 6a-c.

Buccella frigida (Cushman) var. *calida* Cushman & Cole, 1930, p. 98, pl. 13, fig. 13a-c.

Diagnosis

A species of *Buccella* with a raised, evolute dorsal side, the sutures are flush and the surface smooth. The ventral side shows impressed sutures filled with granules, the umbilicus is also granular

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Loc. 9	Loc. 9

Substrate type	Mud	Mud

Superfamily ROTALIACEA Ehrenberg, 1839

Family ROTALIIDAE Ehrenberg, 1839

Subfamily AMMONIINAE Saidova, 1981

Genus *AMMONIA* Brünnich, 1772

Ammonia beccarii batavus (Hofker)

(Plate 28, Figs 1-4)

Rotalina beccarii Williamson 1858, p. 48, pl. 14, figs 90-92.

Streblus batavus Hofker 1951, pp. 498, 340, 341.

Rotalia beccarii Parker 1952, p. 457, pl. 5, fig. 5a, b.

Ammonia batavus (Hofker); Feyling-Hanssen 1964, p. 349, pl. 21, figs 4-13.

Ammonia beccarii (Linné) var. *batavus* (Hofker); Murray 1965, p. 502, pl. 1, figs 1, 1; 2, 2 (stereopairs).

Description

Test free, hyaline, generally bi-convex, although it may be plano or concavo-convex, chambers arranged in a low trochospire, evolute on the dorsal side involute on the ventral side, the sutures of the last few chambers are often deeply fissured, earlier sutures are flush on the dorsal side. Two to four whorls are visible on the dorsal side with 8-10 chambers in the last whorl. The periphery is sub-round to round. The umbilicus is usually marked with a robust calcite boss, which may often be divided into two or three parts, the sutures of the ventral side are deeply fissured and may be very slightly sinuous, they are ornamented with tubercular growths. In less well developed specimens the umbilicus may be broad with many irregular slender bosses often covered with granules. The aperture is an interiomarginal opening.

Remarks

See remarks for *A. beccarii limnetes* below.

	Live Occurrence	**Dead Occurrence**
Very common	Locs 4,9,12,15,17,18	Locs 1,12,15,18
Common	Locs 8	Locs 4,8,14,
Moderate	Locs 1,14	Locs 3,9,11
Rare		
Extremely rare	Locs 3,11,16	

Substrate type	Mud, Mixed, Sand	Mud, Sand, Mixed

Ammonia beccarii limnetes (Todd & Bronniman)

(Plate 28, Figs 7-9)

Rotalia beccarii (Linné) 1952 var. *sobrina* Parker, p. 457, pl. 5, figs 7a, b.

Rotalia beccarii (Linné) 1953 variant C, Parker, Phleger & Peirson, p. 13, pl. 14, figs 29-30.

Streblus limnetes Todd & Bronniman, 1957, p. 38, pl. 10, figs 4a-c.

Ammonia limnetes (Todd and Bronniman); Haynes, 1973, pp.189-190, pl. 18, figs 7-9, pl. 19, fig. 8, pl. 30 fig. 8.

Diagnosis

A small to medium size sub-species of *A. beccarii*, usually with only two entire whorls and commonly 6-8 chambers in the final whorl. The sutures on the ventral side are deeply fissured but less ornamented, usually with granules, they also exhibit a prominent inflection which is the widest point of the sutural fissure, the umbilicus is stellate, filled with the ends of the chambers.

Remarks

It is clear that in the study area a definite morphological line dividing these subspecies cannot be drawn, rather they seem to fit into a graduated series of *A beccarii batavus* to *A beccarii limnetes* which is illustrated by Plate 28, with some specimens showing taxonomic features from both subspecies, hence an arbitrary line is drawn which may be subjective depending of the subspecies definition. The test condition of *A beccarii limnetes* and its affect on taxonomy are further discussed in Chapter 9, Section 9.16.7.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate	Loc. 15	Locs 1,4,12,14,15,17,18,
Rare	Loc. 9	Locs 3,8,9,11,16
Extremely rare	Locs 4,14	

Substrate type	Mud, Mixed, Sand	All

Family ELPHIDIIDAE Galloway, 1933

Subfamily ELPHIDIINAE Galloway, 1933

Genus *ELPHIDIUM* de Montfort, 1808

Elphidium crispum (Linné)

(Plate 29, Figs 6-7)

Nautilus crispus Linné 1758, p. 709.

Polystomella crispa (Linné); Lamark, 1822, p. 625, pl. 1, fig. 2d-f

Elphidium crispum (Linné); Cushman and Grant, 1927, p. 73, pl. 7, fig. 3a-b.

Diagnosis

Test large (up to 2000μm in diameter), compressed, bi-convex, lenticular, with a keeled acute periphery, chambers are arranged in an involute planispire, the sutures are curved back particularly near the periphery and represented on the surface by broad calcite ridges, the fossettes are broad and crossed by long retral processes. The umbilical area is represented by a broad, glassy, pitted calcite boss. The aperture is irregular interiomarginal and marked by a series of round tubercles.

	Live Occurrence	**Dead Occurrence**
Very common	Locs 4,15,17,18	Locs 4,11,17
Common	Loc. 1	Locs 3,8,14,16,18
Moderate	Locs 9,11	Locs 1,15
Rare	Loc. 14	Locs 9,12
Extremely rare	Locs 8,12,16	

Substrate type	Mixed, Sand/Mud	Sand/Mixed, Gravel, Mud

Elphidium macellum (Fichtel & Moll)
(Plate 29, Figs 8)

Nautilus macellus Fichtel & Moll 1798, p. 66, var. β, pl. 10, figs h-k.

Elphidium macellum (Fichtel & Moll); Montfort 1808, p. 15.

Polystomella macella (Fichtel & Moll) var. *aculeata* Silvestri 1901, p. 45.

Elphidium macellum (Fichtel & Moll) var. *aculeatum* (Silvestri) Cushman 1949, p. 27, pl. 5, fig. 10.

Elphidium crispum (Linné) subsp. *spinosum* Atkinson 1969, p. 537, fig. 6, fig. 4a-b.

Diagnosis

A species of *Elphidium* with a compressed test, bi-convex, lenticular, with an acute periphery which is sometimes keeled, chambers arranged in an involute planispire, the sutures are backwards curved and represented on the surface by calcite ridges, the fossettes are broad and crossed by long retral processes. Juveniles of *E. macellum* often develop a spinose keel, the spines are the outermost continuation of the septal ridges. The umbilicus is usually composed of several small flattened bosses which are the inner most ends of the septal ridges.

Remarks

E. macellum and *E. crispum* have been considered as one species (*E. crispum*) for this study because juveniles *E crispum* and juveniles and adults of *E. macellum* are very difficult to distinguish. Specimens of *E. macellum* tend to be smaller and may have fewer chambers than *E. crispum*. The presence of peripheral spines, which is sometimes used to distinguish the two species is known to be a juvenile feature (Haynes, 1973). The glassy boss, typical of *E. crispum* is only prominent in large adults. It is for these reasons that they are regarded as one species for the purpose of this study.

Elphidium cuvillieri Levy

(Plate 29, Figs 4-5)

Elphidium cuvillieri Lévy, 1966, p. 5, pl. 1, fig. 6.

Description

Test free, hyaline, very slightly compressed, approximately twelve chambers are planispirally coiled in the final whorl, involute, round to slightly lobate in outline (indented at the septa) the wall is porous the umbilicus is composed of a glassy circular plate imperforate except for a few round circular pits, the septa are gently backward curving and marked by a series of circular pits, the periphery is round. The aperture is a series of small interiomarginal openings.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate	Locs 4,9,15,18	Locs 15,18
Rare	Loc. 11	Locs 1,3,4,9,12,14,16,17
Extremely rare	Locs 3,12,14,16,17	Locs 6,11

Substrate type	Mud/Mixed, others	All types

Elphidium earlandi Cushman

(Plate 29, Figs 9-10)

Elphidium earlandi Cushman 1936, p. 85, pl. 15, fig. 5a, b.

Description

Test free, hyaline, planispirally coiled, compressed, involute, periphery and outline round, typically 6-8 chambers in the final whorl, the sutures are marked by elongate fossettes filled with tubercles and crossed by robust retral processes. The umbilicus is flat has small tubercles and is encircled by several small bosses.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		Loc. 9
Extremely rare	Loc. 1*	Locs 1,3,4,12,15,16,17

Substrate type	Sand	All

*One occurrence

E. gerthi Van Voorthuysen / ***E. exocticum*** Haynes

(Plate 29, Figs 11-12, Plate 30, Fig. 1)

Elphidium gerthi Van Voorthuysen, 1957, p. 32, pl. 23, fig. 12a-b.

Elphidium exocticum Haynes, 1973, p. 198, pl. 24, figs 8-9: pl. 26, figs 2, 3, 6, 8: pl. 28, figs 1-4.

Diagnosis

A species of *Elphidium* with a slightly compressed test, periphery sub-round, typically 10 chambers in the final whorl, the septa are slightly backwards curving, and composed of tubercular, fingernail shaped fossettes and short retral processes. The umbilicus is an almost complete ring of tubercles encircling an irregular round flat boss.

Remarks

This species is similar to *E. williamsoni* but differs in its compressed test with sub acute periphery and most distinctively, its umbilical boss. It resembles *E. gerthi* very closely, figured by Murray (1971) pl. 67, figs 1-7. It also matches the description of *E. exoticum* very well, figured by Haynes (1973) pl. 24, figs 8-9: pl. 26, figs 2, 3, 6, 8: pl. 28, figs 1-4, unfortunately the wall structure has not been viewed in thin section which makes allocation to this species uncertain.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		Loc. 18
Moderate		Loc. 15
Rare		Locs 1,12,9,
Extremely rare	Locs 1,12,15,16,18	Locs 3,4,8,11,14,16,17

Substrate type	All types	Mud/Mixed, others

Elphidium margaritaceum (Cushman)

(Plate 30, Figs 2-4)

Polystomella macella Heron-Allen & Earland 1909, p. 696, pl. 21, fig. 3a-b.

Elphidium advenum (Cushman) var. *margaritaceum* Cushman 1930, p. 25, pl. 10, fig. 3.

Elphidium margaritaceum (Cushman) Voorthuysen 1958, p. 32, pl. 23, fig. 13.

Diagnosis

A species of *Elphidium* in which the test is compressed, sometimes lobate in outline, the periphery is acute, specimens have 8-12 chambers in the final whorl, which are reasonably inflated, sutures are backwards curving and very impressed, they are crossed by several short retral processes. The surface is densely covered with tubercles and appears frosted.

	Live Occurrence	**Dead Occurrence**
Very common		
Common		
Moderate		
Rare		
Extremely rare	Loc. 4	All locations

Substrate type	Mixed?	All

Elphidium williamsoni Haynes

(Plate 30, Figs 5-6)

Polystomella umbilicatula Williamson 1858, 42, pl. 3, figs 81, 82.

Elphidium umbilicatum (Williamson); Lévy *et al.*, 1969, p. 96, pl. 1, figs 6a-b; pl. 2, figs 1-2.

Elphidium excavatum Cushman 1930, p. 21, pl. 8, figs 4-7.

Cribronion cf. *alvarezianum* Lutze, 1965, p. 101, pl. 15, fig. 46.

Elphidium williamsoni Haynes, 1973, p. 207, pl. 24, fig. 7: pl. 25, fig 6-9: pl. 27, figs 1-3.

Diagnosis

This inflated species of *Elphidium* has a round periphery, up to 14 chambers in the final whorl, a flat umbilicus sometimes bearing a small calcite boss, The sutures are straight to slightly curved, impressed and crossed by retral processes.

	Live Occurrence	**Dead Occurrence**
Very common		
Common	Loc. Plym	Loc. Plym
Moderate		Locs 1,12,
Rare		Locs 3,4,8,9,14,15,16,17,18
Extremely rare	Locs 12,15,17	Loc. 11

Substrate type	Mud, Sand	All types

CLASS OSTRACODA

Ostracods were generally uncommon at any of the locations sampled. The ostracods encountered were usually disarticulated, or articulated empty valves; very few were stained and/or contained appendages and hence presumed living at the time of collection. For these reasons, and that the study was aimed primarily at foraminifera, the ostracods were not collected in a systematic and quantitative fashion. When ostracods were present within samples, representatives were extracted but their abundance is not plotted within tables. The species, or genera, recorded are listed where known, with a brief note regarding their occurrence.

Order MYODOCOPIDA
Suborder MYODOCOPINA
***Cypridina* sp.**
(Plate 36, Fig. 1)

Comments

This was one of the most common representatives of the Ostracoda. Frequently individuals were stained red, articulated and with appendages intact and protruding from the valves. This strongly suggests that they were living at the time of collection. Individuals were recorded from muddy locations within the Sound, often in large numbers (hundreds). In other samples they were very rare or absent.

Order PODOCOPIDA

Suborder PODOCOPINA

Genus *LOXOCONCHA* Sars 1866

Loxoconcha rhomboidea (Fischer)

(Plate 36, Figs. 2-4; Fig. 4 male valve)

Cythere rhomboidea sp. nov. Fischer, 1855, p. 656.

Loxoconcha impressa (Baird); Brady, 1868, p. 443, pl. 25, figs 35-40.

Loxoconcha rhomboidea (Fischer); Athersuch and Whittaker, 1976, p. 81-90.

Comments

This species was relatively common at most locations throughout the Sound, irrespective of sediment type. It was never common; usually only 2-3 individuals or valves were present. It was rarely, if ever, observed stained and was often disarticulated.

Genus *COSTA* Neviani 1928.

Costa runcinata (Baird)

(Plate 36, Figs 5-7)

Cythereis runcinata sp. nov. Baird, 1850, p. 256, pl. 18, figs 7-9.

Cythera runcinata (Baird); Brady and Norman, 1889, p. 160, pl. 15, figs 24, 25, 30 & 31.

Costa edwardsii (Roemer) *runcinata* (Baird): Ruggieri 1962, p. 5, pl. 8, fig. 6, text fig. 2.

Costa runcinata (Baird); Athersuch, Horne and Whittaker, 1989, p. 142, pl. 4, fig. 4.

Comments

This species was rarely, if ever encountered stained. Often disarticulated, it was more common in muddy sediments than in sandy sediments.

Genus *SEMICYTHERURA* Wagner 1957

Semicytherura acutiscostata (Sars)

(Plate 36, Figs 8-9)

Cytherura acutiscostata sp. nov. Sars, 1866, p. 76.

Semicytherura acutiscostata (Sars); Wagner, 1957, p. 83, pl. 38, figs 3-4.

This species of ostracod is one of the rarer forms recorded. Often found articulated although never stained, it is restricted mainly to the muddy locations (particularly Location 9).

Semicytherura sp.

(Plate 36, Fig. 10)

This is a rare species of ostracod only encountered occasionally, often in muddy sediments. It was never observed stained, although valves were often articulated.

THECAMOEBIANS

Arcella **sp.**

(Plate 35, Fig. 9)

Comments

This species of thecamoebian was very rare, only occurring in the Plym estuary where it was uncommon. It was never stained red and presumably live at the time of collection.

Pontigulasia **sp.**

(Plate 35, Fig. 10)

Comments

A fragile, flask shaped species of thecamoebian which was found in the Plym estuary, as well as a few sites in the northern Sound. It was always very rare. It was never observed stained red and, presumably, live at the time of collection.

ANNELIDA

This entry deals only with members of the Class Polycheata which produce agglutinated, or calcareous worm tubes. These apart quite common in some samples and may provide micro-habitats for foraminifera. In some cases the agglutinated tubes may utilise foraminiferal tests in their construction. The worm tubes are not dealt with quantitatively but are recorded in a qualitative manner.

Species 1 (Plate 37, Fig. 4)

Comments

This small slender species, is coarsely agglutinated. It is constructed almost exclusively of shell fragments which are laid one over the other, overlapping like roof tiles. It is rare and occurred in mixed sediments (sand and silt).

Species 2 (Plate 37, Fig. 5)

Comments

This species is rare. The tube is constructed of well sorted sand grains, and is relatively small and tapered. It occurs in silts / sandy sediments.

Species 3 (Plate 37, Fig. 6)

Comments

These tubes are very common (live and dead) in clay and silt dominated sediments as well as mixed sediments. They are positioned with only a few centimetres protruding from the sediment surface. The tubes are, on average, several centimetres in length and approximately 5 mm in width. They are composed of silt and sand although the outer surface included larger detrital material. The size of the agglutinated grains varies depending on the type of substrate, being more coarsely agglutinated in sands and finer in muds. The figured specimen is coarsely agglutinated, making use of apart from large sand grains, a gastropod, and three foraminifera.

Species 4 (Plate 37, Fig. 7)

Comments

This calcareous species is coiled in a tight planispire. It is evolute and ornamented with ribs. It is found consistently in sandy or gravely locations. It is rare and the tubes were always empty.

Species 5 (Plate 37, Fig. 8)

Comments

This species is commonly attached to, or encrusting, any hard surface, either planispirally coiled or freeform (randomly meandering on hard surfaces). It is also recorded living.

Non Ostracod CRUSTACEA

Members of the Crustacea were uncommon in samples, although they were consistently present within many samples and warrant a very brief mention. They are not treated taxonomically, but the most common forms have been figured.

Copepoda

(Plate 37, Fig. 1)

Comments

The most common of all the Crustacea> They are most abundant in mud rich locations, although never exceeding one or two dozen in number. They are often stained a vivid red.

Isopoda

(Plate 37, Fig. 2)

Comments

Generally rare; similar to the copepoda but much larger in size. Most abundant in mixed sediment and mud locations.

Sea spider

(Plate 37, Fig. 3)

Comments

This was the rarest of the Crustacea. It was recorded several times from shallow, sandy locations, particularly near Drake's Island.

CHAPTER FOUR

4. PLYM ESTUARY

4.1. Introduction

The Plym Estuary (Figure 4.1) is a relatively small, shallow, estuary with low tidal power (*pers. comm.* Fiona Fitzpatrick) that results in the partial segregation of water masses north of Laira Bridge. Its maximum and minimum recorded river inflows of 31.01m^{3}s and 0.12m^{3}s respectively (South West Water, 1979 public records), imply that at high tide salinities are only slightly brackish (salinities of 30‰ and greater being common). The presence of the common British upper-middle shoreface seaweed, *Ascophyllun nodosum,* attached to rocks on the estuary bank within the high water zone, indicates near normal marine salinities at high tide.

The living and dead foraminiferal assemblages of the Plym Estuary have been investigated and documented including species composition, populations dynamics and the relationship between the living and dead assemblages i.e. the taphonomic processes which may be acting on the foraminiferal tests. No previous foraminiferal data were available for the estuary.

Unlike the sample sites within the Sound, the Plym Estuary is intertidal and can be sampled on foot. This allows more access to the area and, as a result, apart from the main monthly sample, a variety of sampling strategies could be attempted (cores, spot samples, transect samples, etc.) in order to generate a more detailed understanding of the estuary. The Plym Estuary samples form a naturally separate section aside from the overall study and are, therefore discussed in this chapter.

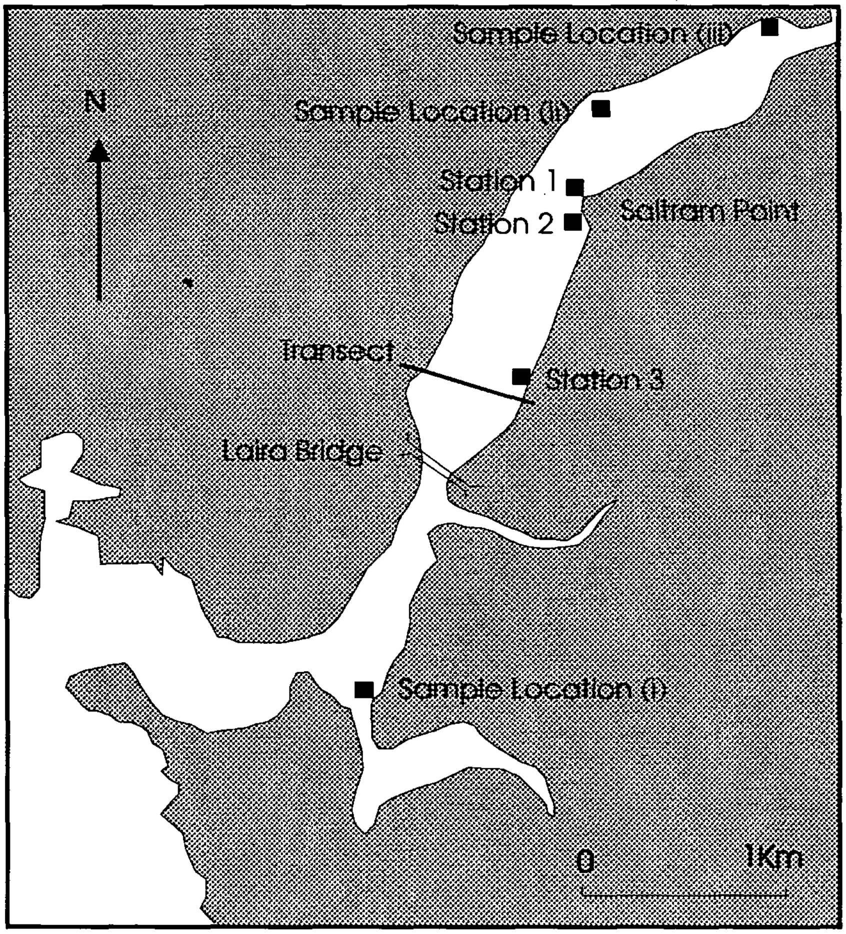


Figure 4.1. Map of Plym Estuary, showing all sample locations

4.1.1. Sampling

Due to a lack of research on the foraminiferal abundances and distributions within the Plym Estuary three stations on the eastern side, between Saltram Point and Laira Bridge, were initially sampled on the 21st of June 1993 (Figure 4.1). Stations 1 and 2 are located by Saltram Point while Station 3 is located 400m north of the Laira Bridge. All stations recorded live and dead foraminiferal tests, Station 3 was the most suitable as live foraminifera were most abundant and was sampled every month for 11 months (1994). In addition to these samples, microlateral distribution samples and two cores were taken from the Station 3 site. A transect across the estuary was sampled near Station 3. Three other locations i, ii and iii (Figure 4.1) were sampled once to provide information of foraminiferal assemblages from distal areas of the estuary (Data in Appendix 1)

Annual production of foraminifera is calculated (Table 4. 1) using the following method:- Production = sum of values from the simplified population dynamics equation $N_{i+1} = N_i + B - D$ (where N_{i+1} = the new population size, N_i = the original population size, B = births and D = deaths) over a period of 1 year (after Murray, 1991).

	Total Live Foraminifera	Gains	Losses
December	46	0	0
January	288	242	0
March	374	86	0
April	399	25	0
May	4125	3726	0
June	1055	0	3070
July	1066	11	0
August	1063	0	3
September	82	0	981
October	986	904	0
November	79	0	907
Total	9563	4994	4961

Table 4.1. Annual production of foraminifera at Station 3, showing total live foraminifera and the amount gained and lost each month.

4.2. Results

The substrate at Station 1 consisted of a medium to coarse grained sand containing granitic fragments; Station 2, a medium grained muddy sand, and; Station 3 a soft muddy sediment. The same species (live and dead) were present at all three stations, although most abundant at Station 3 which was then sampled every month when exposed at low tide.

Station 3 is located approximately 10 m from the bank of the estuary. It lies approximately 2 m below the Mean High Water Spring tide. The site is aerially exposed for several hours during the tidal cycle and as a result it has potentially large salinity variations, these may be influenced by the low turbulence of the overlying water body, precipitation on site during exposure, evaporation and tidal cycle: spring or neap tides, etc. Temperature measurements were not taken but are undoubtedly far more variable than for sublittoral and submarine areas. When the mudflats are exposed for long periods they probably develop similar temperatures to the ambient air temperature. Solar radiation during sunny weather may result in considerable heating of the surface when the mudflats are exposed. Haynes and Dobson (1969) reported temperatures of between 30°C to -1°C on the mudflats of the Dovey Estuary.

Months of sampling	Salinity from pools	Salinity from tyres
December 1993	/	/
January 1994	25	/
February	/	/
March	20	16
April	30	/
May	35	/
June	25	15
July	/	/
August	35	/
September	32	20
October	32	/

Table 4.2. Salinity measurements from Station 3 (‰), Plym estuary / = no data available

The salinity of the Plym Estuary was measured from tidal pools and from car tyres tied around the edge of the jetty at low tide. Salinity could not be measured at other stages of the tidal cycle because access to the jetty was not available as it is not directly connected to the land.

The salinity was quite variable from pools on the surface of the mudflats as compared with water trapped within the tyres, measurements were taken at each sampling time (Table 4.2). The salinity of the water from the tyres although not systematically recorded was always lower than that of the mudflat pools below, this may indicate that the uppermost layer of estuarine water is more brackish than the water below as the less dense river water will float on the denser incoming marine water. The relatively small river input means the brackish surface layer is also small. As the tide recedes some of the brackish water layer is trapped in the tyres but recedes over the marine waters below allowing higher salinity water to collect in pools on the mudflat. The small inflow of the River Plym results in the near normal marine salinities often recorded. The river channel salinity is probably much more variable, fresh at low tide with river water and brackish/marine at high tide.

4.2.1. Live Assemblage

Analysis of the samples from Station 3, presented as yearly average percentages, revealed a restricted live foraminiferal fauna with a Fisher Alpha Diversity Index of less than one. The live assemblage although composed of three species, is essentially bi-specific with *Haynesina germanica* (Ehrenberg) dominant with 89%, *Elphidium williamsoni* Haynes, subordinate with 10% and *Ammonia beccarii batavus* Hofker sparse with 1% (Figure 4.2).

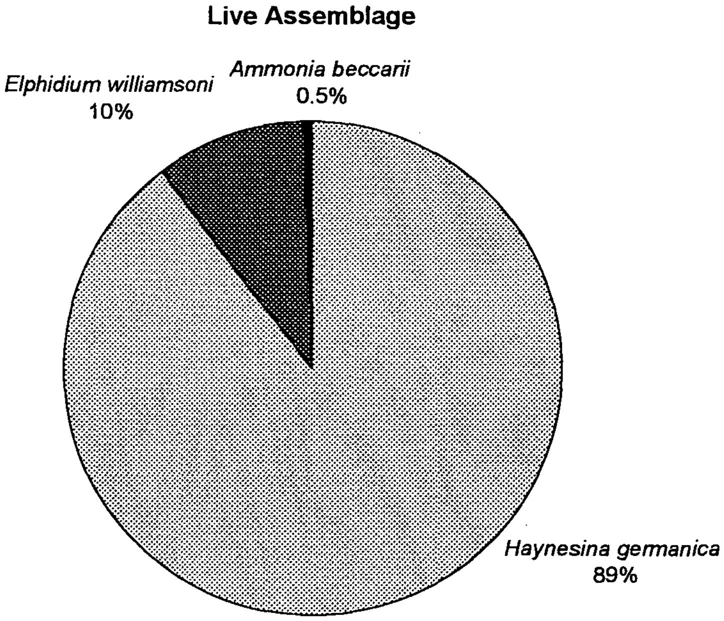
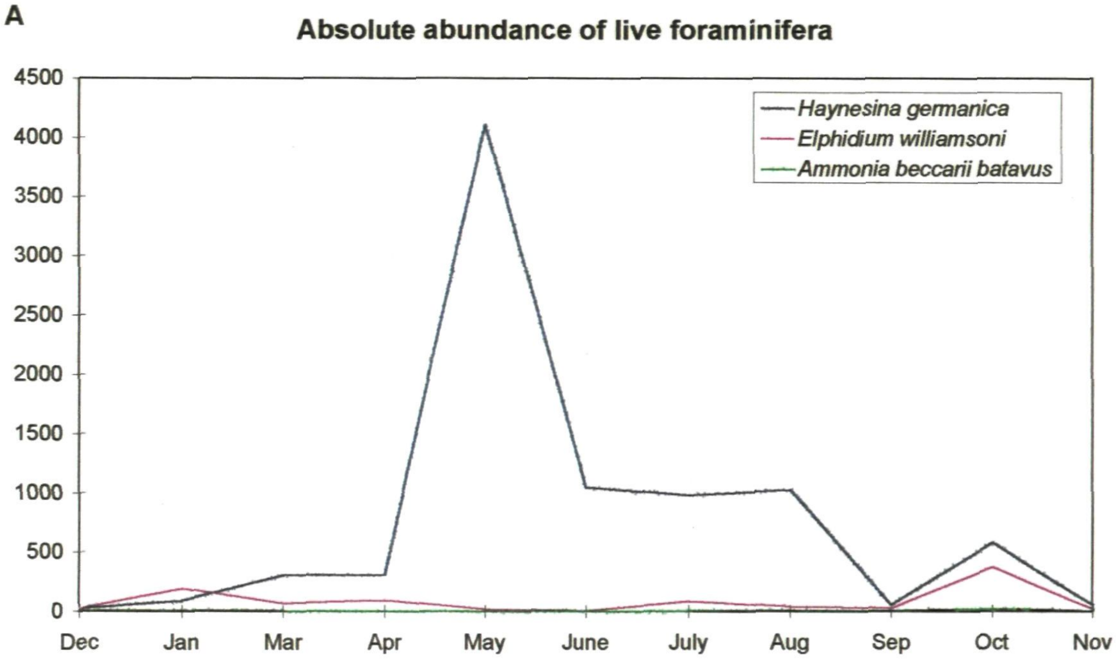
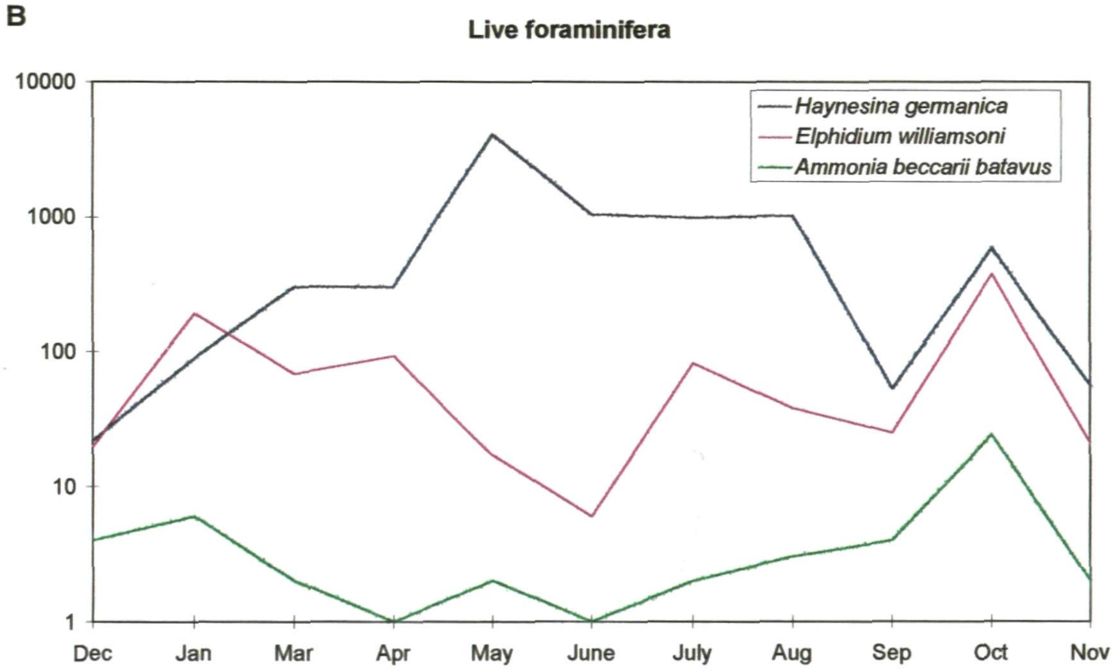


Figure 4.2. Total live assemblage throughout the year from Station 3.

Haynesina germanica was present in very low numbers during the winter months, but numbers increased slowly during late winter and early spring, the abundance increased sharply to their maximum (over 4000 individuals per 100 cm^3) in May (Figs 4.3 a&b). The abundance then decreased and levelled off; but remained at an elevated level for the summer months.





Figures 4.3 A&B. Live foraminifera from Station 3 plotted in A; absolute abundance and B; logarithmic plot.

Populations of *E. williamsoni* exhibited a very minor peak during January as did *A. beccarii* (Figure 4. 3b), during which *H. germanica* was not abundant. *E. williamsoni* and *A beccarii* then exhibited a negative correlation with *H. germanica* throughout the summer, and reached low numbers during May and June (Figure 4. 3b). During September, numbers of *H. germanica* and *E. williamsoni* dropped to very low levels, but in October abundances of all three species exhibited a positive correlation and increased dramatically. *Haynesina germanica* exhibited a relatively small increase in abundance during October in comparison with its summer abundance, but *E. williamsoni* and *A. beccarii* attained their highest abundance during October. After October, all three species declined once again. Of the three species only *H. germanica* bloomed during spring and summer, *E. williamsoni* and *A. beccarii* were sparse throughout the spring and summer, but all three species bloomed in the autumn (October)

Most live foraminifera recovered from the September sample exhibited a prominent green colouration (throughout the test) and this was particularly evident in *E. williamsoni*. This is thought to be caused by algal chloroplasts; either symbiotic, or representing the food type consumed during this period (autumn).

4.2.2. Dead Assemblage

The dead foraminiferal assemblage was very similar to the live in terms of species relative abundance (Figure 4.4 and 4.5). This suggests similar rates of test production among these species and uniform taphonomic alteration. Some tests exhibit frosted surfaces, punctures and occasionally broken ultimate chambers, indicating abrasion and/or possible dissolution (Murray, 1989). The dead assemblage exhibited a wide range of test sizes with little evidence of sorting. Empty tests of *H. germanica* were dominant forming 92% of the dead assemblage, with sparse empty tests of *E. williamsoni* (7%) and *A. beccarii* (1%). Other species represented in the dead assemblage were very rare, usually forming much less than 1%. The very rare forms included brackish water species such as *Miliammina fusca* (Brady) and *Jadammina macrescens* (Brady) together with extremely rare marine forms such as *Elphidium crispum* (Linné), *Brizalina pseudopunctata* (Höglund) and *Quinqueloculina* sp. Apart from these occasional rare species the dead assemblage almost perfectly mirrors the live species assemblage. The dead assemblage remained relatively constant throughout the year as it represents the sum of past test production. Species proportions throughout the year within the dead assemblage were not affected by the major summer (May, June, July, August) bloom of *H. germanica* and subsequent deaths and contribution of foraminiferal tests to the dead assemblage. The possible reasons for this are:-

(1) The dead assemblage may be large enough not to be affected by seasonal contributions of tests.

(2) The large bloom of *H. germanica* may have been restricted to limited areas within the estuary.

(3) Transport and dispersion of the newly produced tests.

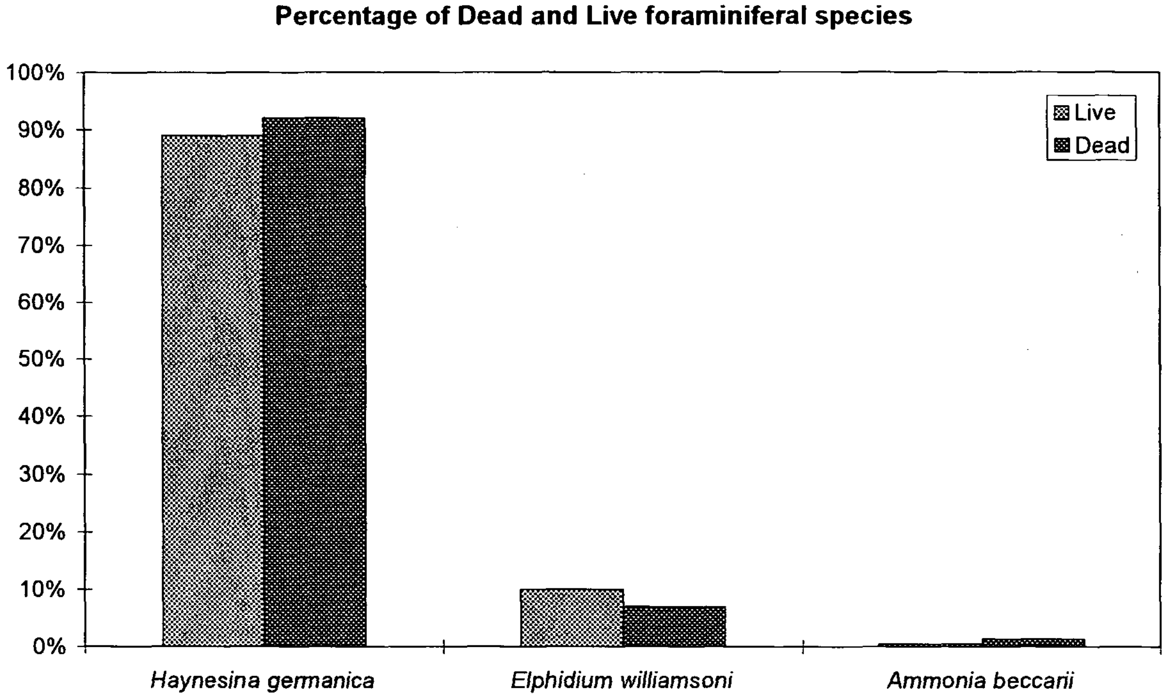


Figure 4.4. Comparison between species percentages within the dead and live assemblages from Station 3.

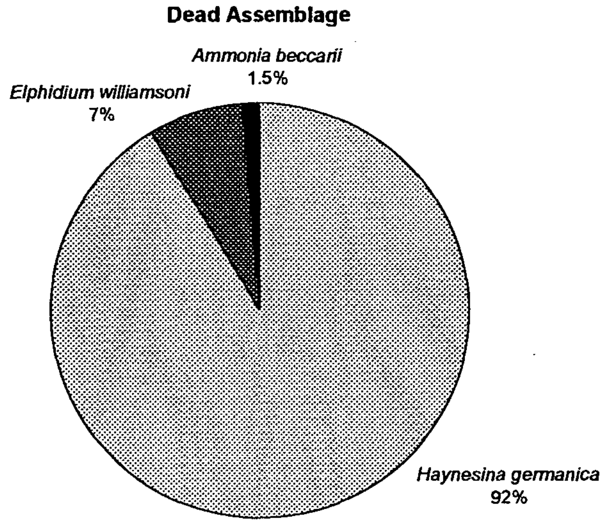


Figure 4. 5. Total dead assemblage throughout the year from Station 3.

4.3. Vertical distribution of live foraminifera

A core 8 cm in length, and 8 cm in diameter was taken at Station 3. Analysis of the samples at 3 mm intervals showed that most live foraminifera (97%) occurred within the top 1 cm of sediment, whilst 94% occurred in the uppermost 3 mm (Figure 4.6).

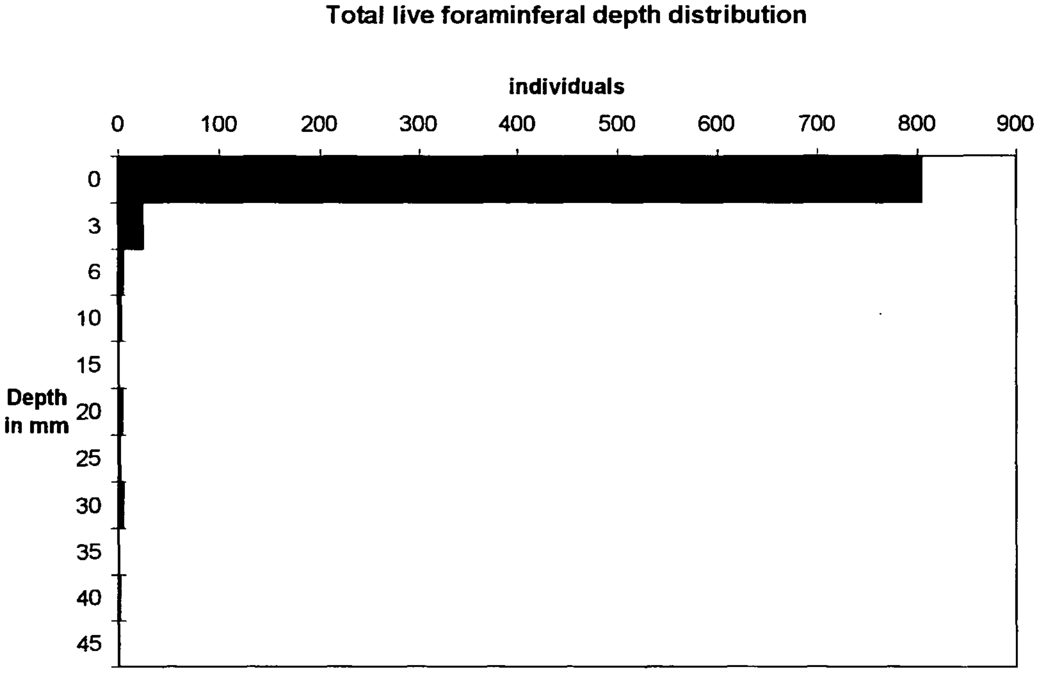


Figure 4. 6. Depth distribution of total live foraminifera from Station 3, taken from core data.

The live foraminifera were composed of *H. germanica* and *E. williamsoni*. Both species exhibit a very similar distribution, indicating that they inhabit a similar area within the substrate (Figure 4 .7).

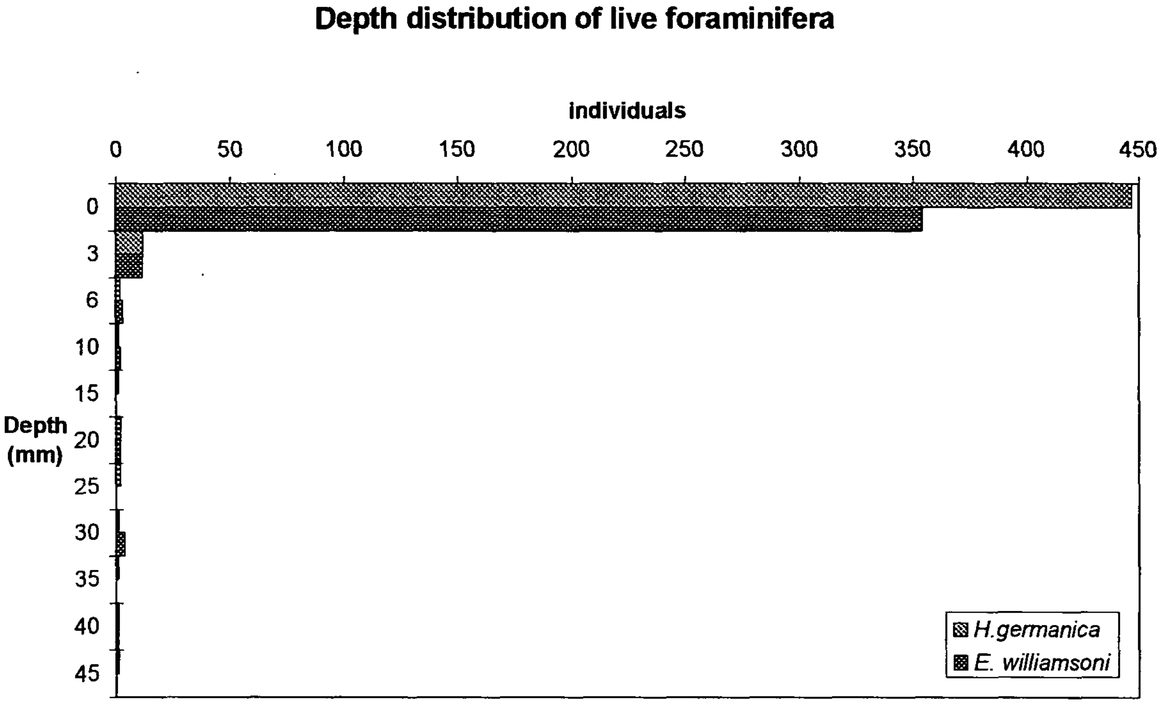


Figure. 4. 7. Depth distribution of *H. germanica* and *E. williamsoni* from the core data of Station 3

The sediment is a micaceous mud with a pronounced orange-brown layer 2-6 mm thick of oxidised material (Figure 4.8). Below this oxidised layer, the sediment gradually becomes darker in colour until charcoal-black and probably anoxic (hydrogen sulphide detected) at 10 mm - 20 mm. Polychaete bioturbation is observed down to at least 8 cm depth and this explains the patchy areas of oxidised mud in this zone. The polychaete bioturbation may explain the rare occurrence of live foraminifera observed below the oxidised layer.

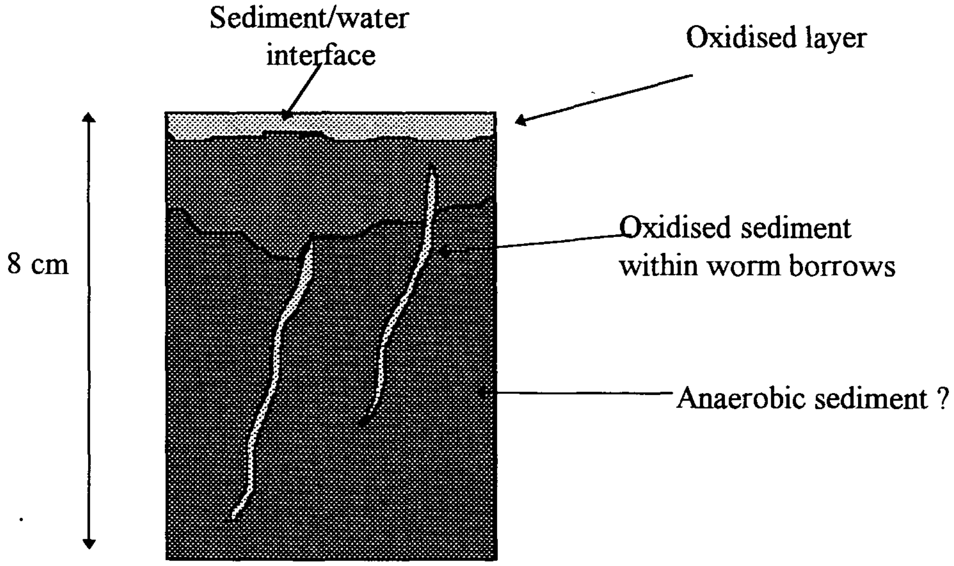


Figure 4. 8. Description of short core from Station 3, to determine the vertical distribution of live foraminifera.

4.4. Palaeontological Implications

A core (40 cm in length) was taken from Station 3 for the purpose of identifying the fossil potential of foraminifera in the very early stages of burial. The core was composed almost entirely of cohesive pale clay (kaolinite rich) with perhaps 5-10% muscovite mica derived from the china clay pits of Lee Mill and South Dartmoor. The three species present are similar in morphology and composition. They have perforate walls composed of radial laminated calcite; *H. germanica* and *E. williamsoni* are moderately inflated planispiral forms, whilst *A. beccarii* is a moderately inflated, very low trochospiral form. Test size of all the taxa ranges from 63µm to 300µm. These similarities in size, composition and morphology suggest that they will be subject to similar hydrodynamic and taphonomic treatment. Foraminifera are preserved in similar relative abundances (Figure 4.9) as observed in the live assemblage (Figure 4.2) and the present dead assemblage at the surface (Figure 4.5) but absolute abundance was lower in the sub-surface dead assemblage. Empty foraminiferal tests were picked out of one sub-sample (of 100 cm^3) taken from the core, and compared to other sub-samples from the core. These show remarkably similar absolute abundances of empty tests within 100 cm^3. The total number of empty tests in one sub-sample was 1368, whereas the total annual production of live foraminifera collected within 100 cm^3 samples was 4997. Hence the successfully buried and preserved foraminifera represent only 27% of annual production at Station 3 for 1994. The reasons for this may be as follows:-

1 A relatively small proportion of tests are successfully buried at the present rate of sediment accumulation, perhaps due to test loss through destruction (which include mechanical abrasion, dissolution and predation) and/or transportation. Transport of tests into the Sound has certainly occurred (See Chapter 9).

2 Past and perhaps present sedimentation rates may be relatively high and dilute the tests relative to the volume of sediment.

3 Production may have been lower in the past and increased significantly recently Undoubtedly production varies from year to year but it seems likely that only

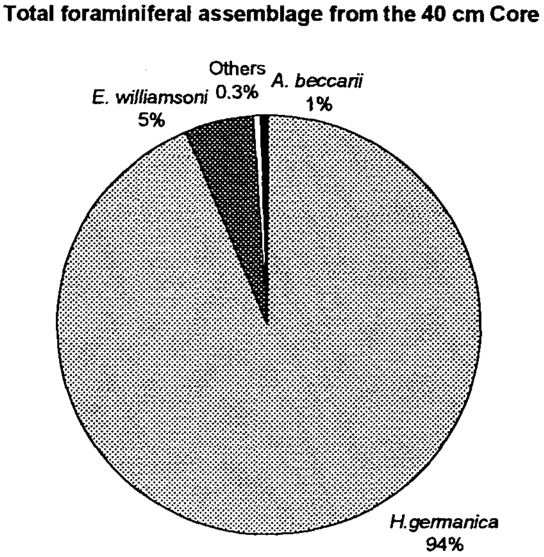


Figure 4.9. The proportions of the sum of the species from the entire 40 cm palaeontological core.

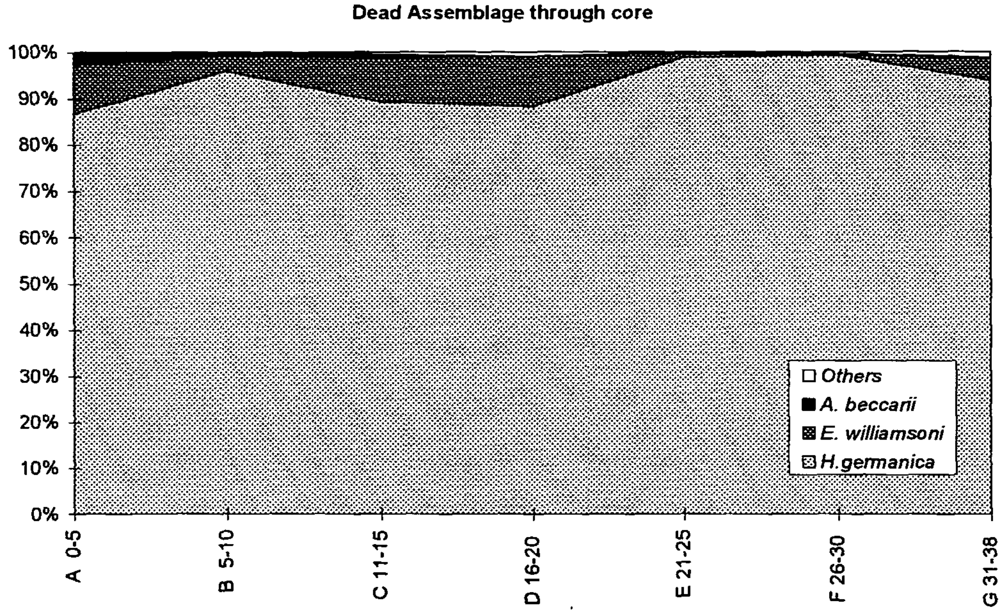


Figure 4.10. Variation of species percentage abundance throughout the 40 cm core. Other species never exceed 0.3% of the assemblage.

The dead assemblage from the 40 cm core shows no significant trends throughout the core, although the relative abundance of *E. williamsoni* is lowest in the bottom half of the core (Figure 4.10).

4.5. Lateral Variation Across The Channel

Six samples of 100 cm^3 from the top 1 cm of the sediment surface, were retrieved from an east-west transect 400m north of the Laira Bridge (Figure 4.11). All live foraminifera were picked out and the dead assemblage analysed qualitatively.

Transect samples show that the Plym Estuary displays a normally graded sedimentary profile consisting of three distinct sedimentological facies (Figure 4.11). Facies A, a very soft sticky mud, contained an abundant live assemblage and an ample indigenous dead assemblage, which included very small numbers of exotic species. Live and dead foraminifera were abundant in Facies B, a partially consolidated silty mud. The dead assemblage contained small numbers of exotic species essentially marine in origin, but was dominated by indigenous species. Both facies A and B represent are estuarine mudflat. The absolute live abundances ranged from 356 to 948 individuals (per 100 cm^3) dominated by *H. germanica*, except for sample 'Trans 2' (the only sample from facies B)

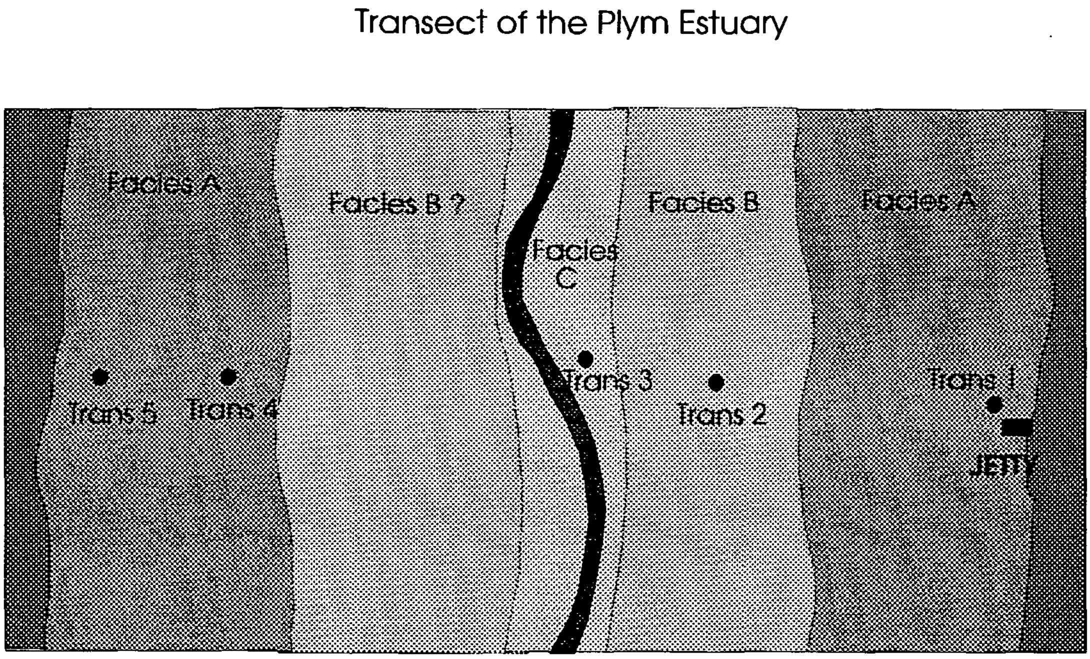

Transect of the Plym Estuary

Figure 4.11. Idealised representation of transect through the Plym Estuary, showing transect sample sites (black dots) and sedimentological facies (not to scale). Gradational boundaries are indicated by dotted lines

which exhibits the highest total abundance but displays a slightly larger proportion of *E. williamsoni*. (Figures 4.12, 4.13 and Table 4.3 a&b). Facies C, a shelly sand, represents the channel deposit, which because of its nature and situation probably experiences large salinity fluctuations. Live foraminifera are sparse or absent and a second sample taken at this site was also barren of live foraminifera. The sparse live assemblage was dominated by *E. williamsoni*, with minor numbers of *H. germanica* The dead assemblage was dominated by large *E. williamsoni* tests (with perhaps 5% of individuals deformed as seen in Plate 31, Figure 5) which may represent a current-altered deposit and/or be the product of a highly stressed environment. Exotic species are rare, although empty thecamoebians tests are present, having been transported down river. Two species of bivalves are very common, both live and dead, within the estuary. *Mya arenaria* and *Cerastoderma edule* are both typical inhabitants of the lower shore face and estuaries, and are species which can tolerate salinities of between 20‰-36‰.(Fish and Fish, 1989).

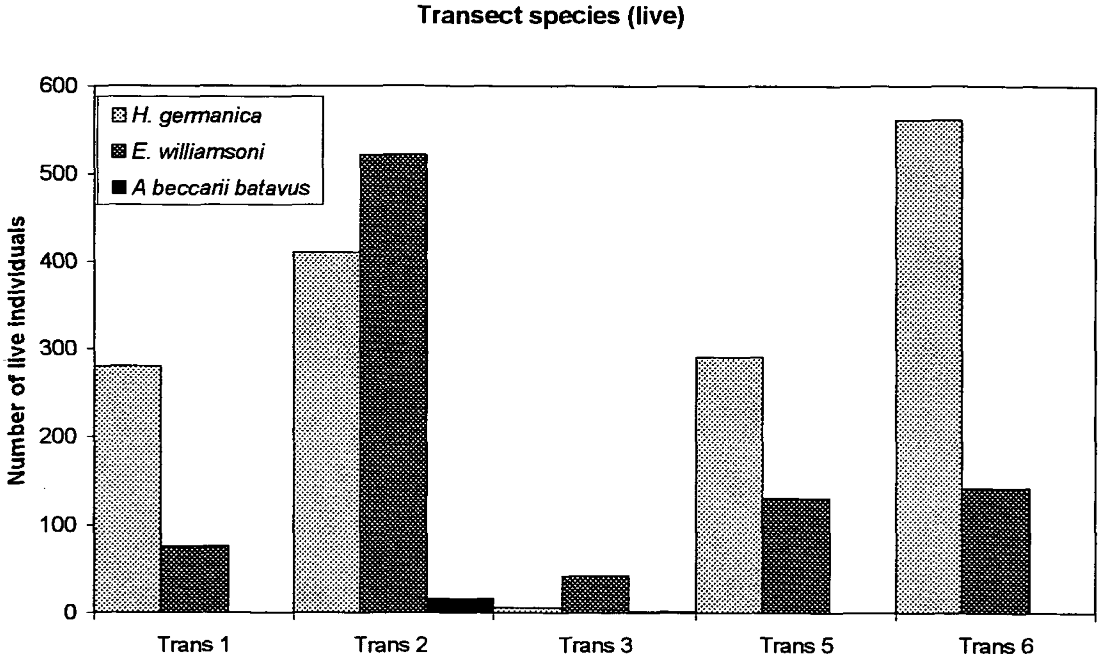


Figure 4.12. Abundance of foraminiferal species across transect of the Plym Estuary (Absolute Abundance).

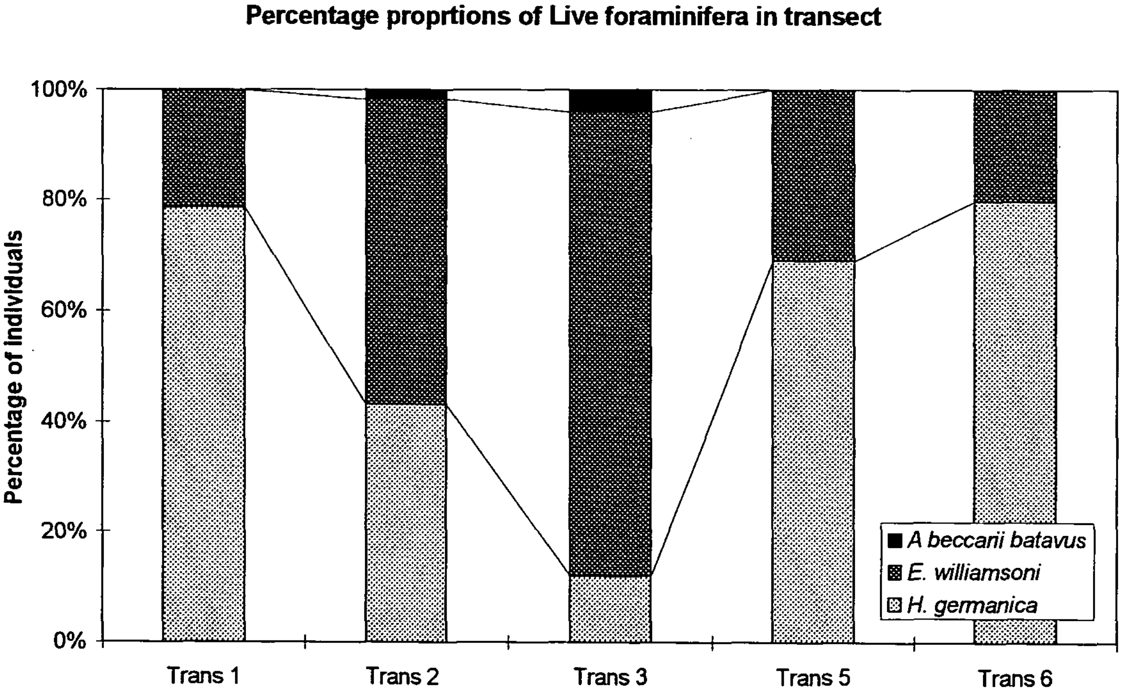


Figure 4.13. Abundance of foraminiferal species across transect of the Plym Estuary (Percentage abundance), although absolute values were lowest in Trans 3.

Absolute Live Foraminifera	**Trans 1**	**Trans 2**	**Trans 3**	**Trans 5**	**Trans 6**
	Facies A	**Facies B**	**Facies C**	**Facies A**	**Facies A**
H. germanica	280	410	6	290	562
E. williamsoni	76	522	42	130	142
A. beccarii batavus	0	16	2	0	0
Total	**356**	**948**	**50**	**420**	**704**

Percentage of live Foraminifera	Trans 1	Trans 2	Trans 3	Trans 5	Trans 6
	Facies A	Facies B	Facies C	Facies A	Facies A
H. germanica	79	43	12	69	80
E. williamsoni	21	55	64	31	20
A. beccarii batavus	0	2	4	0	0

Table 4.3 a&b. Absolute and percentage abundance of foraminiferal species from a transect across Plym Estuary.

The dead assemblage was carefully scanned qualitatively. It is dominated by the three main species *H. germanica, E. williamsoni* and *A. beccarii batavus*, with a very small number of exotic species. Exotic species are not present in samples Trans 1 and 6. Trans 2 and 5 exhibit a very small numbers of exotic species: *Reophax scottii, Deuterammina (Lepidodenterammina) ochracea* var. *sinuosa, E. scabrum, Quinqueloculina* sp. Thecamoebians are also present (dead). At sample Trans 3, representing the channel deposits, exotic forms (*R. scottii, E. crispum, E. scabrum, Brizalina spathulata, Deuterammina,* etc.) are most abundant although still only a very small part of the dead assemblage. Thecamoebians are also present (dead).

4.6. Microlateral Variation

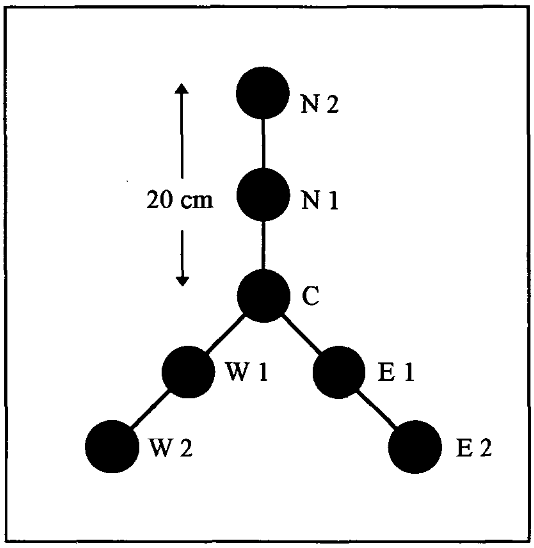


Figure 4.14. Pattern of sampling for microlateral variation.

Station 3 was sampled on 12th March 1995, one central sample, three samples radiating out 10 cm from this point and three more samples radiating out 20 cm from the original sample point were taken (Figure 4.14) with an additional two samples taken at 1 m and 10 m distances from the original sample point. The samples were collected during the spring bloom, and hence exhibited the largest assemblage densities and numerical variations. The samples of 15 cm^3 show considerable abundance variation on a centimetre scale within a uniform substrate (mudflat), yielding between 202 and 57 live foraminifera per 15 cm$^{3.}$ (Figure 4.15). Despite this, the proportions of species throughout all the samples remained similar 61% to 76% of *H. germanica,* 24% to 39% of *E. williamsoni,* and <1% of *A. beccarii* (Figure 4.16 and Table 4.4 and 4.5) Samples from 1m and 10 m distances exhibit abundances and species proportions consistent with those mentioned. The retrieval of one sample per month at Station 3 can result in significant variation in the absolute number of live foraminifera retrieved (although the use of relatively large samples may have reduced some microlateral variation). It is concluded that this area of tidal mudflat showed reasonable, but not extreme variation in numbers of live foraminifera. The relative proportions of species remained reasonably constant microlaterally (several centimetres laterally).

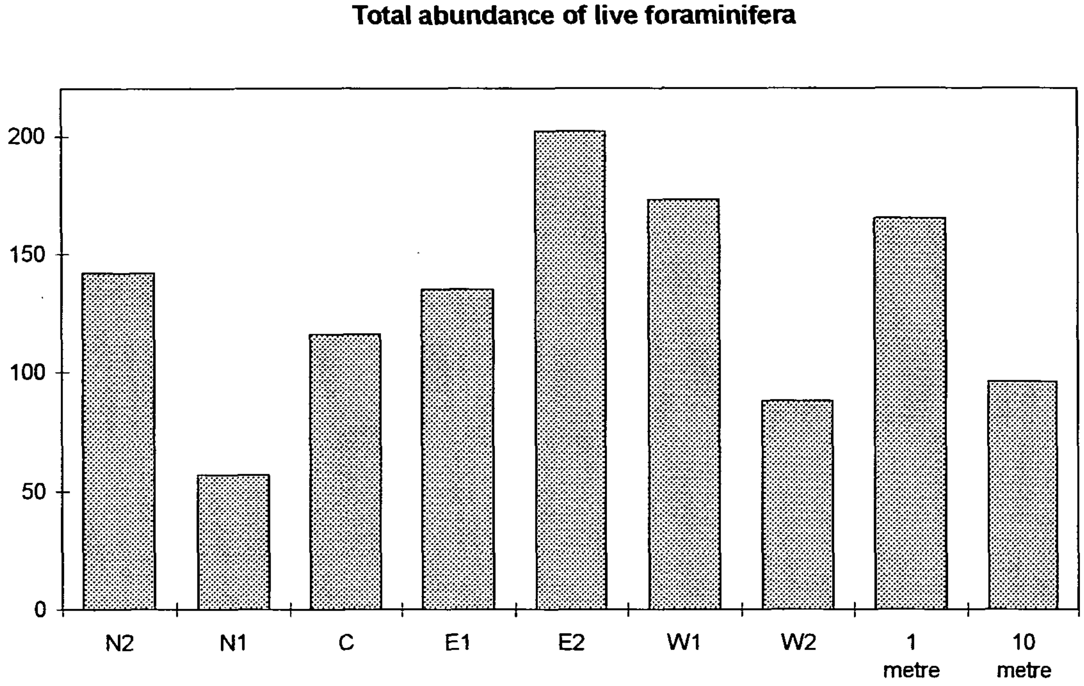


Figure 4.15. Absolute abundance of live foraminifera from microlateral sample suite.

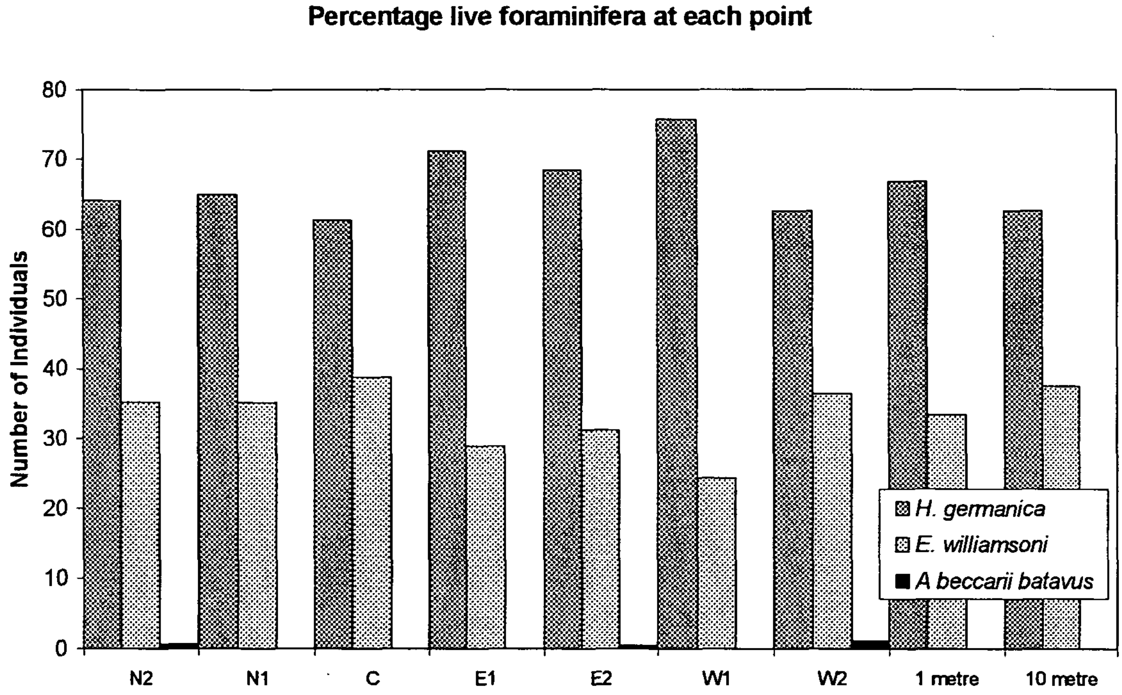


Figure 4.16. Percentage proportions of live foraminiferal species from microlateral sample suite.

Abs abundance	**N2**	**N1**	**C**	**E1**	**E2**	**W1**	**W2**	**1 m**	**10 m**
H. germanica	91	37	71	96	138	131	55	110	60
E. williamsoni	50	20	45	39	63	42	32	55	36
A beccarii	1	0	0	0	1	0	1	0	0
Total	**142**	**57**	**135**	**135**	**202**	**173**	**88**	**165**	**96**

Table 4.4. Absolute abundance of live foraminiferal species and total live foraminifera from microlateral distribution.

%	**N2**	**N1**	**C**	**E1**	**E2**	**W1**	**W2**	**1 m**	**10 m**
H. germanica	**64**	**65**	**61**	**71**	**68**	**76**	**63**	**67**	**63**
E. williamsoni	**35**	**35**	**39**	**29**	**31**	**24**	**36**	**33**	**37**
A beccarii	**1**	**0**	**0**	**0**	**1**	**0**	**1**	**0**	

Tables 4.5. Percentage abundance of foraminiferal live species for microlateral distribution.

4.7. Macrolateral Variation

Spot samples taken from other locations i-iii (Figure 4.1) provide additional information regarding foraminiferal distributions within the estuary. The samples were collected in May 1995 from the uppermost 1 cm for an area of approximately 50 cm^3, using a plastic ring. The samples were analysed qualitatively for live and dead foraminifera. Samples close to the mouth of the estuary (i) exhibited a living normal estuarine foraminiferal fauna of *H. germanica*, and *E. williamsoni*. Sediment coarser than the 125µm fraction is dominated by *H. germanica* and *E. williamsoni* in the dead assemblages, but in sediment of <125µm, the estuarine dead assemblage was greatly enriched by a diverse exotic marine fauna of mainly *E. scabrum*, and *R. scottii* with lesser numbers of *Quinqueloculina* spp, *L. gracilis, Buliminella elegantissima, Cribrostomoides jeffreysii, Fissurina lucida, Fissurina orbignyana, Globulina gibba, Brizalina pseudopunctata* and *B. variabilis.* All these species typically have small to very small adult size, which suggests that they are probably transported in suspension into the lower estuary from the adjacent marine environment.

A sample recovered 2 km upstream from Laira bridge (ii) contains a very similar fauna to that of Station 3, although less abundant. The live and dead assemblages are dominated by *H. germanica* with small numbers of *E. williamsoni*. The dead assemblage contains a higher proportion of tests of *Miliammina fusca*.

A final sample from the uppermost part of the estuary (iii), contains a very sparse live fauna of *H. germanica* and *M. fusca*. The dead assemblage, also sparse, is dominated by the agglutinated foraminifera *M. fusca* and *J. macrescens* with minor amounts of *H. germanica*. Empty thecamoebian tests and disarticulated ostracods valves are also recorded although they are only a minor component of the dead assemblage.

4.8. Discussion

The live and dead foraminiferal fauna of the Plym Estuary is typical of estuarine environments in Britain. These are characterised by a low diversity calcareous assemblage, while in the upper estuary and marsh environments, there are increased numbers of agglutinated species.

Previous studies of estuaries in southern England, such as the Hamble (Alve and Murray, 1994), the mouth of the Tamar (Ellison, 1984), the Exe (Murray, 1983) have shown similar low diversity faunas, typified by two or three calcareous species, and the presence of agglutinated species (Boltovskoy and Wright, 1976).

The Plym Estuary is an estuary of low tidal power north of Laira Bridge. The virtual absence of exotic species implies it is microtidal (Wang & Murray, 1983) and, as a result, the dead assemblage accurately reflects the averaged live assemblage. However, close to the mouth of the Plym Estuary (Loc. i) the dead assemblage was enriched by the addition of small transported marine forms, probably suspended in the water column during high tides and storms (Murray, 1987). The upper part of the estuary (Loc. iii) contains a less abundant live fauna of *H. germanica* and *M. fusca*, whilst the dead assemblage was composed of *H. germanica, E. williamsoni, M. fusca* and *J. macresens*, thus reflecting the high estuary and marsh influence on the foraminiferal assemblages.

Most sites sampled within the estuary show a characteristic dominance of *H. germanica* over *E. williamsoni* within the live assemblage Figures 4.2 and 4.3a&b. Transect samples indicate that *E. williamsoni* increases in proportion in the live assemblage towards the centre of the estuary becoming predominant in the channel deposits, although the abundance of living foraminifera are the lowest in the transect of the channel. As flow rates (and turbulence) are undoubtedly higher and salinity fluctuations greater in the channel area, the abundance of foraminifera in this harsh environment is lowest. *Elphidium williamsoni* is better able to cope with the channel conditions and becomes superior numerically over *H. germanica*. Figure 4. 12 and 4.13.

The sedimentology of the estuary is essentially clay and silt (clay rich at the edges and silt rich towards the centre. The channel and areas of higher energy are sandy, but they represent only a very small part of the estuary. The vertical distribution of live foraminiferal species is strongly restricted to the uppermost 3 mm of the clay/silt sediment, which coincides with the layer of oxidised material. Below the oxidised layer the sediment is dark grey and rapidly becomes black with increasing depth and probably low in oxygen. These observations suggest that the foraminifera cannot tolerate the conditions below the oxidised zone. Sampling the uppermost 1 cm of the sediment is therefore entirely justified.

The live foraminiferal species from Station 3 generally display a negative correlation throughout the spring and summer (Figure 4.3a&b). *Haynesina germanica* appears to increase numerically as *E. williamsoni* and *A. beccarii* decrease. This trend suggests that these species may be competing with each other. Alternatively physico-chemical differences may explain *H. germanica* superiority over *E. williamsoni* and *A. beccarii* during the spring and summer months. The exception to this occurs in the autumn when a positive correlation is observed in all three species.

As mentioned earlier the fauna of the mudflats is susceptible to the ambient temperature and other weather conditions. The abundance of *H. germanica* shows a broad correlation with sunshine levels as the times of bloom as May, June, July and August have the highest levels of sunshine (and day length), October 1994 was also a sunny month (during which all species bloomed). Rainfall was very low for two to three weeks before the foraminiferal blooms and reasonably low during the blooms. Foraminiferal blooms exhibit a positive correlation with temperature. The main bloom begins in May as daily maximum and minimum temperatures exhibit a marked increase, temperatures reach a peak in July/August, then decline during September, but increase slightly during October.

Abiotic factors may directly influence foraminiferal abundances by providing favourable conditions for their growth and reproduction. Abiotic factors also indirectly influence other flora and fauna such as bacteria and algae (diatoms) etc. which may provide a food source for the foraminifera.

The green colouration in living tests, which is so prominent during the autumn bloom, is assumed to be caused by algal chloroplasts (symbiotic or simply as a food type). Leutenegger (1984) discussed a known chloroplast association with the elphidiids and the nonionids to which *E. williamsoni* and *H. germanica* belong. Lopez (1979) compared the efficiency of chloroplasts harboured by these two species; *E. williamsoni* needs to replace 65 chloroplasts per hour and *H. germanica* 20 chloroplasts per hour in order to maintain a constant assemblage of chloroplasts. The photosynthetic activity of the chloroplasts could account for 40 to 100% of the respiratory needs of *E. williamsoni,* and 10 to 20% in *H. germanica* (Lopez, 1979).

The study of the green colouration is beyond the scope of this study. Further research is needed to determine the exact nature of the green inclusions as they may be an important factor during the October bloom for *E. williamsoni*. Their presence may explain how it apparently manages to compete with *H. germanica* with greater success during this period. The presence of green inclusions is believed to be less important for *H. germanica,* because far larger assemblages of this species are present when the green colouration is not evident (during the summer). *Elphidium williamsoni* exhibits maximum numbers in the autumn when the green inclusions are particularly prominent. This is the only season when *E. williamsoni* blooms while the abundance of *H. germanica* is elevated.

4.9. Conclusions

1 The Plym Estuary has low tidal power and is relatively small. The low rates of freshwater inflow from the River Plym result in near normal salinities at high tide.

2 Monthly samples collected over one year at Station 3, reveal a low diversity live assemblage composed of three hyaline rotaliid species; *Haynesina germanica* (89%), *Elphidium williamsoni* (10%) and *Ammonia beccarii batavus* (1%).

3 The dead assemblage was remarkably similar to the live assemblage, implying uniform taphonomic processes. Exotic species were generally very rare.

4 A transect across the estuary reveal three sedimentological facies. The two tidal mudflat facies (A&B) yield high foraminiferal abundances in which *H. germanica* is usually dominant. A shelly sand facies (C), representing the channel, contains very sparse live foraminiferal assemblages dominated by *E. williamsoni*.

5 Microlateral distribution of total living specimens is quite variable, although the relative proportions of live species were reasonably constant on the tidal mudflat.

6 At macrolateral distances agglutinated foraminifera were more common in the uppermost part of the estuary. Live foraminifera are scarce, while small (<125µm) exotic marine foraminifera form a significant proportion of the dead assemblage near the mouth of the estuary.

7 *Elphidium williamsoni* blooms in October; *H. germanica* blooms in May and again in the October. *Ammonia beccarii batavus* remains sparse throughout the year.

CHAPTER FIVE

5. PLYMOUTH SOUND SEDIMENT DESCRIPTION

5.1. Introduction

Sediment samples were collected from 12 sub-tidal sites within and around Plymouth Sound using a grab sampler ('Murray grab') deployed form the vessel *Sepia*, as described in Chapter 1. Each sample was described briefly on board the *Sepia* immediately after collection including sediment grainsize, composition, sorting, etc.. Other parameters such as temperature, depth and salinity were also measured. The initial descriptions made on board the *Sepia* were supplemented by further descriptions made as the samples were being processed in the laboratory. The preliminary descriptions are included in Appendix 2.

Once processed (washed to remove clay and silt) the sediments were sieved at half phi intervals (63µm, 90µm, 125µm, etc.) to determine the distribution of sediment within each sample (Figure 5.1). As some samples contained clay and silt, which were normally washed away (during the processing of the samples for foraminiferal analysis), duplicate samples were retrieved from muddy areas at the same time as the foraminiferal samples were collected. The duplicate samples show the complete range of particle sizes present including the <63µm fraction. Further information about the <63µm fractions was attained by analysis of this fraction down to 1µm (Figure 5.2). This analysis using the Mulvern Instrument Master Sizer is also described in Chapter 2, Section 2.5.

5.2. Idealised Description for each Location

Idealised descriptions have been produced for each sample location. Their location within the Sound are shown in Figure 1.1 (Chapter 1).

Location 1 is situated just outside the breakwater at a depth of 15m to 20m. Occasionally the grab sample water (water retained in the grab bucket from the sediment/water interface) was slightly muddy, commonly it was clear. The samples obtained over the course of the year were remarkably consistent and showed little variation (Figure 5.1). They consisted of very fine to fine sands, with a very small element of medium/coarse sands (less than 5%). Sediment coarser than coarse sand was not present. A very small amount of silt was also present (perhaps 2% or 3%). Location 1 is typified by well sorted, well washed, very fine to fine sands, with little variation throughout the year.

Location 3 is a shell gravel consisting almost entirely of bivalve fragments. The samples ranged from medium sand to small pebbles in size, although the majority consisted of coarse to very coarse sand in essentially a unimodal distribution (Figure 5.1). The water within the grab bucket was occasionally slightly cloudy, but usually clear. This shell gravel sediment is interpreted as a very high energy deposit which is reasonably well sorted and well washed. Sediment samples are very consistent throughout the year.

Location 4 is situated in the middle of Plymouth Sound in an area of mixed sediment (sand, gravel and mud). Samples generally consisted of muddy sands with some gravels, although occasionally they consisted primarily of sands, or primarily of muds. The samples occasionally exhibited a polymodal grain size distribution (Figure 5.1). Sediment was distributed in size from <63µm up to 8000µm, with peaks at the <63µm (very fine to fine sand), 1000µm (coarse to very coarse sand) and 8000µm fraction (small pebbles). The <63µm (silt and clay) fraction revealed a normal distribution of silt (11%) and clay (4%), see Figure 5.3.

The sediment was very poorly sorted and showed considerable lateral variation. Samples differed from month to month and this was assumed to be due mainly to sampling in a slightly different position. This sediment is suggestive of a moderate to low energy environment. The coarse element, some of which is of biogenic origin, may be a lag or remnant deposit from a previous environment (as the building of the breakwater has caused a general reduction of wave energy received by the Sound).

Location 8 is situated in the south east of Plymouth Sound, within an area of cuspate and parallel sand waves. Samples were generally clean and well washed but occasionally slightly muddy. The sediment ranged from fine to very coarse sand, the proportions of which showed some variation. Samples either exhibited a peak at the fine sand fraction or coarse to very coarse sand fraction or both. Very small amounts of pebbles were present. The samples from this location are moderately to poorly sorted but generally clean of silt and mud. They represent moderately high energy conditions.

Location 9 is situated inside (north of) the Breakwater and as a result is protected from high energy conditions. Samples were very similar throughout the year, being composed of small amounts of very fine sand, dark grey silt and clay (an average of approximately 67% silt and clay) See Figures 5.1 and 5.2. Living and dead worm tubes and gastropods were common at this location. The sediment was very soft and devoid of any coarse clastics. It reflects the lowest energy conditions in the Sound.

Location 11 is located near the middle of Plymouth Sound, south of Drake's Island at the Melampus Beacon. Sediment ranged from fine to very coarse sand but it generally consisted of fine to medium sand, with smaller amounts of coarse sand and granules. It was clean and well washed. The sediment is classified as a clean, moderately well sorted sand, indicative of relatively high energy.

Location 12 is close to the mouth of the River Tamar. The sediments are composed of black silt and clay (average of 51%), very fine to fine sand, with lesser amounts of granules, small pebbles, shell fragments and worm tubes (see Figures 5.1 and 5.2). The sediment at this locality was firm and compact. This area is generally subjected to low energy conditions, with higher energy periods as a result of tidal scour.

Location 14 is situated very close to the northern side of Drakes Island. The sediment consisted of clean well washed yellow to grey sands, which exhibited a unimodal distribution from very fine to medium sands. Samples are well sorted, well washed sand indicative of moderate energy.

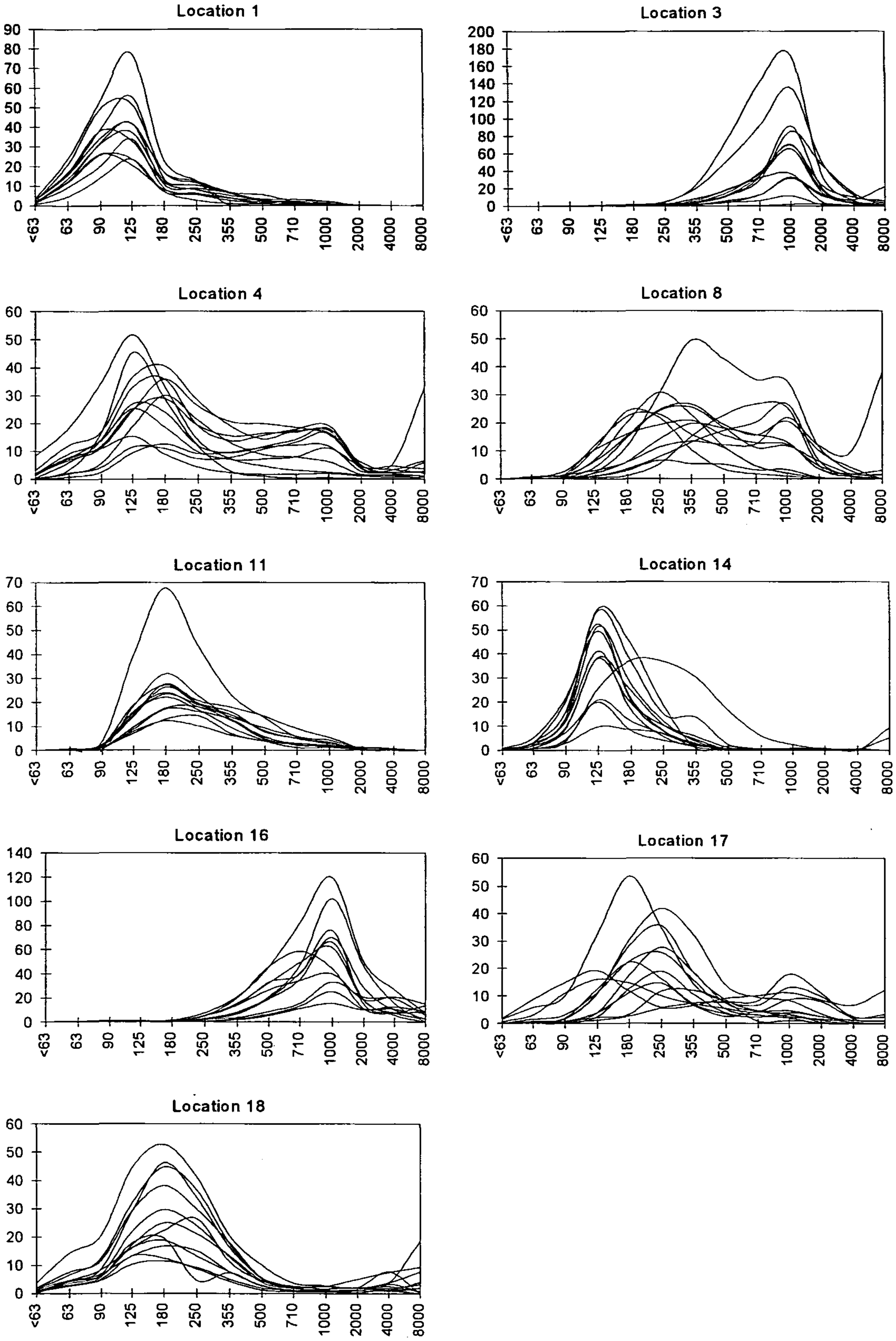


Figure 5.1 The sediment distribution for all samples composed of predominantly mixed, sand and gravel sediments. The Y axis refers to the weight of sediment in grams while the X axis sieve fractions in microns.

Location 15 is located south of the Mountbatten breakwater and thus is relatively protected from the discharge of the Plym Estuary. The sediment is generally soft and unconsolidated. It is dominated by clays and silts (55%), with reasonable amounts of very fine to fine sands. Worm tubes are abundant at this location. A normal distribution is present in material below the 63µm fraction (Figure 5.3). This sediment reflects low energy conditions.

Location 16 is situated on the western side of the Sound. It is very similar to the sediment at Location 3. Particle size ranges from medium sand to small pebbles, although the distribution is unimodal and dominated by coarse to very coarse sand (Figure 5.1). The sediment is clean, well washed, and reasonably well sorted. It represents a high energy deposit.

Location 17 is situated on the eastern side of the Sound. The sediment is very variable in nature. Clean sands were recovered at times and at other times the sediment was very muddy. On one occasion two attempts (the grab was deployed twice) were made. Both samples were recovered in the space of a few metres, one dominated by clean sand the other by mud. The sediment ranged from 1µm to >8000µm with most samples showing a bimodal distribution with peaks at the fine/medium and very coarse sand (Figure 5.1). Other samples showed a polymodal distribution with further peaks at the 8000µm fraction. The sediment was poorly sorted and may represent the gradational boundary between moderately high and low energy areas.

Location 18 is located very near to Location 17 (approximately 100 metres south). The sediment is much less variable, consisting of muddy sand. That usually shows a bimodal distribution. The first and largest peak occurring in the very fine to medium sand, with a second minor peak occurring in the granules to small pebbles fraction (Figure 5.1). The samples contained approximately 20% silt and clay (Figure 5.2). The sediment was very poorly sorted and indicates low to moderate energy conditions.

Plym sediment is almost entirely clay and silt (on average 82%), with a very small amount of very fine sand. Much of the coarse material was composed of organic detritus such as twigs, leaves and shell debris. The sediment reflects very low energy conditions.

The sediment sampled in and around Plymouth Sound fall into four natural categories:-

Four muddy sites

Location 9, close to the inside (north) edge of the Breakwater,

Location 12, near the mouth of the river Tamar and

Location 15 on the south side of the Mountbatten breakwater.

Plym in the Plym Estuary at site 3.

Four sandy sites of various grainsize,

Location 1 a fine to medium sand outside the Breakwater,

Location 8 a coarse sandy by the Melampus Beacon,

Location 11 generally a medium grained sand moderately sorted

Location 14 a medium grained sand on the north side of Drakes Island.

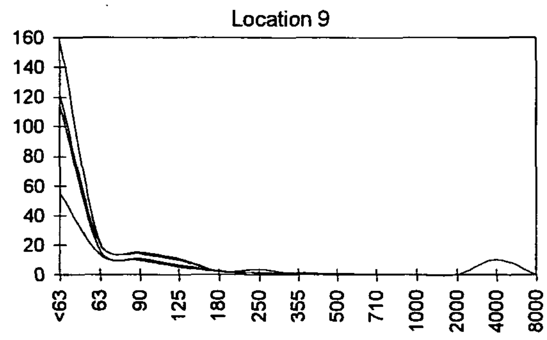
Two shell gravels

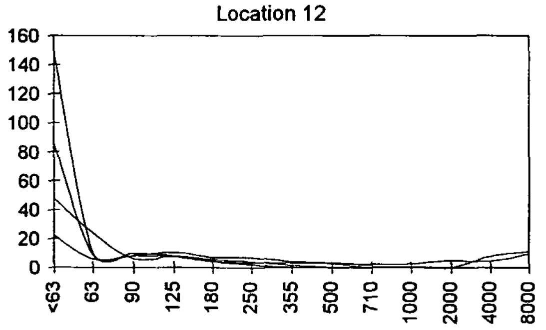
Location 3 and **16** on the south western side of the Sound.

Three mixed sediments of sand, mud and sometimes gravel

Location, 4 in the south eastern Sound

Location 17 & 18, near the Anchorage and Withyhedge beacons in the eastern Sound, although Location 17 varies considerably from clean sand to silty clay.





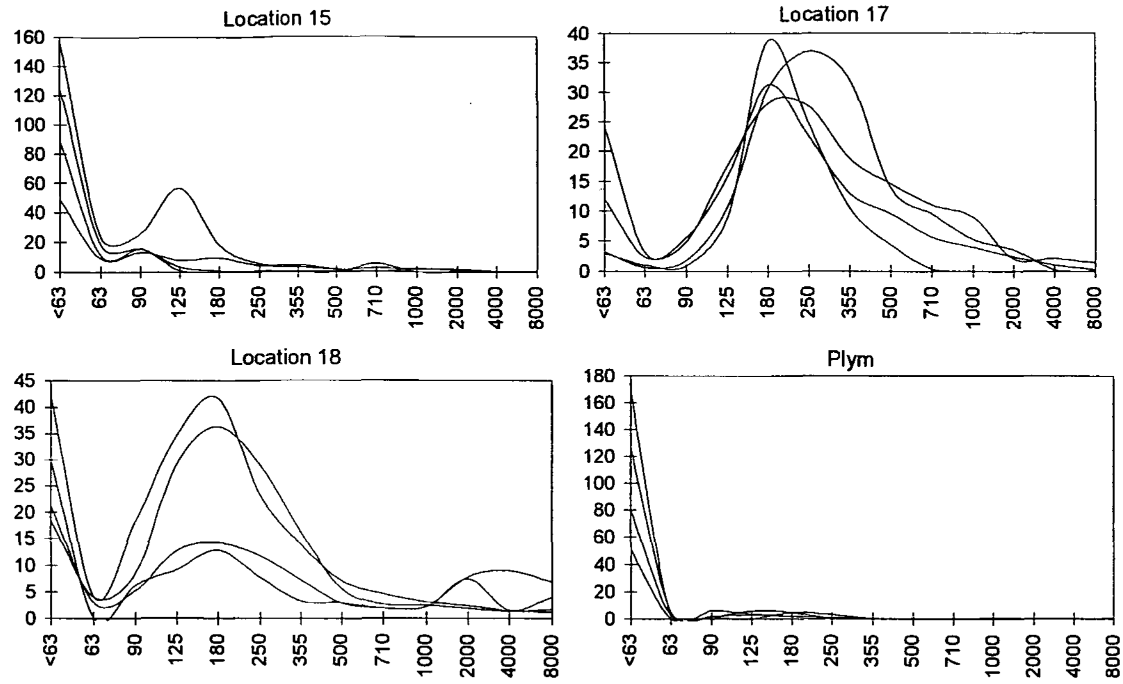
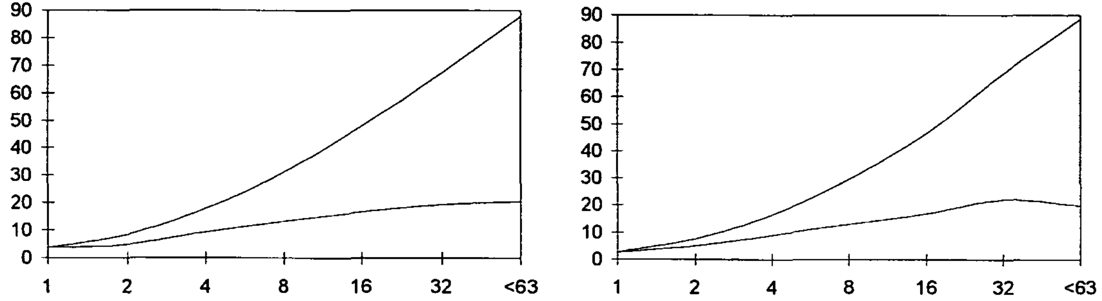


Figure 5.2 Sediment distribution for samples composed of significant amounts of silt and clay (data from duplicate samples). The Y axis refers to the weight of sediment in grams while the X axis sieve fractions in microns.

5.3. Silt and Clay

All samples contained some silt and clay even if only in trace amounts. Samples from mixed sediment facies contained on average 10 to 20% silt and clay, while samples from mud facies contained over 50% silt and clay. All locations from both these sediment groups were analysed to determine the proportions of silt and clay in them. Most samples showed a normal distribution exhibiting a reduction in abundance from coarse silt to clay (Figure 5.3). Several samples showed a minor peak at the 32μm fraction, which is particularly evident at Location 17.



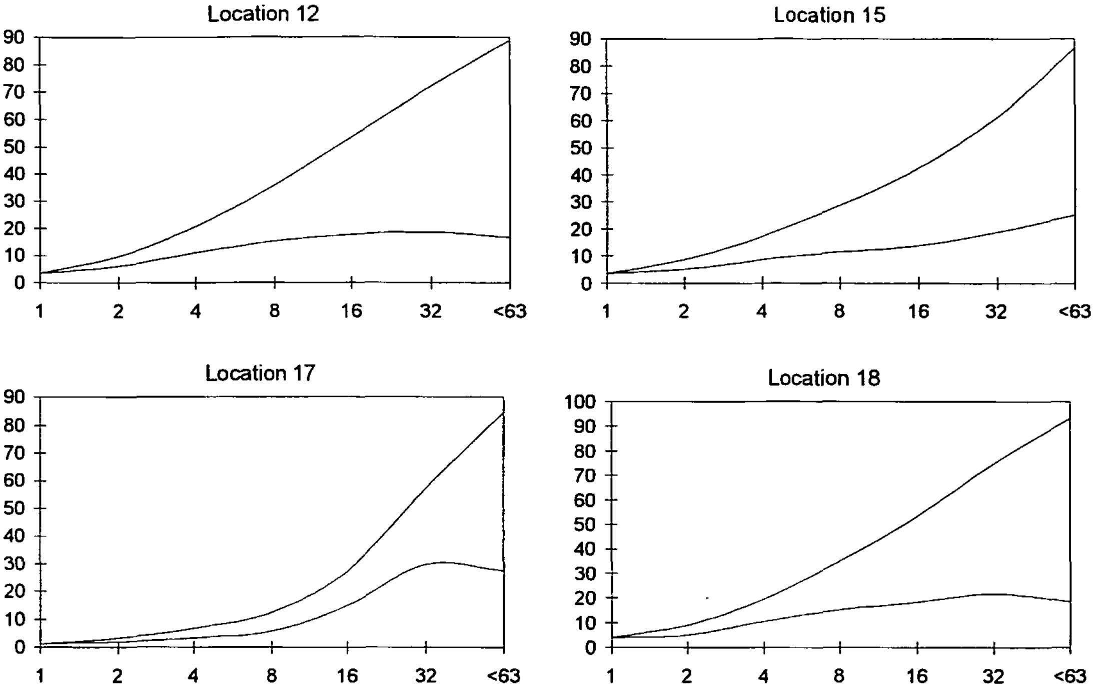


Figure 5.3 Sediment distribution for less than 63μm fraction of mud and mixed sediment samples (data from duplicate samples). The Y axis refers to the percentage of sediment while the X axis size in microns.

5.4. Conclusion

The sediment descriptions and Figures 5.1 and 5.2 show that a wide range of sedimentological facies is present within Plymouth Sound. Some of these facies remained remarkably consistent throughout the year while others showed a greater degree of variability.

CHAPTER SIX

6.0 VERTICAL DISTRIBUTION OF FORAMINIFERA WITHIN THE SEDIMENTARY FACIES OF PLYMOUTH SOUND

6.1. Introduction

Sediment cores were retrieved in June 1994 and April 1995 from a range of sedimentological facies in Plymouth Sound (Figure 6.1). The cores were sub-divided into sections and analysed for live (stained) and dead (unstained) foraminifera.

Foraminiferal samples for the main study (see Chapters 8, 9 and 10) were retrieved by use of a surface sediment grab known as the 'Murray grab'. This grab was designed for the collection of benthonic foraminifera from sub-tidal sites and is superior to other comparable grabs in that it collects only the upper 1 cm from the sediment/water interface for a defined surface area of 100 cm^2 (yielding a volume of 100 cm^3). The flocculent layer at the sediment/water interface often contains a rich and delicate meiofaunal assemblage (Gooday, 1986; Murray, 1987) and most sampling devices disturb or lose part of this layer (Douglass *et al.*, 1978; Thiel, 1983; Eleftheriou & Holme, 1984; Gooday, 1986). The Murray Grab takes samples with minimal disruption and does not allow winnowing of fine sediment due to sealing of the sample within a water-tight rubber seal. The grab collects the upper 1 cm of the sea bed in most sedimentary facies, although in soft muddy sediments a deeper section may be removed.

The purpose of this study was to examine the efficiency of the Murray Grab and to verify that sampling of the top 1 cm of sediment provides a representative sample of the foraminiferal assemblage as well as collecting the portion of the sediment which contains the highest numbers of living foraminifera. Species which may not be present, or under-represented, in such a sampling programme are identified.

Various authors have determined from core data that foraminiferal species have well-defined depth habitats (see Kitazato, 1981, 1994; Gooday, 1986; Moodley, 1990; Buzas *et al.*, 1993; Corliss & Van Weering, 1993; Hunt & Corliss, 1993; Jorissen *et al.*, 1994; Rathburn & Corliss, 1994) and that organic content of the sediment may affect their position in the sediment (Corliss, 1985, 1991; Jorissen, 1992). To ascertain the depth to which foraminifera were living in the sample area, nine cores were taken by diver. Different sedimentary facies often contain different foraminiferal assemblages (Slama, 1954; Hada, 1957; Haake, 1971; Boltovskoy & Wright, 1976; Kaminski *et al.*, 1988) and therefore six areas of different sedimentary facies were cored for analysis.

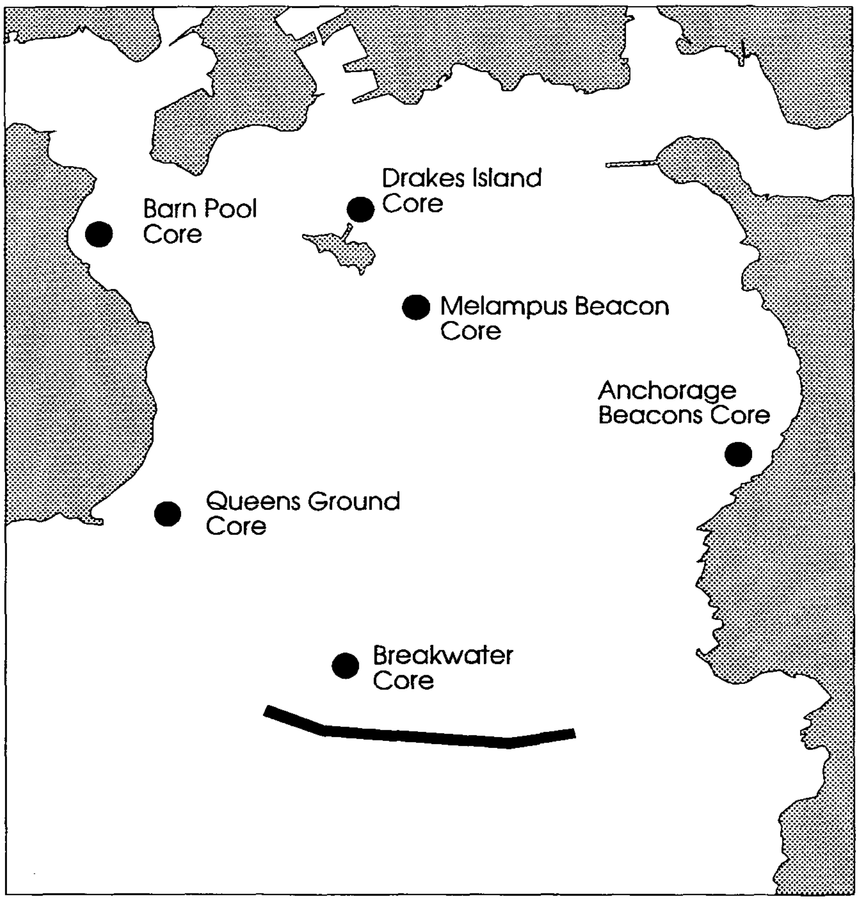


Figure 6.1 Map of Plymouth Sound showing locations of all core sites

The positions of the core localities are shown in Figure 6.1. The samples ranged from low-energy areas; characterised by muddy sediments, to areas of high-energy; characterised by shell gravels. It is believed that sediment particle size is a very important factor influencing foraminiferal species distribution on and in the sediment, as it may influence chemical parameters within the biotope, such as oxygen, organic content, pH and Eh (Boltovskoy & Wright, 1976; Murray, 1991).

Nine cores were taken from six sites, although the foraminiferal data from three cores was extremely sparse. This study comprised a relatively small number of samples as it was designed to evaluate the Murray grab in different sedimentary facies. Four cores of 48 cm length and 4.4 cm diameter were taken by diver in June 1994 from the areas of Withyhedge Beacon, Drake's Island, Barn Pool and Queen's Ground. Five cores of 48 cm length and 4.4 cm diameter were taken by diver in April 1995 in the areas of Withyhedge Beacon, Drake's Island and Barn Pool. Because of poor weather conditions, the Queen's Ground core could not be repeated and was replaced by a core from Melampus Beacon. An additional sample was taken inside the Breakwater (Figure 6.1). The first set of cores were taken in 1994 and the second set in 1995 to allow for inter-annual variations in the foraminiferal assemblages. Core recovery was variable ranging between 18 cm and 48 cm of sediment.

The cores were sealed on the sea bed and kept in an upright position until frozen in the laboratory. The frozen cores were then sectioned. The topmost 1 cm of the core formed section 1, the next 2 cm section 2, three further lengths, each of 5 cm, became sections 5a, 5b, and 5c. The remainder of each core was divided into 10 cm lengths, as sections 10a, 10b, and 10c. Cores were taken from the sediment/water interface downwards, in cases of poor recovery the lower part of the sediment column was not retrieved.

The upper 1 cm section in all cores provided a volume of 15.2 cm^3. Foraminiferal numbers in all sections of each core were divided by the length of the section to standardise living abundance with volume, i.e. foraminiferal abundances are given as number of foraminifera per 15.2 cm^3.

6.2. Mean particle size down core

Figure 6.2 shows the mean particle size of each sample through each of the cores and shows how the cores differed (vertically) sedimentologically and therefore energetically. From Figure 6.2 it can be seen that the mean particle size remained

	Withyhedge Beacon		Barn Pool		Drake's Island	
	1994	1995	1994	1995	1994	1995
1	0.202	0.172	0.237	0.752	0.18	0.18
2	0.231	0.187	0.187	0.660	0.18	0.18
5A	0.299	0.189	0.174	0.664	0.20	0.19
5B	0.219	0.199	0.195	0.646	0.19	0.22
5C	0.233	0.213	0.187	0.727	0.18	0.23
10A	0.277	0.227	0.200	0.727	0.20	0.20
10B	0.261	0.213				0.21

	Queensground	Melampus	Breakwater
	1994	1995	1995
1	0.78	0.30	0.13
2	0.86	0.33	0.23
5A	0.91	0.44	0.13
5B	0.81	0.30	0.14
5C	0.80	0.32	0.14
10A		0.33	0.12
10B			0.12
10C			0.12

Figure 6.2. Mean particle size (mm) throughout sediment cores (core section labels are shown on the left). The Barn Pool core (1995) displays unusually high mean values due to the presence of large pebbles.

reasonably constant down the core at each site. The hydrodynamics of the area determine the sediment particle size. The velocity of currents and the particle size of the sediment are intrinsically related because of the correlation between the velocity of water and the size of particles which the water is capable of moving. Particle size therefore commonly reflects the degree of wave or current agitation in the depositional environment. Fine-grained sediments are normally deposited in areas of quiet water (Arnold, 1974), whereas coarse-grained sediments typify areas of strong wave and current activity (Leutenegger, 1983). Figure 6.3 shows the percentage of silt and clay within the sediments of the core areas. The amount of clay and silt is believed to be a significant factor in influencing chemical and biological parameters within the sediment.

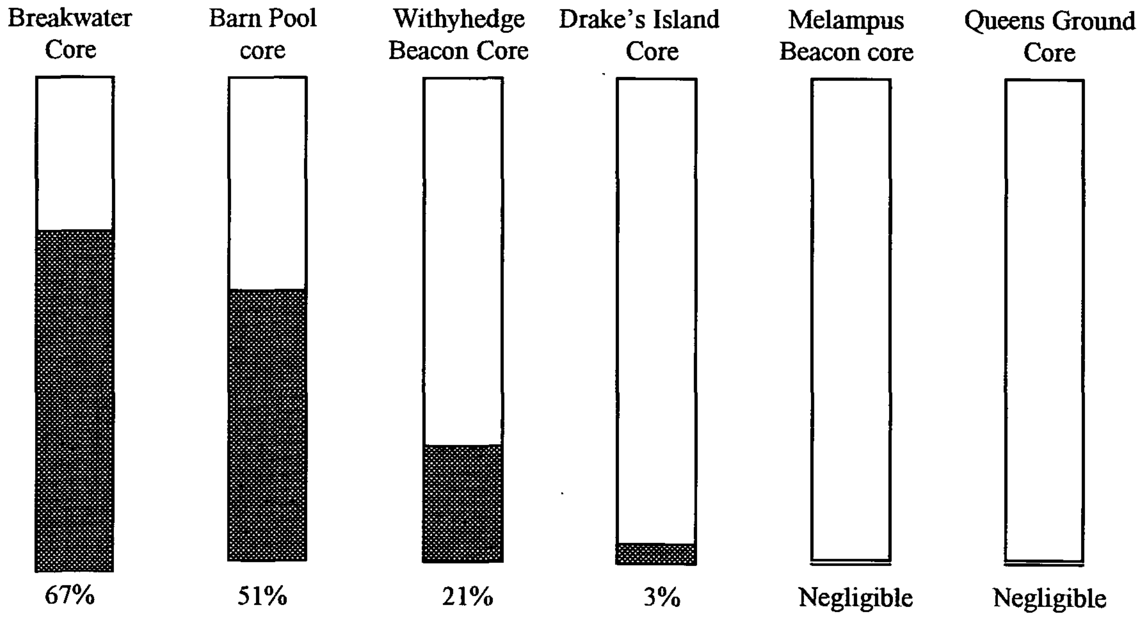


Figure. 6.3. Average percentage of clay and silt (shaded area) from multiple surface samples within sediments form the areas cored.

6.3. Description of the cores

The Breakwater core was dominated by silt and clay, with only minor amounts of very fine sand. The core was structureless with little change in colour or sediment type observed throughout its length. The Breakwater site represented possibly the lowest-energy environment within Plymouth Sound.

The Barn Pool cores exhibited a distinctive medium-brown silt and clay portion in the upper 1 cm, representing the depth of the oxidised sediment. Below this, the remainder of the core was of black fine sand, silt, clay, and to a lesser extent, pebbles and shell fragments. It is thought that the Barn Pool site was subject to low current activity interspersed by brief periods of tidal scour.

The Withyhedge Beacon cores were characterised by poorly-sorted medium-grained sand, silt and clay, representative of low to moderate energy levels. The cores displayed a light brown silty section in the upper 1 cm, representing the oxidised sediment. Below the uppermost 1 cm, the sediment of sand, silt and clay became very dark brown to charcoal-grey. The section between 17-29 cms of the core retrieved on the 30th April 1994 exhibited sediment of a slightly lighter colour than that above or below it. Both cores from this site exhibited subtle variability (slightly mottled appearance) of sediment type and colour throughout their length.

The Drake's Island cores consisted of medium-grained well-sorted sands. The upper 2 cm consisted of fine/medium clean grey sand, followed by light brown sand with small amounts of silt, grading into a sand which contained a greater proportion of silt and became dark grey. This well-sorted sediment is thought to be representative of moderate to high energy conditions.

The Melampus Beacon core consisted of medium to coarse well-sorted sands; pale grey at the surface and gradually becoming darker down the core. This deposit is believed to represent high-energy conditions.

The Queen's Ground core consisted of medium/coarse sand to fine shell gravel. The core was very uniform in composition, except for a slight fining in particle size down the core. It is thought to be representative of a very high-energy environment.

6.4. Live Assemblages

All the cores with the exception of Withyhedge Beacon and Queens Ground contained disappointingly low numbers of live foraminifera, although most cores contained sufficient live foraminifera for interpretations to be made. Figures 6.4 to 6.8 show that all but one of the cores (Withyhedge Beacon; April 1995) yielded the highest living foraminiferal densities within the top 1 cm.

The cores of Barn Pool contained a modest foraminiferal fauna of 44 individuals in 1994 and 33 individuals in 1995. The foraminifera showed a sharp decline in live foraminiferal densities down the core; 61% and 67% of all foraminifera occurred within the top 1 cm; 84% and 67% within the uppermost 3 cm (Figure 6.4).

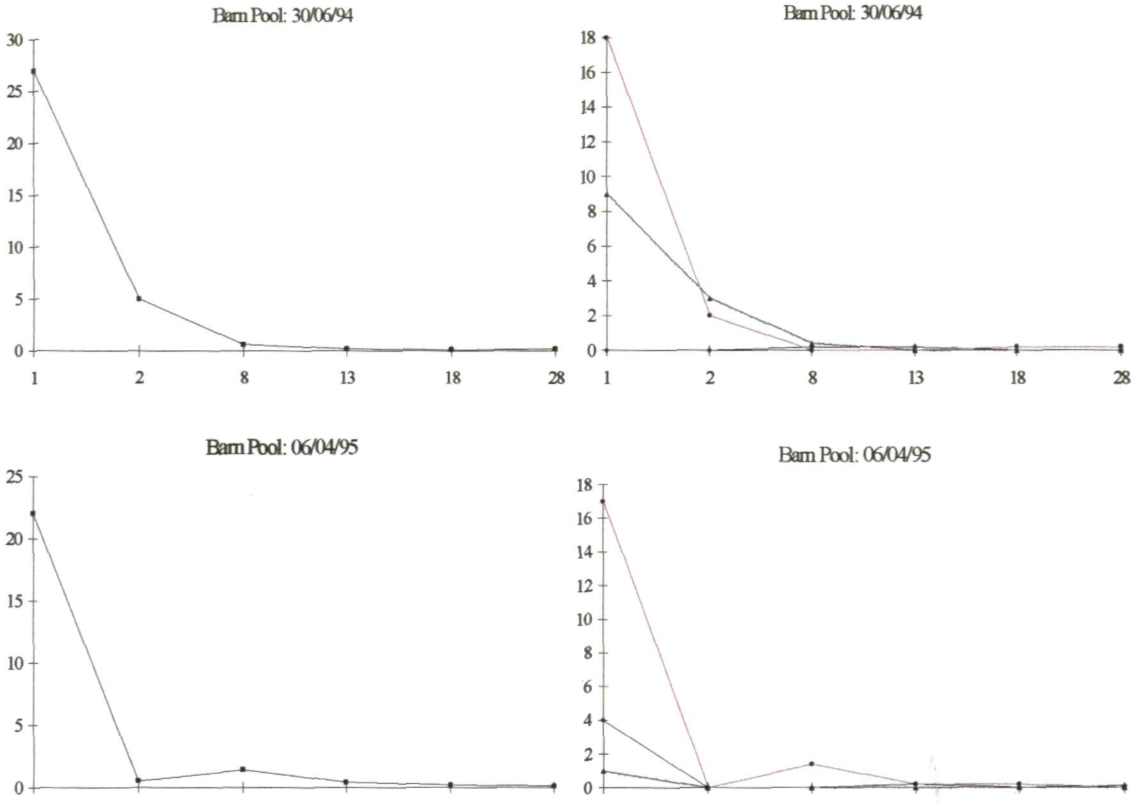
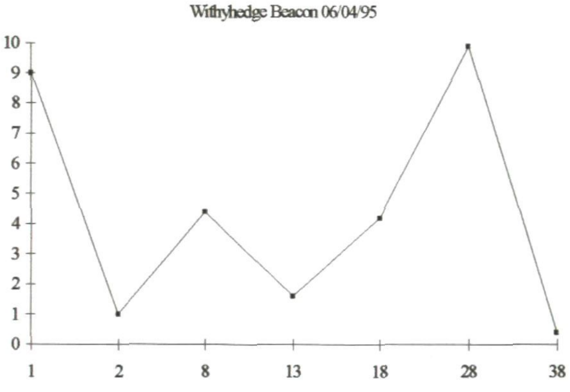
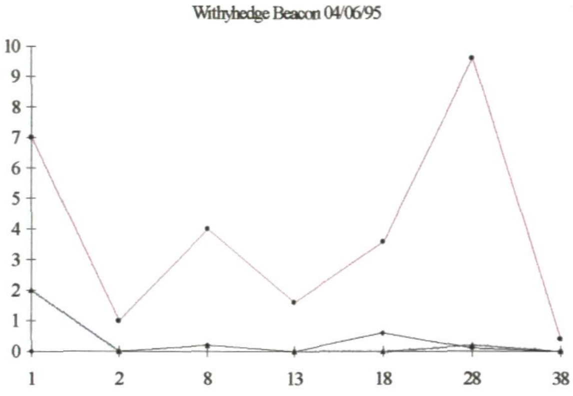


Figure 6.4 The distribution of foraminifera at Barn Pool for 1994 and 1995. Total live foraminifera on the left, live foraminifera divided on the basis of tests type; Porcellaneous (black), Hyaline (pink) and Agglutinated (blue). Number of individuals are shown of the Y axis while depth down the core is shown on the X axis.

The principal live species from the Barn Pool cores were *A. beccarii batavus* (which occurred almost entirely within the uppermost 1 cm) and *Eggerelloides scabrum* (Williamson) which was distributed unevenly throughout the upper 8 cm.

The Withyhedge Beacon cores contained the most abundant and diverse (over 400 individuals in total composed of 20 species) live assemblage of all the cores from Plymouth Sound. Two hundred and thirty seven live individuals were present within the cores in 1994 and 165 in 1995. Withyhedge Beacon showed foraminiferal densities of 56% (June, 1994) and 6% (April, 1995) within the top 1 cm (Figure 6.5). Both cores from Withyhedge Beacon exhibited unusually high densities (33% and 73%) of live foraminifera in the combined 5c and 10a sections of the core (which corresponded to 13 cm to 28 cm depth). *Ammonia beccarii batavus, Elphidium crispum* (Linné) and *Nonion depressulus* (Walker and Jacob) were the most abundant taxa in both cores. The high abundance of subsurface *E. crispum* was very unusual. Specimens of this species were measured (across their maximum diameter) and plotted to ascertain further information about their population structure. Figure 6.10 shows the size range of *E. crispum* from the surface (section 1), subsurface at 13 cm - 18 cm (section 5c) and the deep subsurface at 18 cm - 28 cm (section 10a).





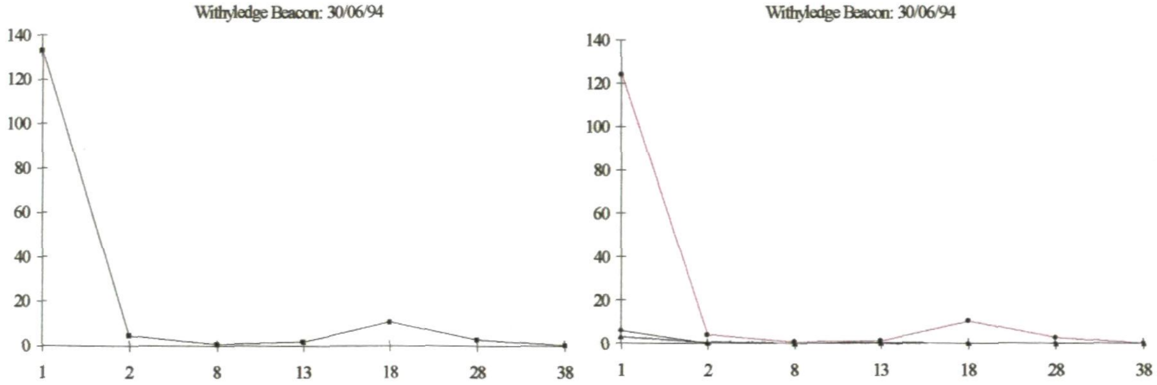
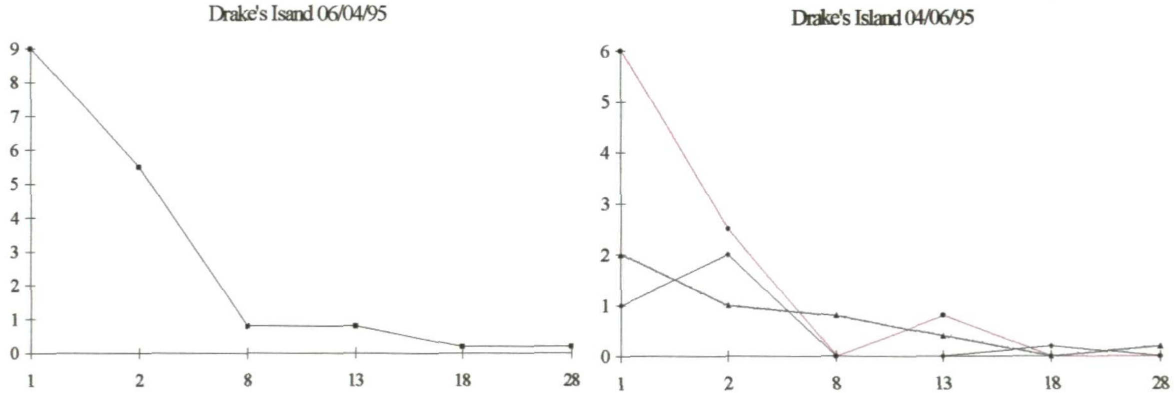


Figure 6.5 The distribution of foraminifera at Withyhedge Beacon for 1994 and 1995. Total live foraminifera on the left, live foraminifera divided on the basis of tests type; Porcellaneous (black), Hyaline (pink) and Agglutinated (blue). Number of individuals are shown of the Y axis while depth down the core is shown on the X axis.

The cores from Drake's Island contained a sparse fauna of 4 live individuals in 1994 and 31 in 1995. The foraminifera showed a more gradual reduction in densities: 29% of all stained foraminifera occurred within the top 1 cm, and 64% occurred within the upper 3 cm, the live foraminifera from the 1994 core occurred within the top 3 cm but due to their scarcity this result is not meaningful (See Figure 6.6). The principal live species from the Drake's Island cores were *Psammosphaera bowmani* Heron-Allen and Earland which occurred throughout the cores in reasonable number, but was difficult to distinguish stained protoplasm from possible stained bacterial contamination. Live *A. beccarii batavus* occurred almost entirely within the uppermost 1 cm of the core.



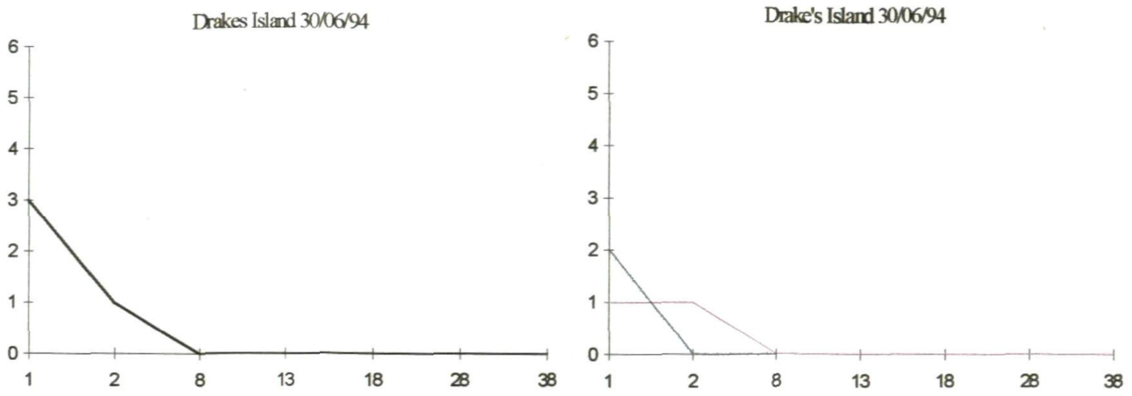


Figure 6.6 The distribution of foraminifera at Drake's Island for 1994 and 1995. Total live foraminifera on the left, live foraminifera divided on the basis of tests type; Porcellaneous (black), Hyaline (pink) and Agglutinated (blue). Number of individuals are shown on the Y axis while depth down the core is shown on the X axis.

A total of 135 live foraminifera were recorded from the Queen's Ground core. They exhibited a very diffuse distribution with 29% occurring in the top 1 cm, 63% within the top 3 cm and 90% in the uppermost 8 cm of the core (Figure 6.7). The dominant live species in the Queen's Ground core were the agglutinated *Cribrostomoides jeffreysii* (Williamson) and *Textularia truncata* (Defrance group). Juveniles of the genus *Quinqueloculina* occurred throughout the core and *Planorbulina mediterranensis* d'Orbigny was most abundant between 3 cm and 8 cm.

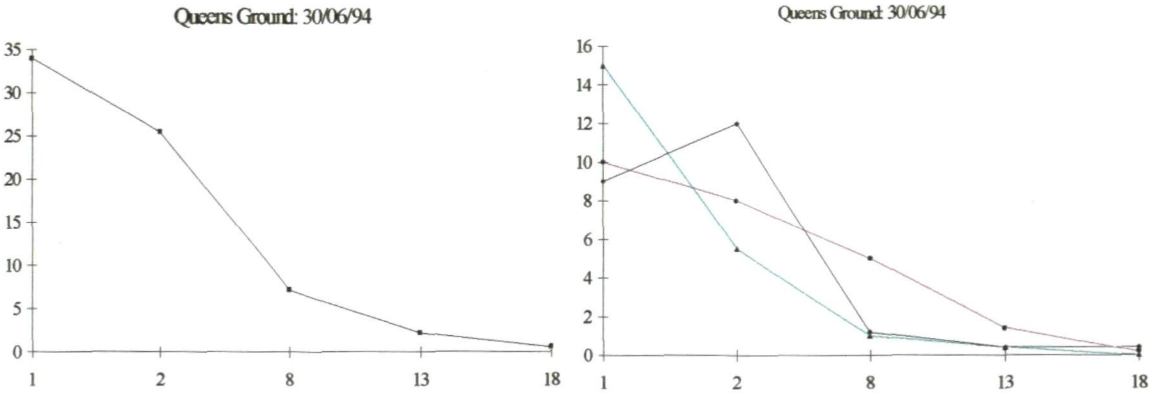


Figure 6.7 The distribution of foraminifera at Queens Ground for 1994. Total live foraminifera on the left, live foraminifera divided on the basis of tests type; Porcellaneous (black), Hyaline (pink) and Agglutinated (blue). Number of individuals are shown on the Y axis while depth down the core is shown on the X axis.

The Melampus Beacon and Breakwater cores both retrieved in 1995 contained an extremely sparse fauna of 7 and 4 live individuals respectively. Because of this they are of little significance (Figure 6.8).

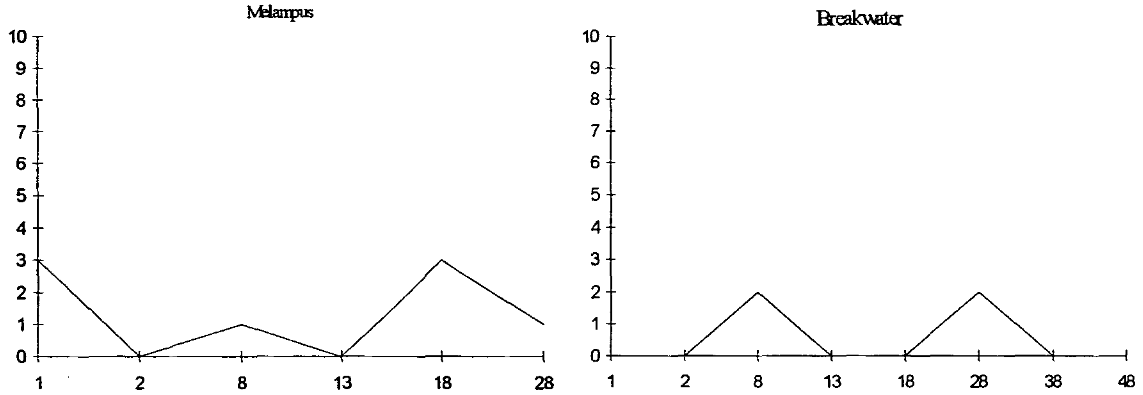


Figure 6.8 The distribution of foraminifera at Melampus Beacon (left) and the Breakwater (right) for 1995. Number of individuals are shown of the Y axis while depth down the core is shown of the X axis.

6.4.1. Test type

The live foraminifera within the cores were sub-divided into categories on the basis of test type. Figures 6.4 to 6.8 show that hyaline taxa were most abundant dominating all sections of all cores except the Queen's Ground core (Figure 6.7), which was dominated by agglutinated taxa in the upper 1 cm and by porcellaneous taxa in section 2 (2 cm and 3 cm). The hyaline taxa accounted for the pattern of distribution of stained foraminifera in all other cores except that from Drake's Island (Figure 6.6), where agglutinated taxa were significant from section 2 (2 cm and 3 cm) onwards

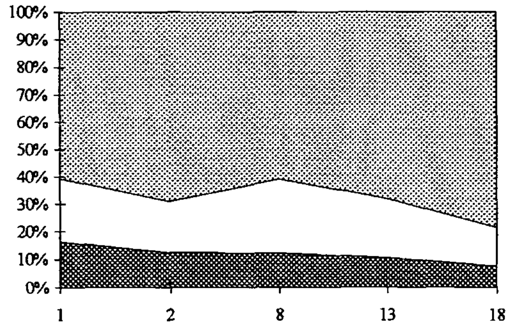
The distribution of the commonly-occurring live foraminifera are shown in Table 6.1. Those usually occurring within the upper 1 cm are regarded as epifaunal to shallow infaunal; those commonly occurring below the uppermost 1 cm are regarded as infaunal; a third category exists for live foraminifera which commonly occur below the uppermost 1 cm and throughout the lower portions of the cores; deep infaunal

	Depth in sediment		Habit
	< 1cm	> 1cm	
Textularia truncata	14	12	Epi / SI
Miliolina auberiana	3	1	Epi / SI
Miliolinella subrotunda	5	6	Epi / SI
Quinqueloculina oblonga	4	9	Epi / SI
Quinqueloculina seminulum	1	3	Epi / SI
Quinqueloculina cf. *seminulum*	3	4	Epi / SI
Brizalina pseudopunctata	6	2	Epi / SI
Brizalina spathulata	4	3	Epi / SI
Elphidium gerthi	2	4	Epi / SI
Rosalina williamsoni	3	11	Epi / SI
Reophax scottii	6	1	Epi / SI
Bulimina marginata	4	2	Epi / SI
Nonion depressulus	15	42	I
Globulina gibba	0	3	I
Cribrostomoides jeffreysii	6	12	I
Quinqueloculina sp	1	11	I
Bulimina gibba	1	6	I
Elphidium cuvillieri	1	4	I
Planorbulina mediterranensis	4	23	I
Eggerelloides scabrum	5	12	I
Ammonia beccarii	35	84	I*
Elphidium crispum	96	97	I*
Fissurina lucida	0	15	DI
Miliolinella circularis	0	18	DI

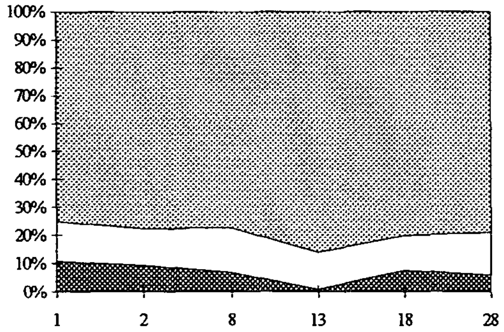
Table 6.1 Epi / SI refers to foraminifera which commonly occur within the top 1 cm of the sediment, presumed to be epifaunal or shallow infaunal. I, refers to strong infaunal tendencies, I* refers to infaunal tendencies influenced greatly by the unusual distributions within the Withyhedge Beacon cores, and DI refers to deep infaunal habits. Most foraminifera show a range of habits which are generalised in the final column.

6.5. Dead Assemblages

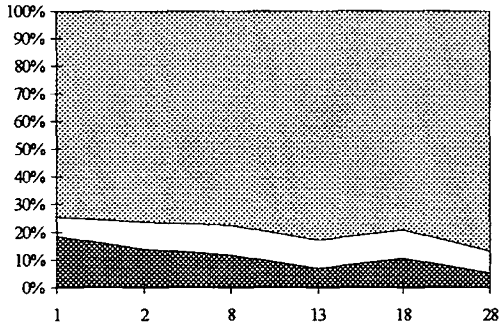
The relatively low-energy environments of the Breakwater, Barn Pool and Withyhedge Beacon exhibited a low proportion of porcellaneous taxa (less than 10% on average). Increased energy levels and particle size (represented by the Drake's Island and Melampus Beacon cores) were reflected by an increase in porcellaneous taxa. In the very high-energy environment of Queen's Ground the porcellaneous taxa increased in abundance to over 20% of the taxa and the agglutinated fauna also became more abundant. From Figure 6.9 it can clearly be seen that porcellaneous taxa generally increase with energy.



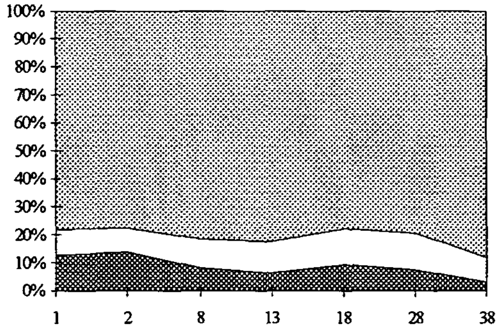
Queens Ground Core 94 (Dead)



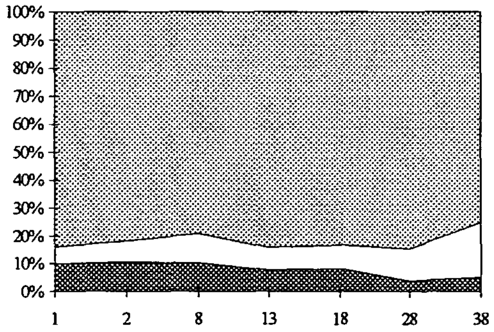
Melampus Core 95 (Dead)



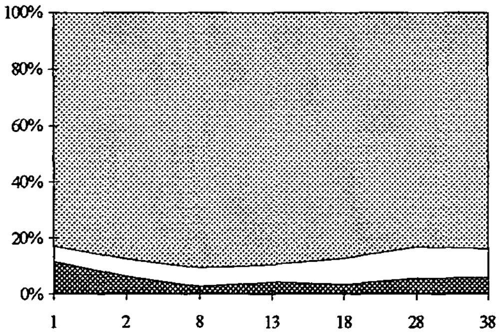
Drakes Island (Dead) 95



Drakes Island Core 94 (Dead)



Withyhedge Beacon Core 94 (Dead)



Withyhedge Beacon Core 95 (Dead)

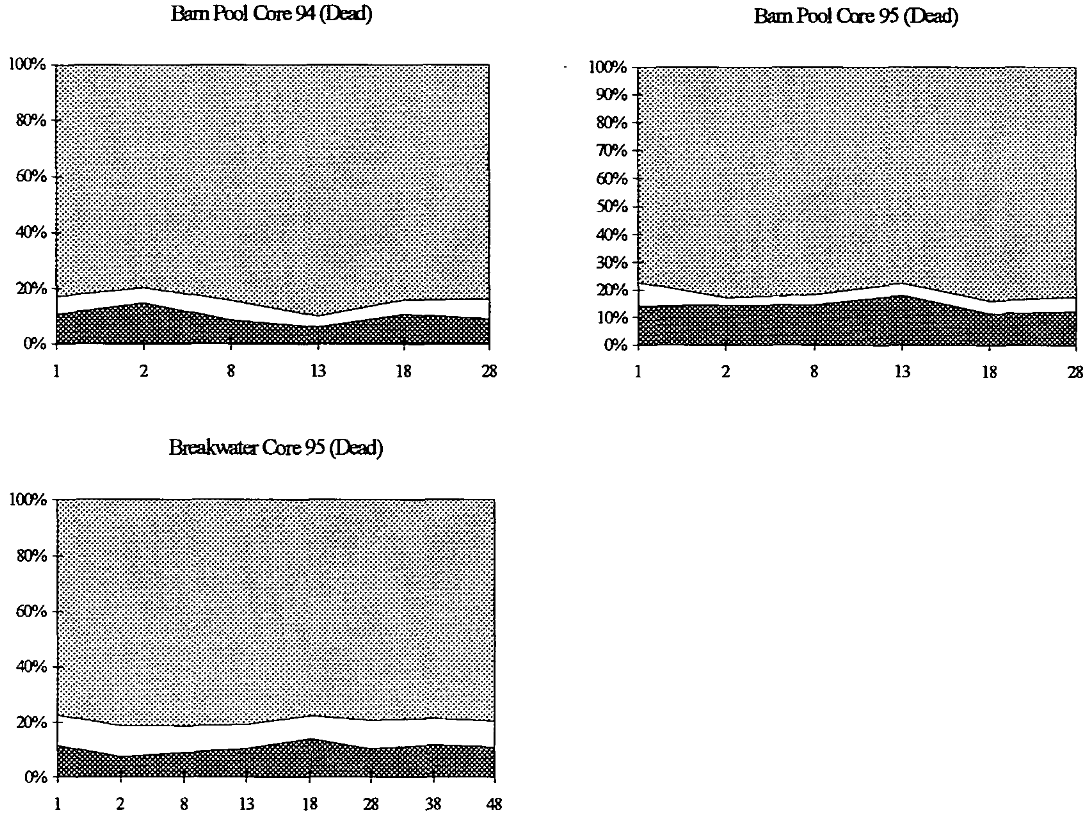


Figure 6.9 The percentage of test types throughout all of the cores; Hyaline - pale grey, Porcellaneous - white and Agglutinated - dark grey. Percentage abundance is shown on the Y axis while depth down the core is shown in cm on the x axis.

6.5.1. Species

The individual cores showed little change in abundance of principal taxa vertically down the core. Sand and gravel cores all exhibited a slight decrease (3% or 4%) in agglutinated taxa down the cores (Figure 6.6), perhaps due to the preferential destruction of agglutinated forms within the burial environment.

6.6. Correlation between Cores and Surface Samples

A comparison of the cores which contained a relatively abundant foraminiferal fauna, with surface grab samples for the same period reveals a very good correlation. Most of the species from the cores are represented by species from the grab samples (Table 6.5). Two discrepancies between core and surface samples are the high amount of *N. depressulus* within the Withyhedge Beacon core (21 individuals) and the lower abundance within surface samples (5 individuals). This may be due to its deep infaunal habit. The other discrepancy is the large amount of *Q. oblonga* in surface samples as compared with core samples from Barn Pool. Considering the patchy nature of foraminiferal assemblages and the fact that the core and surface samples probably did not come from exactly the same location the correlation between both sets of samples is very good.

CORES SAMPLES VS SURFACE SAMPLES	**Queens ground**		**Barn Pool**		**Withyhedge core**	
	cores samples	surface samples	cores samples	surface samples	cores samples	surface samples
Ammonia beccarii batavus	1	2	15	78	13	110
Ammoscalaria pseudospiralis						1
Asterigerinata mamilla	1	1				
Bolivina pseudoplicata	1		1			
Brizalina pseudopunctata	1	5	4	3	2	20
Brizalina spathulata		1		6	5	18
Brizalina variabilis				1		3
Bulimina elongata			1	3		11
Bulimina gibba					5	3
Bulimina marginata					2	
Clavulina obscura				1		
Cribrostomoides jeffreysii	9					
Lenticulina crepidula		1				1
Eggerelloides scabrum			8		2	
Elphidium cuvillieri	1			2	4	4
Elphidium crispum				1	160	124
Elphidium gerthi	4				2	2
Fissurina lucida	1		1		1	
Fissurina marginata	1		1			
Fissurina orbignyana			1			
Fissurina quadrata		1				
Rosalina williamsoni	14	26				
Gavelinopsis praegeri						
Globulina gibba	1					2
Haynesina germanica		2				
Lagena laevis					1	1
Lagena semistriata					1	2
Massilina secans						6
Quinqueloculina auberiana	1				3	
Miliolinella circularis	11	4			2	
Miliolinella subrotunda	11					
Nonion depressulus				1	21	5
Nonionella turgida var. *digitata*	2					
Patellina corrugata	1	1		1		
Planorbulina mediterranensis	27	21				
Psammosphaera bowmani					1	
Pyrgo williamsoni						2
Quinqueloculina sp.	11	9				
Quinqueloculina aspera I			1			3
Quinqueloculina cf. *cliarensis*						2
Quinqueloculina lata					2	1
Quinqueloculina oblonga	1	2		6	2	49

Quinqueloculina seminulum	3		1	2		9
Quinqueloculina williamsoni						1
Quinqueloculina cf. *lata seminulum*	5					
Reophax fusiformis			7			
Reophax scottii				3		3
Stainforthia concava cf. *loeblichi*				3		4
Textularia truncata	23	29			1	
Textularia earlandi			1		1	

Table 6.2 The foraminifera recorded from the cores (three most abundant cores shown) are compared with foraminifera retrieved from surface samples for the same period.

6. 7. Discussion

The total live assemblages in the cores examined ranged from 3 to 240 specimens and was composed of a total of 30 species. Foraminiferal contamination from surface layers (surface sediment being trapped on the inside of the core tube particularly near the aluminium collar at the base of the core tubes) is believed to have occurred because of the presence of small amounts of oxidised surface sediment close to the base of the core tubes, but this is not thought to have significantly affected the results.

All the cores contained different foraminiferal assemblages. The live assemblage was generally dominated by hyaline taxa. All live species were represented in the dead assemblage.

The distribution patterns of live foraminifera within the cores are correlated to sedimentary facies. Particle size and sorting of the sediment probably alters the depth of oxygenation of the sediment and the chemical parameters of sediments. The lower energy facies (those dominated by silt and clay) undoubtedly have different chemical characteristics than sandy facies. It seems reasonable that the amount of oxygen and available food strongly affect species distribution throughout the sediment (Jorissen, 1992). Muddy sediments exhibited very high numbers of live foraminifera within the uppermost centimetre which declined sharply with depth and this is in agreement with numerous other studies (Gooday, 1986; Jorissen *et al.*, 1994; Castignetti, 1996). The gradual decline of living foraminifera down the cores of sandy sediments may be associated with the greater availability of food and oxygen throughout this type of sediment (due to increased permeabilities). Sandy sediments represent a more dynamic environment and foraminifera may be prone to burial in such sediments.

Cores from Withyhedge Beacon showed an unusual vertical distribution of live foraminifera. The unusual distribution at this site was mainly due to *E. crispum* occurring in large numbers at depth. Both cores (taken at an interval of nearly one year) showed 57% and 7% within the uppermost centimetre, and 33% and 73% of living foraminifera at 13 cm to 28 cm depth, whereas other sections of the cores contained very few live specimens. Most species were more abundant within this lower section of sediment than they were at the surface irrespective of their morphology. *Elphidium crispum* has a typical epifaunal morphology (Severin, 1983; Corliss & Chen, 1988; Corliss & Fois, 1991) and its well-documented harbouring of algal chloroplasts (Leutenegger, 1984; Lee *et al.* 1988; Lee & Lee, 1989; Lee & Anderson, 1991) also imply an epifaunal mode of life. Both cores were dominated by three species between 13 cm to 28 cm: the normally epifaunal *E. crispum*; the infaunal *N. depressulus* (Murray, 1991) and the infaunal *A. beccarii batavus* (Murray, 1991). Other live species in this zone were *Brizalina spathulata* (Williamson), *Bulimina gibba* (Fornasini), *Buliminella elegantissima* (d'Orbigny) and *Fissurina lucida* (Williamson). Rathburn & Corliss (1994) identify an organic oxygen rich zone at 15 cm depth which supports a live assemblage of foraminifera. This zone was associated with turbidite activity. Radio isotope data (Chapter 7) suggest that sediment mixing through storms, bioturbation and other disturbance extends only down to a possible maximum of 17 cm in this area. Contamination through the coring process could not account for such large numbers of these live species and others present at depth. Subsurface reproduction of foraminifera has been documented to reproduce at 3 mm depth (Frankel, 1972), and although specimens of the most abundant taxa were composed almost entirely of adults, it seems unlikely that the deep occurrence of live foraminifera within the sediment was due to reproductive activities. Subsurface *E. crispum* from both Withyhedge cores show less size range variation than surface specimens. Deep sections of core contained mainly adults with few juveniles in the 1994 core and only adults in the 1995 core (Figure. 6.10) which exclude the possibility that this is a reproductive event. Analysis of meteorological data has revealed that there were no exceptional wind or rain conditions prior to the sampling date, so potential burial by storm activity has been discounted. The observation by Palmer *et al.* (1986) that storm activity and increased flow rates caused foraminifera to vertically migrate is not appropriate as these phenomena were not present. These deep sub-surface occurrences of foraminifera were observed at the same depth and locality on subsequent years, as yet it is speculated that these species perhaps colonised this portion of the sediment to access food, or that this section of sediment may be less heavily predated than the surface sediment and the foraminifera subject to less intraspecific competition. Foraminiferal life positions probably vary with environmental conditions and time (Jorissen, 1992; Buzas *et al.*, 1993; Alve & Bernard, 1995) and further research is required to establish if this assemblage in deep sediments persists at the depth found throughout an annual cycle. Foraminifera living deep within the sediment have been documented by numerous workers (Corliss, 1985; Moodley & Hess, 1990; Corliss & van Weering, 1992; Murray, 1992), although the dominant species within the 13 cm to 28 cm zone (*E. crispum*) has not previously been recorded as having a deeply infaunal habit.

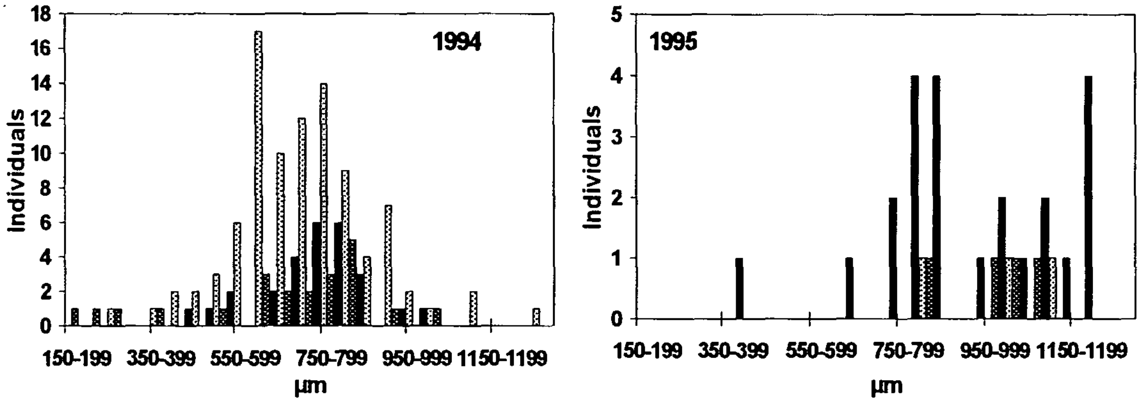


Figure 6.10 Size distribution of *Elphidium crispum* from Withyhedge Beacon cores for 1994 and 1995. Foraminifera from the 1 cm section - white, 13 18 cm section grey and 18 - 28 cm section - black. Abundance show on Y axis.

Localities for which two cores were retrieved in different years revealed that foraminifera distribution within the sediment exhibit moderate inter-annual variation but are reasonably consistent.

The efficiency of the Murray Grab to retrieve a significant and representative part of the living foraminiferal assemblage by sampling the top 1 cm of the sediment is evaluated. Samples collected by this method are representative of the total live assemblage within muddy sediments, but less representative of the live assemblage within sandy sediments: a deeper section of 3 cm depth would be advantageous in sandy sediments as porcellaneous forms may be under-represented (these forms exhibited their highest abundance within the 2 cm and 3 cm zones). Numerical abundance and biomass may be significantly under-estimated in areas of sandy and gravelly sediments by sampling the uppermost 1 cm. Although deep infaunal species may be under-represented as a result of sampling the top 1 cm, live species which commonly occurred in the subsurface were also present in the top 1 cm: hence a proportion of species assumed to be deeply infaunal were represented at the surface. Foraminiferal species sampled by the Murray Grab and the cores were compared and, generally, correlation was good. Almost all species collected from the cores are represented in the Murray Grab samples. From Table 6.1, the life-position of the more commonly encountered living foraminiferal species has been tentatively inferred from their distribution within the cores. Definitive conclusions of depth habitats could not be drawn as live foraminiferal abundance was too low.

6.8. CONCLUSIONS

(I) A small proportion of living foraminifera are generally found to be living at great depth. Live foraminifera (including taxa which are regarded as infaunal) are very abundant within the uppermost centimetre of muddy facies, but had a more diffuse distribution and are most abundant within the uppermost 3 cm of sandy sediments

(II) Sampling live and dead specimens has shown that the maximum abundances of living foraminifera occur within the upper 1 cm of cores (with the exception of Withyhedge Beacon in April, 1995). The sampling of sandy sediments may result in a collection of a significantly reduced living assemblage. The upper 1 cm of all the cores contain representatives of infaunal taxa, although the infaunal and deeply infaunal taxa may be under-represented in Murray Grab samples.

(III) Withyhedge Beacon cores reveal the normally epifaunal *Elphidium crispum*, together with *Nonion depressulus* and *Ammonia beccarii batavus,* living at comparatively great depths (13-28 cm). These unusual results require further research to ascertain the extent and causes of the observed phenomenon.

(IV) The dead assemblages were generally characteristic of their environments. There were no discernible trends within the distribution of species throughout the cores, although analysis of test types showed a small decrease of agglutinated taxa down the cores.

CHAPTER SEVEN

7. RADIO ISOTOPES AND SEDIMENT ACCUMULATION

7.1. Introduction

Recent sediments (deposited within the last 200 to 300 years) can be dated using radioactive isotopes. These isotopes have a variety of origins. Caesium 137 (^{137}Cs) is produced during nuclear fission and its presence in the environment is due to nuclear weapons testing or to releases from nuclear reactors. The widespread global dispersal of ^{137}Cs within the environment began with nuclear tests in 1952 (Perkins and Thomas, 1980). Lead 210 (^{210}Pb) has an atmospheric origin or can be derived from sediments containing ^{210}Pb. It can be used to date sediments up to a few hundred years. Beryllium 7 (^{7}Be) has a cosmic origin, and with a particularly short half life is used to determine rates of sediment mixing. Cobalt 60 (^{60}Co) is derived almost entirely from nuclear powered submarines while potassium 40 (^{40}K) is abundant in clay minerals.

In May 1995 sediment cores were retrieved using plastic core tubes with an internal diameter of 7.5 cm and length of 60 cm, from 3 areas dominated by mud rich sediments within Plymouth Sound; Anchorage Beacons, Barn Pool and the Breakwater (Figure 7.1).

7.2. Core Areas and Descriptions

Radio-isotopes are most abundant in fine grained sediments, particularly clay, fine silt and organic material, and to which they are strongly absorbed (Tamara and Jacobs, 1960; Brisbin *et al.*, 1974; Ritchie and McHenry, 1990), and are virtually absent from clean sands and gravels. In order to measure whether radio-isotopes are present, and in what amounts, samples must be rich in fine grained sediments.

Sediments which have highly variable amounts of clay, silt and sand i. e. heterolithic sediments, may create problems in interpreting the isotope profiles.

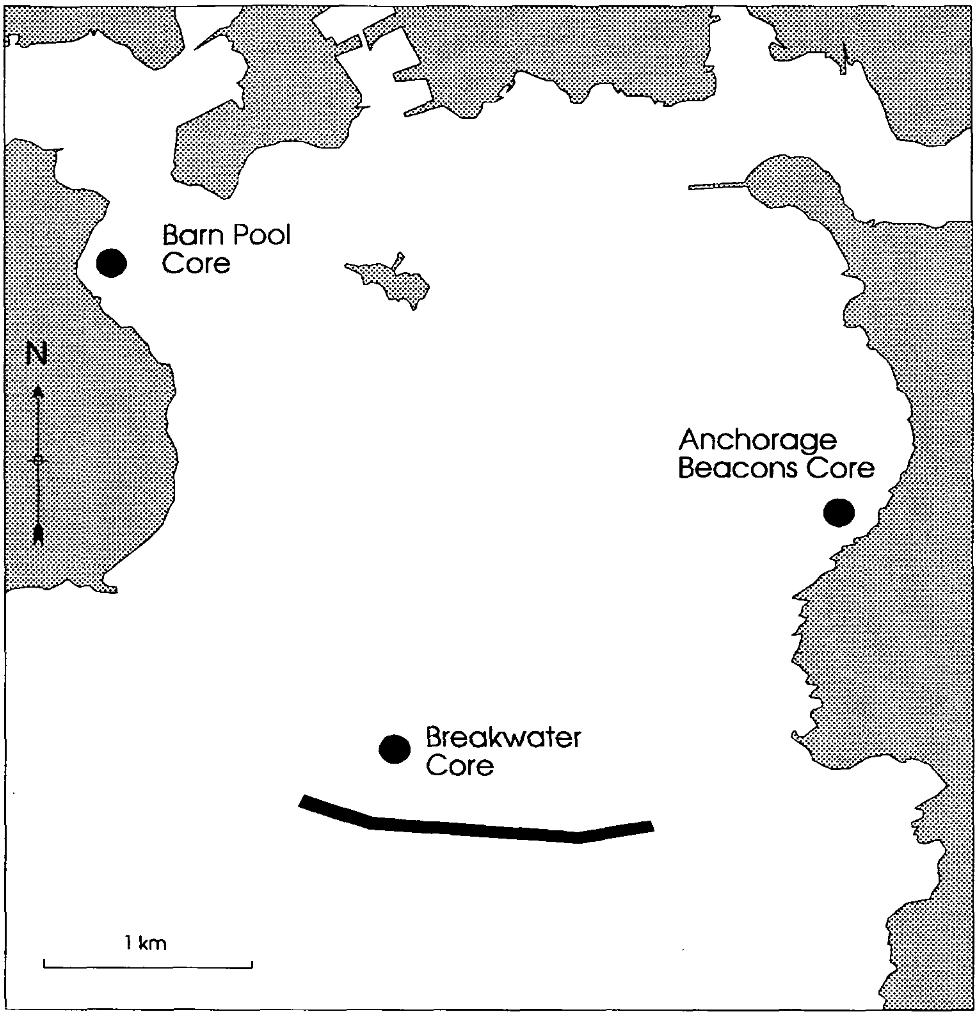


Figure 7.1 Map of Plymouth Sound showing the areas from which the cores were collected.

The Anchorage Beacons site is situated on the eastern side of the Sound (Figure 7.1). It is the least protected site analysed for radio-isotopes and also has the lowest levels of silt and clay (approximately 30%) although it is relatively homogenous. The sediments of Anchorage Beacons and the other core localities are described in more detail in Chapter 5.

Anchorage Beacons Core Description

The Anchorage Beacons core was approximately 38 cm in length. The uppermost 1 cm was composed of brown oxidised sediment, below this the sediment was fairly uniform, dark grey, cohesive clayey sand, with occasional shell fragments and small pebbles.

Barn Pool is located in the north west corner of Plymouth Sound within a natural embayment near the mouth of the Tamar Estuary (Figure 7.1). The sediment at Barn Pool includes a range of grain sizes but is dominated by black silt and clay (approximately ≥50%). The firm, compact sediment and the presence of pebbles suggests that this area, although generally low energy, experiences periods of higher energy, perhaps due to tidal scour. Worm tubes (living and dead) were present in this area, as were the disarticulated valves of several bivalve species. This suggests that the sediment may be reworked by various processes.

Barn Pool Core Description

A sediment core 41 cm in length was retrieved. The uppermost few centimetres were of brown, sandy mud which graded into approximately 20 cm of black silt. At 22 cm another gradational boundary occurs below which the sediment is coarser, firmer and paler in tone. Other features of the core were several bivalves at 22 cm below the surface and a large pebble at 25 cm below the surface.

The Breakwater site is the most sheltered and as a result is dominated by very soft silt and clay rich sediments (approximately 70%-80% silt and clay). This area of the breakwater is relatively undisturbed by wave action or dredging. An abundant macrofauna was present, including a variety of living worm tubes, gastropods and bivalves.

Breakwater Core Description

The Breakwater core displays a thin, oxidised sediment layer in the uppermost 1 cm of the core. From 0 cm to 24 cm there is abundant evidence of bioturbation, mainly the burrows of small worms, below 24 cm there is no evidence of bioturbation and the core sediment is structureless and homogenous. Other features of the core are an articulated bivalve (dead) approximately 3 cm in diameter, at 12 cm below the surface. At 22 cm below the surface a large watery lens of orange organic material was present, its origin is unknown.

7.3. Caesium 137

The first major emissions of ^{137}Cs occurred in 1952 and so the first occurrence of ^{137}Cs within the cores is taken as correlating with the 1952 fallout (although there may be a time lag of several months or a year between atmospheric emission of ^{137}Cs and its deposition). Caesium 137 emissions form two distinctive peaks in the northern hemisphere during 1958 and 1963/4 (Cambray *et al.*, 1981). The ^{137}Cs in all cores showed variable distributions decreasing down core without significant spikes. The peak emissions of ^{137}Cs are unrecognisable. This suggests the ^{137}Cs has been mobilised or reworked vertically within the sediment. A number of studies (Robbins and Edgington, 1975; Hakanson and Kallstrom, 1978; Krezoski and Robbins, 1985; Sharmer *et al.,* 1987) have reported the redistribution of ^{137}Cs. In general, any reworking of the sediment broadens the ^{137}Cs peaks and makes interpretation more difficult, however such redistribution should not change the position of any major ^{137}Cs horizons (Pennington *et al.*, 1973; Wise 1980; Cambell, 1982).The first occurrence of the ^{137}Cs is used to calculate the maximum sediment accumulation rate. Caesium 137 may migrate downwards within the sediment through bioturbation and wave action (Robbins and Edgington, 1975; Hakanson and Kallstrom, 1978; Krezoski and Robbins, 1985; Sharmer *et al.,* 1987), but is unlikely to completely move upwards within the sediment. The calculated accumulation rate is, therefore, a theoretical maximum and may be less if the ^{137}Cs has been moved downwards after deposition. In areas of low sediment accumulation, reworking of ^{137}Cs and the inability to sample in sufficient detail (to determine ^{137}Cs horizons) may create an indistinct ^{137}Cs profile (Ritchie and McHenry, 1990).

7.4. Lead 210

Lead 210 is derived from eroded or reworked sediments, soils, or from the atmosphere. The Radium isotope ^{226}Ra decays to form an inert gas ^{222}Rn, which rapidly decays to form ^{210}Pb. Lead 210 is then removed from the atmosphere and transported to the ground by rain, snow or dry fallout. Theoretically sediments labelled with ^{210}Pb, deposited and buried within a relatively undisturbed environment of constant sediment accumulation (assuming a constant supply of ^{210}Pb) should exhibit a smooth decrease downwards as the ^{210}Pb decays with time. An example of this can be observed within salt marsh and some lake sediments (Oldfield and Appleby, 1984).

The ^{210}Pb data from all the cores exhibits a very irregular trend down the core, suggesting a quite different environment to the lake or salt marsh example described above. The ^{210}Pb profile reflects a dynamic environment in which sediment accumulation has not been constant and/or the sediment has been reworked by storms or bioturbation. Within the Anchorage Beacons and Barn Pool cores at 23 cm and 24 cm respectively an area of very low ^{210}Pb values occurs (by diluting the original sediment with sediment of very low ^{210}Pb content). A reduction in ^{40}K also correlates with low ^{210}Pb levels at Barn Pool. At Barn Pool this lower value coincides with a gradational boundary within the sediment core, further indicating a change in style of sedimentation. These anomalies at both these locations may represent prominent storm events but because both of these very low ^{210}Pb values come from areas with different sediment accumulation rates they are unlikely to be related even though they occur at a similar depth.

7.5. Radio-Isotopes within the Sediment Cores

The first occurrence of ^{137}Cs at Anchorage Beacons is detected at a depth of 17 cm giving a maximum sediment accumulation rate of 17 cm per 43 years (1952-1995) or an average of 0.40 cm/yr. Lead 210 correlates very well with this rate giving an accumulation rate of 0.42 cm/yr.

The first occurrence of ^{137}Cs at Barn Pool is detected at 29 cm suggesting a possible maximum sediment accumulation rate of 29 cm per 43 yrs or an average of 0.67 cm/yr. The ^{210}Pb data suggest a very different rate of 0.19 cm/yr.

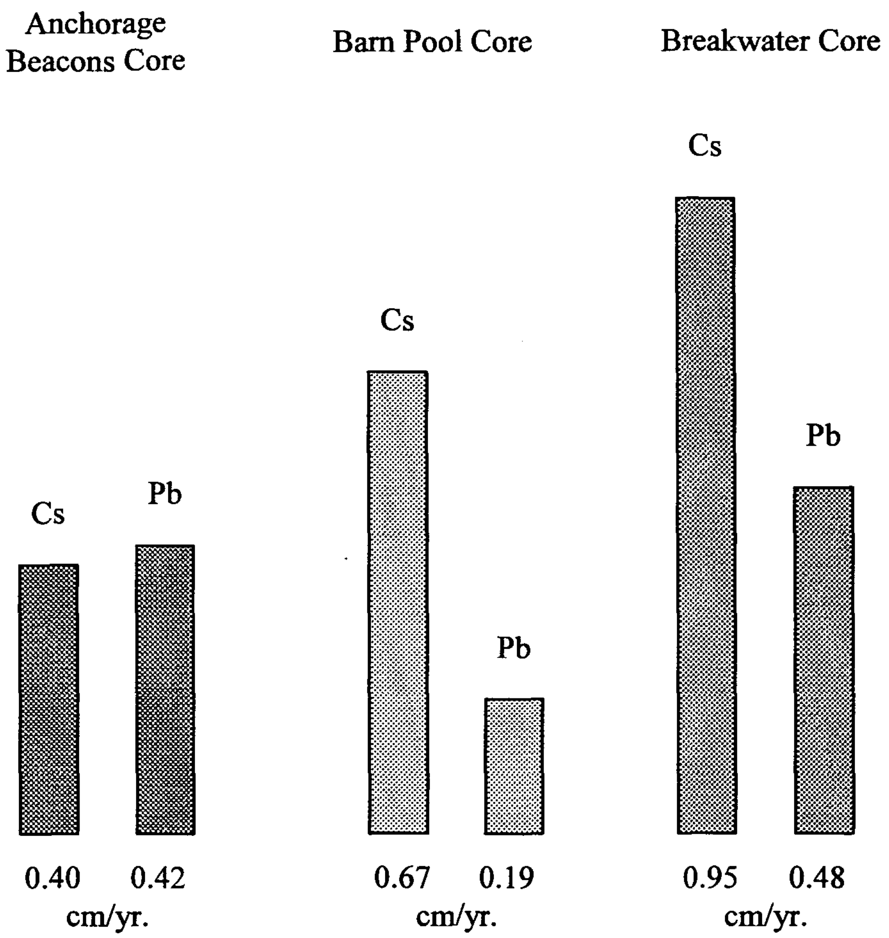


Figure 7.2 Sediment accumulation rate (centimetres per year) for each locality, calculated using Caesium 137 (left) and Lead 210 (right).

The first occurrence of ^{137}Cs at the Breakwater was detected at the base of the core inferring that caesium continues down beyond the core The possible sediment accumulation rate is therefore ≥ 41 cm per 43 yrs or on average ≥ 0.95 cm/yr. Lead 210 data gives a sediment accumulation rate of 0.48 cm/yr.

The large discrepancy in sediment accumulation rates calculated by ^{210}Pb and ^{137}Cs at Barn Pool and the Breakwater may be due to errors in measuring isotope activity or in calculating accumulation rates. Assuming that these errors are negligible, a possible explanation for the lowest occurrence of the ^{137}Cs is that it has been mechanically moved down within the sediment by dynamic processes as both cores were retrieved from fine grained environments with abundant worm tubes. It is possible that bioturbation may have resulted in a lower ^{137}Cs first occurrence.

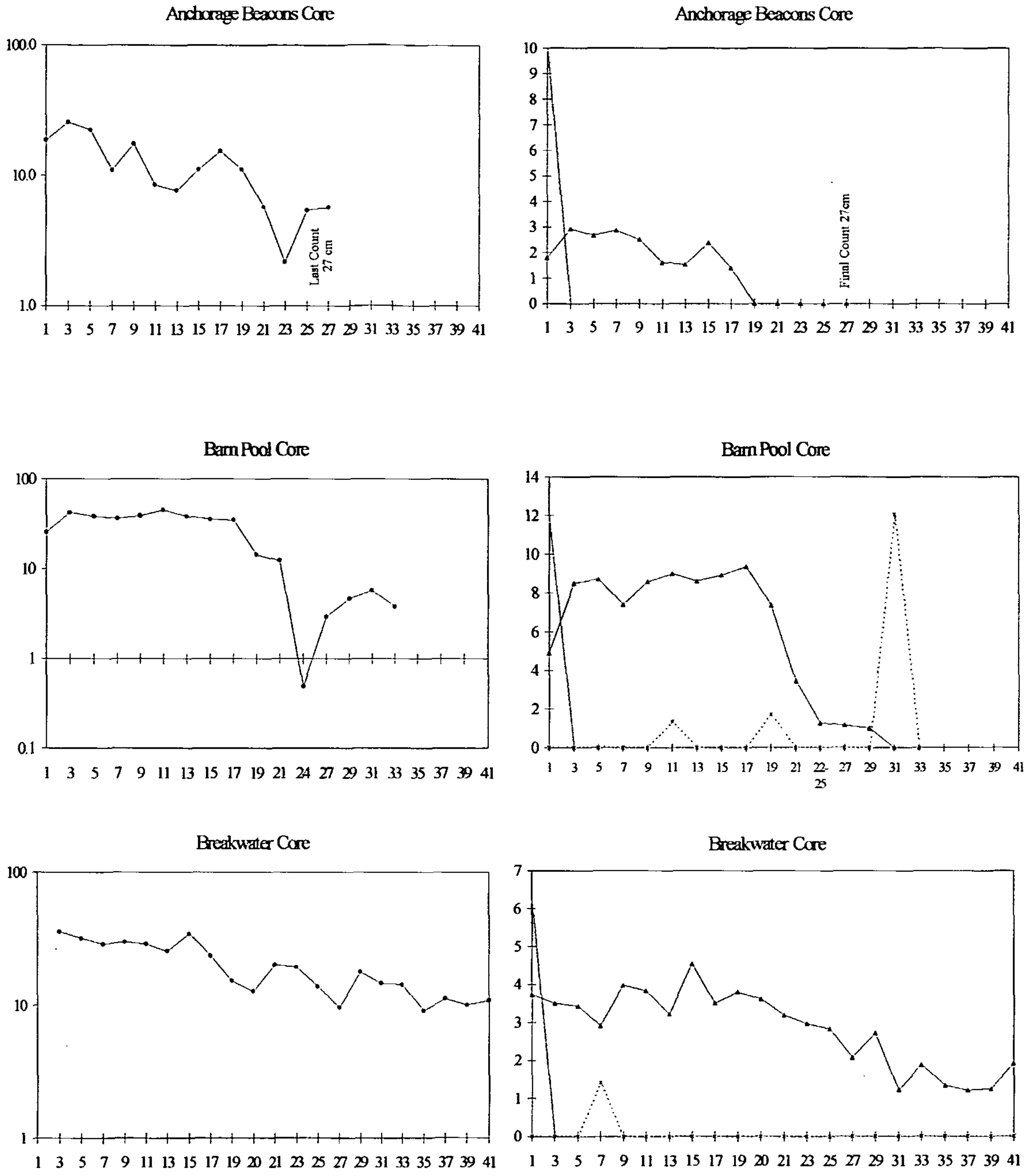


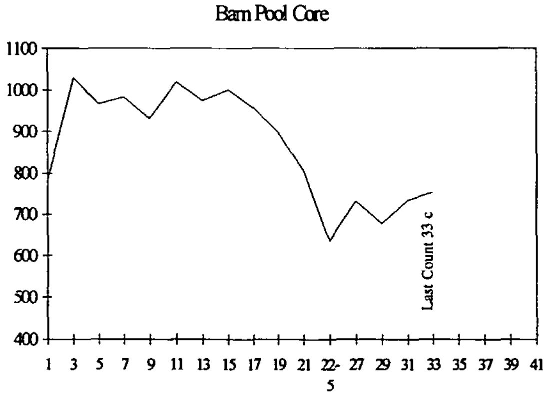
Figure 7.3 On the left column, profiles of lead 210 from the three cores (the X axis are cm down the core, the Y axis are Bq per Kg. The right column shows the profiles of caesium 137 (black), Beryllium 7 (blue) and Cobalt 60 (purple). The X axis represents depth down the core, the Y axis the quantity of isotope (Bq per Kg).

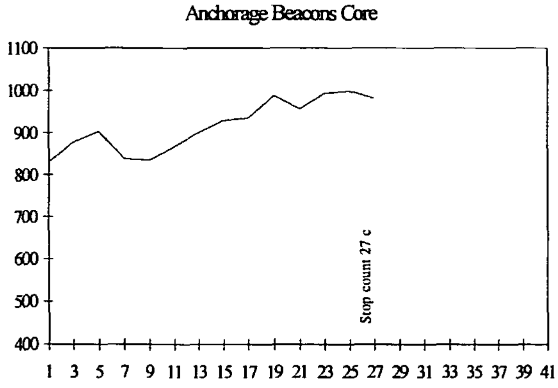
7.6. Other Radio Isotopes

The occurrence of ^{60}Co is very isolated and discontinuous. It does not provide very much useful information. The largest peak of ^{60}Co occurred at 31 cm depth in the Barn Pool core which is likely to be a spurious data point resulting from an error in measurement or contamination. This view is further reinforced by its occurrence before the occurrence of ^{137}Cs i.e. pre 1952. A bivalve from the same core showed a very high level of ^{60}Co.

Beryllium 7 is derived from cosmic sources and is concentrated in the stratosphere. Because it has a very short half life (53.3 days) it is a good indicator of rapid sedimentation or mixing of surface sediment with deeper sediment. Its signal is only detectable for a few weeks or months before decay renders it too weak. In all of the cores ^{7}Be is present within the top 1 cm but absent from the next sample at 3 cms.

Potassium 40 is derived from radioactive potassium within clay minerals. The abundance of ^{40}K is proportional to the amount of clay minerals present within the cores. Potassium 40 provides additional information about the history of sedimentation within the area although its signal is affected by bioturbation, sediment mixing, dewatering and compaction. Anchorage Beacons and the Breakwater cores show a relatively constant amount of ^{40}K (Figure 7.4). The Barn Pool core shows quite high amounts of ^{40}K for the same period but below 22 cm the amount of ^{40}K shows a sharp drop and remains low, which almost certainly reflects a change in sedimentology.





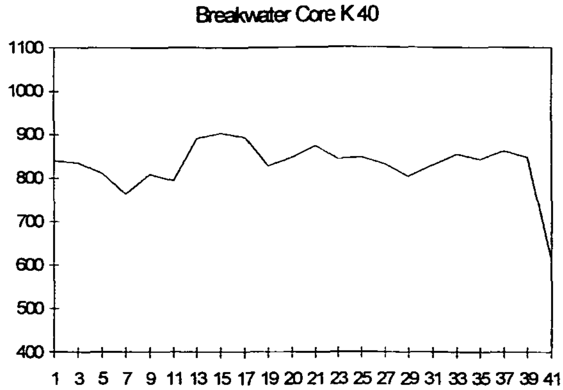


Figure 7.4 The profiles of Potassium 40 throughout the three cores. The X axis represents depth down the core, the Y axis the quantity of isotope (Bq per Kg).

7.7. Discussion

The combined use of ^{210}Pb and ^{137}Cs has proved very useful in calculating sediment accumulation rates at the three localities within Plymouth Sound. Caesium 137 and ^{210}Pb have often been used in conjunction (Mackenzie *et al*,. 1979; Pourchet and Pinglot, 1989). Both (^{137}Cs and ^{210}Pb) isotope sediment accumulation rates exhibit a very good similarity at Anchorage Beacons where the sediment accumulation rate is about 0.40 cm/yr. (Figure 7.2). At Barn Pool and the Breakwater there is a large disparity between sediment accumulation calculated using ^{210}Pb and ^{137}Cs (Figure 7.2). These areas were characterised by worm tubes and other macrofauna and it is likely that this macrofauna resulted in the downward mixing of the ^{137}Cs bearing sediment so resulting in a thicker layer of sediment containing ^{137}Cs and subsequently a larger calculated rate of sediment accumulation. The use of ^{137}Cs alone would have resulted in erroneous sediment accumulation rates. Lead 210 has a deeper more even distribution and because of the way the accumulation rate is determined (regression of ^{210}Pb data points to provide an average rate with spurious data points removed) it is less likely to be disturbed by bioturbation and so result in a more accurate accumulation rate.

The distribution and profiles of both the ^{137}Cs and the ^{210}Pb isotopes throughout the sediment are very indicative of the sedimentary environment within these areas. Caesium 137 usually has a very irregular profile showing several prominent ^{137}Cs spikes (correlating to peaks in emissions of this isotope in 1958, 1963/4 and 1986). These spikes are not evident in any of the cores and, generally, the profile of ^{137}Cs showed only very minor variation. This has been interpreted as the result of a dynamic environment where sedimentation may not be constant and may be reworked by various processes (waves, tides and bioturbation). The ^{210}Pb profile implies a similar environmental history as its distribution should gradually diminish with depth, in a relatively smooth line. Instead the ^{210}Pb profiles of all the cores exhibit many peaks and troughs indicative of a dynamic sedimentary environment with periods of low sediment accumulation (high ^{210}Pb) and high accumulation (low ^{210}Pb), possibly as a result of storm events.

The ^{210}Pb and ^{137}Cs isotopes are ideally suited for dating low energy environments which have a constant sedimentation rate such as lakes, reservoirs and salt marshes (Robbins and Edgington, 1975; Appleby *et al.,* 1979; Pourchet and Pinglot, 1989; Ritchie and McHenry, 1990)

The distribution of the ^{7}Be isotope indicates that, although the environment is dynamic, sediment turn over and mixing are not very rapid, at least in the period proceeding the recovery of the cores.

The highest sediment accumulation rates of approximately 0.48 cm/yr. were recorded at the Breakwater site. This relatively high rate may reflect a large capacity for sediment accommodation, due to the presence of the Breakwater. Anchorage Beacons on the eastern side of the Sound displays sediment accumulation rates of 0.40 cm/yr., this indicates a reasonable capacity for sediment accommodation. The very low accumulation rate of 0.19 cm/yr. exhibited by Barn Pool indicates that at this locality there is little room for sediment accommodation or that scour removes and ensures that sedimentation levels are low (Barn Pool is least protected by the breakwaters).

7.8. Conclusion

- At two of the three areas there is a disparity between sediment accumulation rates based on ^{137}Cs and ^{210}Pb which results from sediment mixing probably by bioturbation.

- The sediment accumulation rate for Anchorage Beacons on the eastern side of the sound is 0.40 cm/yr.

- The sediment accumulation rate for Barn Pool at the north western end of the Sound are 0.19 cm/yr. (^{137}Cs has been reworked downwards at this site).

- The sediment accumulation rate for the Breakwater at the southern end of the Sound are 0.48 cm/yr.(^{137}Cs has been reworked downwards at this site).

- Both ^{210}Pb and ^{137}Cs indicate a dynamic and turbulent sedimentary history in which sediment mixing by macrofauna and storms has occurred.

CHAPTER EIGHT

8.0 THE LIVE ASSEMBLAGE

8.1. Morphogroups and inferred modes of life

The foraminiferal test shape reflects its mode of life (feeding strategy and position within/on the substrate) and environment. The test is suited to the mode of life of the foraminifera; e.g. an attached form may have a plano or concavo-convex test allowing it a large attachment area with little resistance to currents and waves. A suspension feeder may have a delicate branching test with large surface area. The energy of the living environment may also be reflected in the construction of the test. Within Plymouth Sound, many elongate, thin, delicate tests of some species of nodosarids are found living exclusively in muddy low energy environments, while the strong fusiform tests of some miliolids are found in high energy areas.

Lipps (1983) suggests that passive and active herbivores living within the photic zone are commonly trochoid, lenticular or flattened in form. Haynes (1981) estimates that these forms make up 52% of rotaliids throughout the geological record. Herbivores may be passive at times of abundant food and active when food is sparse. Lipps (1983) observed *Rosalina* in passive and active feeding states on algae, whilst *Cibicides* was only observed feeding passively on algae.

Many foraminifera are probably omnivorous at one time or another, not feeding exclusively on only one food type. Omnivores appear not to have a particular test preference associated with this generalist feeding mode. Carnivory is believed to be a less common feeding strategy, although foraminifera have been observed trapping small arthropods. within their pseudopodia (Buchanan and Hedley, 1960). No particular test form is associated with this type of feeding.

Suspension feeders usually have an erect test with aperture/s pointing away from the substrate. Suspension feeders are often cemented on hard substrates or rooted in soft substrates (Lipps, 1983). Morphologies which allow deployment of pseudopodia in two or more dimensions are suited to suspension feeding. Suspension feeders may also possess tests with large surface areas (Lipps, 1983) as this allows more area from which to deploy pseudopodia.

Detritivores and scavengers (feeding mainly on bacteria and plant fragments) may live on the sediment surface, although many probably burrow through the sediment in search of food. Detritivores, which commonly live within the sediment, have elongate tests thereby maintaining volume while reducing cross sectional area. This reduces the force needed to move through the sediment (Lipps, 1983).

Parasitism was reported by Haynes (1981) in *Lagena* and *Discorbis mediterranensis* (in this study *Discorbis mediterranensis* = *Planorbulina mediterranensis*), whilst Lipps (1983) speculates that many species with spherical/oval tests and/or long necks may have a parasitic mode of life.

Within the photic zone, foraminifera adopting an epifaunal feeding strategy or mode of life may also harbour symbionts. Lipps (1983) associates symbiont bearing foraminifera with large, complex, heavily calcified tests. These are often discoidal in form thereby increasing the surface to volume ratio.

Many workers have successfully used foraminiferal morphogroups as indicators of feeding strategies and modes of life (Chamney, 1976; Jones and Charnock, 1985; Koutsoukos and Hart, 1990), to delineate biofacies (Severin, 1983) and; as indicators of the amount of organic carbon (Corliss and Chen, 1988) and oxygen (Bernard, 1986) in marine environments

Table 8.1 shows the feeding strategies that have been inferred from morphology. Additional data on mode of life and feeding strategy is inferred from the sediment cores which were discussed within Chapter 5. Studies from other areas have been useful in ascertaining morphology and mode of life (Murray, 1991; Corliss and Fois, 1990; Koutsoukos and Hart, 1990; and Jones and Charnock, 1985).

Table 8.1 shows the principal morphogroups, feeding strategies and inferred life position of the more common taxa. Also shown are the most commonly associated sediment types with each morphogroup and the inferred energy levels.

The morphogroup numbers (1 to 12) are shown with a letter prefix denoting the test type (e.g. H for hyaline test, A for agglutinated, P for porcellaneous; A6, H6 and P6 all have a conical morphology but a different wall type). Differentiating between test type may provide additional refinement to the morphogroup interpretation. For example, foraminifera species within the same morphology but different test type may have dissimilar feeding strategies or life position. Although this apparently goes against the principles of morphogroups, some authors exclude various test types from their analysis. Corliss and Fois (1991) based their study on calcareous fauna alone as have Corliss and Chen (1988), whereas Jones and Charnock (1985) have applied their model only to agglutinated faunas. The segregation of test type in morphological studies suggests inherent differences within these groups. The system adopted in this study allows test types to be analysed together or separately.

Corliss and Chen (1988) observe that in conditions of high organic carbon and/or oxygen, infaunal morphogroups predominate, while in conditions of low organic carbon and/or oxygen, epifaunal morphogroups predominate. This is because when little food or oxygen are available a less energetic mode of life is advantageous but plentiful food and/or oxygen can sustain higher energy modes of life which may have greater success.

	Morphology	Examples	Mode	Position	Sediment type	Energy
1	Rounded planispiral to low trochospiral	*E. williamsoni, A. beccarii*	Herbivore	infaunal to epifaunal free	muds	low
2	Flattened planispiral	*Cyclogyra, Spirillina*	Herbivore?	epifaunal clinging	~	moderate?
3	Biconvex lenticular	*Lenticulina, E. crispum*	Herbivore, Detritivore	epifaunal free	sand, muddy sands	moderate to low
4	Plano-convex to Concavo-convex	*Cibicides, Rosalina, Planorbulina*	Herbivore, Detritivore Suspension	epifaunal attached	sands gravels	high
5	Cylindrical	*Dentalina, R. moniliformis*			muds	low
6	Conical	*Eggerelloides, Bulimina*	Detritivore	infaunal	muds	low to moderate
7	Tapered pyramidal to wedge shape	*Textularia*	Detritivore	epifaunal clinging	gravels/sand large tests muds	very high large tests low
8	Fusiform	*Q. lata, Q. seminulum*	Herbivore Detritivore	epifaunal free/clinging infaunal free	gravel/sands, mixed, muds	high to low
9	Flattened fusiform	*Q. cliarensis, Massilina*	Herbivore (Epiphytic)	epifaunal clinging infaunal free	all types	high to low
10	Flattened tapered	*Brizalina Spiroplectammina*	Detritivore	infaunal free	muds	low
11	Spherical/subspherical	*Globulina, Lagena*	Parasite? Omnivore Detritivore	infaunal	muds	low
12	Tubular flattened, branching	*Cornuspira*	Suspension	epifaunal/infaunal	muds, mixed	low

Table 8.1. 12 morphogroups are shown; feeding strategy and mode of life are inferred. The morphogroups are labelled with a number from 1 to 12; subgroups have then been created by attaching a letter in front of the group number to denote test type. H indicates hyaline, P porcellaneous and A agglutinated, e.g. P8 would refer to a fusiform test which is porcellaneous whilst A6 an agglutinated test which is conical

8.2. Location 1

8.2.1. Introduction

This location is characterised by clean, fine, well-sorted sands. It represents the most marine site as it is the only station situated outside the Breakwater. Foraminiferal abundance and diversity were generally low.

8.2.2 Foraminiferal Abundance

The total density of foraminifera throughout the year (Figure. 8.1) was greatly influenced by the abundance of *Elphidium crispum*. The abundance of other species of foraminifera was very low (< 20 individuals in total). From December to March the total foraminiferal abundance was very low. Abundance increased slightly during April and May (40 individuals), dropped during June but exhibited a relatively large peak of 179 individuals (120 individuals of *E. crispum* alone) during July. This represents the maximum observed number of individuals that the site was able to support. Abundance then dropped to very low numbers for the remainder of the year.

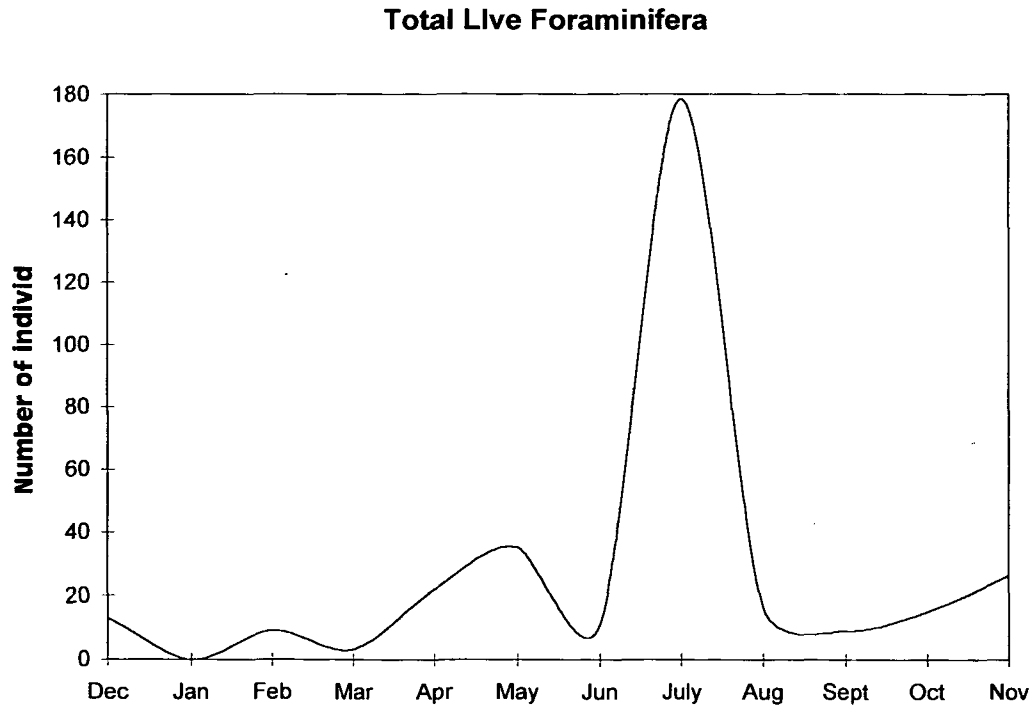


Figure. 8.1. Total abundance of foraminifera (per 100cm^3 of sediment) at Location 1, between December 1993 and November 1994.

A yearly total of 226 foraminifera (per 100 cm^3) were produced at this locality. Losses and gains were small throughout most of the year but production was high in July and immediately followed by equally high losses in August (Figure 8.2).

	Total Live	**Gains**	**Losses**
December 1993	13	0	0
January 1994	0	0	13
February	9	9	0
March	3	0	6
April	22	19	0
May	35	13	0
June	11	0	24
July	179	168	0
August	17	0	162
September	9	0	8
October	15	6	0
November	26	11	0
	339	**226**	**213**

Table 8.2. Production is calculated on the following: Gains=Births>deaths, Losses = deaths>Births. Highs in production (April and July) are rapidly followed by high losses (May and August). Production (gains) and mortality or removal (losses), both are low but the similarity between the totals indicates a complete cycle/s.

8.2.3. Species Abundance

Elphidium crispum was the principal species accounting for 40% of the assemblage. *Ammonia beccarii batavus* accounted for 19%, while other important species at this locality were *N. depressulus* (7%), *Q. oblonga* (5%), *P. mediterranensis* (4%). *Elphidium scabrum* and *Q. lata* which accounted for 3% of the assemblage.

	Absolute	**%**
Elphidium crispum	**136**	40
Ammonia beccarii batavus	**65**	19
Nonion depressulus	**23**	7
Quinqueloculina oblonga	**18**	5
Planorbulina mediterranensis	**15**	4
Eggerelloides scabrum	**11**	3
Quinqueloculina lata	**11**	3
Psammosphaera bowmani	**9**	3
Bulimina elongata	**6**	2
Miliolinella circularis	**6**	2
Quinqueloculina seminulum	**5**	1

Brizalina pseudopunctata	4	1
Elphidium gerthi	3	1
Textularia truncata	3	1
Elphidium cuvillieri	3	1
Massilina secans	3	1
Textularia sagittula	3	1
Bulimina gibba	2	1
Rosalina williamsoni	2	1
Quinqueloculina aspera II	2	1
Clavulina obscura	2	0
Quinqueloculina aspera I	2	0
Reophax scottii	2	0
Spiroplectammina wrightii	2	0
Brizalina striatula	1	0
Elphidium earlandi	1	0
Stainforthia concava var. *loeblichi*	1	0

Table 8.3. All species recorded at Location 1 throughout the year in order of abundance. Values in absolute (Abs.) and percentage (%) abundance.

8.2.4. Species Distribution

During December 1993, January and February 1994, foraminiferal abundance were very low. *Quinqueloculina lata, Q. oblonga, A. beccarii batavus* and *Elphidium crispum* were represented by very few individuals (Figures 8.2 and 8.3).

From March to June numbers of all these species remained low and several other species were only recorded over a short period. *Eggerelloides scabrum* appeared during May, *N. depressulus* during April to July; abundance of these foraminifera was also very low. During July *Psammosphaera bowmani* Heron-Allen and Earland and *P. mediterranensis* occurred as discontinuous populations, although *E. crispum* which had been found in very low numbers exhibited a large peak of 120 individuals. During August to November foraminiferal abundance was again very low.

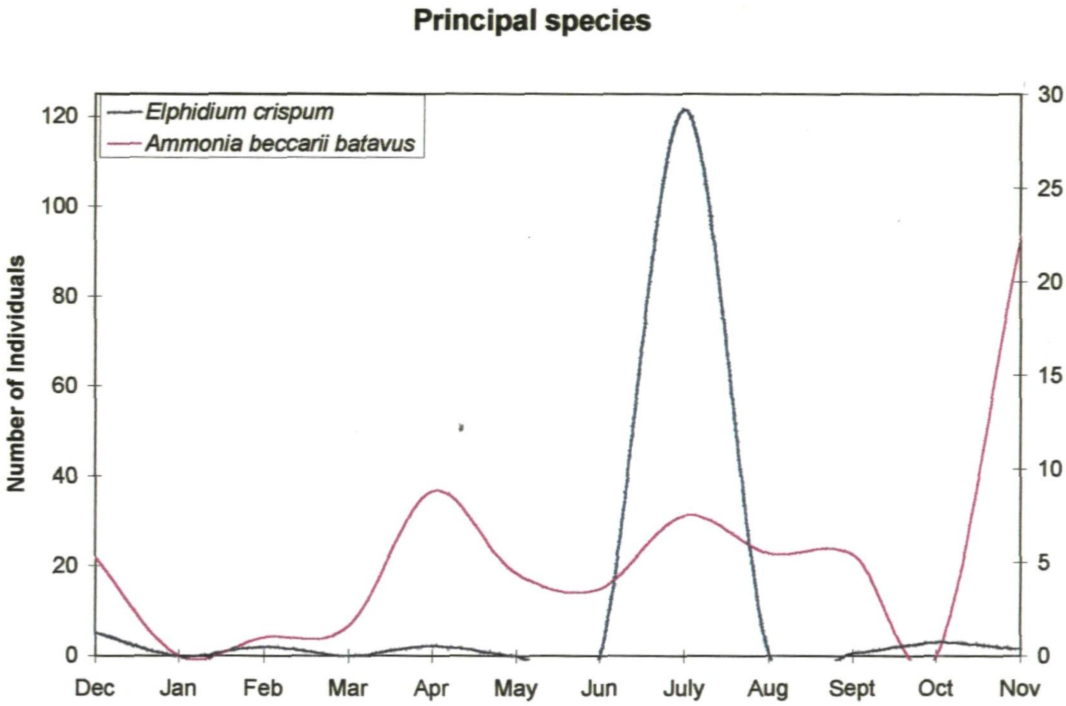


Figure. 8.2. Species trends of the two most abundant species plotted separately from other species because of the difference in scale. *Elphidium crispum* is plotted on the left axis and *Ammonia beccarii batavus* on the right or secondary axis.

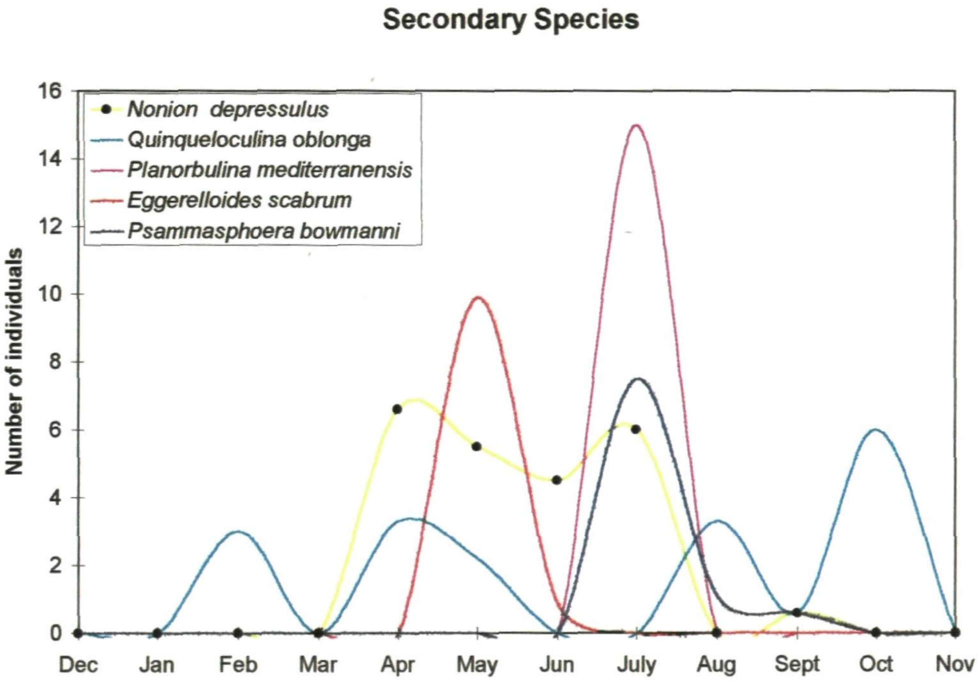


Figure. 8.3. Species trends of minor species; many taxa occur as isolated populations and are not found consistently throughout the year.

8.2.5. Diversity

Diversity was moderate to low during the higher foraminiferal abundances of the summer but very low for the remainder of the year due to very low abundance of foraminifera. Figure 8.4 shows two peaks in diversity, firstly in May as foraminiferal abundance increased slightly and a second peak of similar magnitude in July as foraminiferal abundance reached a maximum. A total of 27 species were recorded from Location 1 throughout the year. The yearly total (sum of all live foraminifera throughout the year) Fisher Alpha diversity was 7.

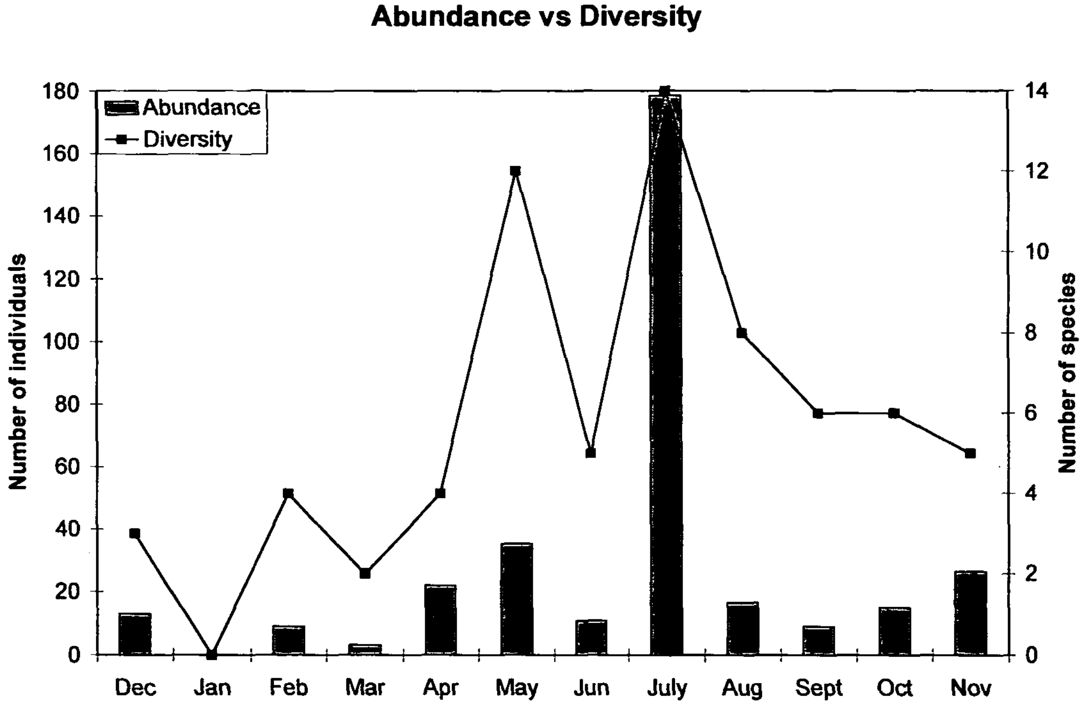


Figure. 8.4. Comparison of species abundance against species diversity throughout the year at Location 1

8.2.6. Morphogroups

Table 8.4 shows the abundance of foraminiferal species and their morphogroup allocation. The most common groups are the free living epifaunal species which belong to the keeled planispirals (H3) and the fusiform group (P8). Other important groups are the free living rounded planispirals (H1) which tend to be infaunal. *Planorbulina mediterranensis* and *Rosalina williamsoni* represent the attached plano-convex morphogroup (H4).

Location 1 is dominated by free living epifaunal species (*E. crispum* and the species belonging to the genus *Quinqueloculina)*. Also important are the infaunal free living species such as *A. beccarii batavus* and *N. depressulus*. The presence of attached species indicates the close proximity of hard substrates (rock or plant) and/or the presence of suitable fragments for attachment.

MG		Abs	%
H3	*Elphidium crispum*	136	40
H1	*A. beccarii batavus*	65	19
H1	*Nonion depressulus*	23	7
H4	*Planorbulina mediterranensis*	15	4
H6	*Bulimina elongata*	6	2
H10	*Brizalina pseudopunctata*	4	1
H1	*Elphidium gerthi*	3	1
H1	*Elphidium cuvillieri*	3	1
H6	*Bulimina gibba*	2	1
H4	*Rosalina williamsoni*	2	1
H10	*Brizalina striatula*	1	0
H1	*Elphidium earlandi*	1	0
H8	*Stainforthia* cf. *concava* var. *loeblichi*	1	0
	Total	263	78

MG		Abs	%
A6	*Eggerelloides scabrum*	11	3
A7	*Textularia truncata*	3	1
A7	*Textularia sagittula*	3	1
A5	*Clavulina obscura*	2	0
A8	*Reophax scottii*	2	0
A7	*Spiroplectammina wrightii*	2	0
	Total	21	6
P8	*Quinqueloculina oblonga*	18	5
P8	*Quinqueloculina lata*	11	3
P9	*Psammosphaera bowmani*	9	3
P8	*Miliolinella circularis*	6	2
P8	*Quinqueloculina seminulum*	5	1
P9	*Massilina secans*	3	1
P8	*Quinqueloculina aspera* II	2	1
P8	*Quinqueloculina aspera* I	2	0
	Total	55	16

Table 8.4. Foraminifera are divided into three general groups; hyaline, porcellaneous and agglutinated and allocated morphogroups (columns labelled MG). Both the absolute (Abs.) and percentage (%) values of each species are shown.

8.2.7. Discussion

Species trends throughout the year are generally discontinuous, with occurrences of species often confined to one or two samples (months). The principal species *E. crispum* is absent or occurs in very low abundance (single figures) except during July where 179 individuals are recorded (Figure 8.2). This type of occurrence is typical of many of the major species, which suggests that:-

Food and associated favourable conditions are very variable. This variability is subsequently reflected within foraminiferal trends throughout the year. Particularly affected are the more opportunistic species which can rapidly increase (and decrease) their population size.

Foraminifera have a very patchy distribution within this area.

The nature of the environment at this locality (i.e. turbulent sea with strong currents) allows the transport of live foraminifera into the sample site from adjacent areas. The transported foraminifera may be out of equilibrium with the site and exceed the carrying capacity of the site (the number of foraminifera that the available resources are able to sustain) and die, reducing the population to normal (very low) levels. This may account for the short lived increase in abundance observed.

The exceptions to this pattern are *A beccarii batavus, Q. lata* and *Q. oblonga*, which are found in low abundance but exhibit a stable distribution throughout the year.

Foraminiferal populations exhibit a poor correlation with temperature and salinity. A partial correlation with temperature for the species *E. crispum, P. mediterranensis*, and *P. bowmani* is observed during July as they achieve maximum abundance associated with a rapid increase in sea temperatures (Figure 8.93). This correlation does not continue as the sea temperature reached a peak during August and remained high until at least November, whilst foraminiferal abundance dropped sharply during August and remained low for the rest of the year. Foraminiferal blooms may be triggered by abiotic factors such as temperature (directly or indirectly) but are controlled by other factors such as the abundance of food, competition, etc..

The low abundance of many species in June may be the result of a temperature induced reproductive event in which many parents dies and the juveniles were not large enough to be detected.

The generally low abundance of foraminifera may be due, in part, to the nature of the substrate. Fine sands have a high degree of mobility making colonisation difficult for many species. This site probably has low levels of nutrients and food available, resulting in a discontinuous and low abundance of foraminifera.

8.3. Location 3

8.3.1. Introduction

This site is characterised by coarse shelly sands and shell gravels. It is one of the highest energy sites within the Sound. Foraminiferal assemblages at this site were low in abundance but of relatively high diversity.

8.3.2. Foraminiferal Abundance

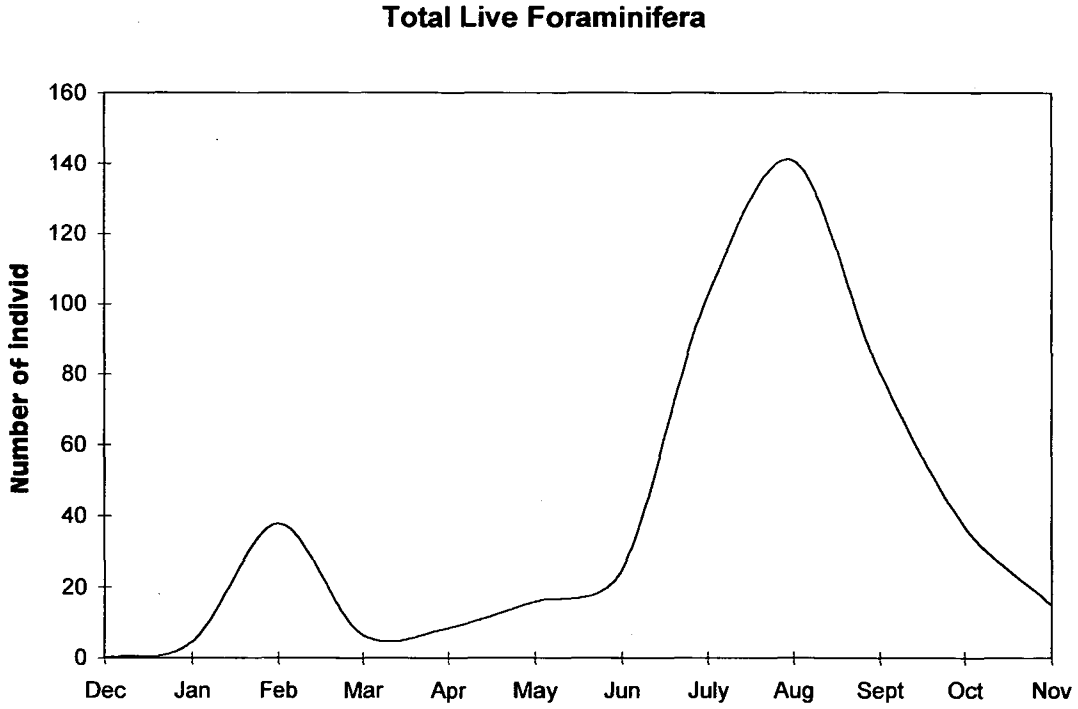


Figure. 8.5. Total abundance of foraminifera (per 100cm^3 of sediment) at Location 3, between December 1993 and November 1994.

A sample could not be collected in December 1993 because of bad weather. Foraminiferal abundance was very low during the first half of the year although a small increase in abundance was observed during February (the coldest month) see Figure 8.5. The abundance of foraminifera rose sharply in July and continued to increase in August, when it attained a maximum of 141 individuals. After August foraminiferal abundance dropped sharply until November when sampling stopped. The total yearly observed production was 172 individuals.

	Total Live	Gains	Losses
December 1993	0	0	0
January 1994	4	4	0
February	38	34	0
March	7	0	31
April	9	2	0
May	16	7	0
June	25	9	0
July	102	77	0
August	141	39	0
September	80	0	61
October	37	0	43
November	15	0	22
Total	**474**	**172**	**157**

Table. 8.5. Production of foraminifera at Location 3. Production during July was sustained and increased in August. Thereafter, losses were incurred during September, October and November.

8.3.4. Species Abundance

Location 3 is characterised by a low abundance of foraminifera. The maximum abundance of 141 individuals was reached during August and this may indicate the maximum observed number of foraminifera the site was able to sustain. The principal species were *T. truncata* and *R. williamsoni,* which made up 22% and 21% of the assemblage respectively. Other important species which characterised this area were *Quinqueloculina* spp. (12%), *P. mediterranensis* (10%) and *M. subrotunda* (9%). *Cribrostomoides jeffreysii* (5%), *T. earlandi* (4%) and *M. circularis* (4%) were also important.

	Abs.	%
Textularia truncata	**104**	22
Rosalina williamsoni	**99**	21
Quinqueloculina spp.	**55**	12
Planorbulina mediterranensis	**45**	10
Miliolinella subrotunda	**41**	9
Cribrostomoides jeffreysii	**22**	5
Textularia earlandi	**20**	4
Miliolinella circularis	**19**	4

Quinqueloculina cliarensis	**10**	2
Ammonia beccarii batavus	**7**	2
Brizalina pseudopunctata	**7**	1
Spiropthalmidium acutimargo var. *emaciatum*	**6**	1
Patellina corrugata	**4**	1
Quinqueloculina cf. *lata/seminulum*	**3**	1
Clavulina obscura	**3**	1
Massilina secans	**2**	1
Quinqueloculina williamsoni	**2**	1
Haynesina germanica	**2**	0
Asteriginata mamilla	**2**	0
Quinqueloculina lata	**2**	0
Bolivina pseudoplicata	**2**	0
Cibicides pseudoungerianus	**2**	0
Fissurina marginata	**1**	0
Technitella sp 2 (earbud form)	**1**	0
Eggerelloides scabrum	**1**	0
Bulimina gibba	**1**	0
Cyclogyra involvens	**1**	0
Elphidium cuvillieri	**1**	0
Brizalina spathulata	**1**	0
Lenticulina crepidula	**1**	0
Nonion depressulus	**1**	0
Technitella teivyense	**1**	0
Quinqueloculina aspera II	**1**	0
Quinqueloculina bicornis	**1**	0
Reophax moniliformis	**1**	0
Technitella legumen	**1**	0
Quinqueloculina cf. *cliarensis*	**1**	0
Fissurina quadrata	**0**	0

Table 8.6. All species recorded at Location 3 throughout the year in order of abundance. Values in absolute (Abs.) and percentage (%) abundance.

8.3.3. Species Distribution

Foraminiferal abundance was very low until July. The exception was the appearance of *Textularia earlandi* which reached its maximum abundance (18 individuals) during February (the coldest month) and was absent (or negligible) for all other months (Figure 8.7). During July all of the principal species increased sharply in abundance; *Textularia truncata* reached its maximum abundance of 43 individuals and *Quinqueloculina* spp. (mainly unidentified juveniles) reached their maximum abundance. *R. williamsoni* and *P. mediterranensis* increased sharply during July but reached their maximum abundance during August (Figure 8.6). *Miliolinella circularis* exhibited a small increase in abundance during September. *Cribrostomoides jeffreysii* and *Miliolinella subrotunda* exhibited a small

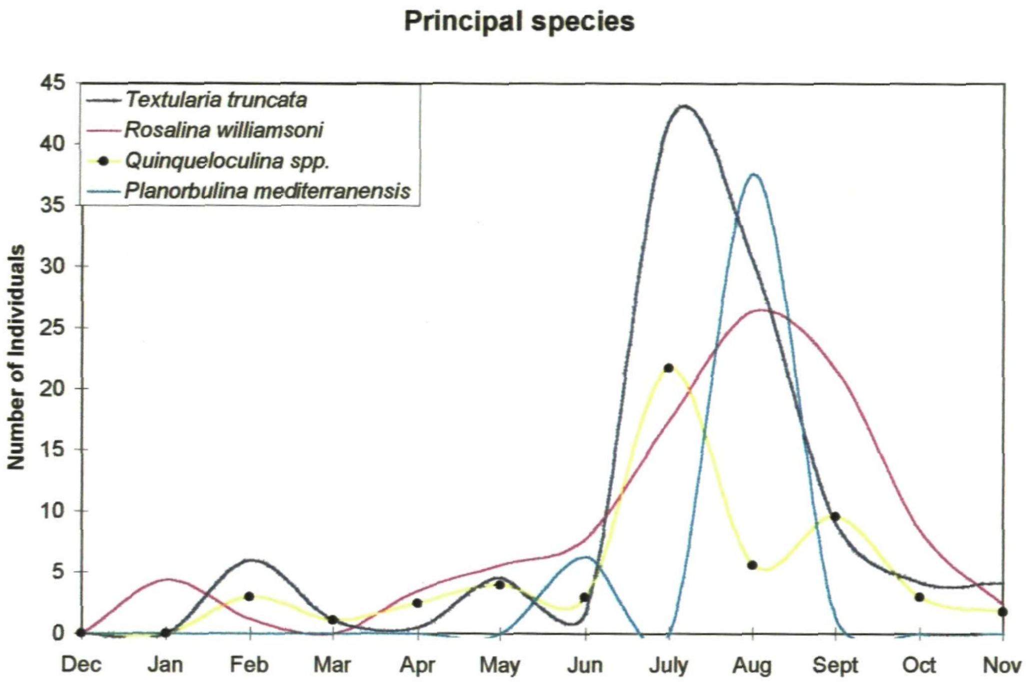


Figure 8.6. Distribution of principal species (species which account for 10% or more of the assemblage) throughout the year at Location 3

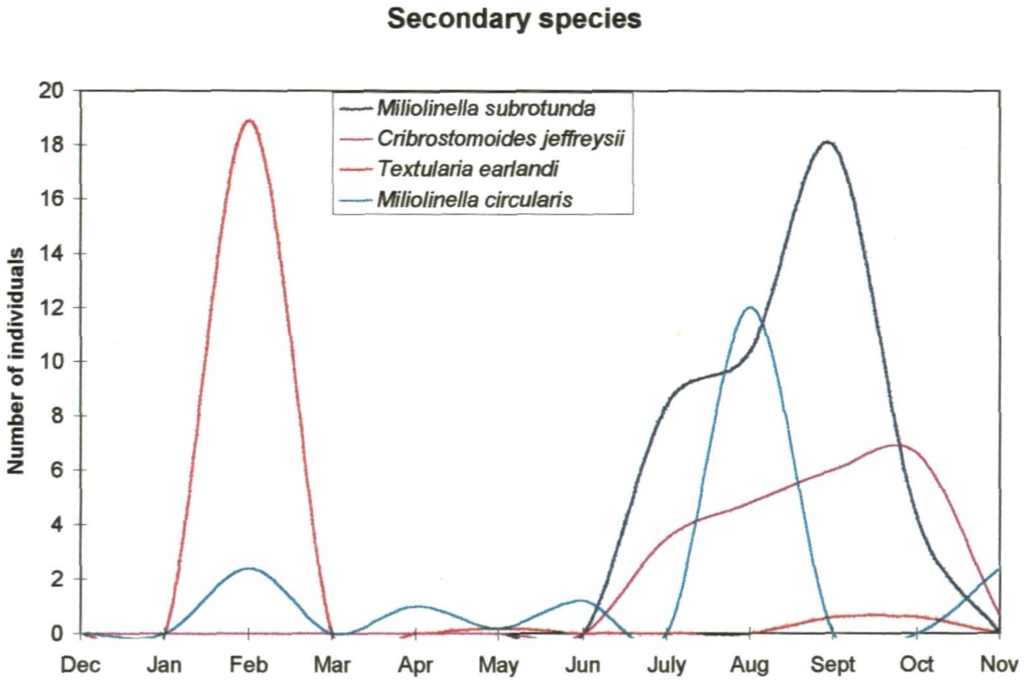


Figure 8.7. Distribution of secondary species (species which account for less than 10% of the assemblage) throughout the year at Location 3.

increase in abundance during October. The month of June represents significant reproduction as thereafter foraminifera become abundant.

8.3.5. Diversity

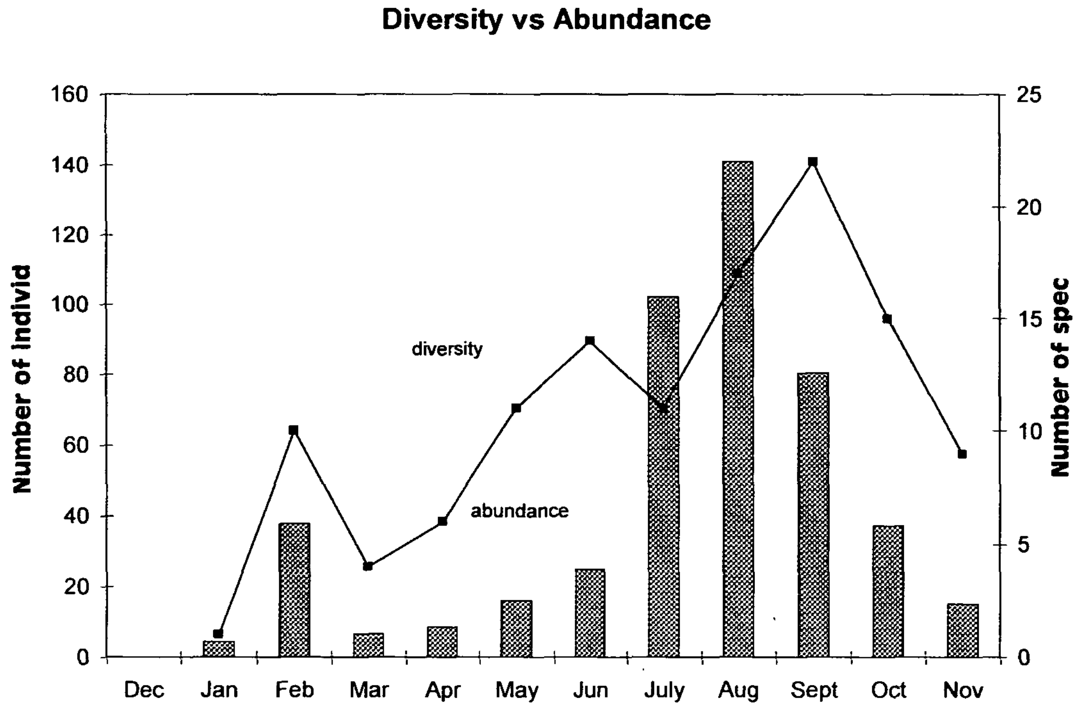


Figure. 8.8. Comparison between foraminiferal abundance and diversity throughout the year at Location 3.

Diversity generally mirrored foraminiferal abundance, being low during the first half of the year (Figure 8.8). Diversity then began to increase during May and June while foraminiferal abundance was low, but dropped during July when foraminiferal abundance increased rapidly and thereafter the abundance maxima (peaks) are out of phase by one month. These trends in the second half of the year may have represented the opportunistic species (*T. truncata*) taking advantage of more favourable conditions creating a high dominance, lower diversity assemblage. As other species appeared (during September) increased interspecific competition may have caused abundance to drop while the diversity increased.

A total of 38 species were recorded throughout the year, resulting in an Fisher Alpha diversity index of 10

8.3.6. Morphogroups

The plano-convex group (H4) of foraminifera which have an attached mode of life (probably not epiphytic because of the lack of large marine plants) are very common accounting for 32% of the assemblage. Important species within this group were *R. williamsoni, P. mediterranensis,* and *Patellina corrugata.* The agglutinated wedge-shaped group A7 was represented by 1 species: *T. truncata* which has a clinging mode of life, comprised 22% of the assemblage. The other important group was the fusiform porcellaneous group (P8) which accounted for 26% of the assemblage. Important species in this group were *Quinqueloculina* spp., *Q. lata/seminulum, M. subrotunda* and *M. circularis.*

MG		Abs	%
H1	*Ammonia beccarii batavus*	**7**	**2**
H1	*Haynesina germanica*	**2**	**0**
H1	*Elphidium cuvillieri*	**1**	**0**
H1	*Nonion depressulus*	**1**	**0**
H10	*Brizalina pseudopunctata*	**7**	**1**
H10	*Bolivina pseudoplicata*	**2**	**0**
H10	*Brizalina spathulata*	**1**	**0**
H11	*Fissurina marginata*	**1**	**0**
H11	*Bulimina gibba*	**1**	**0**
H11	*Fissurina elongate form*	**0**	**0**
H3	*Lenticulina crepidula*	**1**	**0**
H4	*Rosalina williamsoni*	**99**	**21**
H4	*Planorbulina mediterranensis*	**45**	**10**
H4	*Patellina corrugata*	**4**	**1**
H4	*Asteriginata mamilla*	**2.1**	**0**
H4	*Cibicides pseudoungerianus*	**1.6**	**0**
	Total	**177**	**37**

MG		Abs.	%
P2	*Cyclogyra involvens*	**1**	**0**
P8	*Quinqueloculina* spp.	**55**	**12**
P8	*Miliolinella subrotunda*	**41**	**9**
P8	*Miliolinella circularis*	**19**	**4**
P8	*Quinqueloculina* cf. *lata/seminulum*	**3**	**1**
P8	*Quinqueloculina williamsoni*	**2**	**1**
P8	*Quinqueloculina lata*	**2**	**0**
P8	*Quinqueloculina aspera* II	**1**	**0**
P8	*Quinqueloculina bicornis*	**1**	**0**
P8	*Quinqueloculina* cf. *cliarensis*	**1**	**0**
P9	*Quinqueloculina cliarensis*	**10**	**2**
P9	*Spiropthalmidium acutimargo* var. *emaciatum*	**6**	**1**
P9	*Massilina secans*	**2.4**	**1**
	Total	**144**	**30**
A1	*Cribrostomoides jeffreysii*	**21.5**	**5**
A11	*Technitella* sp 2 (ear bud form)	**1.4**	**0**
A11	*Technitella teivyense*	**0.7**	**0**
A5	*Clavulina obscura*	**2.8**	**1**
A5	*Reophax moniliformis*	**0.6**	**0**
A6	*Textularia earlandi*	**20.3**	**4**
A6	*Eggerelloides scabrum*	**1.3**	**0.3**
A7	*Textularia truncata*	**104**	**22**
A8	*Technitella legumen*	**0.6**	**0.1**
	Total	**153**	**32**

Table 8.7. Foraminifera are divided into three general groups; hyaline, porcellaneous and agglutinated and allocated morphogroups (columns labelled MG). Both the absolute (Abs.) and percentage (%) values of each species are shown.

Technitella legumen was found attached to pebbles and shell fragments. *Technitella* sp. 1 (ear-bud form) and *Technitella* sp. 2 were not observed attached to pebbles or shells; they may adhere to pebbles and grains or have a free mode of life. Although the genus *Technitella* accounted for less than 1% of the fauna, it has not been observed living in other sedimentary facies.

Half of all morphogroups present are composed of species which have an attached or clinging mode of life, while over one quarter are fusiform with a free epifaunal/infaunal mode of life

8.3.7. Species size

Surprisingly most of the individuals examined from the shell gravel throughout the year are very small. The majority lie within the 63μm fraction, although they are also common within the 125μm fraction, although occasionally very large specimens were present. The reasons for this may be:-

> Reproduction occurs early in adulthood because of optimum conditions hence individuals do not reach large dimensions.
>
> Many of the specimens may be juveniles as small specimens are only common in the summer.
>
> The harshness of the physical environment promotes the survival and success of small specimens although the reasons for this are unknown.

8.3.8. Discussion

Salinity remains constant throughout the year at this locality (Figure 8.94). Temperature is low from December to April (between 9°C and 10°C) and begins to rise slightly during May. By July the temperature is over 14°C. Foraminiferal abundance increases greatly during July and this may be a consequence of the increased temperature (and presumably increased food supply). Temperature and foraminiferal abundance both peak during August, but the correlation fits less well after August as temperature remains elevated (although declining) whilst foraminiferal abundance drops sharply. Two species display a very good correlation with temperature; *M. subrotunda* exhibits high abundance from July to September and *C. jeffreysi* from July to October (the period of highest sea temperatures).

For many of the principal species increased sea temperatures of 12-14°C and above (reached in June and July) may be a trigger for reproduction and so a significant increase in abundance (because a rise in temperature may increase food production) observed in July and August. The rapid decline in the late summer and early autumn results from factors other than temperature, probably the depletion of the food source and greater competition. Calculations of production (Table 8.5) show a sustained increase of foraminifera in July to August and a gradual decrease (over three months) in foraminifera towards the end of the year. This suggests that food was available over a prolonged period and perhaps not totally exhausted.

The general low abundance of foraminifera is probably due, in part, to the harshness of the environment, as this site represents one of the highest energy environments within the Sound. The shell gravel substrate is probably very unstable as sampling may indicate the presence of moderately large ripples, perhaps sand waves. Often the grab was deployed and retrieved empty, only for the next deployment to deliver an extremely overfull scoop. This was never experienced when sampling other facies.

8.4. Location 4

8.4.1. Introduction

Location 4 is characterised by a mixed sediment of muddy sands. Abundance and diversity of foraminifera is high.

8.4.2. Foraminiferal Abundance

The abundance of foraminifera was very variable at this location, it fluctuated markedly in several cycles of high to low abundance a pattern to which the principal species *Elphidium crispum* contributed significantly (Figure 8.9). From December to February abundance was reasonably stable. It increased in March to just over 400 individuals, dropping rapidly in April to approximately 100 individuals. Abundance increased again to just below 600 individuals in May but dropped again in June to a low of 200 individuals. During July abundance increased to just over 600 individuals but subsequently drops to just below 200 individuals during August. Abundance increased significantly during September to its maximum of just over 1000 individuals. During November it decreased but remained elevated.

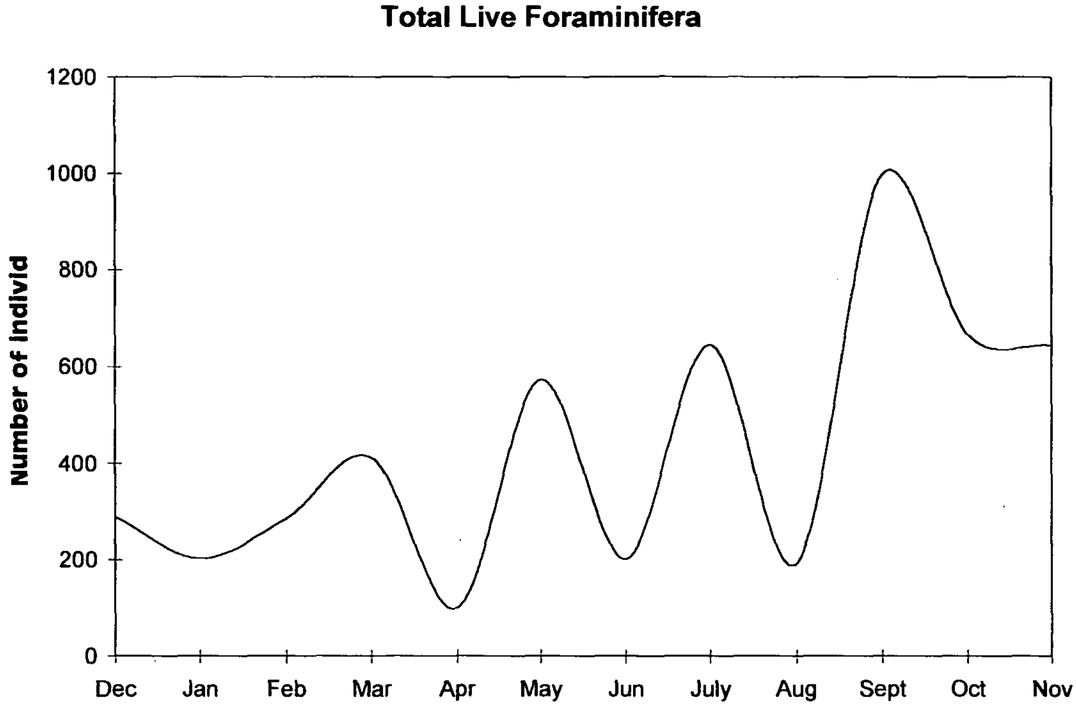


Figure. 8.9. Total abundance of foraminifera (per 100cm^3 of sediment) at Location 4, between December 1993 and November 1994.

Maximum abundance of foraminifera was reached during September (1000 individuals). This represented the maximum observed number of foraminifera the site supported at any one time. A production rate of 1929 foraminifera per year was recorded. Four periods of production were identified (February/March, May, July and September) immediately followed by mortality or removal (Table 8.8).

	Total Live	Gains	Losses
December 1993	289	0	0
January 1994	203	0	86
February	285	82	0
March	413	128	0
April	100	0	313
May	573	473	0
June	202	0	371
July	645	443	0
August	193	0	452
September	996	803	0
October	667	0	329
November	643	0	24
Total	**5207**	**1929**	**1575**

Table 8.8. High production is followed in the subsequent month by high removal (mortality). This pattern is very characteristic of Location 4.

8.4.3. Species Abundance

Elphidium crispum was the most abundant species making up nearly half of the assemblage (49%) while *A beccarii batavus* accounted for 29% of the assemblage and *Q. oblonga* 10% of the assemblage. Other secondary species at this locality were *Q. seminulum, Stainforthia concava* var. *loeblichi, Brizalina psuedopunctata, Brizalina spathulata* and *Eggerelloides scabrum,* all approximately 1% abundance each (Table 8.9).

	Abs.	%
Elphidium crispum	**2545**	**49**
Ammonia beccarii batavus	**1497**	**29**
Quinqueloculina oblonga	**519**	**10**
Quinqueloculina seminulum	**109**	**2**
Stainforthia concava var. loeblichi	**70**	**1**
Brizalina pseudopunctata	**56**	**1**
Eggerelloides scabrum	**53**	**1**
Brizalina spathulata	**47**	**1**
Ammoscalaria pseudospiralis	**34**	**1**
Elphidium cuvillieri	**26**	**1**
Rosalina williamsoni	**21**	**0**
Textularia sagittula	**20**	**0**
Buliminella elegantissima	**20**	**0**
Pyrgo depressa	**15**	**0**
Bulimina gibba	**14**	**0**
Quinqueloculina sp.	**13**	**0**
Quinqueloculina mediterranensis	**9**	**0**
Lagena gracilis	**8**	**0**
Brizalina variabilis	**8**	**0**

	Abs	%
Lenticulina orbiculatis	**3**	**0**
Polymorphina cf. *novangliae*	**3**	**0**
Bulimina marginata	**3**	**0**
Dentalina sp.	**3**	**0**
Reophax scottii	**3**	**0**
Cornuloculina balkwilli	**2**	**0**
Rosalina globularis	**2**	**0**
Lenticulina crepidula	**2**	**0**
Technitella teivyense	**2**	**0**
Ammonia beccarii limnetes	**2**	**0**
Elphidium earlandi	**2**	**0**
Quinqueloculina aspera III	**2**	**0**
Quinqueloculina lata	**2**	**0**
Technitella legumen	**2**	**0**
Cribrostomoides jeffreysii	**1**	**0**
Miliolinella circularis	**1**	**0**
Nonionella sp.	**1**	**0**
Quinqueloculina oblonga var. *lata*	**1**	**0**
Spiroloculina excavata	**1**	**0**

Nonionella turgida var. *digitata*	8	0
Bolivina pseudoplicata	7	0
Quinqueloculina aspera II	6	0
Quinqueloculina cf. *cliarensis*	6	0
Miliammina fusca	6	0
Nonion depressulus	5	0
Quinqueloculina aspera I	5	0
Psammosphaera bowmani	5	0
Planorbulina mediterranensis	4	0
Quinqueloculina bicornis	4	0
Textularia earlandi	4	0
Textularia truncata	4	0
Lagena semistriata	3	0
Fissurina lucida	3	0
Asterigerinata mamilla	1	0
Fissurina marginata	1	0
Portatrochammina murrayi	1	0
Jadammina macresens	1	0
Reophax fusiformis	1	0
Spiroloculina sp.	1	0
Genus 3	1	0
Clavulina obscura	1	0
Quinqueloculina sp. 5	1	0
Miliolinella subrotunda	1	0
Ammoscalaria runiana	1	0
Astacolus crepidulus	1	0
Buccella frigida	1	0
Cyclogyra involvens	1	0
Globulina gibba var. *myristiformis*	1	0

Table 8.9. All species recorded at Location 4 throughout the year in order of abundance. Values in absolute (Abs.) and percentage (%) abundance.

8.4.4. Species Distribution

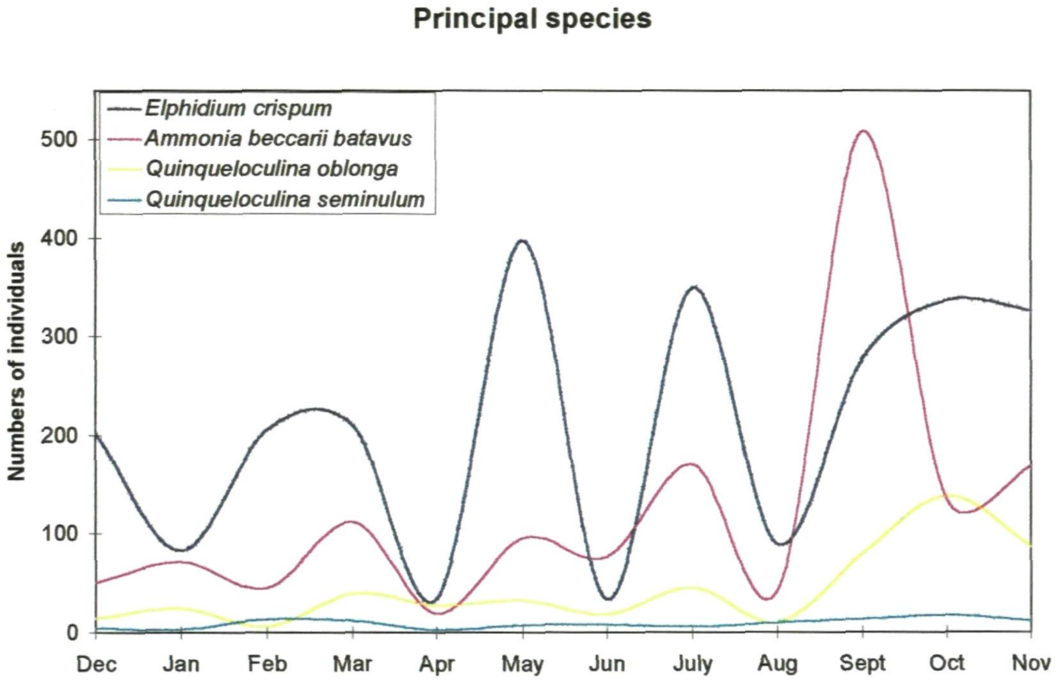


Figure. 8.10. Distribution of principal species (species which account for 10% or more of the assemblage) throughout the year at Location 4. (*Q. seminulum* is not a principal species but is included because its stable but low distribution throughout the year is evident).

Elphidium crispum exhibited an extremely variable trend dissimilar to the other principal species. During December *E. crispum* exhibited a moderately high abundance of 202 individuals which dropped to 83 individuals in January. Abundance rose to 206 individuals for February and March but dropped once more during April to a low of 35 individuals.

The years maximum abundance of 397 individuals for *E. crispum* is reached during May. Abundance then dropped rapidly to 34 individuals during June and rose to 350 individuals during July. *Ammonia beccarii batavus,* which exhibited low and variable abundance during this period, showed an increased abundance during July which coincided with that for *E. crispum*. All species exhibited very low abundances during August. In September *A. beccarii batavus* became the dominant species with 508 individuals, the highest abundance of all species at this locality. *Elphidium crispum* increased to 277 individuals and it remained at this elevated level for the remainder of the year. *Ammonia beccarii batavus* dropped sharply during October but remained moderately abundant during October and November. *Quinqueloculina oblonga* showed its highest abundance during the later part of the year, peaking during October. *Quinqueloculina seminulum* remained remarkably constant, albeit low in abundance, throughout the year (Figure 8.10).

8.4.5. Diversity

Foraminiferal diversity correlated well with abundance, peaks in diversity were associated with peaks in foraminiferal abundance (Figure 8.11). The exception was in July where a maximum monthly diversity of 30 species was attained, although the maximum abundance of individuals occurred during September. This highest abundance, but moderate diversity assemblage may have been due, in part, to the large bloom of *A. beccarii batavus* during September. It occurred immediately after a period of very low abundance and may represent the opportunistic *A. beccarii batavus* increasing in abundance during this period more rapidly than other species. As other species became established, increased interspecific competition may have caused *A. beccarii batavus* to have declined in abundance and diversity to rise.

A total of 68 species were documented from the locality throughout the year resulting in an Fisher Alpha diversity index of over 11.

Diversity vs Abundance

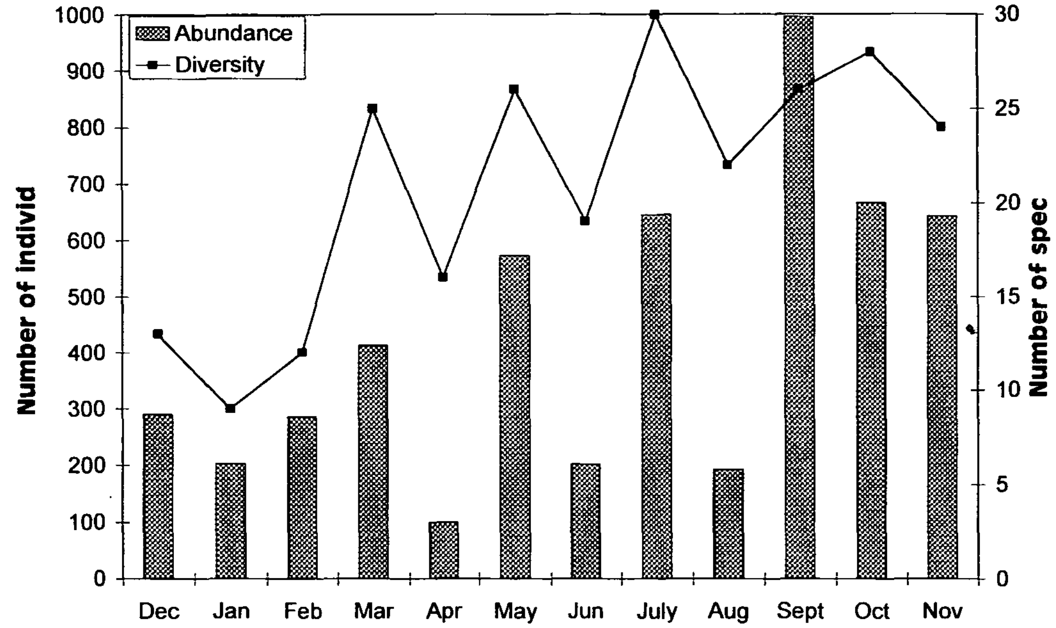


Figure 8.11. Comparison between foraminiferal abundance and diversity throughout the year at Location 4.

8.4.6. Morphogroups

MG	species	Abs	%
H1	*A. beccarii batavus*	1497	29
H1	*Elphidium cuvillieri*	26	1
H10	*Brizalina pseudopunctata*	56	1
H10	*Brizalina spathulata*	47	1
H3	*Elphidium crispum*	2545	49
H4	*Rosalina williamsoni*	21	0
H6	*Bulimina gibba*	14	0
H8	*Stainforthia concava* var. *loeblichi*	70	1
H8	*Buliminella elegantissima*	20	0
	Total	4296	83

MG	species	Abs	%
A11	*Pyrgo depressa*	15	0
P8	*Quinqueloculina oblonga*	519	10
P8	*Quinqueloculina seminulum*	109	2
P8	*Quinqueloculina* spp.	13	0
	Total	656	13
A1	*Ammoscalaria pseudospiralis*	34	1
A6	*Eggerelloides scabrum*	53	1
A7	*Textularia sagittula*	20	0
	Total	107	2

Table 8.10. Foraminifera are divided into three general groups; hyaline, porcellaneous and agglutinated and allocated morphogroups (columns labelled MG). Both the absolute (Abs.) and percentage (%) values of each species are shown.

The three principal species accounted for 88% of the assemblage and morphogroup analysis was dictated by these species (Table 8.10). The keeled planispiral group (H3), with an epifaunal mode of life, were represented by *E. crispum*; they accounted for 49% of the assemblage. The infaunal/epifaunal rounded planispirals (H1), represented by *A. beccarii batavus* and *Elphidium cuvillieri,* accounted for almost 30%, while the porcellaneous fusiform group (P8) of *Q. oblonga, Q. seminulum* and *Quinqueloculina* spp. accounted for 12% of the assemblage. The fusiform group, although generally regarded as epifaunal may contain species which have strong infaunal tendencies.

8.4.7. Discussion

The principal species exhibit little correlation with temperature and salinity. Salinity remains constant for most of (January to October) the year. Temperature begins to rise in May and June but foraminiferal abundance falls to very low values in June (Figure 8.10). Temperature reaches a maximum in August whilst foraminiferal abundance again falls to low levels during this month. The low foraminiferal abundances in April, June and August may reflect periods of reproduction during which adult mortality was high. A very broad correlation with temperature exists for *A. beccarii batavus* and *Q. oblonga*, as these species are more abundant in the latter part of the year when temperature is higher. This generally poor correlation suggests that foraminiferal trends are not directly influenced by temperature and salinity. *E. crispum* is known to harbour chloroplasts which may be symbionts (Leutenegger, 1984; Lee *et al.* 1988; Lee & Lee 1989; Lee & Anderson, 1991) hence a correlation with the amount of sunshine and day length might be expected. Abundance of *E. crispum* is high during the sunny months of May and July and specimens which contained abundant green chloroplasts were recorded, particularly during July. Maximum levels of sunshine (and greatest day length) were recorded in June when the abundance of *E. crispum* was very low, hence the sunniest month exhibits a negative correlation. This appears to suggest that levels of sunshine and day length are not primarily responsible for the observed trends of *E. crispum.*

The principal foraminiferal species exhibit good correlation with each other and belong to different morphogroups implying different feeding strategies which suggests that interspecific competition is moderate to low. *Elphidium crispum* exhibits regular large fluctuations in abundance. This may be a response to varying food such as blooms of phytoplankton (Myers, 1943) perhaps linked with other important environmental variables. When the environment is favourable and food is available the population increases rapidly until there are sufficient individuals of that species to utilise all of the available food (or other resources). If the food is not renewed at a fast enough rate it becomes depleted and diminishes. Once most of the food has been used, intraspecific competition increases causing the population size to drop rapidly. The food source then has time to recover and increase in abundance allowing the cycle to begin once more. Alternatively *E. crispum* may be feeding on various blooms of different taxa which have a staggered timing. *Elphidium crispum* is the dominant species at this locality and interactions between it and other species are thought less influential upon its distribution throughout the year. It is possible that predation may strongly influence the population size of *E. crispum* (for a summary on the effects of predation see Lipps, 1984). Myers (1943a) recorded that 3-5% of *E. crispum* from Plymouth Sound contained the developmental stages of the parasite *Trophosphera planorbulinea* within their tests, as well as nematode worms. It is also possible that the marked fluctuations which affect all of the principal species may be a trend generated by sampling as this pattern is unlike any other in this study.

Juveniles of *E. crispum* were observed only during July and September reflecting reproduction during these periods. The cyclic pattern of abundance for *E. crispum* can be explained by reproductive events during these periods, fluctuations during the first half of the year may be due to other factors as juveniles were not observed. Perhaps patchiness and or sampling anomalies or unobserved reproductive events.

The large bloom of *A. beccarii batavus* in the autumn (Figure 8.10) is assumed to be due to an improvement within the environment i.e. the abundance of a specific food type most appropriate for its feeding strategy during September. Alternatively there may be a temporary reduction in interspecific competition as suggested earlier on page 244 Juveniles of *A. beccarii batavus* were observed during March, July and September which correspond to peaks in abundance of this species (see Figure. 8.10). Each maximum in abundance associated with reproduction is soon followed by a decline in abundance and this may reflect high rates of juvenile mortality.

8.5. Location 8

8.5.1. Introduction

Location 8 is an area of medium to coarse mobile sands in which sand waves are present. An extremely meagre abundance of foraminifera is recorded although diversity is moderate.

8.5.2. Foraminiferal Abundance

During December to March no live foraminifera were recorded from the area. In April to June, August, October and November abundance of foraminifera consisted of a few specimens. A peak of 42 individuals occurred in July and the maximum of 65 individuals was recorded in September. Abundance was generally extremely low (Figure 8.12).

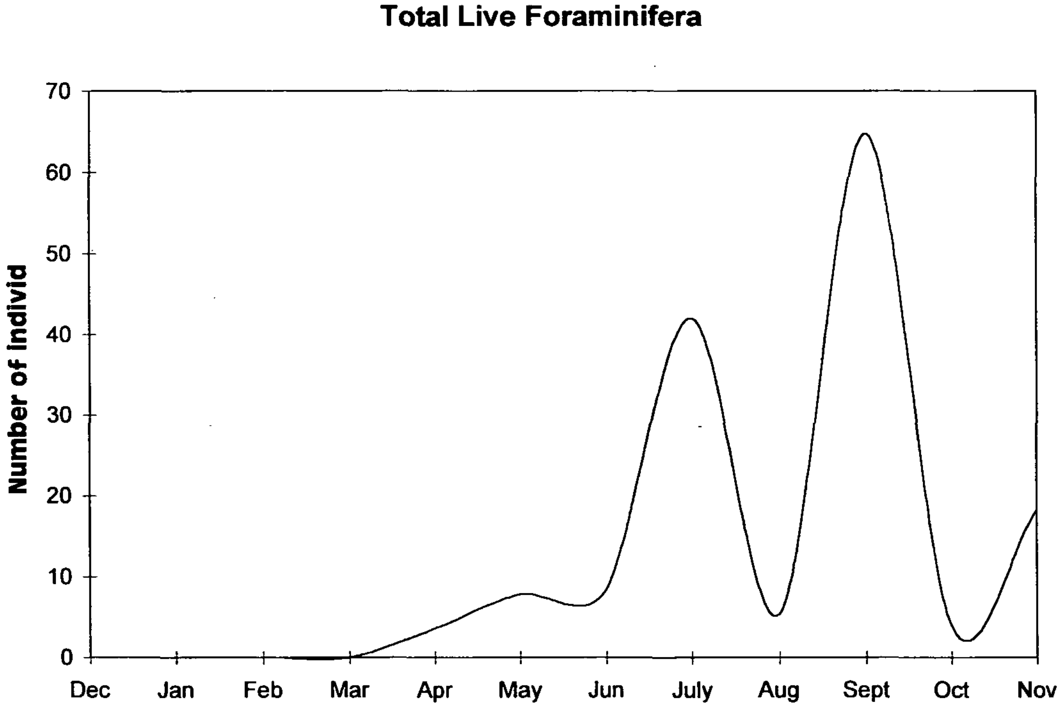


Figure. 8.12. Total abundance of foraminifera (per 100cm^3 of sediment) at Location 8, between December 1993 and November 1994.

A total of 116 individuals were produced in one year. As can be seen in Table 8.11 production is always followed by losses of a similar magnitude.

	Total Live	Gains	Losses
December 1993	0	0	0
January 1994	0	0	0
February	0	0	0
March	0	0	0
April	4	4	0
May	8	4	0
June	8	0	0
July	42	34	0
August	5	0	37
September	65	60	0
October	4	0	61
November	18	14	0
Total	**154**	**116**	**98**

Table 8.11, Production of foraminifera at Location 8. Significant production is followed by similar mortality (or removal).

The assemblage showed a high degree of species evenness (low dominance), with *A. beccarii batavus* making up 36% of the assemblage. The other species accounted for roughly similar amounts. *Quinqueloculina lata,* which is normally rare or absent within the Sound was relatively common at this location.

	Abs.	%
Ammonia beccarii batavus	**56**	36
Quinqueloculina lata	**21**	14
Brizalina pseudopunctata	**9**	6
Elphidium crispum	**8**	5
Miliolinella circularis	**8**	5
Quinqueloculina seminulum	**8**	5
Eggerelloides scabrum	**5**	3
Quinqueloculina oblonga	**4**	3
Quinqueloculina spp.	**4**	3
Textularia truncata	**4**	2
Quinqueloculina williamsoni	**3**	2
Quinqueloculina aspera I	**3**	2
Rosalina williamsoni	**3**	2
Bulimina elongata	**3**	2
Massilina secans	**2**	2
Cibicides lobatulus	**2**	1
Adelosina (normal)	**2**	1
Quinqueloculina aspera II	**2**	1
Planorbulina mediterranensis	**1**	1

Uvigerina sp	**1**	1
Nonion depressulus	**1**	1
Pateoris hauerinoides	**1**	1
Psammosphaera bowmani	**1**	1
Quinqueloculina cf. *cliarensis*	**1**	1
Quinqueloculina bicornis	**1**	1

Table 8.12. All species recorded at Location 8 throughout the year in order of abundance. Values in absolute (Abs.) and percentage (%) abundance..

8.5.3. Species Distribution

The principal species were *A. beccarii batavus* and *Q. lata.* The latter exhibited a maximum of 17 individuals during July, whilst *A. beccarii batavus* exhibited a maximum of 37 individuals during September. Other species occurred as a few isolated individuals during May, July and September.

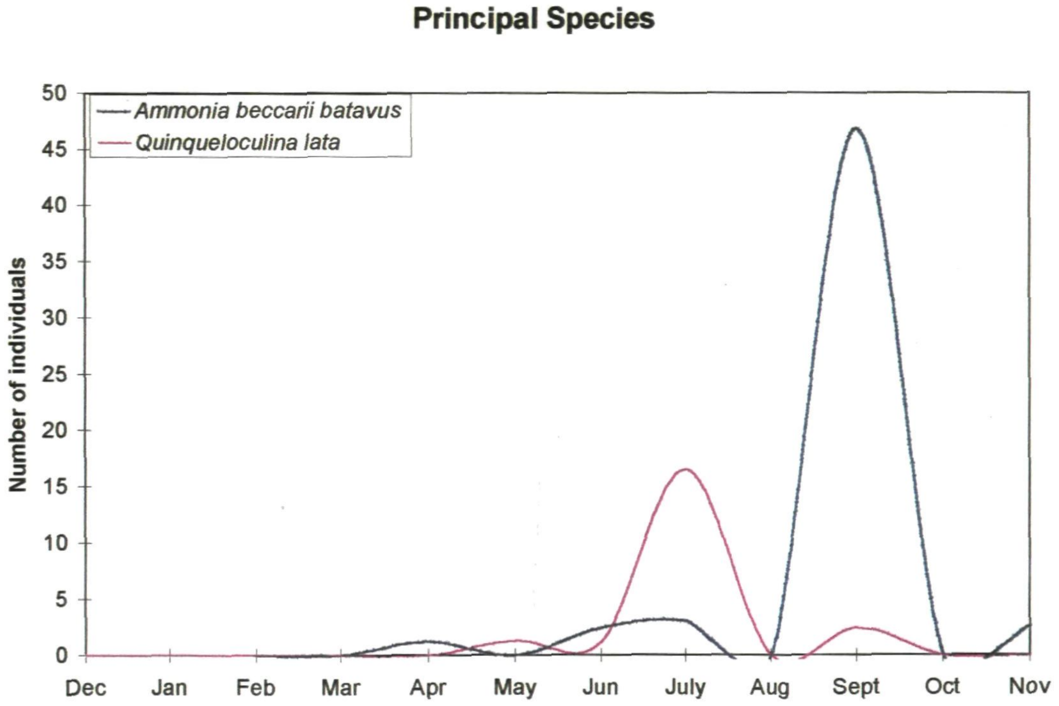


Figure. 8.13. Distribution of principal species (species which account for 10% or more of the assemblage) throughout the year at Location 8. The two principal species have very simple trends occurring as isolated peaks once during the year.

8.5.3. Diversity

A total of 154 individuals were recorded from this locality, diversity was high for such low numbers of individuals. A total of 25 species were observed, resulting in an Fisher Alpha diversity index of above 10. Diversity almost perfectly mirrored abundance of individuals (Figure 8.14).

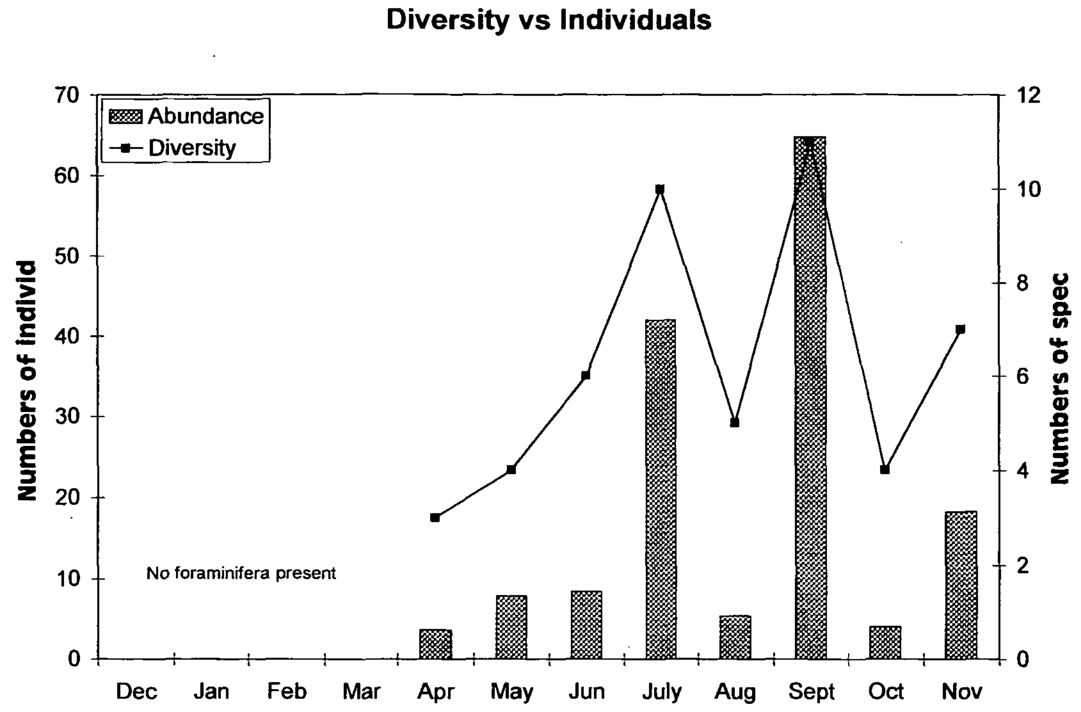


Figure 8.14. Comparison between foraminiferal abundance and diversity throughout the year at Location 8.

8.5.4. Morphogroups

37% of the assemblage belonged to the rounded planispiral group (H1) which is the most common morphogroup in the Sound. 34% of the assemblage belonged to the porcellaneous fusiform free living group (P8), which usually occurred in low abundances but are very abundant at this locality. As seen in Table 8.13 the remaining foraminifera belonged to a varied range of other morphogroups.

MG		Abs	%
H1	*Ammonia beccarii batavus*	**56**	**36**
H1	*Nonion depressulus*	**1**	**1**
H10	*Brizalina pseudopunctata*	**9**	**6**
H3	*Elphidium crispum*	**8**	**5**
H4	*Rosalina williamsoni*	**3**	**2**
H4	*Cibicides lobatulus*	**2**	**1**
H4	*Planorbulina mediterranensis*	**1**	**1**
H6	*Bulimina elongata*	**3**	**2**
H8	*Uvigerina* sp.	**1**	**1**
	Total	**84**	**55**
A6	*Eggerelloides scabrum*	**5**	**3**
A7	*Textularia truncata*	**4**	**2**
A11	*Psammosphaera bowmani*	**1**	**1**
	Total	**10**	**6**

MG		Abs	%
P11	*Adelosina normal*	**2**	**1**
P8	*Quinqueloculina lata*	**21**	**14**
P8	*Miliolinella circularis*	**8**	**5**
P8	*Quinqueloculina seminulum*	**8**	**5**
P8	*Quinqueloculina oblonga*	**4**	**3**
P8	*Quinqueloculina* spp.	**4**	**3**
P8	*Quinqueloculina williamsoni*	**3**	**2**
P8	*Quinqueloculina aspera* I	**3**	**2**
P8	*Quinqueloculina aspera* II	**2**	**1**
P8	*Quinqueloculina bicornis*	**1**	**1**
P9	*Massilina secans*	**2**	**2**
P9	*Quinqueloculina* cf. *cliarensis*	**1**	**1**
P9	*Pateoris hauerinoides*	**1**	**1**
	Total	**60**	**39**

Table 8.13. Foraminifera are divided into three general groups; hyaline, porcellaneous and agglutinated and allocated morphogroups (columns labelled MG). Both the absolute (Abs.) and percentage (%) values of each species are shown.

8.5.5. Discussion

The two maxima in foraminiferal abundance (July and September) correlate with the blooms of foraminifera from most other localities (especially sand facies localities) within the Sound. In this medium to high energy sandy facies the presence of *A. beccarii batavus* as the dominant species is surprising as it usually dominates in lower energy, muddy, environments (although it is dominant, it is present in relatively small numbers). Calculations of productivity show production immediately followed by losses which may suggest that food is not abundant and when present, it is depleted very quickly. The lack of live foraminifera during the first four months of the study and 5 months represented by single figure abundances, is another unusual observation. These factors may suggest that a large component of the foraminifera recovered do not live or reproduce in this constantly shifting environment but are swept in from adjacent areas or colonise it during favourable conditions (the largest amount of immigration occurs when foraminifera were abundant elsewhere). This may account for the relatively high diversity and range of morphogroups. The isolated and discontinuous occurrences of species suggests that this may be true.

Despite the very low abundance of foraminifera, the porcellaneous taxa of morphogroups P8 (fusiform free living) and to a lesser extent the porcellaneous flattened free living/clinging group (P9), are much more abundant than in the remainder of the Sound. This suggests that these species may represent the true autochthonous foraminiferal fauna. Their test type and morphology are well suited to a shifting moderate to high energy environment.

8.6. Location 9

8.6.1. Introduction

Location 9 is situated just inside the Breakwater. It has the finest grain size sediment within the Sound, being composed almost entirely of silt and clay. The site produces the highest abundance of individuals and the greatest diversity of species.

8.6.2. Foraminiferal Abundance

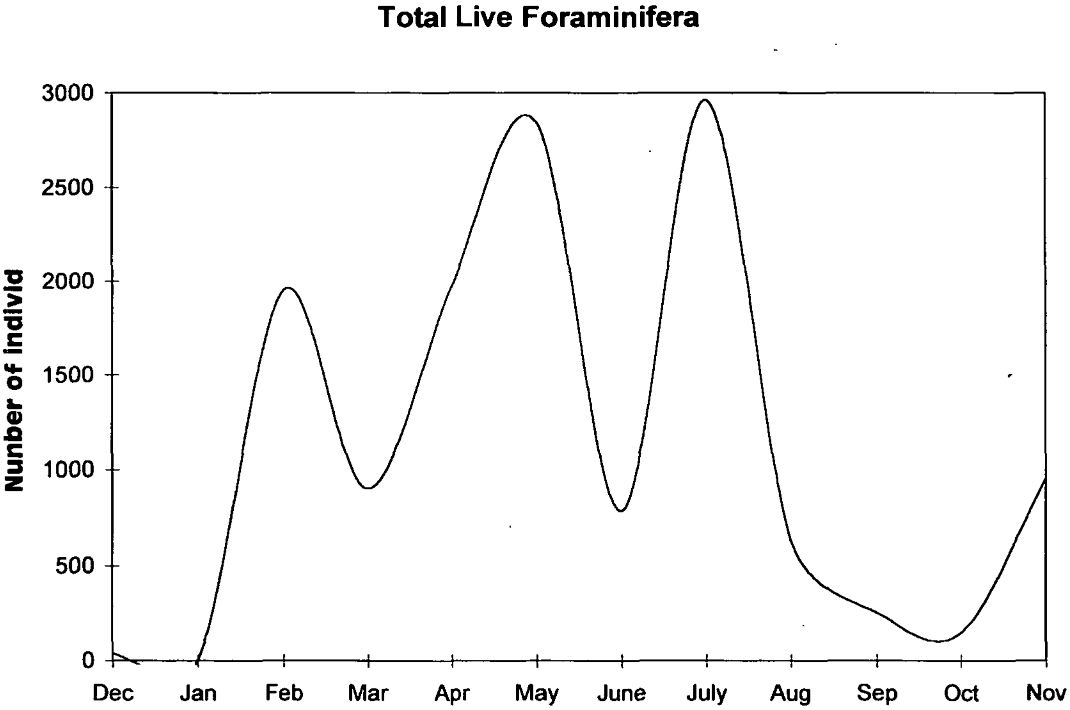


Figure. 8.15. Total live abundance of foraminifera (per 100cm^3 of sediment) at Location 9, between December 1993 and November 1994.

Foraminiferal abundance was very low in December and live foraminifera were almost absent in January (4 individuals). Abundance rose very sharply in February to 1951 individuals, it then dropped sharply to 903 individuals in March. April exhibited a large increase to nearly 2000 individuals. Abundance continued to rise in May when it reached 2851 individuals. During June, abundance dropped sharply to 787 individuals, then rose sharply in July to its maximum of 2965 individuals (Figure 8.15).

In August abundance dropped sharply to 636 individuals, dropping again in September to 256 individuals and again in October to the low abundance of 144 individuals. November recorded a rise in abundance to 955 individuals. The maximum abundance of 2965 represented the maximum observed carrying capacity of the site.

A total production of 6884 foraminifera per year was recorded. Sustained production implies a sustained food supply. Sustained losses (mortality) imply a gradually diminishing food source. The maximum observed carrying capacity was reached in July with 2965 individuals (Table 8.14).

	Total Live	**Gains**	**Losses**
December 1993	35	0	0
January 1994	4	0	31
February	1951	1947	0
March	903	0	1048
April	1973	1070	0
May	2851	878	0
June	787	0	2065
July	2965	2178	0
August	636	0	2329
September	256	0	381
October	144	0	111
November	955	811	0
	13460	**6884**	**5965**

Table 8.14. Production of foraminifera at Location 9. During April and May production is sustained over two months, followed by losses. In July production is highest and followed by three months of losses.

8.6.3. Species Abundance

The most abundant species was *Brizalina pseudopunctata* (Högland) which accounted for 38% of the assemblage. *Ammonia beccarii batavus* was the second most important species contributing 23% of the assemblage. The third principal species was *Q. oblonga* making 13% of the assemblage.

	Abs.	%
Brizalina pseudopunctata	5082	38
Ammonia beccarii batavus	3084	23
Quinqueloculina oblonga	1747	13
Stainforthia concava var. *loeblichi*	991	7
Brizalina spathulata	656	5
Brizalina variabilis	375	3
Eggerelloides scabrum	321	2
Quinqueloculina seminulum	138	1
Bulimina gibba	104	1
Reophax scottii	87	1
Bulimina elongata	77	1
Pyrgo depressa	73	1
Ammoscalaria pseudospiralis	67	1
Elphidium cuvillieri	57	0
Textularia earlandi	52	0
Bulimina marginata	48	0
Elphidium crispum	43	0
Lenticulina orbiculatis	42	0
Nonionella turgida var. *digitata*	42	0
Brizalina striatula	39	0
Quinqueloculina cf. *cliarensis*	38	0
Cornuspirella diffusa	23	0
Cribrostomoides jeffreysii	20	0
Bolivina pseudoplicata	19	0
Fissurina lucida	17	0
Vaginulina linearis	15	0
Dentalina spp.	14	0
Amphicoryna cf. *scalaris*	13	0
Buliminella elegantissima	12	0
Quinqueloculina mediterranensis	11	0
Reophax fusiformis	11	0
Nonion depressulus	11	0
Cyclogyra involvens	9	0
Ammonia beccarii limnetes	8	0
Astacolus crepidulus	8	0
Genus 3	7	0
Clavulina obscura	7	0
Lagena gracilis	6	0
Lagena substriata	6	0
Quinqueloculina aspera III	6	0
Genus 1	5	0
Trifarina angulosa	6	0
Oolina hexagona	5	0
Psammosphaera bowmani	5	0
Lagena clavata	5	0
Uvigerina sp.	4	0
Quinqueloculina spp.	4	0
Fissurina orbignyana	4	0
Siphogenerinoides sp.	4	0
Globulina gibba	3	0
Buccella frigida	3	0
Fursenkoina fusiformis	3	0
Lenticulina crepidula	3	0
Rosalina williamsoni	3	0
Nodosauria pyrula	3	0
Quinqueloculina sp 5	2	0
Cibicides lobatulus	2	0
Spiroloculina excavata	2	0
Quinqueloculina oblonga var. *lata*	2	0
Polymorphina cf. *novangliae*	1	0
Fissurina quadrata	1	0
Haynesina germanica	1	0
Massilina secans	1	0
Quinqueloculina cliarensis	1	0
Quinqueloculina lata	1	0
Spirallina runiana	1	0
Miliolina circularis	1	0
Quinqueloculina aspera I	1	0
Textularia sagittula	1	0
Fissurina marginata	1	0
Lagena perlucida	1	0
Quinqueloculina aspera II	1	0
Lagena laevis	1	0
Lagena lyellii	1	0
Nonionella sp.	1	0
Reophax moniliformis	1	0
Quinqueloculina auberiana	1	0
Elphidium gerthi	1	0
Quinqueloculina bicornis	1	0

Table 8.15. All species recorded at Location 9 throughout the year in order of abundance. Values in absolute (Abs.) and percentage (%) abundance.

Other important species were *Stainforthia concava* (Hoglund) var. *loeblichi* (Feyling-Hanssen) which was rare or absent at most other localities. *Brizalina spathulata* (Williamson), *Brizalina variabilis* (Williamson) and *E. scabrum*, *Reophax scottii* Chaster and *Pyrgo depressa* (d'Orbigny) were common at no other localities. Species such as *Reophax fusiformis* (Williamson), *Nonion turgida* (Williamson) var. *digitata* (Nørvang), *Astacolus crepidulus* (Fichtel and Moll), the agglutinated foraminifera Genus 3 (Figured in Appendix 8), *Uvigerina* sp., *Rectobolivina* sp. and *Nodosauria pyrula* d'Orbigny occurred nowhere else in Plymouth Sound (Table 8.15).

8.6.4. Species Distribution

Species distributions throughout the year were very similar to the overall foraminiferal trend Figure 8.15. The three principal species *B. pseudopunctata, A. beccarii batavus*, and *Q. oblonga* showed peaks of abundance in February, April/May and July. *Brizalina pseudopunctata* and *Q. oblonga* exhibited their largest abundance in May, while *A. beccarii batavus* displayed a minor peak in May and its largest peak in abundance during July (Figure 8.16).

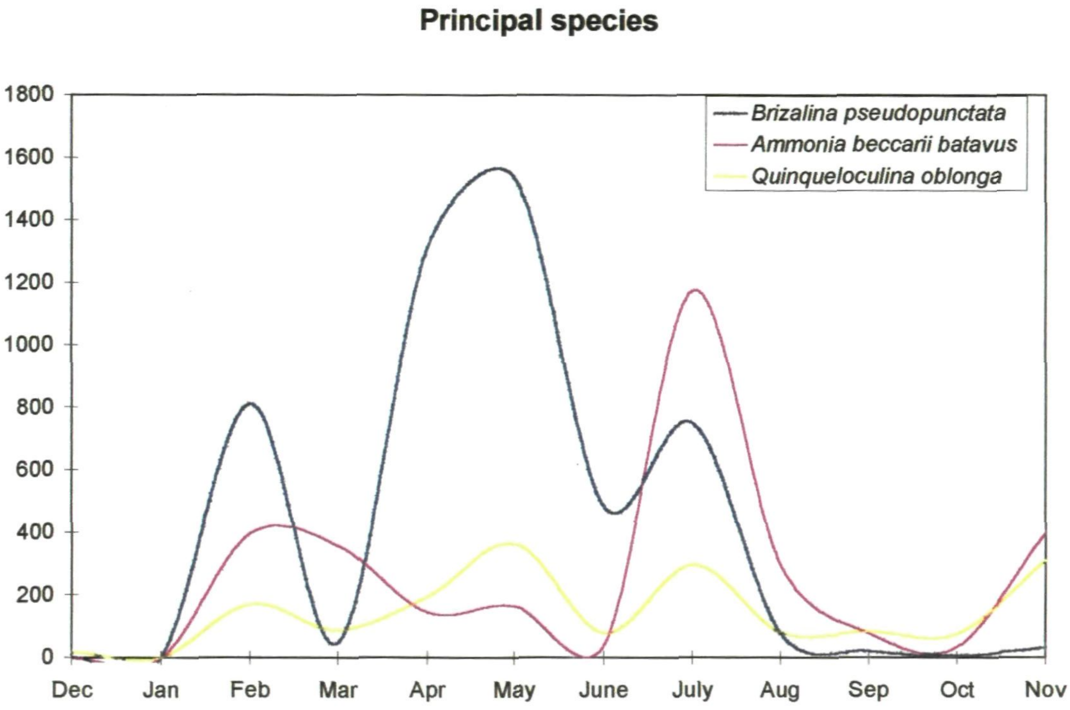


Figure 8.16. Distribution of principal species (species which account for 10% or more of the assemblage) throughout the year at Location 9. Three peaks in abundance can be clearly seen.

As can be seen from Figure 8.17, the important minor species (minor species are those which form less than 10% each of the assemblage) also exhibited a maxima peak pattern of abundance during February, May and July. *Eggerelloides scabrum* exhibited its highest abundance during March, when most other species were at low abundance (with the exception of *A. beccarii batavus* which displayed moderate abundance).

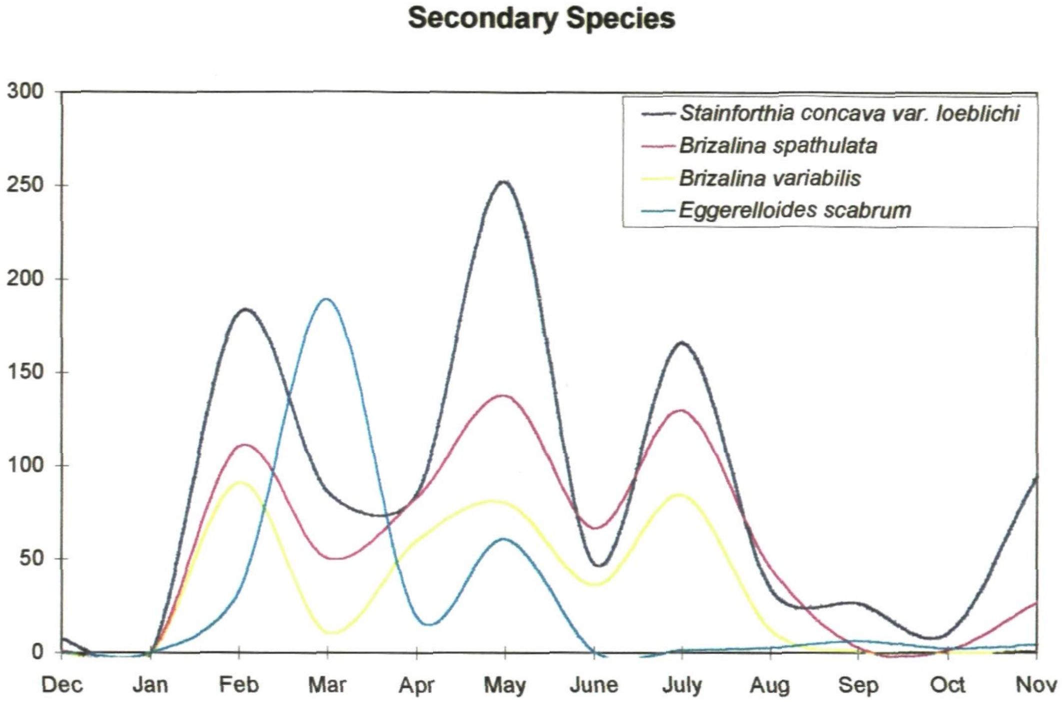


Figure. 8.17. Distribution of secondary species (species which account for less than 10% of the assemblage) throughout the year at Location 9 follow a very similar pattern to that of the principal species, the exception is the distribution of *E. scabrum*.

8.6.5. Diversity

Diversity correlated well with foraminiferal abundance, although abundance attained its maximum in July, while diversity reached a maximum in February and declined throughout the rest of the year (Figure 8.18). This may have been due to the fact that during December and January foraminifera were nearly absent from the area. As favourable conditions developed, many different species colonised the area. With many species established, interspecific competition and changes within the environment (the depletion of a particular food type) caused some species to disappear resulting in decreased diversity, while some of the surviving species increased greatly in abundance during this period.

A total of 78 species were recorded from throughout the year from 13460 individuals resulting in a Fisher Alpha diversity index of 12.

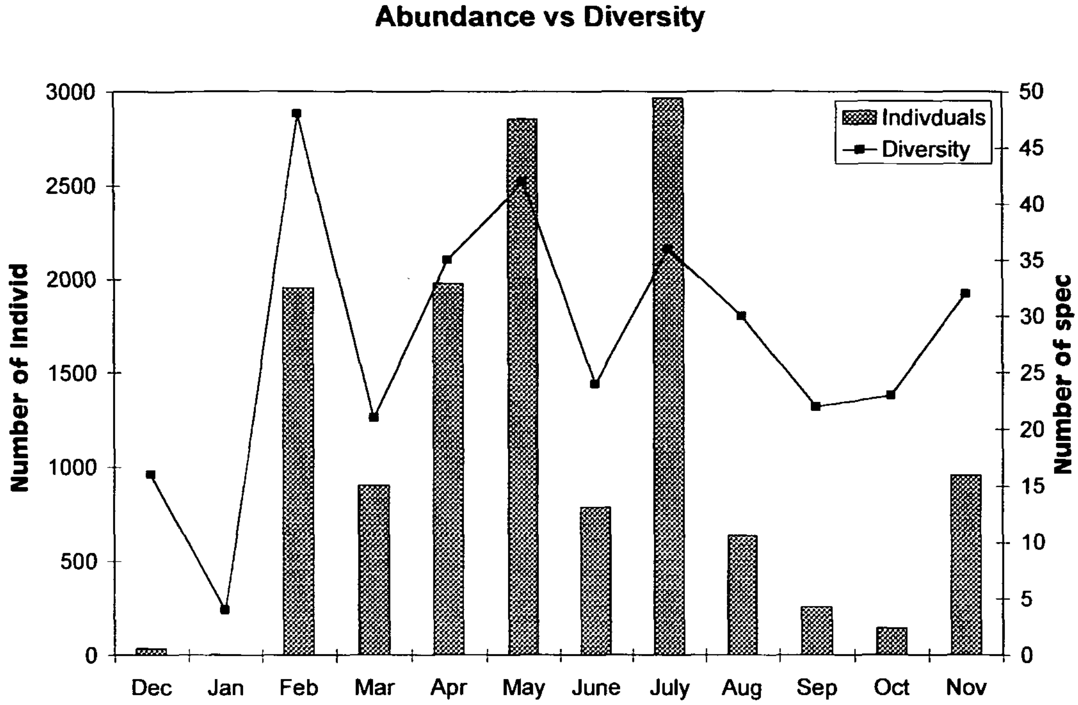


Figure 8.18. Comparison between diversity and number of individuals throughout the year at Location 9.

8.6.6. Morphogroups

Although only 3 or 4 groups constituted the majority of the assemblage, a very wide range of morphogroups were present which reflected the diverse distribution and type of food of the foraminifera. The dominant morphogroup (46%) were the tapered flattened group (H10). These have a free, infaunal, mode of life. Also very abundant were the rounded planispiral group (H1) with 34% of the assemblage; these also have an infaunal mode of life although they may also be epifaunal. The group H10 (tapered flattened) are largely detritivores, whereas the group H1 (rounded planispirals) are probably herbivores. The porcellaneous group P8 (14%) and the hyaline group H8 (7%) are both fusiform and probably largely infaunal. Together they accounted for 21% of the assemblage. All of the 12 basic morphogroups were present (Table 8.16).

MG		Abs.	%
H1	*Ammonia beccarii batavus*	3084	23
H1	*Elphidium cuvillieri*	57	0
H1	*Nonionella turgida* var. *digitata*	42	0
H1	*Nonion depressulus*	11	0
H1	*Ammonia beccarii limnetes*	8	0
H1	*Buccella frigida*	3	0
H1	*Lenticulina crepidula*	3	0
H1	*Haynesina germanica*	1	0
H1	*Nonionella* sp.	1	0
H10	*Brizalina pseudopunctata*	5082	38
H10	*Brizalina spathulata*	656	5
H10	*Brizalina variabilis*	375	3
H10	*Brizalina striatula*	39	0
H10	*Bolivina pseudoplicata*	19	0
H11	*Fissurina lucida*	17	0
H11	*Lagena gracilis*	6	0
H11	*Lagena substriata*	6	0
H11	*Oolina hexagona*	5	0
H11	*Lagena clavata*	5	0
H11	*Fissurina orbignyana*	4	0
H11	*Globulina gibba*	3	0
H11	*Fissurina quadrata*	1	0
H11	*Fissurina marginata*	1	0
H11	*Lagena perlucida*	1	0
H11	*Lagena laevis*	1	0
H11	*Lagena lyellii*	1	0
H2	*Spirillina runiana*	1	0
H3	*Elphidium crispum*	43	0
H3	*Lenticulina orbiculatis*	42	0
H4	*Rosalina williamsoni*	3	0
H4	*Cibicides lobatulus*	2	0
H5	*Astacolus crepidulus*	8	0
H5	*Vaginulina linearis*	15	0
H5	*Dentalina* spp.	14	0
H5	*Amphicoryna* cf. *scalaris*	13	0
H5	*Siphogenerinoides* sp.	4	0
H5	*Nodosauria pyrula*	3	0
H6	*Bulimina gibba*	104	0
H6	*Bulimina elongata*	77	1
H6	*Bulimina marginata*	48	0
H8	*Stainforthia concava* var.		

MG		Abs.	%
A11	*Pyrgo depressa*	73	1
P12	*Cornuspirella diffusa*	23	0
P2	*Cyclogyra involvens*	9	0
P11	*Quinqueloculina* sp. 5	2	0
P8	*Quinqueloculina oblonga*	1747	13
P8	*Quinqueloculina seminulum*	138	1
P8	*Quinqueloculina oblonga* var. *lata*	2	0
P8	*Quinqueloculina lata*	1	0
P8	*Quinqueloculina aspera* I	1	0
P8	*Quinqueloculina aspera* II	1	0
P8	*Miliolinella circularis*	1	0
P8	*Quinqueloculina auberiana*	1	0
P8	*Quinqueloculina bicornis*	1	0
P8	*Quinqueloculina aspera* III	6	0
P8	*Quinqueloculina* spp.	4	0
P9	*Quinqueloculina* cf. *cliarensis*	38	0
P9	*Spiroloculina excavata*	2	0
P9	*Massilina secans*	1	0
P9	*Quinqueloculina cliarensis*	1	0
P9	*Quinqueloculina mediterranensis*	11	0
	Total	2062	15
		Abs.	%
A1	*Ammoscalaria pseudospiralis*	67	0
A1	*Cribrostomoides jeffreysii*	20	0
A10	Genus 1	2	0
A11	*Psammosphaera bowmani*	5	0
A5	*Reophax fusiformis*	11	0
A5	*Clavulina obscura*	7	0
A6	*Eggerelloides scabrum*	321	2
A6	*Textularia earlandi*	52	0
A6	*Reophax moniliformis*	1	0
A7	*Textularia sagittula*	1	0
A8	*Reophax scottii*	87	1
	Total	573	4

	loeblichi	**991**	**7**				
H8	*Buliminella elegantissima*	**12**	**0**				
H8	*Trifarina angulosa*	**6**	**0**				
H8	*Uvigerina* sp.	**4**	**0**				
H9	*Fursenkoina fusiformis*	**3**	**0**				
	Total	**10821**	**81**				

Table 8.16. Foraminifera are divided into three general groups; hyaline, porcellaneous and agglutinated and allocated morphogroups (columns labelled MG). Both the absolute (Abs.) and percentage (%) values of each species are shown.

8.6.7. Discussion.

All of the principal species follow a similar distribution as the total live foraminiferal distribution shown in Figure. 8.15. They exhibit four periods of marked low abundance throughout the year; December/January, March/April, June and August/September/ October, with the exception of *E. scabrum* in March/April when it reaches its species maximum abundance, and *A. beccarii batavus* which in March/April has a moderate population.

The majority of species follow these trends which suggests that rather than being due to species interactions (i.e. inter- and intra-specific competition, etc.), the species distribution is more likely the result of a general reduction in available food, large scale predation or some other environmental fluctuation. The exception to this is the generally low abundance of *A. beccarii batavus* during April, May and June when most other species are abundant or at their maximum. *Ammonia beccarii batavus* may be actively suppressed by *B. pseudopunctata* through competition. The reason *A. beccarii batavus* does not compete successfully is not known but perhaps elongate morphologies within this soft facies are advantageous, although later, *A. beccarii batavus* becomes the dominant species implying perhaps a seasonal factor influences competition, or simply the passive replacement of *Brizalina pseudopunctata* by *A. beccarii batavus*.

Juveniles of most of the common species particularly *A. beccarii batavus* and *S. concava* var. *loeblichi* were recorded from February to September suggesting that reproduction occurred at many periods throughout the year.

8.7. Location 11

8.7.1. Introduction

Location 11 is a medium to coarse grained sandy facies. Foraminiferal abundance and diversity are very low.

8.7.2. Foraminiferal Abundance

Foraminifera were very low in abundance until August (33 individuals) and September where they reached a maximum abundance of 71 individuals (Figure 8.19).

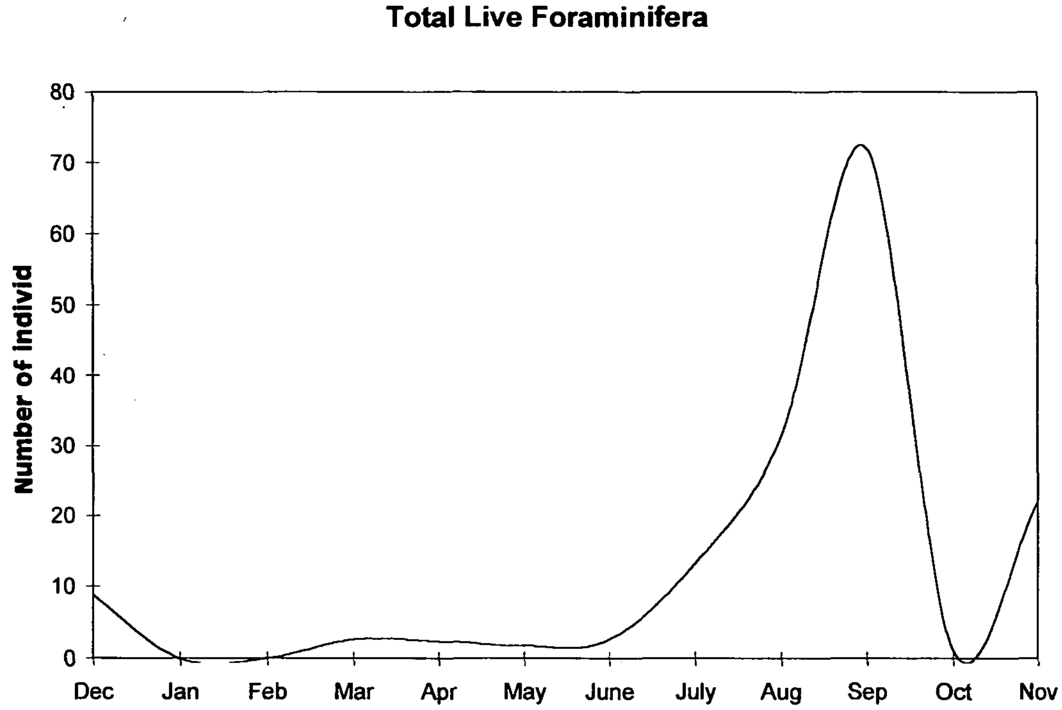


Figure. 8.19. Total live abundance of foraminifera (per 100cm^3 of sediment) at Location 11, between December 1993 and November 1994.

A yearly production rate of 94 tests was recorded. July, August and September represented a period of sustained production, which was followed in October by mortality.

	Total Live	Gains	Losses
December 1993	9	0	0
January 1994	0	0	0
February	0	0	0
March	3	3	0
April	2	0	1
May	2	0	0
June	3	1	0
July	13	10	0
August	31	18	0
September	72	41	0
October	1	0	71
November	22	21	0
	158	**94**	**72**

Table 8.17. Production of foraminifera over one year at Location 11. Gains occurred over 3 consecutive months in late summer and were followed by mortality in October.

8.7.3. Species Abundance

	Abs	%
Elphidium crispum	97	61
Quinqueloculina seminulum	14	9
Ammonia beccarii batavus	10	6
Textularia truncata	5	3
Cibicides lobatulus	4	2
Quinqueloculina spp.	4	2
Psammosphaera bowmani	3	2
Quinqueloculina williamsoni	3	2
Bulimina elongata	2	2
Massilina secans	2	2
Quinqueloculina auberiana	2	1
Quinqueloculina oblonga	2	1
Asterigerinata mamilla	1	1
Globulina gibba	1	1
Planorbulina mediterranensis	1	1
Reophax moniliformis	1	1

Table 8.18. All species recorded at Location 11 throughout the year in order of abundance. Values in absolute (Abs.) and percentage (%) abundance.

Elphidium crispum was the dominant species, accounting for 61% of the assemblage. Of the minor species, *Q. seminulum* and *A. beccarii batavus* were the most important. A total of 158 foraminifera were produced during the year and a maximum of 72 individuals during September represented the observed carrying capacity for the area (Table 8.18).

8.7.4. Species Distribution.

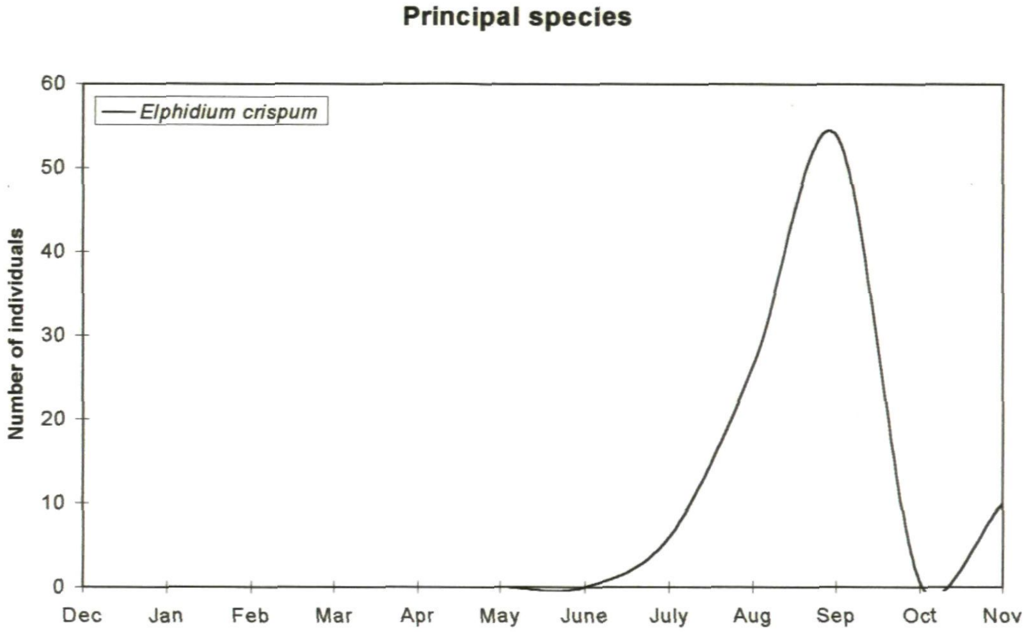


Figure. 8.20. Distribution of principal species (species which account for 10% or more of the assemblage) throughout the year at Location 11.

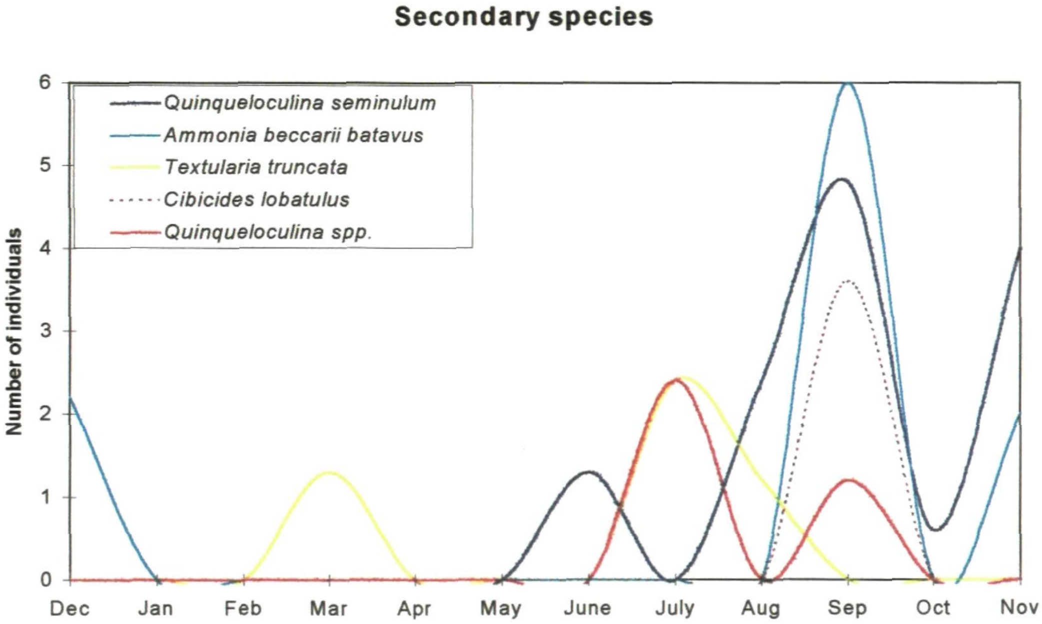


Figure. 8.21. Distribution of secondary species (species which account for less than 10% of the assemblage) throughout the year at Location 11.

Elphidium crispum follows a similar trend to that of the total fauna. It increased in abundance in August, reaching maximum abundance in September. The minor species exhibited a similar pattern, becoming most abundant in July and September.

8.7.5. Diversity

Diversity was generally very low but increased as abundance increased reaching maxima in September and November of only 7 species. A total of 17 species were recorded from this site giving an Fisher Alpha diversity index of 4 (Figures 8.20 and 8.21).

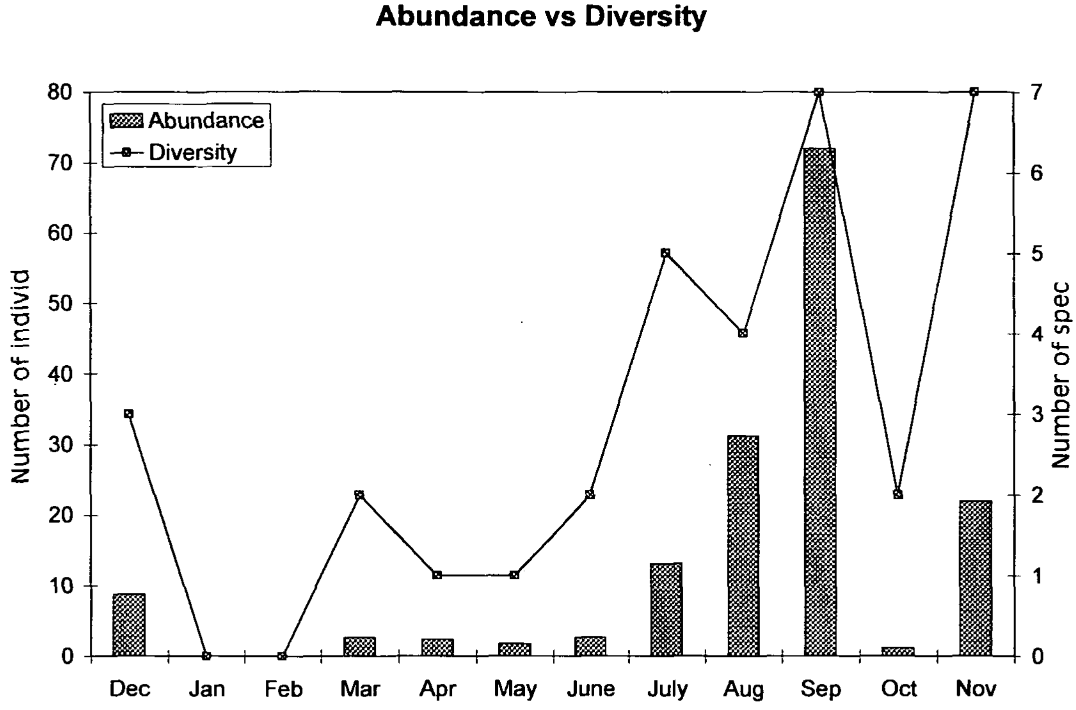


Figure. 8.22. Comparison between foraminiferal abundance and diversity throughout the year at Location 11.

8.7.6. Morphogroups

The lenticular group (H3), represented by *E. crispum,* which is epifaunal, accounted for 61% of the assemblage. The second most important group were the fusiform porcellaneous forms (P8) which are free living epi/infaunal. A small number (4%) of plano-convex forms (H4) which have an attached mode of life, were present (Table 8.19).

MG		Abs.	%
H1	*Ammonia beccarii batavus*	**10.2**	**6**
H11	*Globulina gibba*	**1.2**	**1**
H3	*Elphidium crispum*	**97**	**61**
H4	*Cibicides lobatulus*	**3.6**	**2**
H4	*Planorbulina mediterranensis*	**1.2**	**1**
H5	*Asteriginata mamilla*	**1.2**	**1**
H6	*Bulimina elongata*	**2.4**	**2**
	Total	**117**	**74**

MG		Abs.	%
P8	*Quinqueloculina seminulum*	**14.4**	**9**
P8	*Quinqueloculina* spp.	**3.6**	**2**
P8	*Quinqueloculina williamsoni*	**2.7**	**2**
P8	*Quinqueloculina auberiana*	**2.3**	**1**
P8	*Quinqueloculina oblonga*	**2.2**	**1**
P9	*Massilina secans*	**2.4**	**2**
	Total	**27.6**	**17**
A11	*Psammosphaera bowmani*	**3**	**2**
A6	*Reophax moniliformis*	**1**	**1**
A7	*Textularia truncata*	**4.9**	**3**
A8	Genus 3	**4.4**	**3**
	Total	**13.3**	**8**

Table 8.19. Foraminifera are divided into three general groups; hyaline, porcellaneous and agglutinated and allocated morphogroups (columns labelled MG). Both the absolute (Abs.) and percentage (%) values of each species are shown.

8.7.7. Discussion.

Species are either absent or present in extremely low numbers for all months except August and September. Conditions were able to support more than just a few foraminifera only during August and September. It may be that, as with Location 8 (which is superficially very similar), the nature and mobility of the sediment creates a harsh environment for foraminifera, for which the free living epifaunal forms are most suited. Unlike Location 8 the epifaunal morphogroups H3 and P8 make up at least 77% of the assemblage and because of this, the fauna is probably more likely to be autochthonous as these are the morphogroups best suited to this environment. It is likely that, only as foraminiferal densities reach maximum abundance generally within the Sound (reflecting optimum conditions), that less favourable areas such as this locality are briefly colonised.

8.8. Location 12

8.8.1. Introduction

Location 12 is characterised by a firm, very silty, sandy sediment. The foraminiferal assemblage is dominated by one species, although foraminiferal density and diversity are high.

8.8.2. Foraminiferal Abundance

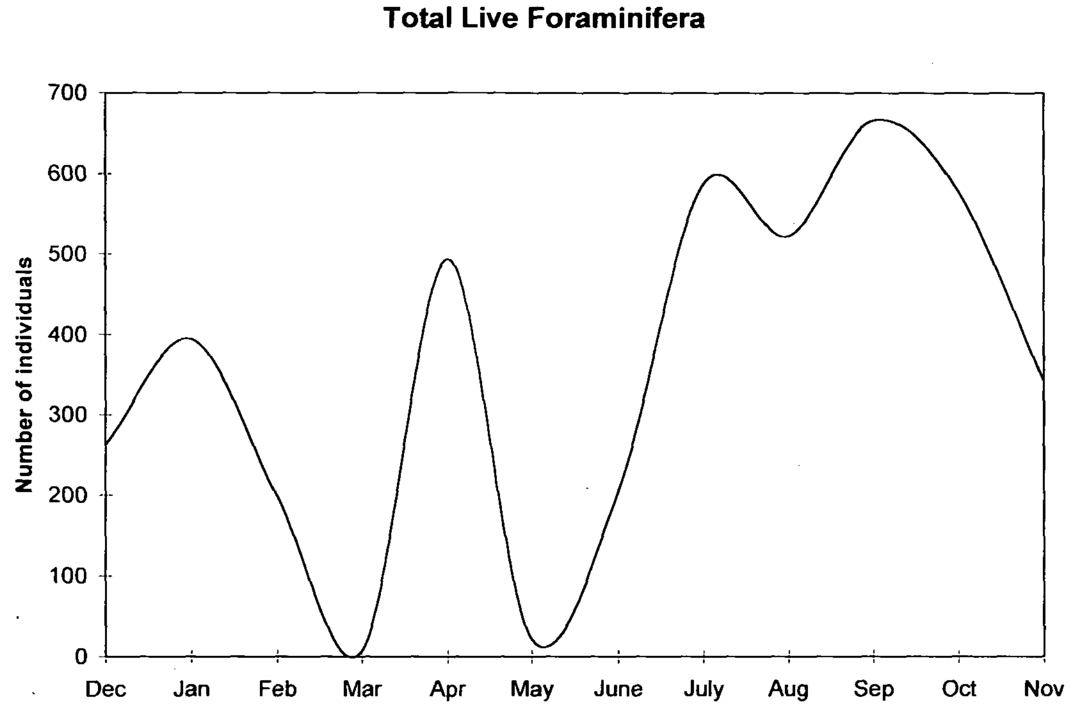


Figure. 8.23. Total abundance of foraminifera (per 100cm^3 of sediment) at Location 12, between December 1993 and November 1994.

The foraminiferal assemblage exhibited a peak in abundance in January of 395 individuals, falling to a very low abundance of 8 individuals in March, and then rising sharply, in April, to 494 individuals. Abundance fell again in May to 22 individuals but rose again June, and remained elevated in July and August. It reached a maximum abundance in September of 666 individuals. During October and November abundance began to fall although it remained relatively high (Figure 8.23).

Yearly production at Location 12 was 1327 foraminifera. Production was sustained from June to September, with minor losses during August. Losses increased during October and November (Table 8.20).

	Total Live	Gains	Losses
December 1993	263	0	0
January 1994	395	132	0
February	198	0	197
March	8	0	190
April	494	486	0
May	22	0	472
June	205	184	0
July	587	382	0
August	523	0	65
September	666	143	0
October	578	0	88
November	343	0	235
	4281	**1327**	**1247**

Table 8.20. Production of foraminifera throughout the year at Location 12.

8.8.3. Species Abundance.

One species completely dominated the assemblage; *A. beccarii batavus* accounted for 83% of the fauna. Of the minor species, *Q. oblonga* (4%) and *E. scabrum* (3%) were relatively common. The majority of species recorded were rare or very rare, usually occurring as a few individuals (single figures) in total throughout the year (Table 8.21).

	Abs.	%
Ammonia beccarii batavus	**3567**	83
Quinqueloculina oblonga	**178**	4
Eggerelloides scabrum	**135**	3
Brizalina pseudopunctata	**55**	1
Brizalina spathulata	**48**	1
Quinqueloculina seminulum	**40**	1
Bulimina elongata	**33**	1
Bulimina gibba	**29**	1
Stainforthia concava var. *loeblichi*	**25**	1
Reophax scottii	**21**	0
Elphidium cuvillieri	**19**	0
Brizalina variabilis	**14**	0
Quinqueloculina cf. *cliarensis*	**11**	0
Quinqueloculina spp.	**11**	0

Elphidium crispum	**10**	0
Psammosphaera bowmani	**10**	0
Cyclogyra involvens	**10**	0
Textularia earlandi	**7**	0
Haynesina germanica	**7**	0
Bulimina marginata	**5**	0
Fissurina lucida	**5**	0
Quinqueloculina auberiana	**4**	0
Buliminella elegantissima	**4**	0
Spiroloculina sp.	**3**	0
Quinqueloculina mediterranensis	**3**	0
Lagena clavata	**3**	0
Quinqueloculina aspera I	**3**	0
Lenticulina orbiculatis	**2**	0
Elphidium gerthi	**2**	0
Elphidium williamsoni	**2**	0
Planorbulina mediterranensis	**2**	0
Textularia truncata	**2**	0
Clavulina obscura	**2**	0
Nonion depressulus	**2**	0
Patellina corrugata	**2**	0
Asteriginata mamilla	**2**	0
Rosalina williamsoni	**2**	0
Quinqueloculina aspera II	**2**	0
Ammoscalaria pseudospiralis	**1**	0
Quinqueloculina sp. 5	**1**	0
Uvigerina sp.	**1**	0
Brizalina striatula	**1**	0

Table 8.21. All species recorded at Location 12 throughout the year in order of abundance. Values in absolute (Abs.) and percentage (%) abundance..

8.8.4. Species Distributions

The distribution of *A. beccarii batavus* was almost identical to that of the total foraminifera which showed high abundance in January, April and during July to November. *Quinqueloculina oblonga* had a less variable occurrence, exhibiting an abundance maxima in April, July and September. *Eggerelloides scabrum* showed a prominent peak in abundance during April but was rare in all other months (Figure 8.24).

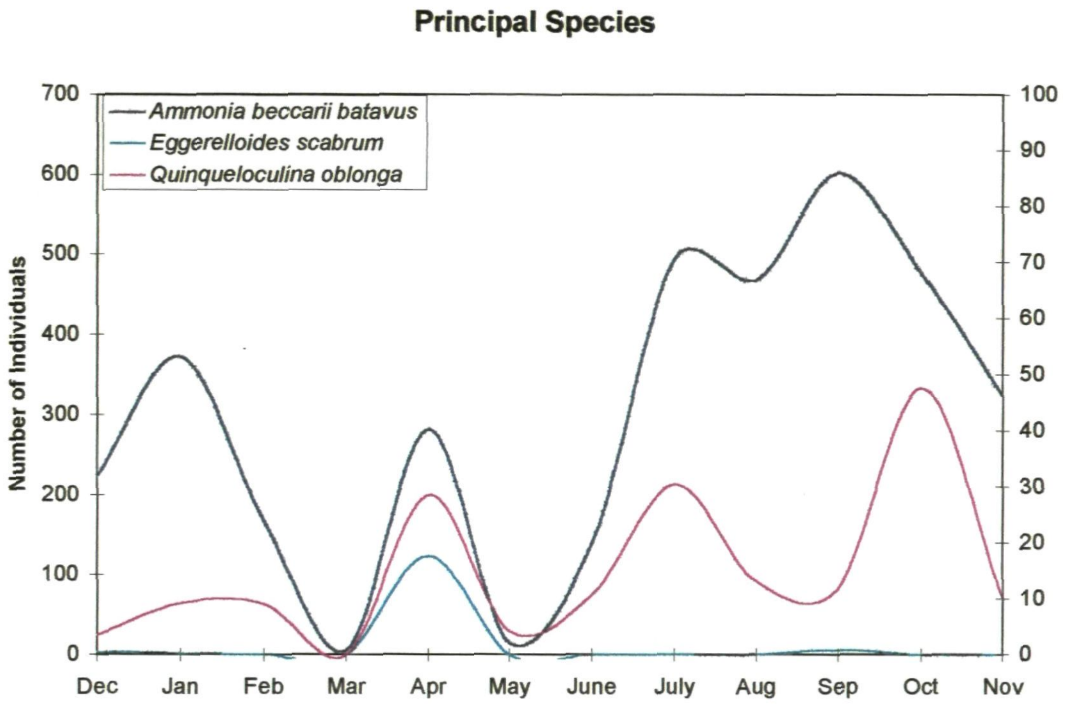


Figure. 8.24. Most important foraminiferal species trends throughout the year. *Quinqueloculina oblonga* is plotted on the left axis.

8.8.5. Diversity

Diversity generally followed abundance, being low in December, January, February and March (Figure 8.25). In April diversity rose sharply and reached its maximum of 20 species, although maximum numbers of individuals were not reached until September. Diversity was high in June, July, August, September and October when foraminiferal abundance was high (although diversity was high in June when abundance was relatively low). This may have reflected an initial period of rapid increase in diversity with the advent of favourable conditions during which most species were established in moderate to low abundance (after a period of very low abundance and diversity). As foraminiferal abundance increased, diversity did not, perhaps due to interspecific competition.

In total, 42 species were recorded throughout the year which results in an Fisher Alpha diversity index of between 6 and 7.

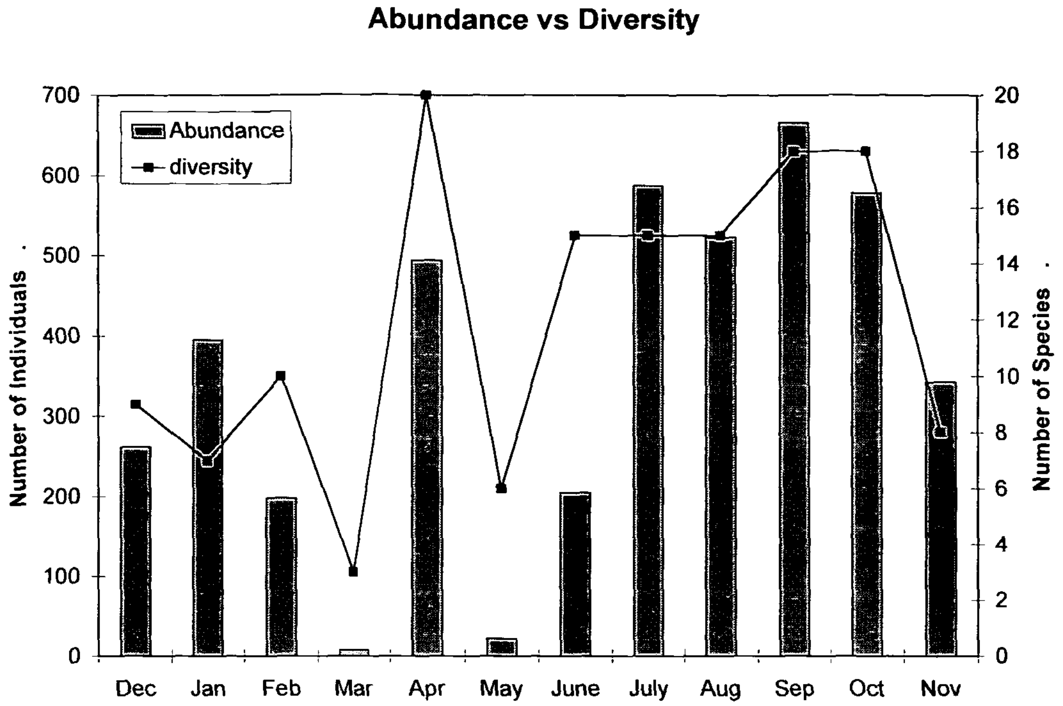


Figure. 8.25. Comparison of species abundance against species diversity throughout the year at Location 12.

8.8.6. Morphogroups

The dominance of *A. beccarii batavus* is reflected in the dominance of the rounded planispiral group H1 (84%), which may be epifaunal but predominantly infaunal herbivores. Other groups which were significant, although relatively minor, are the fusiform porcellaneous P8 group (4%) which may be infaunal or epifaunal and the conical groups H6 and A6 which together form approximately 5% of the fauna (Table 8.22). The conical groups are detritivores and probably infaunal.

MG		Abs	%
H1	*Ammonia beccarii batavus*	3567	83
H1	*Elphidium cuvillieri*	19	0
H1	*Haynesina germanica*	7	0
H1	*Elphidium gerthi*	2	0
H1	*Elphidium williamsoni*	2	0
H1	*Nonion depressulus*	2	0
H10	*Brizalina pseudopunctata*	55	1
H10	*Brizalina spathulata*	48	1
H10	*Brizalina variabilis*	14	0
H10	*Brizalina striatula*	1	0

MG		Abs	%
P2	*Cyclogyra involvens*	10	0
P11	*Quinqueloculina* sp. 5	1	0
P8	*Quinqueloculina oblonga*	178	4
P8	*Quinqueloculina seminulum*	40	1
P8	*Quinqueloculina* spp.	11	0
P8	*Quinqueloculina auberiana*	4	0
P8	*Quinqueloculina aspera* I	3	0
P8	*Quinqueloculina aspera* II	2	0
P9	*Quinqueloculina* cf. *cliarensis*	11	0
P9	*Spiroloculina* sp.	3	0

H11	*Fissurina lucida*	**5**	**0**
H11	*Lagena clavata*	**3**	**0**
H3	*Elphidium crispum*	**10**	**0**
H3	*Lenticulina orbiculatis*	**2**	**0**
H4	*Planorbulina mediterranensis*	**2**	**0**
H4	*Patellina corrugata*	**2**	**0**
H4	*Rosalina williamsoni*	**2**	**0**
H5	*Asteriginata mamilla*	**2**	**0**
H6	*Bulimina elongata*	**33**	**1**
H6	*Bulimina gibba*	**29**	**1**
H6	*Bulimina marginata*	**5**	**0**
H8	*Stainforthia concava* var. *loeblichi*	**25**	**1**
H8	*Buliminella elegantissima*	**4**	**0**
H8	*Uvigerina* sp.	**1**	**0**
	Total	**3839**	**90**

P9	*Quinqueloculina mediterranensis*	**3**	**0**
	Total	**264**	**6**
A1	*Ammoscalaria pseudospiralis*	**1**	**0**
A11	*Psammosphaera bowmani*	**10**	**0**
A5	*Clavulina obscura*	**2**	**0**
A6	*Eggerelloides scabrum*	**135**	**3**
A6	*Textularia earlandi*	**7**	**0**
A7	*Textularia truncata*	**2**	**0**
A8	*Reophax scottii*	**21**	**0**
	Total	**178**	**4**

Table 8.22. Foraminifera are divided into three general groups; hyaline, porcellaneous and agglutinated and allocated morphogroups (columns labelled MG). Both the absolute (Abs.) and percentage (%) values of each species are shown.

8.8.7. Discussion

Ammonia beccarii batavus dominates the assemblage, the reason for this dominance is probably due to the general lower salinity of the site; between 34‰ to 29‰ and on average less than 33‰ (most other sites within the Sound have an average salinity of 34‰ to 35‰). The trend of *A. beccarii batavus* and the other species do not have a strong positive or negative correlation with salinity temporally. Salinity does not directly influence foraminiferal patterns and trends observed throughout the year, but it does influence assemblage structure and composition, as the slightly hyposaline conditions provide *A. beccarii batavus* with an advantage over most other species. Temperature shows a broad correlation with foraminiferal trends which implies it may indirectly responsible for the foraminiferal trend.

The low abundances observed in March and May may be due to a paucity of food and exacerbated by intraspecific competition. Alternatively these periods of low abundance may represent reproductive events during which most adult forms suffered mortality but juveniles were too small to be identified. The increase in diversity and the bloom of *E.*

scabrum and *Q. oblonga* in April (while *A. beccarii batavus* was abundant) may be due to a greater range of food types or the greater abundance of a particular food type as these species belong to different morphogroups with different feeding strategies.

Productivity calculations show two styles of production. In April the very high production is immediately followed by very high losses. This period may represent a major reproductive event as juvenile specimens were recorded. The assemblage is in disequilibrium (perhaps with food supply) in May and the high mortality rates probably result from depleted food. Juveniles are particularly susceptible (*pers. comm.* C. J. Manley). During June most of the *A. beccarii batavus* recorded were juveniles, this represents a second major reproductive event but unlike the reproductive event in March which was followed by high mortality and a sharp decline in abundance of the fauna, mortality rates after June are low and although juveniles are not observed later in the year the population of *A. beccarii batavus* is sustained for several months.

8.9. Location 14

8.9.1. Introduction

Location 14 is characterised by a medium to fine sand facies. Foraminiferal abundance is very low and diversity is moderate to low.

8.9.2. Foraminiferal Abundance

Foraminifera were absent or present in very low abundance for all months except July and September. In July abundance rose to 71 individuals, falling in August to 19 individuals and then recording the maximum abundance of 87 individuals in September. The maximum abundance in September represented the observed carrying capacity for this location.

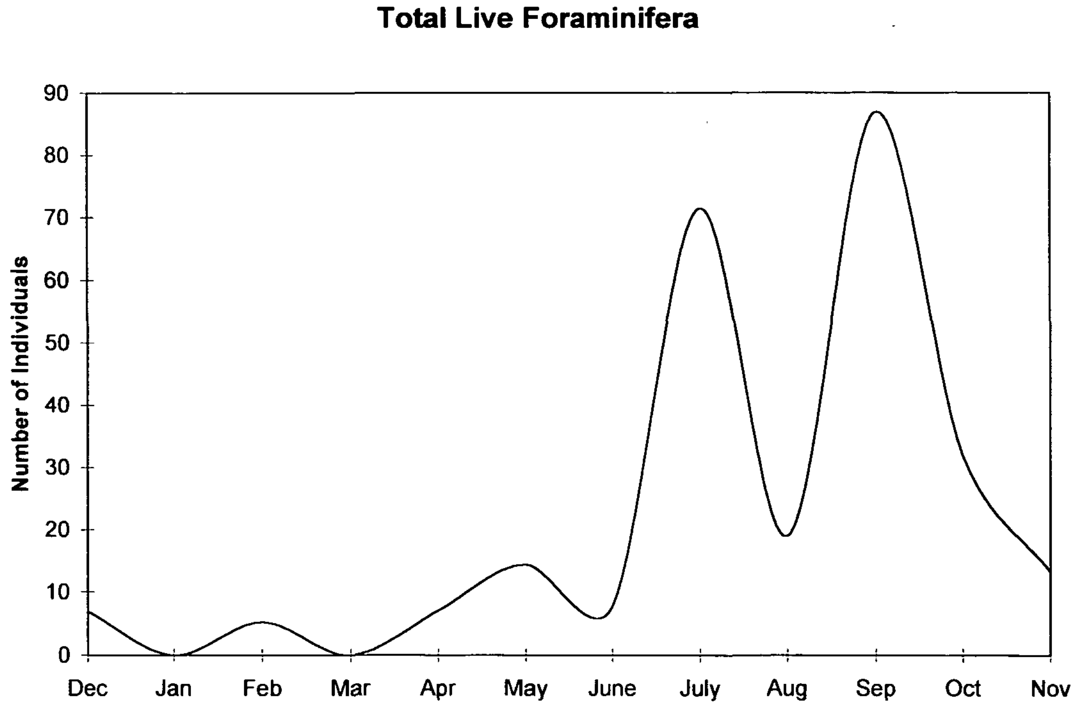


Figure 8.26. Total abundance of live foraminifera (per 100cm^3 of sediment) at Location 14, between December 1993 and November 1994.

A total of 264 individuals were produced throughout the year. Production was nearly always immediately followed by losses at this locality. There was a very good match between total gains and total losses (See Table 8.23).

	Total Live	Gains	Losses
December 1993	7	0	0
January 1994	0	0	7
February	5	5	0
March	0	0	5
April	7	7	0
May	14	7	0
June	8	0	6
July	71	63	0
August	19	0	52
September	87	68	0
October	32	0	55
November	13	0	19
	264	**150**	**144**

Table 8.23. Production of foraminifera at Location 14 throughout the year

8.9.3. Species Abundance

The dominant species was *A. beccarii batavus* which accounted for 68% of the assemblage. The most important minor species was *Q. oblonga*. All other species were very rare (Table 8.24).

	Abs.	%
Ammonia beccarii batavus	179	68
Quinqueloculina oblonga	21	8
Nonion depressulus	9	3
Quinqueloculina aspera I	7	3
Eggerelloides scabrum	5	2
Haynesina germanica	5	2
Quinqueloculina lata	4	1
Elphidium crispum	4	1
Quinqueloculina seminulum	4	1
Elphidium cuvillieri	3	1
Brizalina spathulata	3	1
Quinqueloculina auberiana	3	1
Bulimina elongata	2	1
Massilina secans	2	1
Psammosphaera bowmani	2	1
Cibicides lobatulus	1	0
Ammonia beccarii limnetes	1	0
Globulina gibba	1	0
Quinqueloculina sp. 5	1	0
Cyclogyra involvens	1	0
Quinqueloculina cf. *cliarensis*	1	0
Textularia truncata	1	0
Pyrgo depressa	1	0
Quinqueloculina williamsoni	1	0
Stainforthia concava var. *loeblichi*	1	0
Brizalina pseudopunctata	1	0
Nonionella turgida var. *digitata*	1	0

Table 8.24. List of species recorded from Location 14. Species values are given in absolute amount (Abs.) and percentage amount (%).

8.9.4. Species Trend

The species distributions throughout the year were similar to the total foraminiferal trend. High abundance was observed in July and September (Figure 8.26).

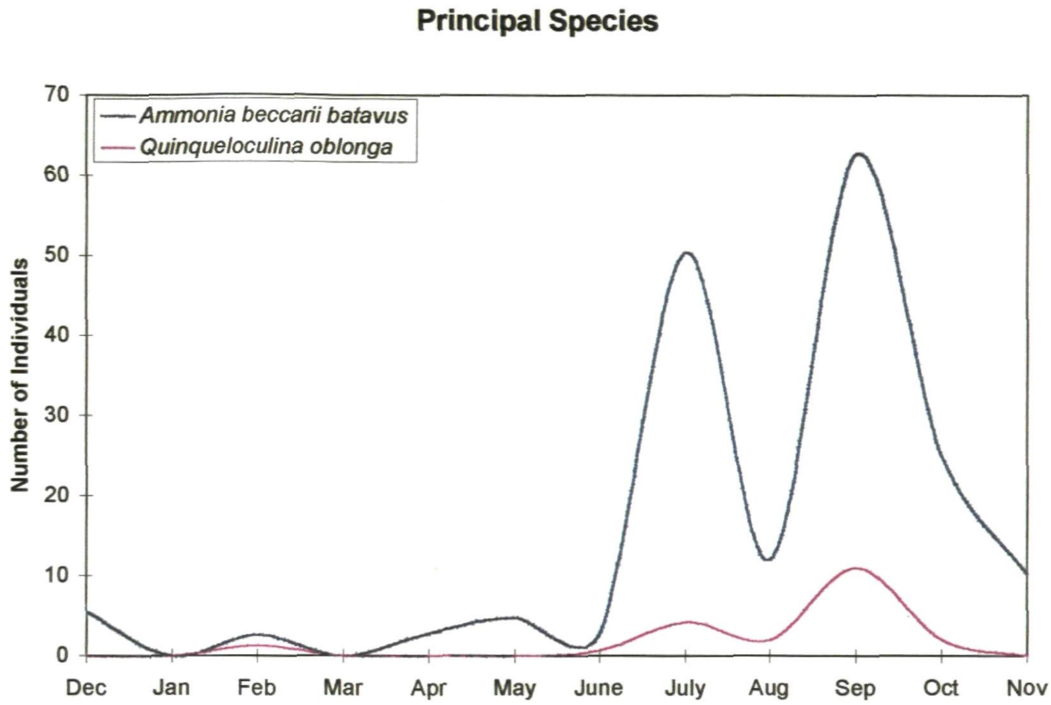


Figure. 8.27. Species distribution of the two most abundant species show a similar trend.

8.9.5. Diversity

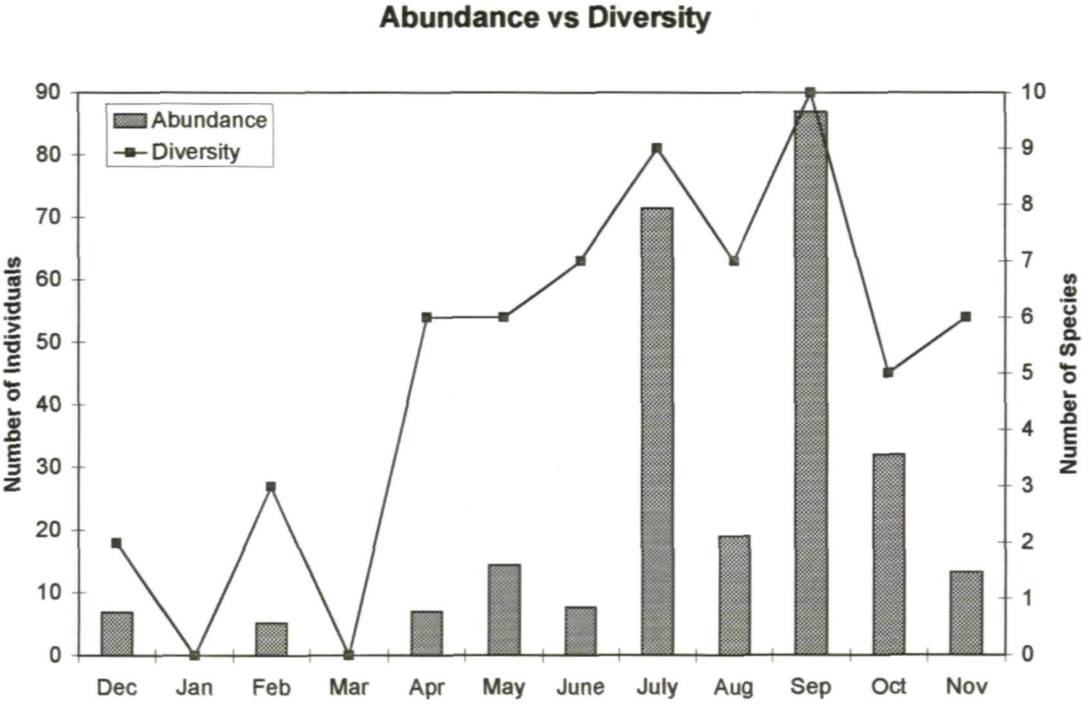


Figure. 8.28. Comparison of species abundance against species diversity throughout the year at Location 14. Diversity almost perfectly mirrors abundance.

Foraminiferal abundance and diversity correlated reasonably well (Figure 8.28). Maximum abundance and diversity coincided in September. The total number of species recorded from this site was 27, giving an Fisher Alpha diversity index of about 7

8.9.6. Morphogroups

The rounded planispirals (H1) were the most common group (75%), which was mainly due to the abundance of *A. beccarii batavus*. The other significant group was the fusiform planispirals (P8) which accounted for 15% of the assemblage (Table 8.25).

MG		Abs,	%
H1	*Ammonia batavus beccarii*	**178.8**	**68**
H1	*Nonion depressulus*	**9.1**	**3**
H1	*Haynesina germanica*	**5.2**	**2**
H1	*Elphidium cuvillieri*	**3.3**	**1**
H1	*A. beccarii limnetes*	**1.3**	**0**
H1	*Nonionella turgida* var. *digitata*	**0.6**	**0**
H10	*Brizalina spathulata*	**2.8**	**1**
H10	*Brizalina pseudopunctata*	**0.6**	**0**
H11	*Globulina gibba*	**1.3**	**0**
H3	*Elphidium crispum*	**3.7**	**1**
H4	*Cibicides lobatulus*	**1.4**	**1**
H6	*Bulimina elongata*	**2.3**	**1**
H8	*Stainforthia concava* var. *loeblichi*	**0.7**	**0**
	Total	**211.1**	**80**

MG		Abs.	%
P11	*Pyrgo depressa*	**0.7**	**0**
P11	*Quinqueloculina* sp. 5	**1.1**	**0**
P2	*Cyclogyra involvens*	**1**	**0**
P8	*Quinqueloculina oblonga*	**21.2**	**8**
P8	*Quinqueloculina aspera* I	**6.8**	**3**
P8	*Quinqueloculina lata*	**3.9**	**1**
P8	*Quinqueloculina seminulum*	**3.6**	**1**
P8	*Quinqueloculina auberiana*	**2.6**	**1**
P8	*Quinqueloculina williamsoni*	**0.7**	**0**
P9	*Massilina secans*	**1.8**	**1**
P9	*Quinqueloculina* cf. *cliarensis*	**1**	**0**
	Total	**44.4**	**17**
A11	*Psammosphaera bowmani*	**1.8**	**1**
A6	*Eggerelloides scabrum*	**5.4**	**2**
A7	*Textularia truncata*	**1**	**0**
	Total	**8.2**	**3**

Table 8.25. Foraminifera are divided into three general groups; hyaline, porcellaneous and agglutinated and allocated morphogroups (columns labelled MG). Both the absolute (Abs.) and percentage (%) values of each species are shown.

8.9.7. Discussion

The dominance of *A. beccarii batavus* is probably a consequence of the slightly hyposaline conditions, (although this site is not as hyposaline as Location 12). The average salinity is 33.6‰ very slightly below normal marine. A general correlation with salinity exists in that foraminifera are most abundant in late summer when salinity is highest. Temperature correlates very generally with foraminiferal abundance.

The foraminiferal assemblage exhibits high abundance only in July and September. This is probably due to the availability of food and favourable conditions during these periods. Production is low, which may reflect a generally low amount of available food. Production is not sustained for more than one month before losses ensue. The available food is either depleted quickly or some other environmental factor such as the instability of the site does not allow the assemblage to develop. Although juveniles were uncommon the low abundance observed in August (the warmest month) may represent a reproductive event which would reflect the maximum abundance in September.

8.10. Location 15

8.10.1. Introduction

Location 15 is characterised by a silty facies. Foraminiferal densities are high, as is diversity.

8.10.2. Foraminifera Abundance

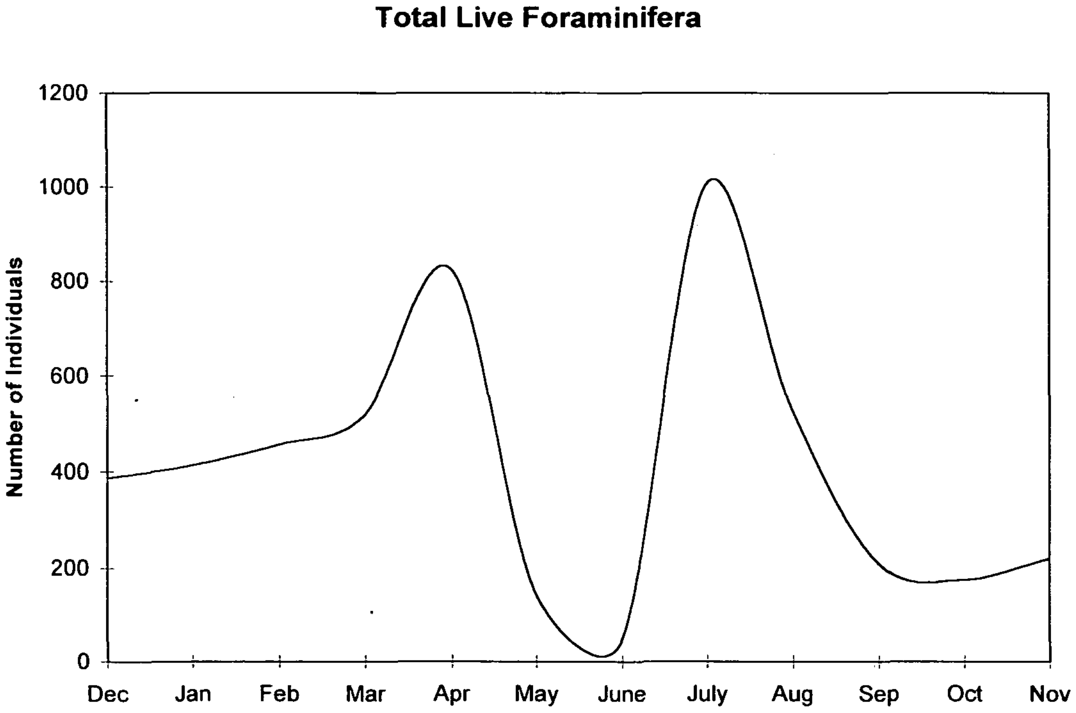


Figure. 8.29. Total abundance of live foraminifera (per 100cm^3 of sediment) at Location 15, between December 1993 and November 1994.

Foraminiferal abundance was elevated and stable from December to March at approximately 400 individuals. It rose, in April, to 825 individuals then fell to very low abundance in May and June (146 and 47 individuals respectively). In July foraminiferal abundance rose sharply to 1007 which represented the maximum observed carrying capacity of the site. Foraminiferal abundance then dropped sharply in August and was stable, but low, in September, October and November, at approximately 200 individuals (Figure 8.29).

Production of tests for one year was 1441. This was sustained from January to April, with losses occurring in June and July. High production was recorded in August, followed by three months of losses (Table 8.26).

	Total live	Gains	Losses
December 1993	387	0	0
January 1994	414	27	0
February	457	41	0
March	520	63	0
April	825	305	0
May	146	0	679
June	47	0	99
July	1007	960	0
August	526	0	482
September	211	0	315
October	176	0	35
November	221	45	0
Total	**4935**	**1441**	**1610**

Table 8.26. Production is calculated and shown throughout the year at Location 15.

8.10.3. Species Abundance

Ammonia beccarii batavus dominated the assemblage with 66% of the fauna. *Elphidium crispum* was the second principal species with 12%. *Eggerelloides scabrum*, *Q. oblonga* and *B.pseudopunctata* were the most important minor species.

	Abs.	%
Ammonia beccarii batavus	**3243**	66
Elphidium crispum	**568**	12
Eggerelloides scabrum	**225**	5
Quinqueloculina oblonga	**205**	4
Brizalina pseudopunctata	**125**	3
Reophax scottii	**82**	2
Brizalina spathulata	**63**	1
Bulimina elongata	**57**	1
Elphidium cuvillieri	**55**	1
Buliminella elegantissima	**53**	1
Stainforthia concava var. *loeblichi*	**49**	1
Ammonia beccarii limnetes	**38**	1
Bulimina gibba	**27**	1
Brizalina variabilis	**22**	0
Quinqueloculina seminulum	**20**	0
Nonion depressulus	**17**	0
Quinqueloculina aspera III	**9**	0
Quinqueloculina aspera I	**8**	0
Fissurina lucida	**6**	0
Ammoscalaria pseudospiralis	**6**	0
Bulimina marginata	**5**	0
Psammosphaera bowmani	**5**	0
Brizalina striatula	**4**	0
Cyclogyra involvens	**4**	0
Quinqueloculina spp	**3**	0
Uvigerina sp.	**3**	0
Clavulina obscura	**3**	0
Haynesina germanica	**3**	0
Textularia sagittula	**3**	0
Trifarina angulosa	**3**	0
Bolovina pseudoplicata	**2**	0
Quinqueloculina aspera II	**2**	0
Lagena clavata	**2**	0
Fursenkoina fusiformis	**2**	0
Textularia earlandi	**1**	0
Elphidium williamsoni	**1**	0
Nonionella sp.	**1**	0
Lenticulina orbiculatis	**1**	0
Elphidium gerthi	**1**	0
Nonionella turgida var. *digitata*	**1**	0
Amphicoryna cf. *scalaris*	**1**	0
Fissurina marginata	**1**	0

Globulina gibba	**1**	0
Quinqueloculina sp. 5	**1**	0
Quinqueloculina cf. *cliarensis*	**1**	0
Cornuspirella diffusa	**1**	0
Elphidium margaritaceum	**1**	0
Rosalina williamsoni	**1**	0
Pateoris hauerinoides	**1**	0
Quinqueloculina williamsoni	**1**	0

Table 8.27. All species recorded at Location 15 throughout the year in order of abundance. Values in absolute (Abs.) and percentage (%) abundance.

8.10.4. Species Distributions

Ammonia beccarii batavus was very abundant during December, January, February and March (Figure 8.29). In April it increased to a maximum abundance of 517 individuals. *Elphidium crispum* exhibited low abundance during this period but *Q. oblonga* and *E. scabrum* rose sharply to their highest abundance during April (Figure 8.30).

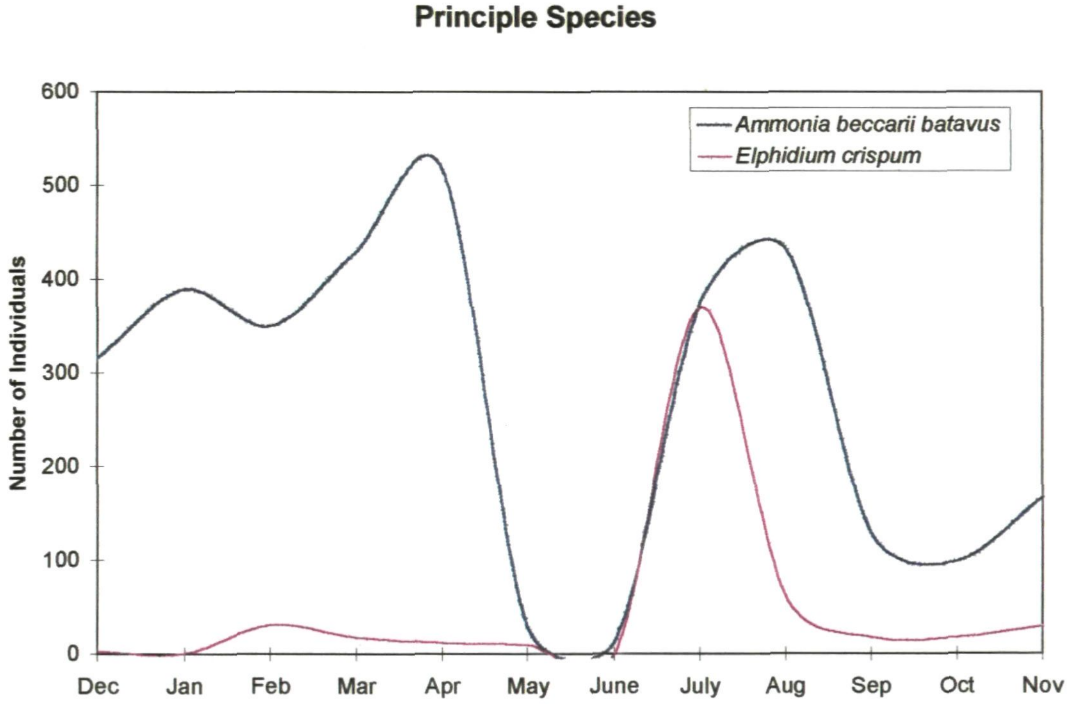


Figure 8.29. The distribution of principal species throughout the year at Location 15.

All species exhibited a very low abundance during May and June. July represented a sharp peak in abundance for all important species, *E. crispum* reached its maximum abundance, as did *B. pseudopunctata.* Most species; decreased in abundance during August and thereafter, except *A. beccarii batavus* which increased in abundance slightly and then decreased in abundance during September.

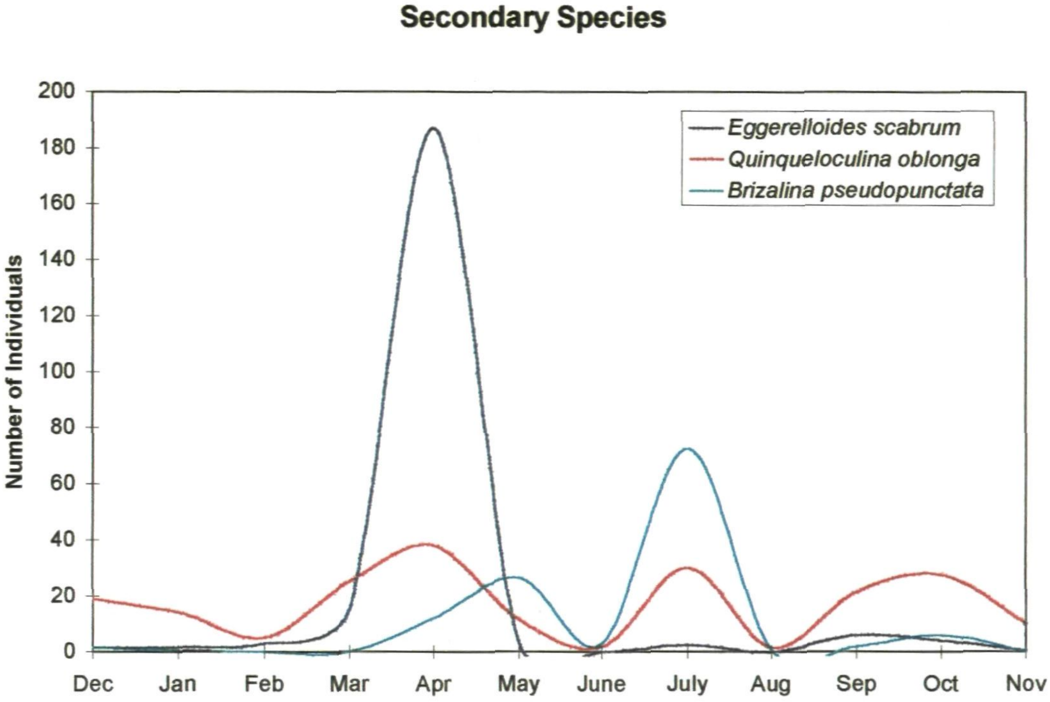


Figure 8.30. Distributional patterns of secondary species (species which usually form less than 10% of the total assemblage) throughout the year.

8.10.5. Diversity

Diversity generally followed abundance but there were several discrepancies in this relationship. In December abundance was moderate and diversity was high. In May abundance fell sharply but diversity increased and in August and September abundance fell but diversity increased and then remained high (Figure 8.31). These discrepancies are characterised by an increase in diversity after abundance had increased and fallen (i.e. the peaks of abundance and diversity are out of phase as diversity lags behind, this is clearly seen in May and, August & September). A maximum of 26 species were recorded during the months of September and August. A total of 52 species were recorded throughout the year resulting in an Fisher Alpha diversity index of 8.

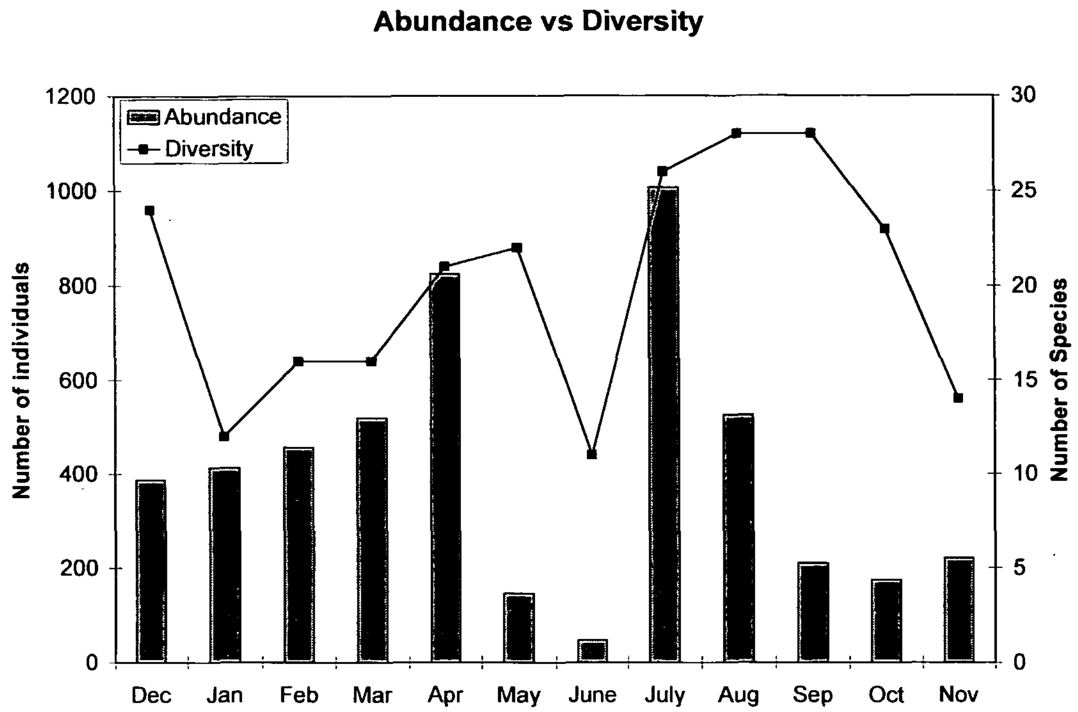


Figure. 8.31. Comparison of species abundance against species diversity throughout the year at Location 15. The maxima of diversity and abundance can be seen to be out of phase in May and August/ September/ October.

8.10.6. Morphogroups

MG		Abs.	%
H1	*Ammonia beccarii batavus*	**3243**	**66**
H1	*Elphidium cuvillieri*	**55**	**1**
H1	*Ammonia beccarii limnetes*	**38**	**1**
H1	*Nonion depressulus*	**17**	**0**
H1	*Haynesina germanica*	**3**	**0**
H1	*Elphidium williamsoni*	**1**	**0**
H1	*Nonionella* sp.	**1**	**0**
H1	*Elphidium gerthi*	**1**	**0**
H1	*Nonionella turgida* var. *digitata*	**1**	**0**
H1	*Elphidium margeritaceum*	**1**	**0**
H10	*Brizalina pseudopunctata*	**125**	**3**
H10	*Brizalina spathulata*	**63**	**1**
H10	*Brizalina variabilis*	**22**	**0**
H10	*Brizalina striatula*	**4**	**0**
H10	*Bolovina pseudoplicata*	**2**	**0**
H11	*Fissurina lucida*	**6**	**0**
H11	*Lagena clavata*	**2**	**0**

MG		Abs	%
P11	*Quinqueloculina* sp. 5	**1**	**0**
P12	*Cornuspirella diffusa*	**1**	**0**
P2	*Cyclogyra involvens*	**4**	**0**
P8	*Quinqueloculina oblonga*	**205**	**4**
P8	*Quinqueloculina seminulum*	**20**	**0**
P8	*Quinqueloculina aspera* III	**9**	**0**
P8	*Quinqueloculina aspera* I	**8**	**0**
P8	*Quinqueloculina* spp.	**3**	**0**
P8	*Quinqueloculina aspera* II	**2**	**0**
P8	*Quinqueloculina williamsoni*	**1**	**0**
P9	*Quinqueloculina* cf. *cliarensis*	**1**	**0**
P9	*Pateoris hauerinoides*	**1**	**0**
	Total	**254**	**5**
A1	*Ammoscalaria pseudospiralis*	**6**	**0**
A11	*Psammosphaera bowmani*	**5**	**0**
A5	*Clavulina obscura*	**3**	**0**

H11	*Fissurina marginata*	**1**	**0**
H11	*Globulina gibba*	**1**	**0**
H3	*Elphidium crispum*	**568**	**12**
H3	*Lenticulina orbiculatis*	**1**	**0**
H4	*Rosalina williamsoni*	**1**	**0**
H5	*Amphicoryna* cf. *scalaris*	**1**	**0**
H6	*Bulimina elongata*	**57**	**1**
H6	*Bulimina gibba*	**27**	**1**
H6	*Bulimina marginata*	**5**	**0**
H8	*Buliminella elegantissima*	**53**	**1**
H8	*Stainforthia concava* var. *loeblichi*	**49**	**1**
H8	*Uvigerina* sp.	**3**	**0**
H8	*Trifarina angulosa*	**3**	**0**
H9	*Fursenkoina fusiformis*	**2**	**0**
	Total	**4356**	**88**

A6	*Eggerelloides scabrum*	**225**	**5**
A6	*Textularia earlandi*	**1**	**0**
A7	*Textularia sagittula*	**3**	**0**
A8	*Reophax scottii*	**82**	**2**
	Total	**325**	**7**

Table 8.28. Foraminifera are divided into three general groups; hyaline, porcellaneous and agglutinated and allocated morphogroups (columns labelled MG). Both the absolute (Abs.) and percentage (%) values of each species are shown.

The morphogroups were controlled by several key species, the dominance of *A. beccarii batavus* was reflected in the dominance of the rounded planispiral group H1 (68%). The 12% of the lenticular group (H3) was entirely due to the presence of *E. crispum*. While both these groups are generally herbivorous the latter tends to be epifaunal whilst the rounded planispirals have greater tendencies to be infaunal. *Quinqueloculina oblonga* and *E. scabrum* dominated the fusiform group P8 (5%) and the conical A6 (5%) groups respectively. Both of these groups are detritivores and probably much more infaunal (the fusiform group P8 are generally epifaunal although the group is dominated by *Q. oblonga* which has distinct infaunal adaptations, principally a very elongate fusiform test rather than the rounded fusiform test of higher energy species).

8.10.7. Discussion

The dominance of *A. beccarii batavus* is not thought to be solely the result of lower salinities because although Location 15 is close to the mouth of the Plym Estuary, the average salinity is over approximately 34‰ (estuarine influences other than salinity may be important). The fine silty substrates (on which *A. beccarii batavus* is always common within the Sound) may provide the optimum food types in abundance, or other favourable conditions, allowing this species to be very successful on such substrates (as it always attaining densities of several hundred per 100 cm^3). Other species cannot compete well, or do not have optimum conditions for their development, at this location.

Whilst *A. beccarii batavus* is common throughout much of the year *E. crispum* is only common during July when species such as *B. pseudopunctata* and *Q. oblonga* are also common. Juveniles of *E. crispum* were recorded during May and June with a very dark colouration (black/green) the significance of the colouration is not known, although it must reflect food type or chloroplasts. The coloured juveniles appeared following a period of low foraminiferal abundance, and may be a response to decreased interspecific competition and/or a general increase in abundance of most species of foraminifera due to increased food supply and favourable conditions.

One reason diversity peaks after foraminiferal abundance (as mentioned above) may be due to the high abundance of foraminifera in April and July being dominated by one or more opportunistic species which rapidly increase their population size in response to environmental improvements (creating a low to moderate diversity assemblage of high abundance). As these opportunistic species decrease, perhaps because of intraspecific competition or depletion of a specific or general food type, other species have the opportunity to establish themselves (perhaps due to the availability of other food types or the better utilisation low levels of food) resulting in a higher diversity but lower abundance assemblage.

Production of foraminifera is sustained over the period from January to April (Table 8.27). April represents a moderately large increase in production which may put the assemblage out of equilibrium As a consequence high losses occur in May with smaller losses in June (as food begins to stabilise and recover). July represents a very high production period which may be a response to a replenished food source or a new food source. The very high production rate is unsustainable and followed by several months of losses (the fact that the losses are gradational implies that food is being depleted slowly and is still present).

Another reason for the distribution of foraminifera at this site may be related to reproduction. Foraminifera attain a maxima in April but rather than mortality through depletion of food in May and June, this period of sea temperature increase may have triggered a significant reproductive event the progeny of which create the abundance maxima in June.

8.11. Location 16

8.11.1. Introduction

Location 16 is characterised by shell gravels and coarse sands and it is one of the highest energy deposits within the Sound. Foraminiferal densities are moderate, whilst diversity is high.

8.11.2. Foraminiferal Abundance

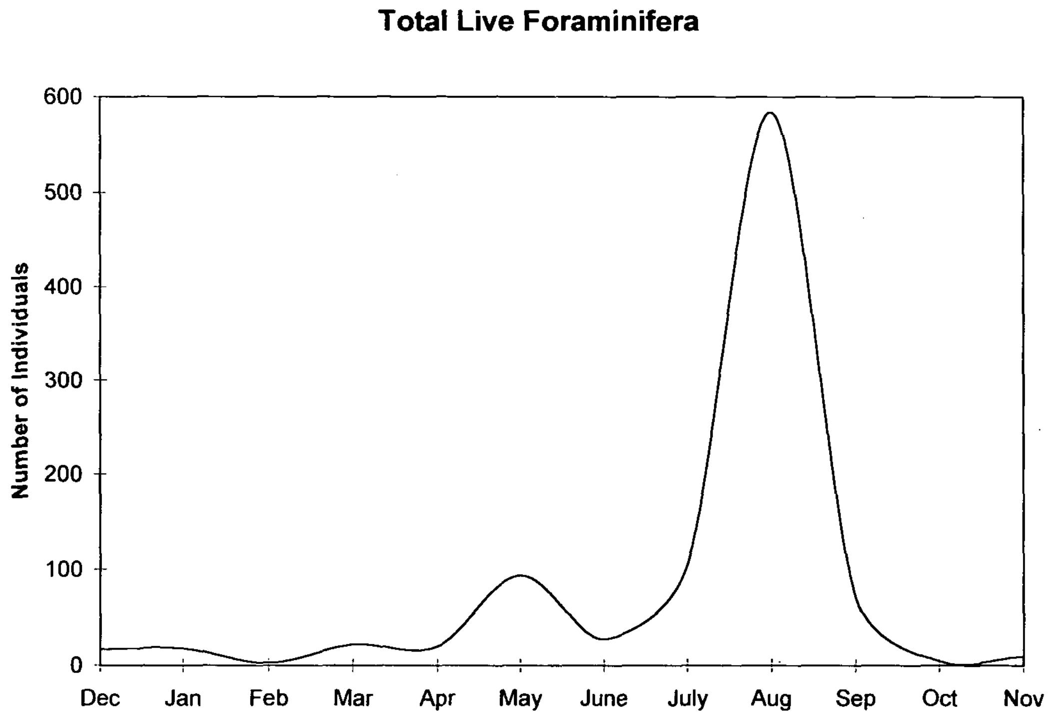


Figure. 8.32. Total abundance of live foraminifera (per 100cm^3 of sediment) at Location 16, between December 1993 and November 1994.

Foraminifera exhibited very low abundance throughout most of the year. A small peak in abundance was present in May, when 94 individuals were recorded. Abundance rose sharply in August, which represented the main bloom in which 584 individuals were recorded. Abundance dropped thereafter and remained low for the rest of the year (Figure 8.32).

The maximum abundance of 584 represented the maximum observed carrying capacity for the locality. A total production of 656 tests was recorded. The period from July to October showed a gradual cycle of increase and decrease of foraminifera.

	Total live	Gains	Losses
December 1993	17	0	0
January 1994	18	1	0
February	3	0	15
March	22	19	0
April	20	0	2
May	94	74	0
June	27	0	66
July	105	78	0
August	584	479	0
September	72	0	512
October	5	0	67
November	10	5	0
Total	**974**	**656**	**662**

Table 8.29. Total gains and losses are very similar, which suggests a system in which there is little emigration and immigration of foraminifera and the cycles of gains and losses are complete.

8.11.3. Species Abundance

	Abs.	%
Rosalina williamsoni	**289**	30
Textularia truncata	**280**	29
Cribrostomoides jeffreysii	**85**	9
Planorbulina mediterranensis	**68**	7
Quinqueloculina spp.	**52**	5
Miliolinella circularis	**26**	3
Miliolinella subrotunda	**23**	2
Quinqueloculina seminulum	**13**	1
Bolovina pseudoplicata	**12**	1
Patellina corrugata	**11**	1

Brizalina pseudopunctata	**10**	1
Haynesina germanica	**8**	1
Brizalina spathulata	**7**	1
Textularia earlandi	**6**	1
Clavulina obscura	**6**	1
Massilina secans	**6**	1
Elphidium gerthi	**6**	1
Quinqueloculina williamsoni	**5**	1
Nonion depressulus	**5**	1
Psammosphaera bowmani	**5**	1
Ammonia beccarii batavus	**4**	0
Elphidium cuvillieri	**4**	0
Fissurina marginata	**4**	0
Asteriginata mamilla	**3**	0
Bulimina marginata	**3**	0
Cibicides pseudoungerianus	**3**	0
Globulina gibba	**2**	0
Technitella teivyense	**2**	0
Buliminella elegantissima	**2**	0
Reophax scottii	**2**	0
Brizalina variabilis	**2**	0
Lenticulina crepidula	**2**	0
Fissurina lucida	**2**	0
Lagena laevis	**2**	0
Quinqueloculina aspera I	**2**	0
Quinqueloculina auberiana	**2**	0
Quinqueloculina oblonga	**2**	0
Trifarina angulosa	**2**	0
Elphidium crispum	**2**	0
Deuterammina (Lepidodeuterammina) ochracea var. *sinuosa*	**1**	0
Eggerelloides scabrum	**1**	0
Quinqueloculina mediterranensis	**1**	0
Bulimina elongata	**1**	0
Quinqueloculina lata	**1**	0

Table 8.30. All species recorded at Location 16 throughout the year in order of abundance. Values in absolute (Abs.) and percentage (%) abundance.

The two principal species were equally dominant; *Rosalina williamsoni* and *Textularia truncata* recording 30% and 29% of the assemblage respectively. Important secondary or minor species were *C. jeffreysii* and *P. mediterranensis*. *Miliolinella circularis*

(Bornemann) and *M. subrotunda* which were generally rare within the Sound but were present in reasonable abundance at this locality (Table 8.30).

8.11.4. Species Distribution

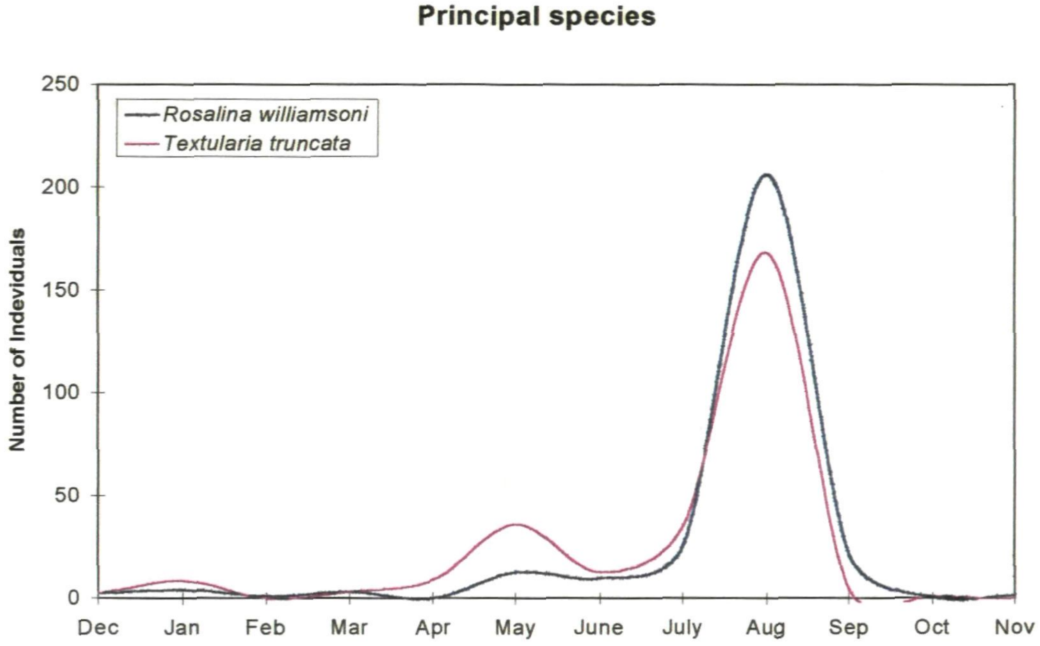


Figure. 8.33. Foraminiferal abundance of the two principal species throughout the year at Location 16.

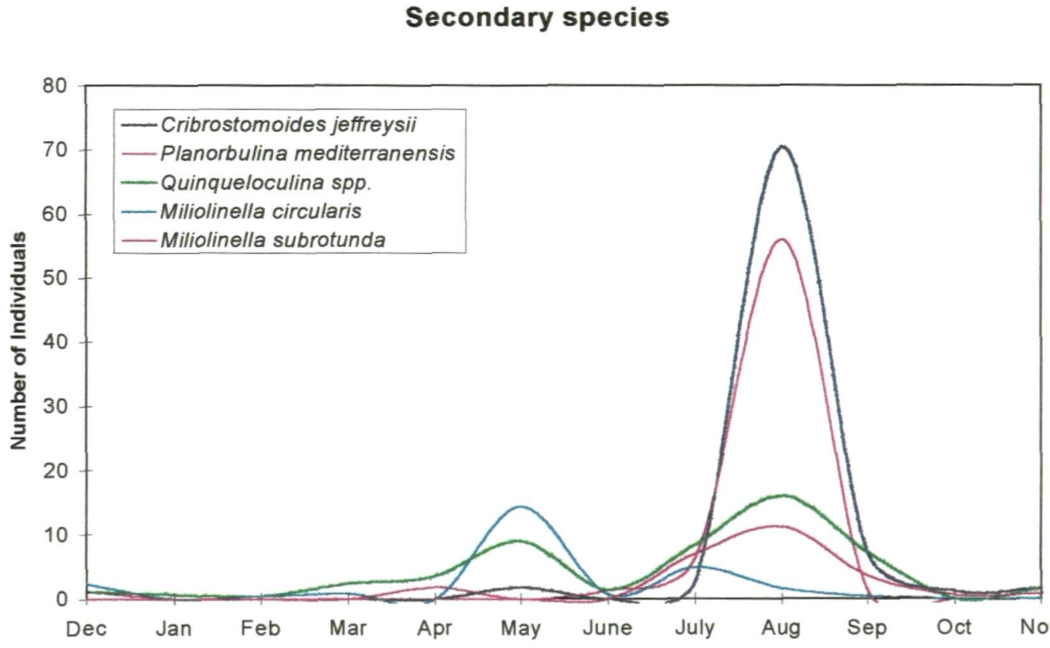


Figure 8.34. Foraminiferal abundance of secondary species throughout the year at Location 16.

All species exhibited very low abundances throughout the early part of the year (Figure 8.33). *Textularia truncata, M. circularis* and *Quinqueloculina* spp. exhibited a small increase in abundance during May. Abundance was low in June, but began to rise in July, rising very sharply in August. All species exhibited their yearly maximum abundances during August, with the exception of the *Quinqueloculina* spp. group (which is mainly composed of unidentified juveniles), Figure 8.34. After August foraminiferal abundance was very low.

8.11.5. Diversity

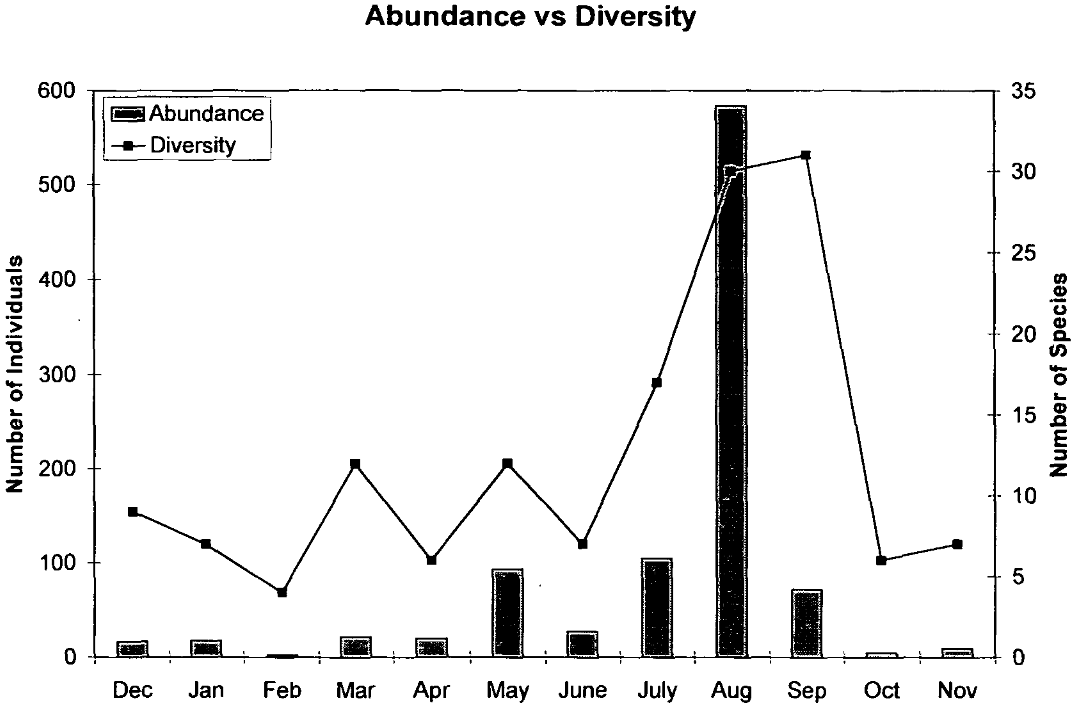


Figure. 8.35. Comparison of species abundance against species diversity throughout the year at Location 16. Diversity follows abundance but the maxima are out of phase in September.

Foraminiferal diversity was low during the first half of the year, but increased sharply in August (30 species) reflecting the abundance of foraminifera during this month. During September abundance fell sharply but diversity remained high and increased slightly. Diversity then fell sharply in October (Figure 8.35).

A Fisher Alpha diversity index of over 20 is derived from 49 species and a total of 174 individuals.

8.11.6. Morphogroups

MG		Abs	%
H1	*Haynesina germanica*	8	1
H1	*Elphidium gerthi*	6	1
H1	*Nonion depressulus*	5	1
H1	*Ammonia beccarii batavus*	4	0
H1	*Elphidium cuvillieri*	4	0
H1	*Lenticulina crepidula*	2	0
H10	*Bolovina pseudoplicata*	12	1
H10	*Brizalina pseudopunctata*	10	1
H10	*Brizalina spathulata*	7	1
H10	*Brizalina variabilis*	2	0
H11	*Fissurina marginata*	4	0
H11	*Globulina gibba*	2	0
H11	*Fissurina lucida*	2	0
H11	*Lagena laevis*	2	0
H3	*Elphidium crispum*	2	0
H4	*Rosalina williamsoni*	289	30
H4	*Planorbulina mediterranensis*	68	7
H4	*Patellina corrugata*	11	1
H4	*Cibicides pseudoungerianus*	3	0
H4	*Asteriginata mamilla*	3	0
H6	*Bulimina marginata*	3	0
H6	*Bulimina elongata*	1	0
H8	*Buliminella elegantissima*	2	0
H8	*Trifarina angulosa*	2	0
	Total	452	46

MG		Abs	%
A1	*Cribrostomoides jeffreysii*	85	9
A11	*Psammosphaera bowmani*	5	1
A11	*Technitella teivyense*	2	0
A4	*Deuterammina (Lepidodeuterammina) ochracea* var. *sinuosa*	1	0
A5	*Clavulina obscura*	6	1
A6	*Textularia earlandi*	6	1
A6	*Eggerelloides scabrum*	1	0
A7	*Textularia truncata*	280	29
A8	*Reophax scottii*	2	0
	Total	389	40
P8	*Quinqueloculina* spp.	52	5
P8	*Miliolinella circularis*	26	3
P8	*Quinqueloculina seminulum*	13	1
P8	*Quinqueloculina williamsoni*	5	1
P8	*Quinqueloculina aspera* I	2	0
P8	*Quinqueloculina auberiana*	2	0
P8	*Quinqueloculina oblonga*	2	0
P8	*Quinqueloculina lata*	1	0
P9	*Miliolinella subrotunda*	23	2
P9	*Massilina secans*	6	1
P9	*Quinqueloculina mediterranensis*	1	0
	Total	132	14

Table 8.31. Foraminifera are divided into three general groups; hyaline, porcellaneous and agglutinated and allocated morphogroups (columns labelled MG). Both the absolute (Abs.) and percentage (%) values of each species are shown.

The plano-convex forms (H4) were the most abundant group accounting for 38% of the assemblage, they are attached passive or active herbivores. The pyramidal or wedge shaped group (A7) was represented by one species; *T. truncata* which accounted for 29% of the fauna. This group is epifaunal and has a clinging mode of life. The fusiform group (P8) accounted for 10% of the fauna, the group may be epi- or infaunal and have a free mode of life. Another important group which only occurred in significant abundance in shell gravels was the rounded planispiral group (A1) which was represented by one species *C. jeffreysii*, it has a clinging mode of life and may be a herbivore or a detritivore.

All of the morphogroups representing significant proportions of the assemblage have an attached or clinging epifaunal mode of life, with the exception of the fusiform group (P8) which are free living and may be epi- or infaunal.

8.11.7. Discussion

The dominance of the attached and clinging species of foraminifera reflects the high energy of the environment and the presence of suitable grains for these species. The rounded planispiral and conical forms of foraminifera, which are dominant at many other locations within the Sound, are represented by a few individuals or completely absent.

The majority of species bloom only in August. This month represents the optimum conditions; sea temperatures are at their highest and salinity is normal. The bloom of foraminifera is very short in duration which may reflect a very ephemeral food supply or the harshness of the environment. Production calculations show sustained production in July and August followed by sustained losses in September and October.

Many species show a small increase in abundance in May which coincides with an increase in sea temperature. The low abundance during June and July as temperatures increased rapidly probably reflects reproduction, as adult foraminifera are most abundant in July and August.

Diversity increases significantly during August but peak diversity (September) is out of phase with abundance, as shown in Figure 8.35. This may be due to an increase of most species abundance, so utilising the favourable conditions within this area during August. Competition is high both inter-specifically but perhaps greater intra-specifically. As conditions deteriorate and the available food declines this causes the population to reduce, and causes some species to disappear; interspecific competition also reduces. This period (September) of lower competition and less food may favour new species with different feeding strategies. Many species which belong to the conical, spherical and cylindrical morphogroups are present during September (these are mainly detritivores) while many of the earlier species are still present in much reduced abundance (as residual populations) or in sharp decline. This may explain why diversity is high while abundance is low.

8.12. Location 17

8.12.1. Introduction

Location 17 is a medium grained moderately sorted sandy facies, usually clean but occasionally muddy. Foraminiferal abundance is high and diversity moderate to high.

8.12.2 Foraminiferal abundance

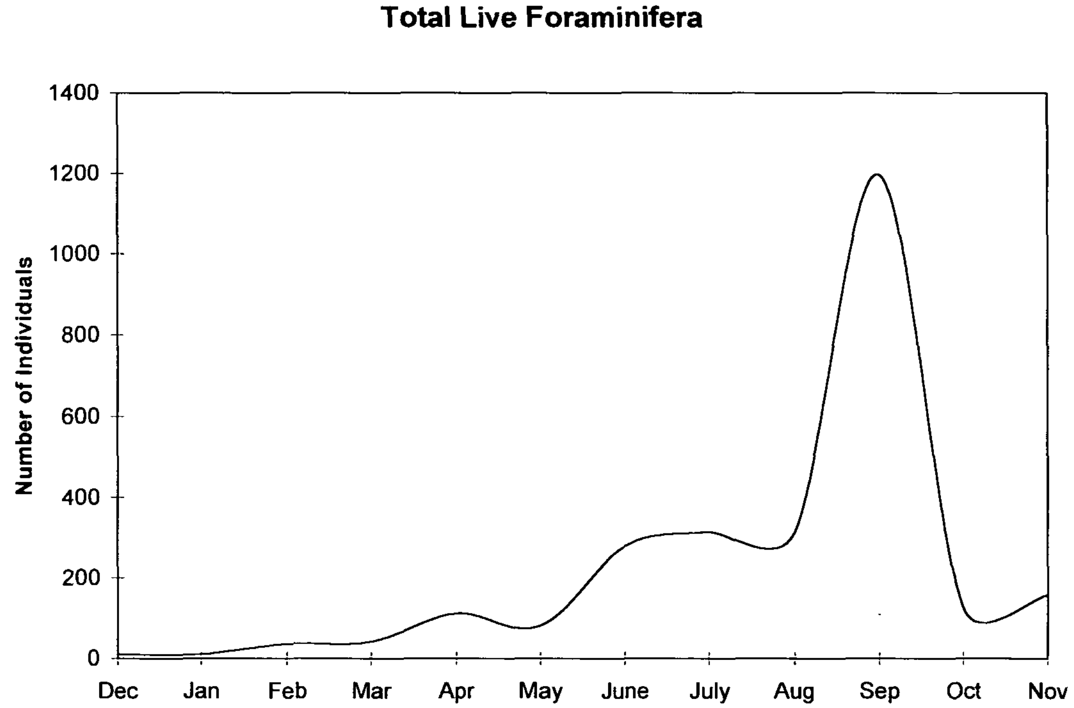


Figure. 8.36. Total abundance of live foraminifera (per 100cm^3 of sediment) at Location 17, between December 1993 and November 1994.

Foraminiferal abundance was very low during the first half of the year but increased in June to 279 individuals, remaining high in July and August. Abundance increased sharply during September (1197 individuals) but it then fell sharply to a low level in October (Figure 8.36).

A total of 1250 individuals were produced throughout the year. The maximum abundance during September represented the maximum observed number of foraminifera the site was able to support. Production of tests was almost constant but low from February to August. In September a large increase in production was observed, which was subsequently followed by very high losses (Table 8.32).

	Total Live	Gains	Losses
December 1993	10	0	0
January 1994	10	0	0
February	36	26	0
March	42	6	0
April	112	70	0
May	82	0	30
June	279	197	0
July	315	36	0
August	314	0	1
September	1197	883	0
October	126	0	1071
November	158	32	0
Total	**2680**	**1250**	**1102**

Table 8.32. Production of foraminifera throughout the year at Location 17. A large increase in production is usually followed by high losses the following month, the production of 887 tests in September was followed by very high losses in October.

8.12.3. Species Abundance

Ammonia beccarii batavus was the dominant species, accounting for just over half of the assemblage. Other principal species were *E. crispum* with 20% and *E. scabrum* with 11%. Important subordinate species were *Q. seminulum, Q. oblonga* and *Q. lata* (Table 8.33).

	Abs.	%
Ammonia beccarii batavus	**1354**	51
Elphidium crispum	**539**	20
Eggerelloides scabrum	**297**	11
Quinqueloculina seminulum	**92**	3
Quinqueloculina oblonga	**90**	3
Quinqueloculina lata	**66**	2
Brizalina pseudopunctata	**25**	1
Textularia sagittula	**17**	1
Quinqueloculina aspera I	**16**	1
Brizalina spathulata	**16**	1

Quinqueloculina spp.	**15**	1
Massilina secans	**14**	1
Nonion depressulus	**13**	0
Bulimina elongata	**9**	0
Quinqueloculina auberiana	**9**	0
Elphidium cuvillieri	**8**	0
Rosalina williamsoni	**8**	0
Clavulina obscura	**7**	0
Reophax scottii	**7**	0
Psammosphaera bowmani	**7**	0
Bulimina gibba	**6**	0
Quinqueloculina aspera II	**6**	0
Textularia truncata	**5**	0
Quinqueloculina mediterranensis	**5**	0
Fissurina lucida	**5**	0
Bolovina pseudoplicata	**5**	0
Stainforthia concava var. *loeblichi*	**4**	0
Quinqueloculina cf. *cliarensis*	**3**	0
Ammoscalaria pseudospiralis	**3**	0
Bulimina marginata	**3**	0
Textularia earlandi	**3**	0
Miliolinella subrotunda	**3**	0
Globulina gibba	**3**	0
Quinqueloculina williamsoni	**3**	0
Cornuspirella diffusa	**2**	0
Brizalina variabilis	**2**	0
Quinqueloculina aspera III	**2**	0
Haynesina germanica	**2**	0
Cibicides pseudoungerianus	**2**	0
Brizalina striatula	**1**	0
Elphidium williamsoni	**1**	0
Quinqueloculina sp. 5	**1**	0
Trifarina angulosa	**1**	0
Lagena semistriata	**1**	0
Miliolinella circularis	**1**	0
Spiroloculina excavata	**1**	0

Table 8.33. All species recorded at Location 17 throughout the year in order of abundance. Values in absolute (Abs.) and percentage (%) abundance.

8.12.4. Species Distributions

The most abundant species at this location can be divided into two groups based on their distribution. The first group includes *A. beccarii batavus, E. scabrum, Q. seminulum* and *Q. oblonga.* This group had very low abundance throughout all of the year except the month of September when a large increase was recorded (although *A. beccarii batavus* showed a moderate abundance in June July and August), See Figures 8.37 and 8.38.

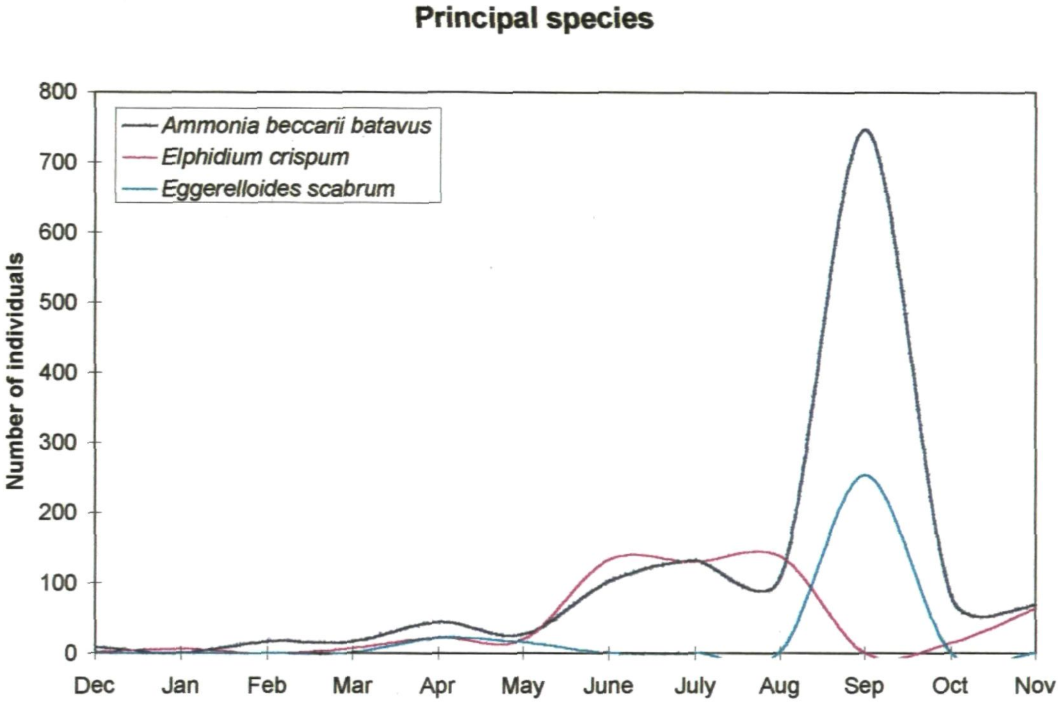


Figure. 8.37. Distribution of the principal species throughout the year at Location 17. *Ammonia beccarii batavus* and *E. scabrum* have opposing trends to *E. crispum* during September.

The second group, composed of *E. crispum* and *Q. lata,* had a more variable distribution but both groups showed very low abundance during September (when the first group blooms). *Elphidium crispum* had elevated abundance during June, July and August and *Q. lata* showed minor peaks in May and November.

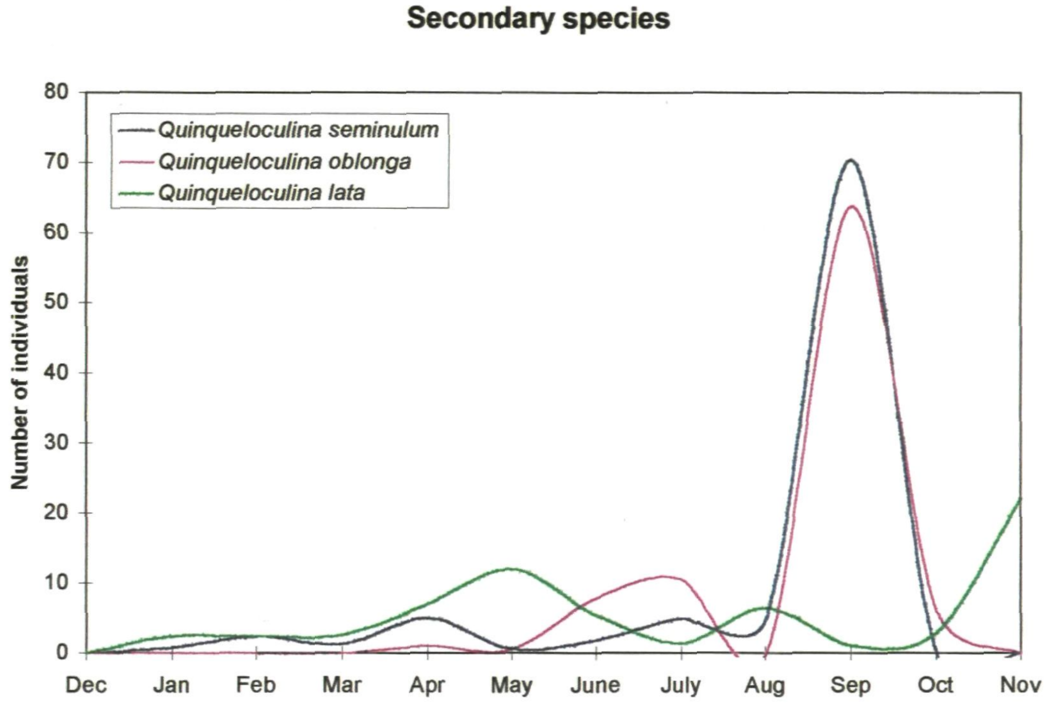


Figure. 8.38. Abundance of subordinate species throughout the year. *Quinqueloculina oblonga* and *Q. seminulum* have opposing trends to *Q. lata* during September.

8.12.5. Diversity

Diversity was low for the first half of the year but rose suddenly in June to a maximum of 28 species associated with a moderate increase in abundance. Diversity then fell, although abundance of foraminifera increased slightly in July and reached a second equal maximum diversity in September which coincided with maximum numbers of foraminifera. Diversity dropped sharply thereafter (Figure 8.39).

In total, 46 species are recorded from this locality, resulting in an Fisher Alpha diversity index of approximately 8.

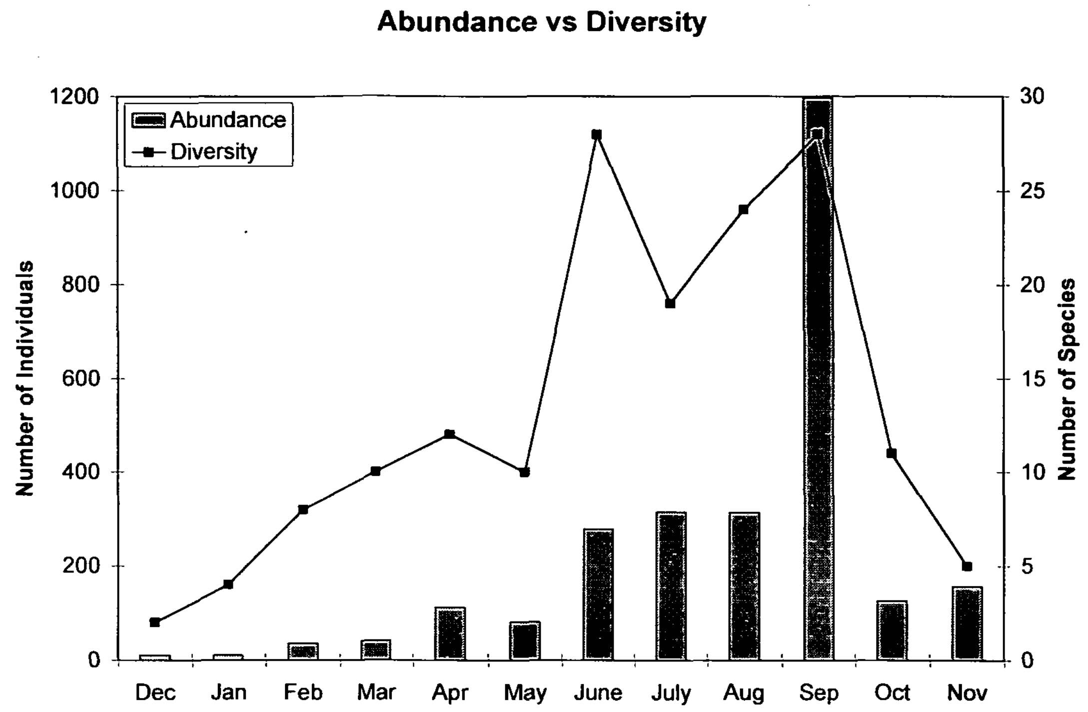


Figure. 8.39. Comparison of species abundance against species diversity throughout the year at Location 17. Two peaks in diversity are observed, the first occurs when abundance is moderate, the second coincides with the maximum abundance of foraminifera.

8.12.6. Morphogroups

The rounded planispiral group H1 was dominant due to the dominance of *A. beccarii batavus* (51%). This group is mainly infaunal and herbivorous. The lenticular group H3 were represented by one species, *E. crispum* (20%) which is predominantly an epifaunal herbivore.

MG		Abs.	%
H1	*Ammonia beccarii batavus*	**1354**	**51**
H1	*Nonion depressulus*	**13**	**0**
H1	*Elphidium cuvillieri*	**8**	**0**
H1	*Haynesina germanica*	**2**	**0**
H1	*Elphidium williamsoni*	**1**	**0**
H10	*Brizalina pseudopunctata*	**25**	**1**
H10	*Brizalina spathulata*	**16**	**1**
H10	*Bolovina pseudoplicata*	**5**	**0**
H10	*Brizalina variabilis*	**2**	**0**
H10	*Brizalina striatula*	**1**	**0**
H11	*Fissurina lucida*	**5**	**0**

MG		Abs	%
P12	*Cornuspirella diffusa*	**2**	**0**
P11	*Quinqueloculina* sp 5	**1**	**0**
P8	*Quinqueloculina seminulum*	**92**	**3**
P8	*Quinqueloculina oblonga*	**90**	**3**
P8	*Quinqueloculina lata*	**66**	**2**
P8	*Quinqueloculina aspera* I	**16**	**1**
P8	*Quinqueloculina* sp.	**15**	**1**
P8	*Quinqueloculina auberiana*	**9**	**0**
P8	*Quinqueloculina aspera* II	**6**	**0**
P8	*Quinqueloculina williamsoni*	**3**	**0**
P8	*Quinqueloculina aspera* III	**2**	**0**

H11	*Globulina gibba*	**3**	**0**
H11	*Lagena semistriata*	**1**	**0**
H3	*Elphidium crispum*	**539**	**20**
H4	*Rosalina williamsoni*	**8**	**0**
H4	*Cibicides pseudoungerianus*	**2**	**0**
H6	*Bulimina elongata*	**9**	**0**
H6	*Bulimina gibba*	**6**	**0**
H6	*Bulimina marginata*	**3**	**0**
H8	*Stainforthia concava* var. *loeblichi*	**4**	**0**
H8	*Trifarina angulosa*	**1**	**0**
	Total	**2007**	**75**

P8	*Miliolinella circularis*	**1**	**0**
P9	*Massilina secans*	**14**	**1**
P9	*Quinqueloculina mediterranensis*	**5**	**0**
P9	*Quinqueloculina* cf. *cliarensis*	**3**	**0**
P9	*Miliolinella subrotunda*	**3**	**0**
P9	*Spiroloculina excavata*	**1**	**0**
	Total	**328**	**12**
A1	*Ammoscalaria pseudospiralis*	**3**	**0**
A11	*Psammosphaera bowmani*	**7**	**0**
A5	*Clavulina obscura*	**7**	**0**
A6	*Eggerelloides scabrum*	**297**	**11**
A6	*Textularia earlandi*	**3**	**0**
A7	*Textularia sagittula*	**17**	**1**
A7	*Textularia truncata*	**5**	**0**
A8	*Reophax scottii*	**7**	**0**
	Total	**346**	**13**

Table 8.34. Foraminifera are divided into three general groups; hyaline, porcellaneous and agglutinated and allocated morphogroups (columns labelled MG). Both the absolute (Abs.) and percentage (%) values of each species are shown.

8.12.7. Discussion

The assemblage is dominated by *A. beccarii batavus* (51%). The two other most common species are *E. crispum* (20%) and *E. scabrum* (11%). The foraminifera generally exhibit their highest abundance in September and do not correlate (positively or negatively) with variations in sea temperature and salinity. These variables affect the assemblage indirectly (perhaps by affecting food or structure of the assemblage). *Ammonia beccarii batavus* and *E. crispum* are moderately abundant during June, July and August. *Elphidium crispum* is represented by many juveniles which exhibit a very dark green colouration during June, the presence of juveniles indicates that reproduction took place probably in May or June. The very dark colouration may represent food (Murray, 1963), symbionts (Lee, 1989) or camouflage (Boltovskoy and Wright, 1976).

During September, *A. beccarii batavus, E. scabrum* and the subordinate species *Q. oblonga* and *Q. seminulum* become extremely abundant, reaching their maximum abundance. *Elphidium crispum* is absent during August. During September *A. beccarii* *batavus*, *E. scabrum* and the subordinate species *Q. oblonga* and *Q. seminulum* decline greatly or become absent, while *E. crispum* and *Q. lata* increase in abundance once more. This trend implies that *A. beccarii batavus*, *E. scabrum Q. oblonga* and *Q. seminulum* actively forced out *E. crispum* and *Q. lata* by competition, or these two groups feed on different food types (September represents a period when the food type for *A. beccarii batavus*, *E. scabrum Q. oblonga* and *Q. seminulum* was abundant and the food type for *E. crispum* and *Q. lata* was absent).

Productivity calculations show a small but sustained production of foraminifera from February to September (with minor losses in May). This suggests an assemblage in equilibrium with the low amount of available food. During September the production rate is very high (3/4 of the yearly total) following reproduction (many juveniles are recorded). The assemblage is out of equilibrium with the available food, which is quickly depleted. As a result, high mortalities are recorded in October.

8.13. Location 18

8.13.1. Introduction

Location 18 is characterised by silty sands. Foraminiferal abundance and diversity are high.

8.13.2. Foraminiferal Abundance

Foraminiferal abundance was generally high, but variable. Abundance was high in December (632 individuals) but it then falls to below 200 individuals in January. In February abundance rose to 679 individuals and fell back slightly in March (545 individuals) but rose again to 1113 individuals in April. Abundance dropped sharply in May to 172 individuals and remained relatively low in June (305 individuals). Maximum abundance of 1314 individuals was reached in July. Abundance dropped sharply in August but remained elevated and stable from August to November (Figure 8.40).

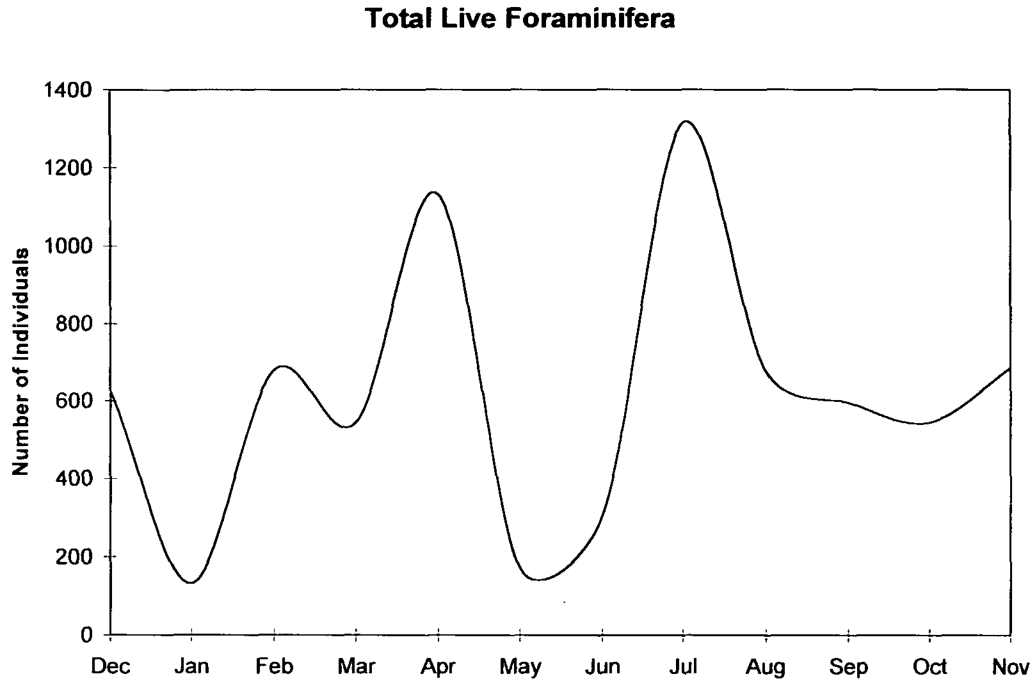


Figure. 8.40. Total abundance of live foraminifera (per 100cm^3 of sediment) at Location 18, between December 1993 and November 1994.

A total of 2418 foraminifera were produced at this locality throughout the year. During the first half of the year a pattern of production (during one month) immediately followed by high mortality (during the following month) was observed. In June this pattern changed; production occurred over two consecutive months, which was followed by high mortality and then a period of relative stability (September, October and November).

	Total Live	Gains	Losses
December 1993	623	0	0
January 1994	133	0	490
February	679	546	0
March	545	0	135
April	1133	588	0
May	172	0	961
June	305	133	0
July	1314	1010	0
August	679	0	636
September	596	0	82
October	545	0	51
November	686	141	0
	7411	**2418**	**2355**

Table. 8.35. Significant production occurs in February, May and July.

8.13.3. Species Abundance

Ammonia beccarii batavus was the dominant species accounting for 50% of the assemblage. *Elphidium crispum* was the second principal species accounting for 30% of the assemblage. Important subordinate species were *Q. oblonga, Q. seminulum* and *E. scabrum*. Species which were rare within the Sound, but more abundant at this locality, are *N. depressulus*, *Ammoscalaria pseudospiralis,* and *Cornuspirella diffusa* (Heron-Allen and Earland).

	Abs.	%
Ammonia beccarii batavus	**3688**	50
Elphidium crispum	**2232**	30
Quinqueloculina oblonga	**475**	6
Quinqueloculina seminulum	**199**	3
Eggerelloides scabrum	**138**	2
Nonion depressulus	**95**	1
Brizalina pseudopunctata	**91**	1
Bulimina elongata	**64**	1
Ammoscalaria pseudospiralis	**55**	1
Brizalina spathulata	**50**	1
Stainforthia concava var. *loeblichi*	**45**	1
Elphidium cuvillieri	**40**	1
Bulimina gibba	**29**	0
Quinqueloculina aspera I	**23**	0
Quinqueloculina cf. *cliarensis*	**19**	0
Brizalina variabilis	**18**	0
Globulina gibba	**15**	0
Cornuspirella diffusa	**12**	0
Reophax scottii	**11**	0
Quinqueloculina aspera III	**10**	0
Quinqueloculina spp.	**9**	0
Textularia sagittula	**8**	0
Fissurina lucida	**8**	0
Rosalina williamsoni	**6**	0
Textularia truncata	**6**	0
Quinqueloculina lata	**6**	0
Nonionella sp.	**6**	0
Elphidium gerthi	**5**	0
Textularia earlandi	**5**	0
Psammosphaera bowmani	**4**	0
Quinqueloculina auberiana	**4**	0
Quinqueloculina mediterranensis	**3**	0

Planorbulina mediterranensis	3	0
Uvigerina sp.	3	0
Quinqueloculina sp. 5	3	0
Haynesina germanica	3	0
Bulimina marginata	2	0
Lagena laevis	2	0
Lenticulina orbiculatis	2	0
Quinqueloculina williamsoni	2	0
Quinqueloculina aspera II	2	0
Lagena semistriata	2	0
Massilina secans	2	0
Lenticulina crepidula	1	0
Cyclogyra involvens	1	0
Lagena clavata	1	0
Pyrgo williamsoni	1	0
Quinqueloculina oblonga var. *lata*	1	0
Spiroloculina excavata	1	0
Miliolinella circularis	1	0
Siphogenerinoides sp.	1	0

Table 8.36. All species recorded at Location 18 throughout the year in order of abundance. Values in absolute (Abs.) and percentage (%) abundance.

8.13.4. Species Distribution

In January all species exhibited very low abundances. During February *A. beccarii batavus* and *Q. oblonga* increased significantly in abundance, but decreased in March. Only *E. crispum* became abundant during March. In April *E. crispum* continued to grow in abundance while *A. beccarii batavus* and *E. scabrum* exhibited a sharp increase to reach their maximum abundances (*E. scabrum* was virtually absent at all other times). In May and June foraminiferal abundance was low. Nearly all species exhibited increased abundance during July (most exhibited their maximum abundance during this month). During August all species declined in abundance. After August most species were present in low abundances, *Q. oblonga* and *Q. seminulum* were slightly elevated and *A. beccarii batavus* was moderately abundant; it exhibited two increases of abundance during this period (Figures 8.41 and 8.42).

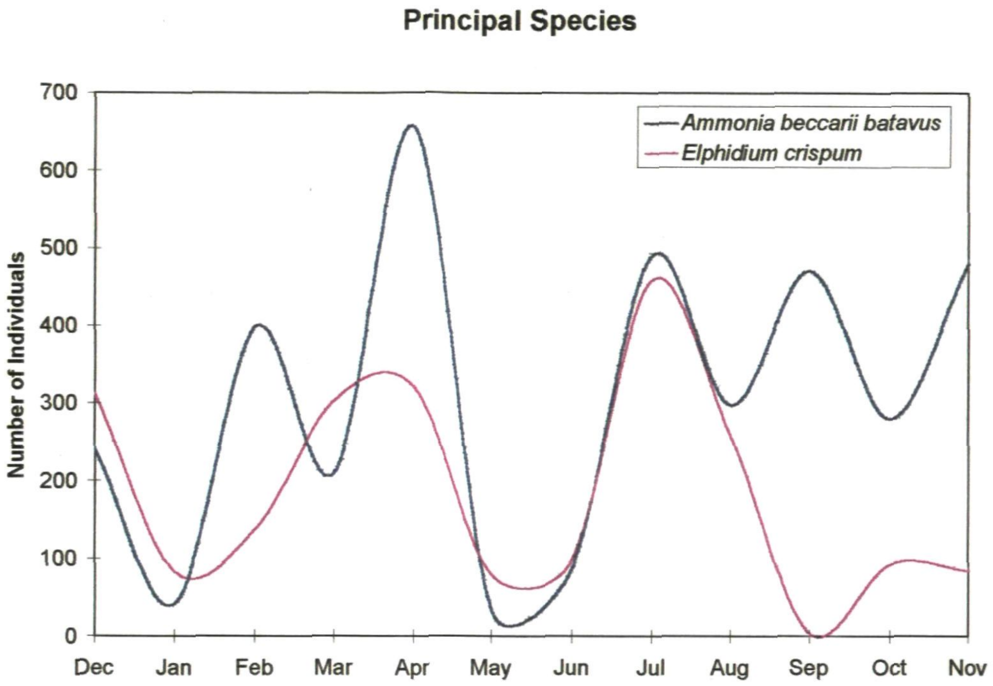


Figure. 8.41. The principal species show different distributions throughout the year, only during May to August are their distributions similar.

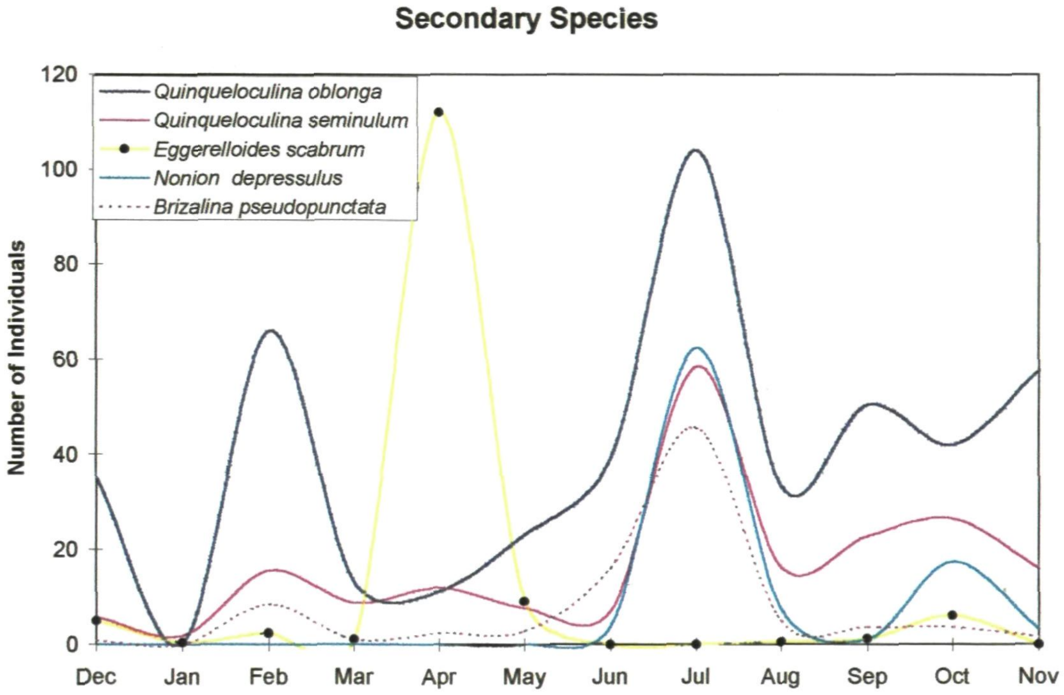


Figure. 8.42. Distribution of subordinate species (less than 10% of the assemblage). Most of the subordinate species have similar distributions from June to August. *Eggerelloides scabrum* is only significant during April.

8.13.5. Diversity

Abundance mirrored diversity during December, January and February but during March (Figure 8.43). When abundance was moderate (545 individuals), diversity fell to its lowest value of 8 species. During April abundance was very high but diversity was low. Maximum abundance occurred during July but maximum diversity occurred in August (33 species) . In November abundance was moderate to high (686 individuals) but diversity fell sharply to 14 species, the second lowest diversity value.

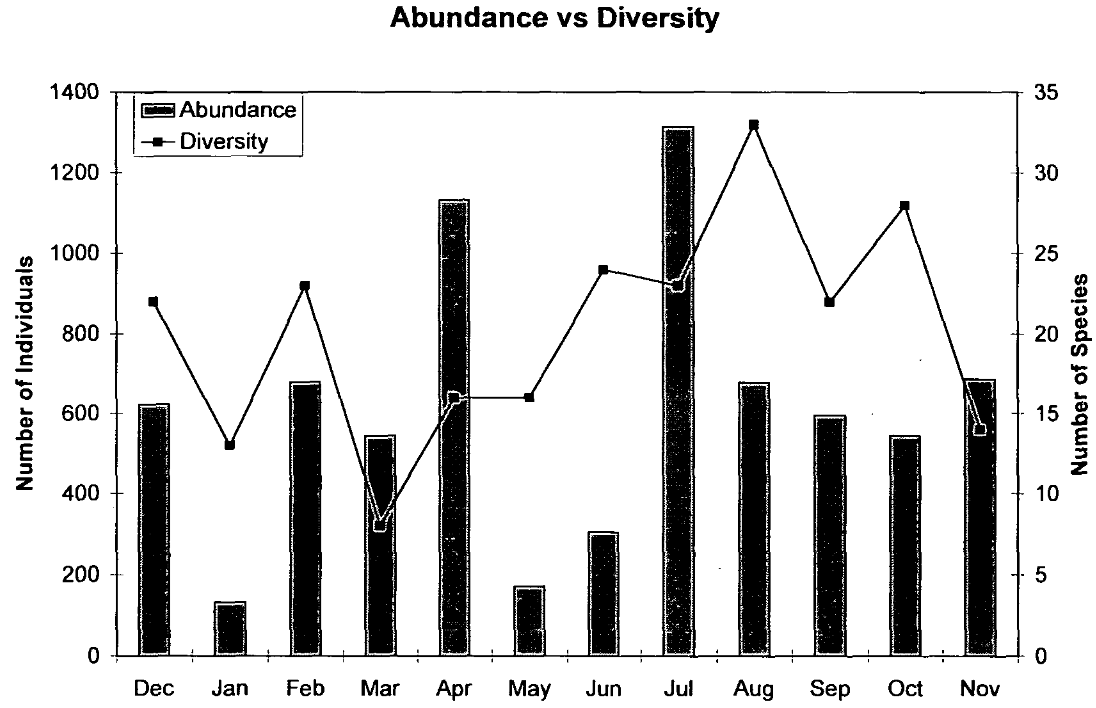


Figure. 8.43. Comparison of species abundance against species diversity throughout the year at Location 18.

A total of 51 species were recorded from Location 18 from 7411 individuals which results in a Fisher Alpha diversity of between 7 and 8.

8.13.6. Morphogroups

The rounded planispiral group (H1) dominated, due mainly to the presence of *A. beccarii batavus*. This group are infaunal herbivores. *Elphidium crispum* represented the lenticular group (H3) with 30% of the fauna; it is mainly an epifaunal herbivore. The other significant group was the fusiform porcellaneous group P8 which are both epi and infaunal and are herbivores or detritivores. All the basic morphogroups were represented at this locality.

MG		Abs	%
H1	*Ammonia beccarii batavus*	3688	50
H1	*Nonion depressulus*	95	1
H1	*Elphidium cuvillieri*	40	1
H1	*Nonionella* sp.	6	0
H1	*Elphidium gerthi*	5	0
H1	*Haynesina germanica*	3	0
H1	*Lenticulina crepidula*	1	0
H10	*Brizalina pseudopunctata*	91	1
H10	*Brizalina spathulata*	50	1
H10	*Brizalina variabilis*	18	0
H11	*Globulina gibba*	15	0
H11	*Fissurina lucida*	8	0
H11	*Lagena laevis*	2	0
H11	*Lagena semistriata*	2	0
H11	*Lagena clavata*	1	0
H3	*Elphidium crispum*	2232	30
H3	*Lenticulina orbiculatis*	2	0
H4	*Rosalina williamsoni*	6	0
H4	*Planorbulina mediterranensis*	3	0
H5	*Rectobolivina* sp.	1	0
H6	*Bulimina elongata*	64	1
H6	*Bulimina gibba*	29	0
H6	*Bulimina marginata*	2	0
H8	*Stainforthia concava* var. *loeblichi*	45	1
H8	*Uvigerina* sp.	3	0
	Total	6411	87

MG		Abs	%
A1	*Ammoscalaria pseudospiralis*	55	1
A11	*Psammosphaera bowmani*	4	0
A6	*Eggerelloides scabrum*	138	2
A6	*Textularia earlandi*	5	0
A7	*Textularia sagittula*	8	0
A7	*Textularia truncata*	6	0
A8	*Reophax scottii*	11	0
	Total	227	3
P11	*Quinqueloculina* sp. 5	3	0
P11	*Pyrgo williamsoni*	1	0
P12	*Cornuspirella diffusa*	12	0
P2	*Cyclogyra involvens*	1	0
P8	*Quinqueloculina oblonga*	475	6
P8	*Quinqueloculina seminulum*	199	3
P8	*Quinqueloculina aspera* I	23	0
P8	*Quinqueloculina aspera* III	10	0
P8	*Quinqueloculina* sp.	9	0
P8	*Quinqueloculina lata*	6	0
P8	*Quinqueloculina auberiana*	4	0
P8	*Quinqueloculina williamsoni*	2	0
P8	*Quinqueloculina aspera* II	2	0
P8	*Quinqueloculina oblonga* var. *lata*	1	0
P8	*Miliolinella circularis*	1	0
P9	*Quinqueloculina* cf. *cliarensis*	19	0
P9	*Quinqueloculina mediterranensis*	3	0
P9	*Massilina secans*	2	0
P9	*Spiroloculina excavata*	1	0
	Total	773	10

Table 8.37. Foraminifera are divided into three general groups; hyaline, porcellaneous and agglutinated and allocated morphogroups (columns labelled MG). Both the absolute (Abs.) and percentage (%) values of each species are shown.

8.13.7. Discussion

Foraminiferal distributions do not exhibit good correlation with temperature and salinity, as abundance is high during the winter and spring when both salinity and temperature are low. The maximum abundance does coincide with maximum sea temperatures but this may be an indirect result of sea temperature influencing food production and reproduction.

During February most species show a moderate increase in abundance. This may be a direct response to increased food. During March, only *E. crispum* increased in abundance and this may reflect a food source to which *E. crispum*'s feeding strategy is well suited (as *E. crispum* is the only significant epifaunal species at this location). Myers (1942b) recorded *E. crispum* reproducing during March in Plymouth Sound. During April *A. beccarii batavus*, *E. scabrum* and *E. crispum* are all common while other species exhibit low abundances. These three taxa all have very different morphologies and feeding strategies. Abundance of foraminifera is low until July when all the most abundant species (except *E. scabrum*) experience increased or maximum abundances. This period (July) may represents a reproductive phase triggered by increased sea temperatures. All species decline in August perhaps as food is depleted although some species remain elevated due to a low or different food supply. Many species exhibit minor increases in abundance during September and October may be taking advantage of lower intra- and inter-specific competition.

The two maxima in abundance are of relatively low diversity may reflect the dominance of the opportunistic species such as *A. beccarii batavus* and *E. crispum.* The highest diversities are attained in August and October and probably reflect lower inter-specific competition and/or a greater range of food types.

The peak in diversity observed in June, while foraminiferal abundance was moderate may be due to an abundance of highly diverse food types.

During May and June when *E. crispum* was in low abundance juveniles of this species were present and they had a prominent green black colouration. During July many of the juveniles of *A. beccarii batavus* displayed aberrant proloculii or coiling planes, The reason for this is unknown as *A. beccarii batavus* attained its highest abundance during July.

8.14. Important Live Foraminiferal Species

8.14.1. Ammonia beccarii batavus

This, the most abundant live species in Plymouth Sound, showed moderate abundance from December 1993 to May 1994. Abundance fell to very low levels in May and June. At the time salinity was normal and temperature was rapidly increasing, both ensuring favourable conditions for foraminifera and food, and it is likely that May and June represents the major period of reproduction for this species. Production tables show high losses (mortality) which correspond to mortality of the parents during reproduction. Most other species exhibited low abundance during this period suggesting a regional factor which affected most of Plymouth Sound i. e. food, temperature, etc..

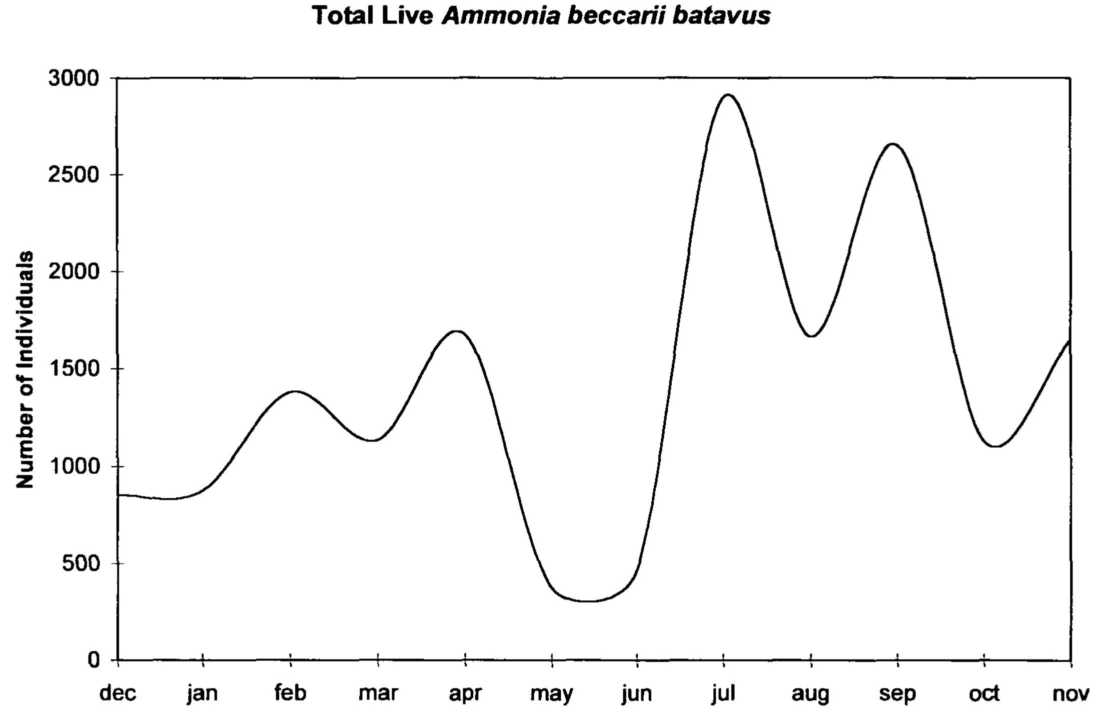


Figure. 8.44. The sum of all *A. beccarii batavus* from all Locations throughout the year.

In July *A. beccarii batavus* attained its greatest numbers. Salinity and sea temperature were both high and stable from July to October. The reduction in abundance during August (maximum sea temperatures) and September may represent other periods of reproduction

Abundance was lower in November when sea temperature and salinity were generally lower. Highest abundances of this species are in the late summer and autumn when sea temperatures were at their highest (Figure 8.44).

Populations of *A. beccarii batavus* at the three mud facies locations were very variable, all three locations rarely correlated with each other (Figure 8.45). However they all exhibited low abundance in May and June as discussed in the previous paragraph, and moderate to high abundance during July. Mud facies generally contained a high abundance of *A. beccarii batavus* (average of 1000 per sample). Reproduction probably occurred at several times throughout the year.

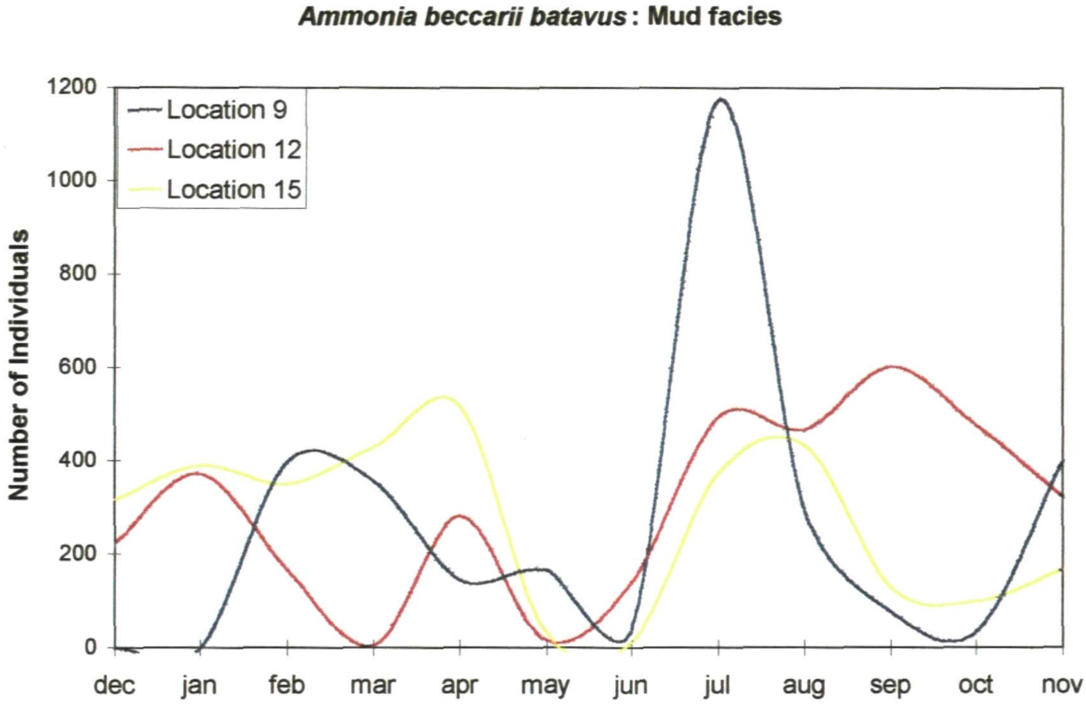


Figure. 8.45. Populations of *A. beccarii batavus* in mud facies throughout the year. Correlation between the sites is poor.

Locations 4 and 17 showed very similar trends of low abundance throughout the year with the exception of September. These distributions exhibit a partial correlation with temperature and salinity. They are probably also the result of abundant food. Populations of *A. beccarii batavus* at Location 18 were very different as they are represented by a series of highs and lows in abundance throughout the year (Figure 8.46). Very low abundance occurred in May and June.

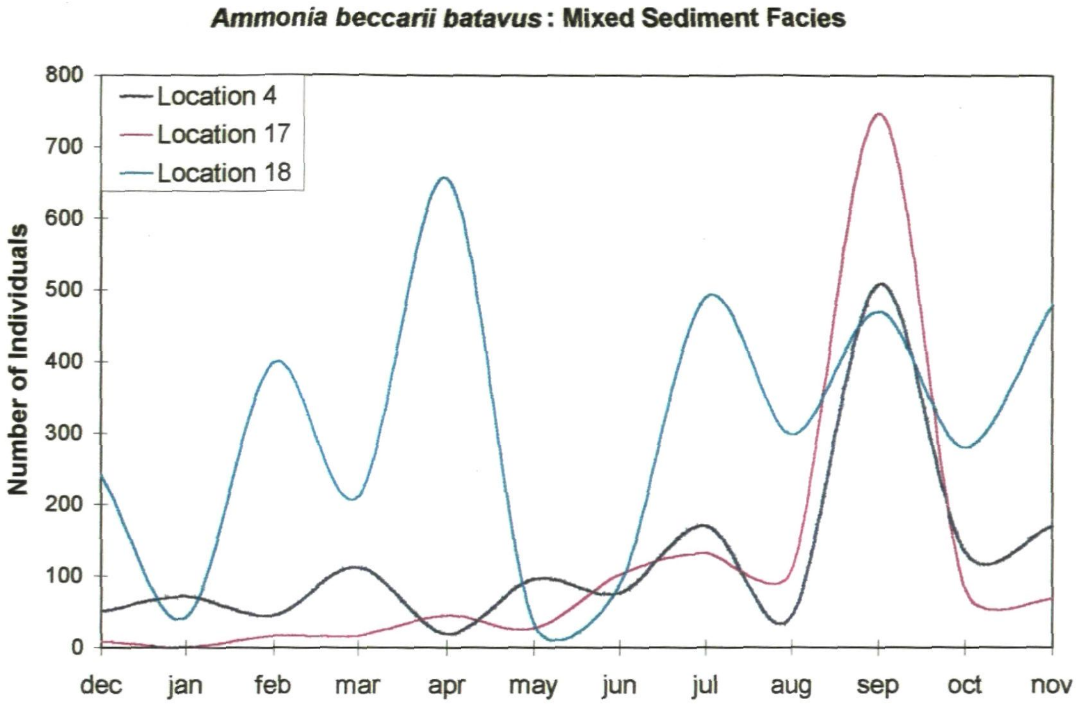


Figure. 8.46. Populations of *A. beccarii batavus* in mixed sediment facies throughout the year. Correlation between the sites is moderately good but Location 18 exhibits a style that is different form Locations 4 and 17 and similar to the mud facies Locations (9, 12 and 15) Figure 8.45.

Foraminifera at Locations 1 and 11 of the sand facies exhibited very low populations of *A. beccarii batavus*. Locations 8 and 14 showed a good correlation showing high abundance in September. Location 14 showed an additional period of high abundance in July. Reproduction occurred in June and August, the periods of rapid temperature increase and maximum temperature. *Ammonia beccarii batavus* was common only in July and or September (Figure 8.47).

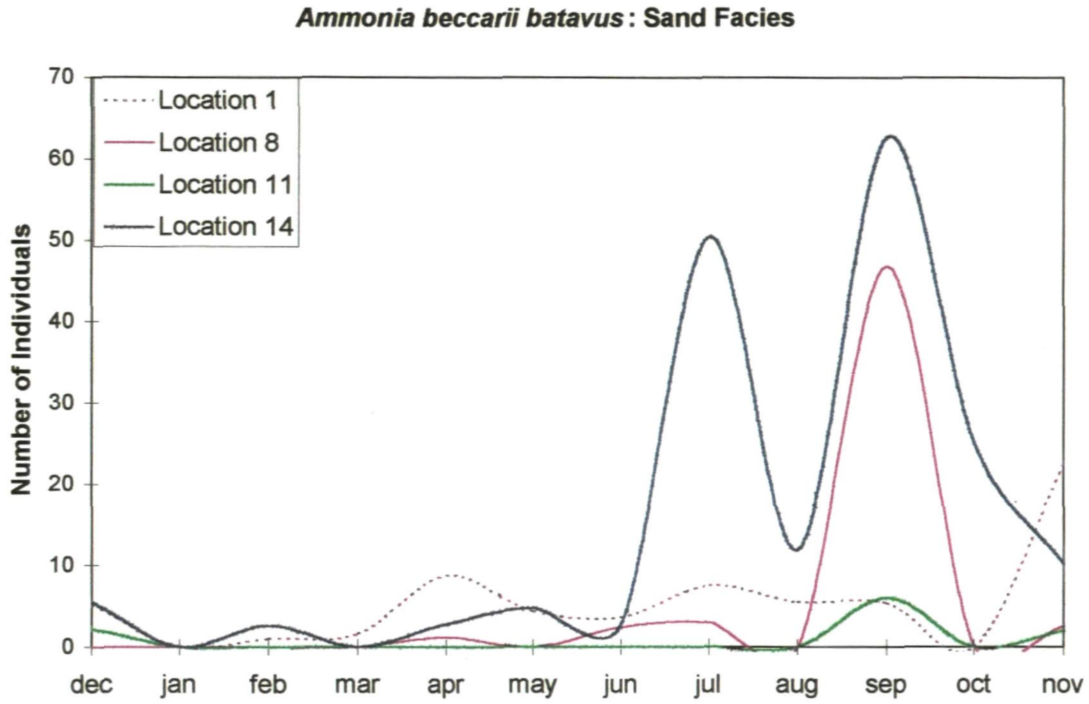


Figure. 8.47. Populations of *A. beccarii batavus* in sand facies throughout the year. Correlation between the sites is moderate between Locations 11 and 14 but Locations 1 and 8 exhibit low abundances only.

Ammonia beccarii batavus was almost absent from the shell gravels and is not figured at those locations.

At Location 4 *A. beccarii batavus* may compete with *E. crispum* in September when both species show increased abundances. *Ammonia beccarii batavus* then declines while *E. crispum* remains abundant (Figure 8.10). It may also be that these two species are feeding upon different food types and are thus not directly competing for food.

At Location 9 foraminifera exhibit three periods of abundance. During the second and largest period of abundance *B. pseudopunctata* is dominant with *S. concava* var. *loeblichi* and several other subordinate species reaching their greatest abundance. During this period from April to June *A. beccarii batavus* exhibits very low abundance which may be the result of active competition with *B.pseudopunctata* and other species. In June *B. pseudopunctata* declines although its still common while *A. beccarii batavus* increases rapidly in abundance, becoming the dominant species (Figure 8.16), further supporting the view that these two species are competing. The reason for the shift in dominance is not known.

At Locations 12 and 15 *A. beccarii batavus* is the dominant species. Its temporal distribution is coincident with the other species, the effects of interspecific competition are not evident. The same is true for the sand facies sites (Location 1, 8, 11 and 14) and the mixed facies of Location 18.

At Location 17 after a long period of foraminiferal scarcity *A. beccarii batavus* and *E. crispum* may be in competition (equal abundances of both species) during June to August (Figure 8.37). In September *A. beccarii batavus* increases rapidly in abundance whilst *E. crispum* declines in abundance. If in competition with each other *A. beccarii batavus* out competes *E. crispum* in September the reasons for this are not known but may be a change in the type or amount of food present (which these species utilise) or a seasonal effect (*E. crispum* is rarely common in the Autumn).

In mud facies and the mixed sediment facies of Location 18 foraminifera show generally high abundance with little correlation between sites. These sites have a greater abundance of food (and *A. beccarii batavus* shows a preference for fine grained sediment substrates) with several blooms of algae and bacteria of varying abundance probably occur throughout the year (at different times for different sites) resulting in a series of high and low abundances of *A. beccarii batavus* throughout the year. The pattern is probably further complicated by the effects of interspecific and intraspecific competition and varying rates of food depletion and recovery.

8.14.2. Elphidium crispum

The pattern of distribution for the sum of all *E. crispum* in Plymouth Sound is shown in Figure 8.48. *Elphidium crispum* exhibits moderate to low abundance from December 1993 to June 1994, this probably reflects low amounts of food and low sea temperatures. Reproduction probably occurs in June which coincides with rising sea temperatures resulting in maximum abundance in July. This may coincide with the occurrence of phytoplankton blooms (Myers,1943). *Elphidium crispum* returns to relatively low abundance for the remainder of the year.

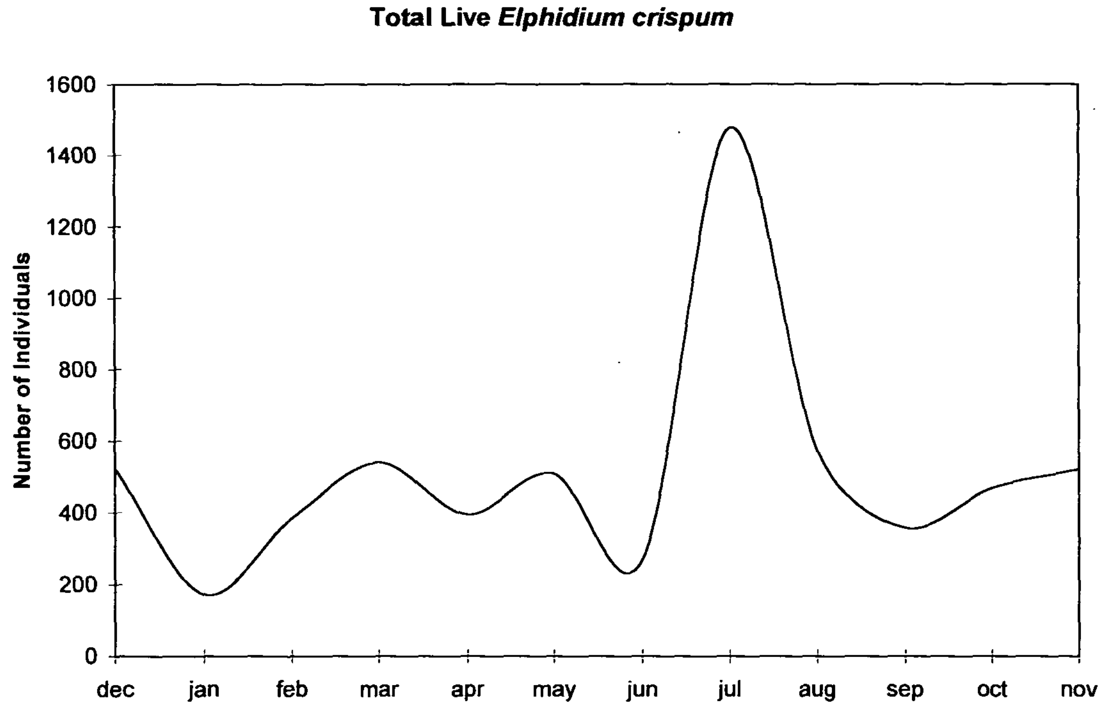


Figure 8.48. Abundance of *E. crispum* for all locations throughout the year. One main period of reproduction probably occurs in June the offspring of which are recognised in July.

Elphidium crispum occurs in very low numbers in all of the mud facies with the exception of Location 15 in July (Figure 8.49). The peak of abundance in July is mirrored at Location 9 (but an order of magnitude lower). *Elphidium crispum* attains maximum abundance throughout the Sound in July, it may be that during this period of high abundance this species colonises or spills over into the less preferable mud facies or that these less favourable facies become favourable for a short period during the year.

Elphidium crispum is most common in the mixed sediment facies of Locations 4, 17 and 18 (Location 17 is sometimes clean sand and this may explain the lower abundance at this site). Its distribution is very variable. Location 17 shows elevated abundance in June, July and August. Both Locations 18 and 4 show high abundance in July but they differ throughout the rest of the year. Location 4 shows abundance maxima in February/March, July and September/ October/November. Location 18 shows abundance maxima in

March/April and July. These maxima are probably the result of blooms of food organisms and sea temperature.

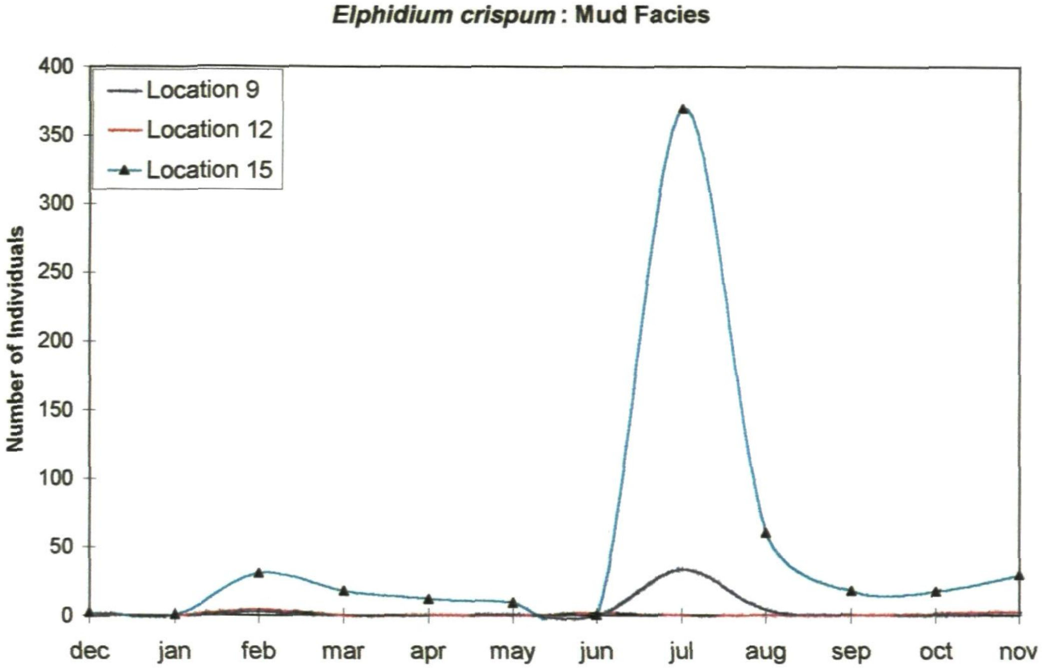


Figure 8.49. Abundance of *E. crispum* for mud facies locations throughout the year. One main period of reproduction occurs in July (or just before) at two locations apart from this *E. crispum* is almost absent from this facies

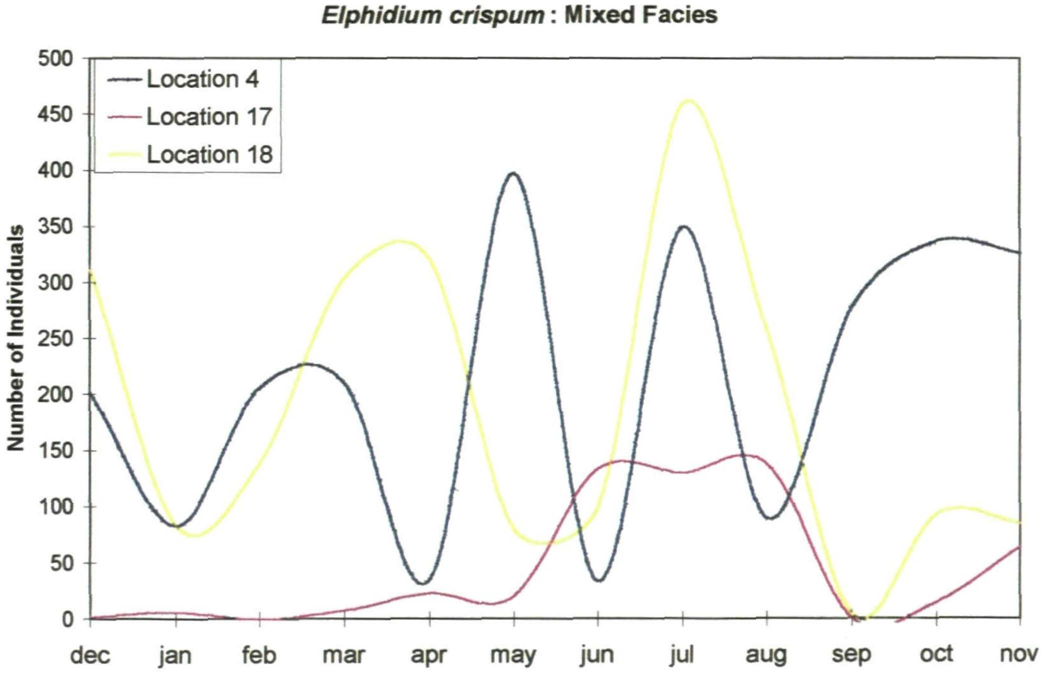


Figure 8.50. Abundance of *E. crispum* for mixed sediment facies throughout the year. Abundance of *E. crispum* is very variable although all station show high abundances in July.

Elphidium crispum is virtually absent from Location 14 (hence not plotted) and very rare at Location 8 (Figure 8.51). At Location 1 it is really only present during July where it is very abundant. This probably reflects the abundance of food and favourable conditions during this period. Location 11 shows moderate abundance during September (which is unusual because this species is generally only common during July and August).

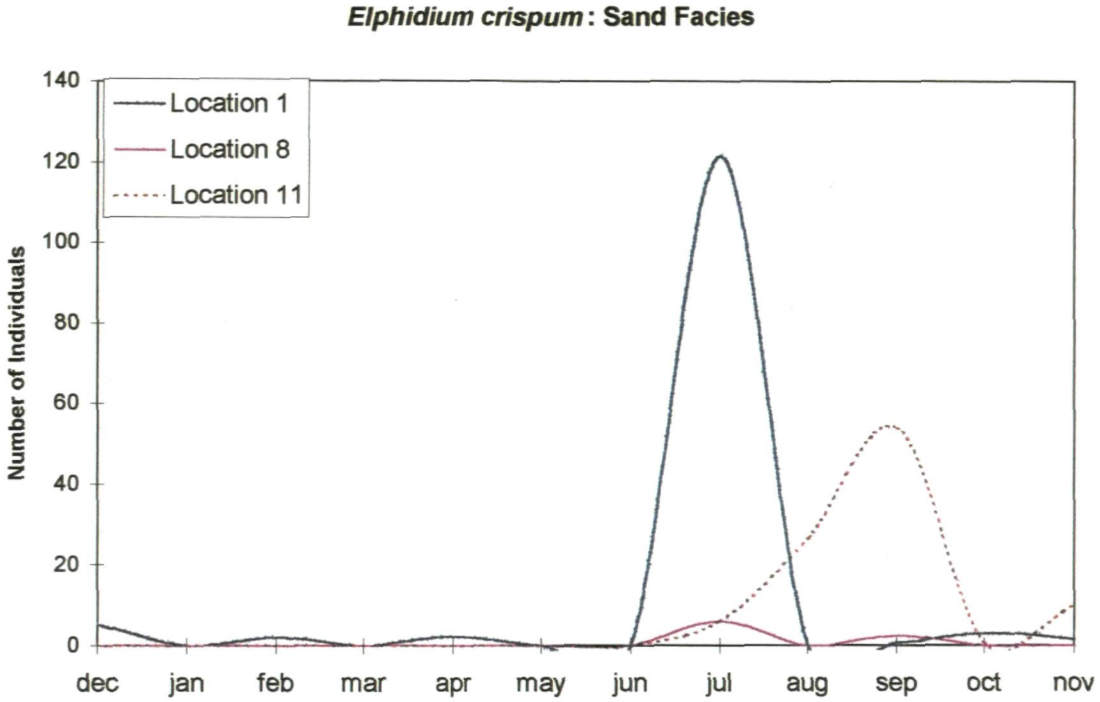


Figure 8.51. Abundance of *E. crispum* for sand facies throughout the year. Abundance of *E. crispum* is very low except for Location 1 in July.

Elphidium crispum is most abundant in mixed sediments, moderate in sands and muds and almost absent from gravels. In sand and mud facies it is present in reasonable numbers in July and virtually absent during the other parts of the year (with the exception of Location 11). The high abundance in July is also observed from the mixed sediment locations, it occurs throughout the Sound and may reflect a continually reproducing bloom of phytoplankton during this period (Myers, 1943) which is linked to higher sea temperatures. The high abundance of foraminifera shows reasonable correlation with temperature. The other periods of high abundance which occur in mixed sediment locations must also reflect increased food and other favourable conditions why these periods of high abundance are limited to two locations, and do not correlate with each other reflect the variability of these mixed sediment locations. Many blooms of *E. crispum* show reasonable correlation to hours of sunshine and day-length which may be important for a species known to have symbionts in other studies (Leutenegger, 1984; Lee e*t al.* 1988; Lee & Lee 1989; Lee & Anderson, 1991).

At many locations, *E. crispum* exhibits a trend coincident with that of other species. At Location 4 *E. crispum* and *A. beccarii batavus* are both abundant in September. *Ammonia beccarii batavus* then declines whilst *E. crispum* remains elevated. Interspecific competition may influence this pattern or the two species may feed on different food.

At Location 17 *E. crispum* and *A. beccarii batavus* are common during June, July and August but in September the abundance of *E. crispum* declines sharply as *A. beccarii batavus* and *E. scabrum* increase sharply in abundance. This trend may reflect *E. crispum* being out competed, or the decline in *E. crispum* maybe due to other reasons but *A. beccarii batavus* and *E. scabrum* increase in abundance.

Elphidium crispum shows a pattern of general scarcity with short periods of great abundance; typically it is most abundant in the late summer. It is only abundant within mixed sediment facies. Its distribution throughout the year reflects sea temperatures and the abundance of food organisms, although is distribution may be influenced slightly by interspecific competition.

Whether *E. crispum* harbours symbionts within the Sound is not known but it shows high abundance during times of high sunshine and day length (although it is scarce in June juveniles are present in reasonable numbers). It does not inhabit bright substrates (which increase light intensity) such as pale sands and gravels but is most common on dark mud rich substrates (this may not be of great importance because the shallow depths of all the sites means that they are well illuminated). During May and June populations of *E. crispum* were generally low. Juveniles with few adults were recorded. These exhibited a prominent dark green to black colouration within the test. This may reflect the presents of chloroplast inclusions or may be recently consumed food. The colouration was however observed in both adults and juveniles (at Location 15, 17 and 18) and only during the months of May and June when day length and sunshine are greatest. Specimens which exhibited a pale green colouration were observed form Location 4 during July.

8.14.3. Brizalina pseudopunctata

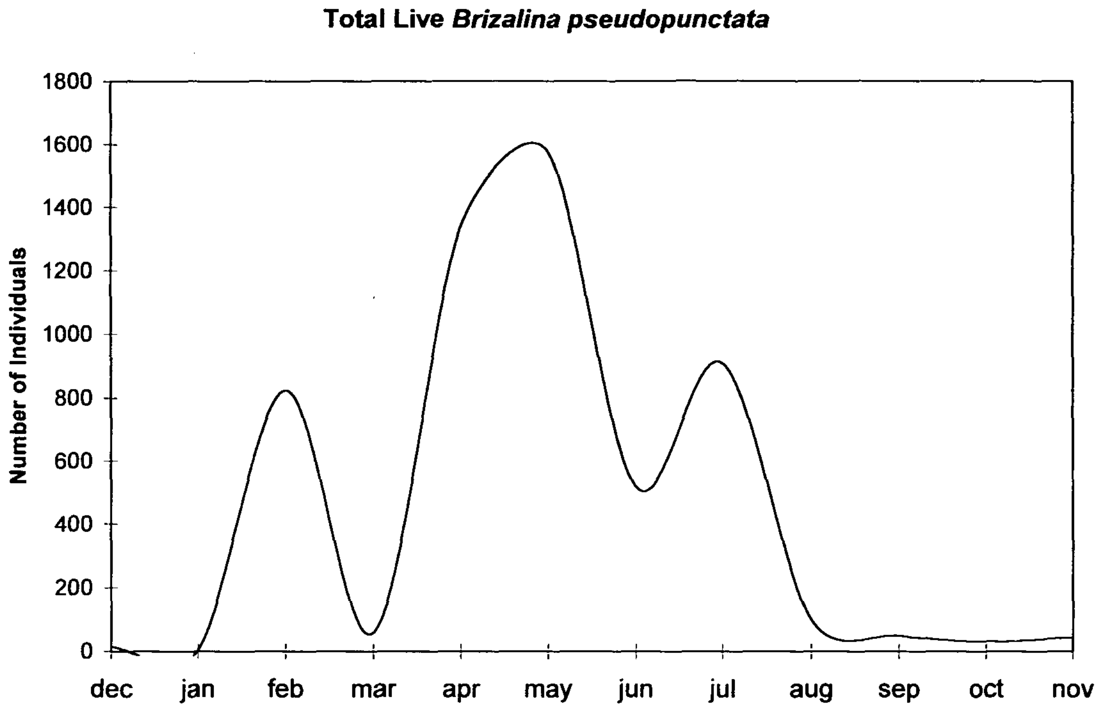


Figure. 8.52. Distribution of total *B. pseudopunctata* throughout the year.

The sum of all *Brizalina pseudopunctata* throughout the Sound shows three periods of high abundance; February, April/May and July (Figure 8.52). This distribution exhibits poor correlation with temperature and salinity, the highest temperatures are from August to October when this species is virtually absent (most other species show low abundance during this period at Location 9 where 90% of all *B. pseudopunctata* occurred). Reproduction may have occurred in January, March and June. These periods show a negative correlation to sea temperature and to a lesser extent salinity. They must be due to some other factor such as abundance of food and lower interspecific competition.

Brizalina pseudopunctata is most abundant in mud facies. Its preference for normal salinity is shown by being very abundant at Location 9 (normal salinity near the

Breakwater) and rare at Location 12 (most hyposaline site in the Sound) where it is almost absent. It is not abundant at Location 15 which is also very near the mouth of the Plym Estuary. Abundance maxima occur in February (only Location 9), April/May (Locations 9 and 15) and July. The three sites show a reasonable correlation (Figure 8.53).

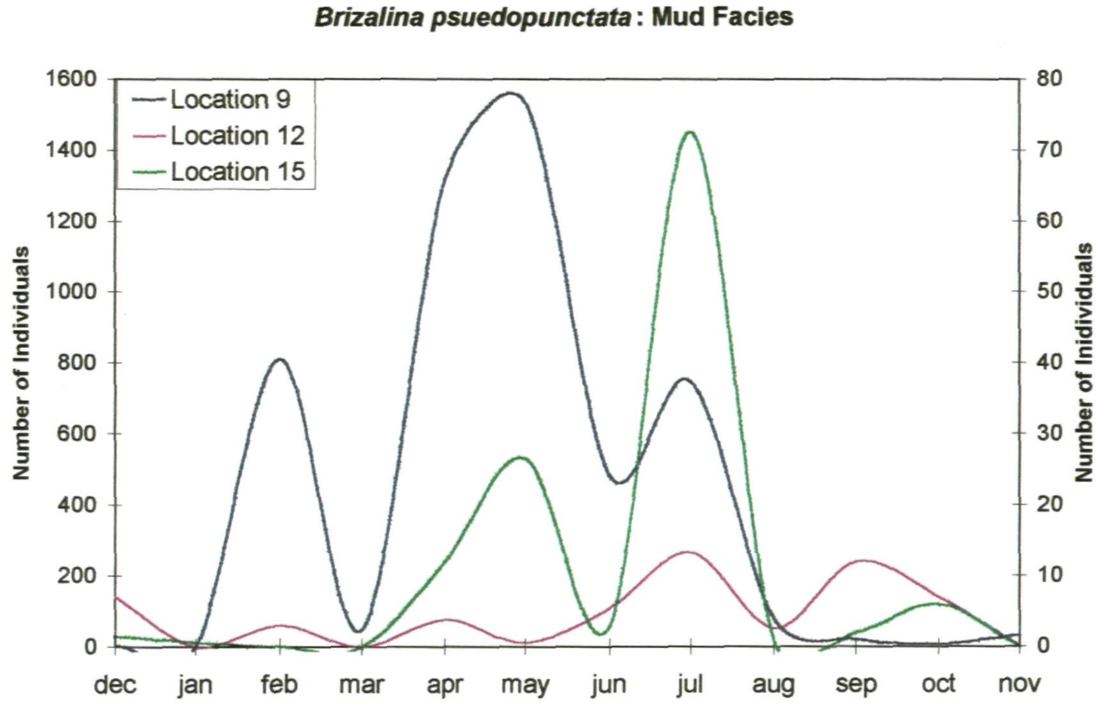


Figure. 8.53. Distribution of *B. pseudopunctata* in mud facies throughout the year. Note that figures for Location 9 are plotted on the left axis and Locations 12 and 15 on the right axis.

Brizalina pseudopunctata is rare in mixed sediments, where it attains its greatest abundance in July. All three mixed sediment sites correlate well (Figure 8.54).

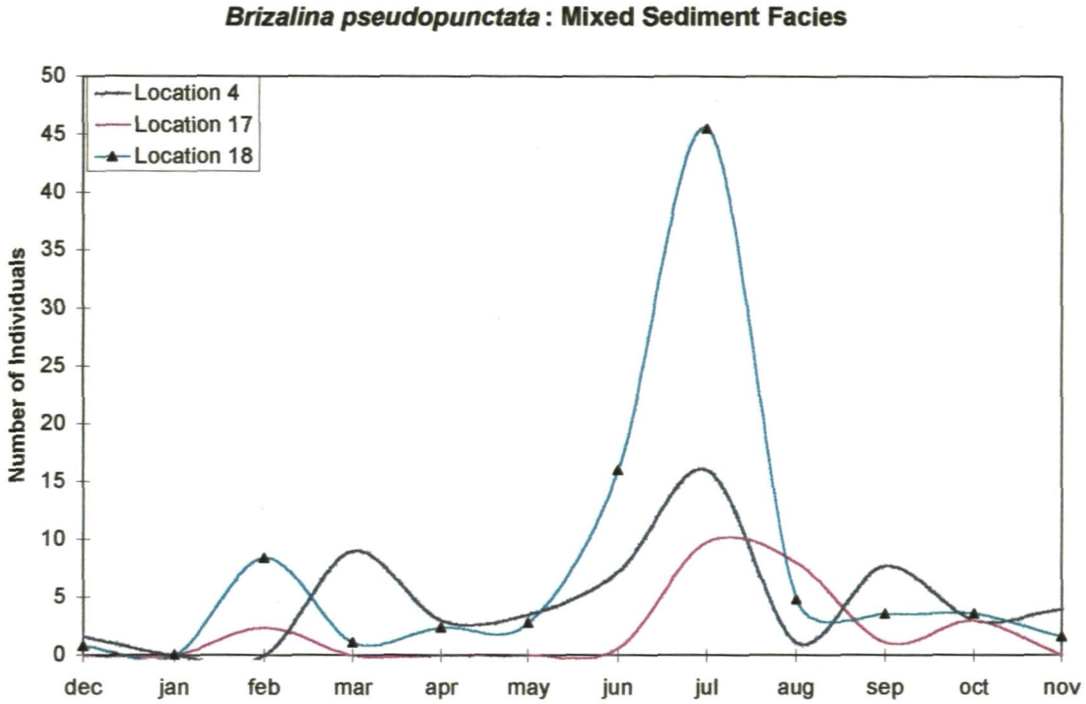


Figure. 8.54. Distribution of *B. pseudopunctata* in mixed sediment facies throughout the year. Abundance is low except during July

Brizalina pseudopunctata is very abundant at Location 9 (where it is the dominant species) and is moderate to low in abundance at the other mud facies and mixed facies. It is virtually absent from sand and gravel facies. It is most abundant in February, April/May and July hence these maxima show little correlation with temperature and salinity and may reflect blooms of food. There is little evidence to indicate that *B. pseudopunctata* is significantly effected by interspecific competition. Its high abundance (at Location 9 only) may indicate a preference for normal marine salinities. The soft muddy facies at Location 9 may be most suitable for its morphology and mode of life; primarily an infaunal detritivore.

8.14.4. Quinqueloculina oblonga

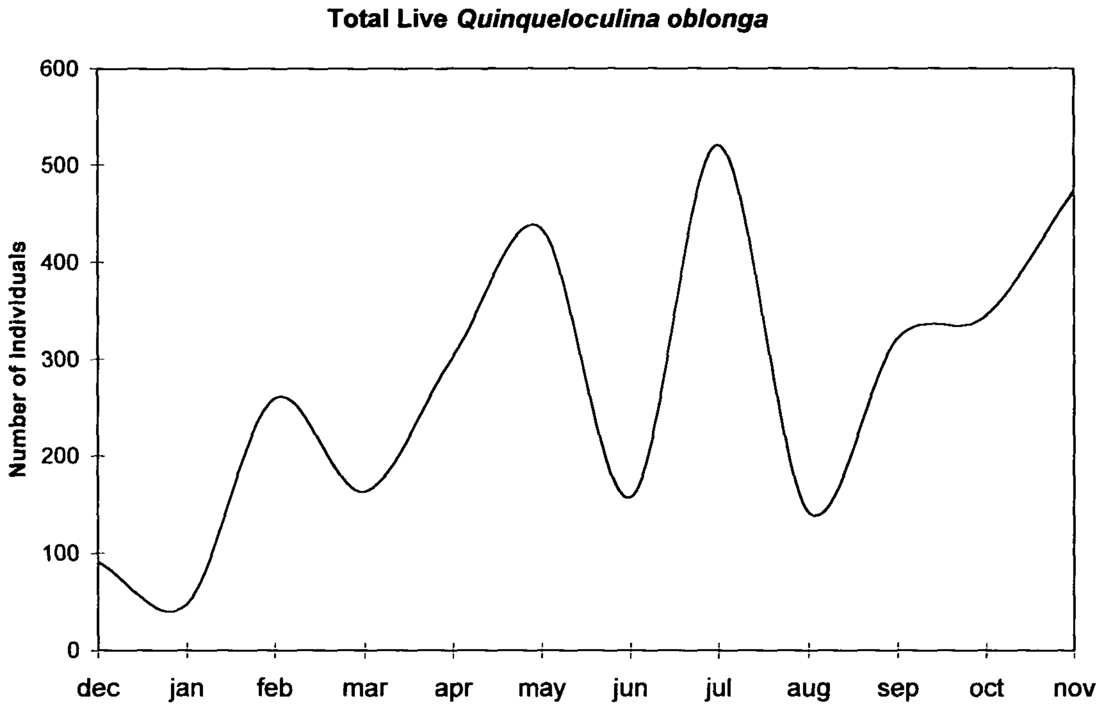


Figure 8.55. The distribution of all *Q. oblonga* throughout the year.

Four periods of maximum abundance are exhibited by this species (Figure 8.55). The first in February when temperature, salinity and levels of sunshine were low, this maxima is probably the result of increased food and or lower interspecific competition. The second in April/May when temperature was generally low but salinity was near normal in most areas of the Sound. This increase in abundance was probably related to increased food. The third maxima in abundance was in July when sea temperature was high (attaining its maximum in August and sunshine its maximum in June). Populations of *Q. oblonga* were high from September to November when temperature, salinity and sunshine were in decline.

Reproduction probably occurred in January and March, but the most significant periods of reproduction coincide with increasing and maximum sea temperatures in June and August.

The general trend shows partial correlation with the abiotic variables of temperature in the summer but linked to food or some other factors earlier in the year. *Quinqueloculina oblonga* was most abundant at Location 9 and has a similar distribution to *B. pseudopunctata* (which was the principal species at Location 9), both have a detritivore morphology.

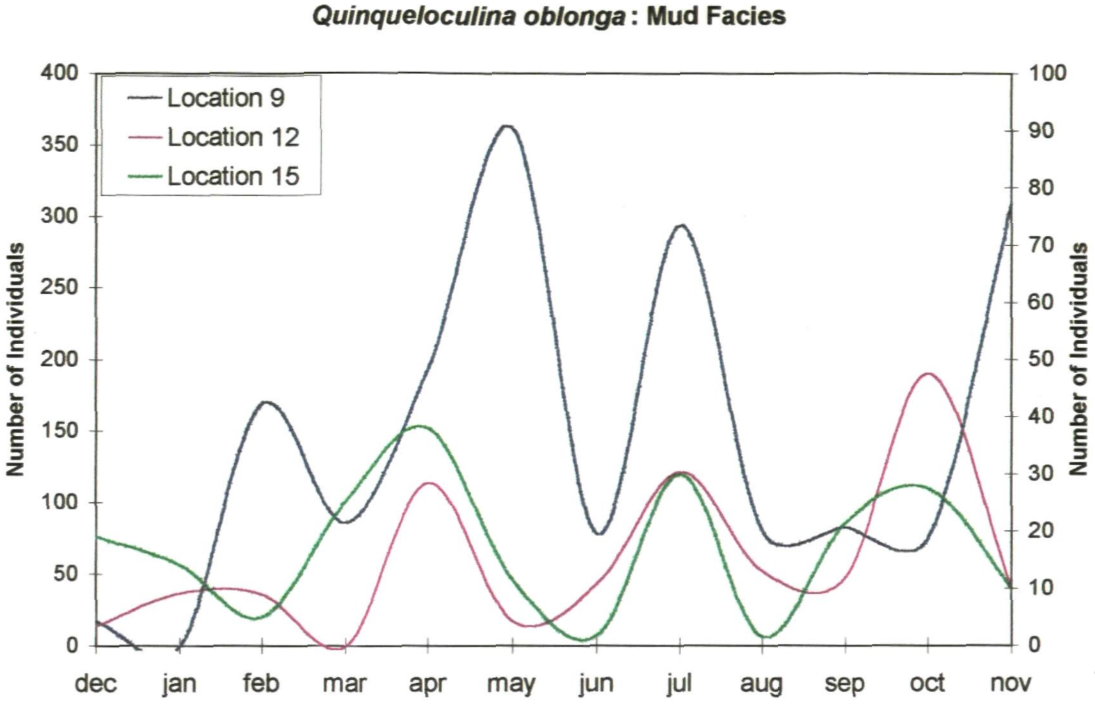


Figure 8.56. The distribution of *Q. oblonga* in mud facies throughout the year. Note Location 9 is plotted on the left Y axis and Locations 12 and 15 on the right Y axis.

The correlation of *Q. oblonga* in the mud facies is reasonable, and very good between Locations 12 and 15 (Figure 8.56). Location 9 shows an increased abundance in February which was not observed at Locations 12 and 15, this may be due to increased food at Location 9 and perhaps unfavourable factors at Locations 12 and 15. *Quinqueloculina oblonga* exhibits an increased abundance at all three Locations in April, but this abundance is sustained and increases during May at Location 9. This probably reflects a greater abundance of food at Location 9. All three Locations show a perfect correlation of increased abundance during July. Locations 12 and 15 show increased abundance in October and Location 9 shows high abundance in November when salinity and temperature both fall sharply. Generally the mud facies sites show reasonable correlation which reflects their similarity.

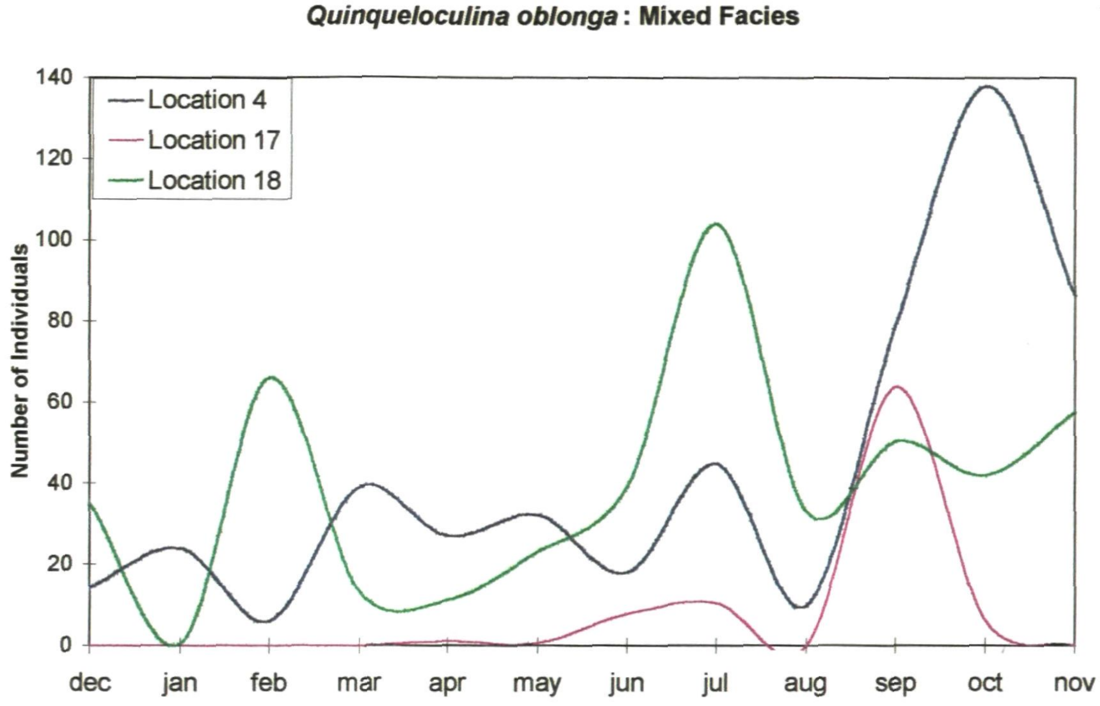


Figure 8.57. The distribution of *Q. oblonga* in mixed sediment facies throughout the year. Correlation between sites is poor.

Quinqueloculina oblonga is only very abundant at Location 9. It is common in other mud and mixed sediment facies but almost absent from sand and gravel sites. Its preference for mud rich sediments is clear from its distribution throughout the Sound. Although it belongs to the fusiform porcellaneous morphogroup, its elongate test suggest that it is adapted for infaunal living, which indicate that this species may be a detritivore or perhaps a combination of herbivore/detritivore. Its distribution throughout the year shows a partial correlation with abiotic factors such as temperature, salinity and sunshine. Its distribution probably reflect blooms of algae, bacteria and associated detritus on which it feeds. The variability of distribution of *Q. oblonga* in mixed sediment sites reflects the variability of these sites in terms of sediment, productivity, food, etc..

The distribution of *Q. oblonga* is either coincident with the distribution of many other species, or it occurs after other species such as at Location 17 where it attains its highest abundances just after the decline of a *A. beccarii batavus* maxima. This fact and its detritivore morphology suggest that it may feed on the detritus created by other species of foraminifera as well as other organisms in general (including food organisms).

8.14.5. Eggerelloides scabrum

The sum of all *E. scabrum* in Plymouth Sound exhibits a period of high abundance in April and a smaller peak in October (Figure 8.58). Between these periods, abundance of *E. scabrum* is extremely low. It is unusual that *E. scabrum* shows low abundance during June to September as these are the periods of highest temperature and salinity.

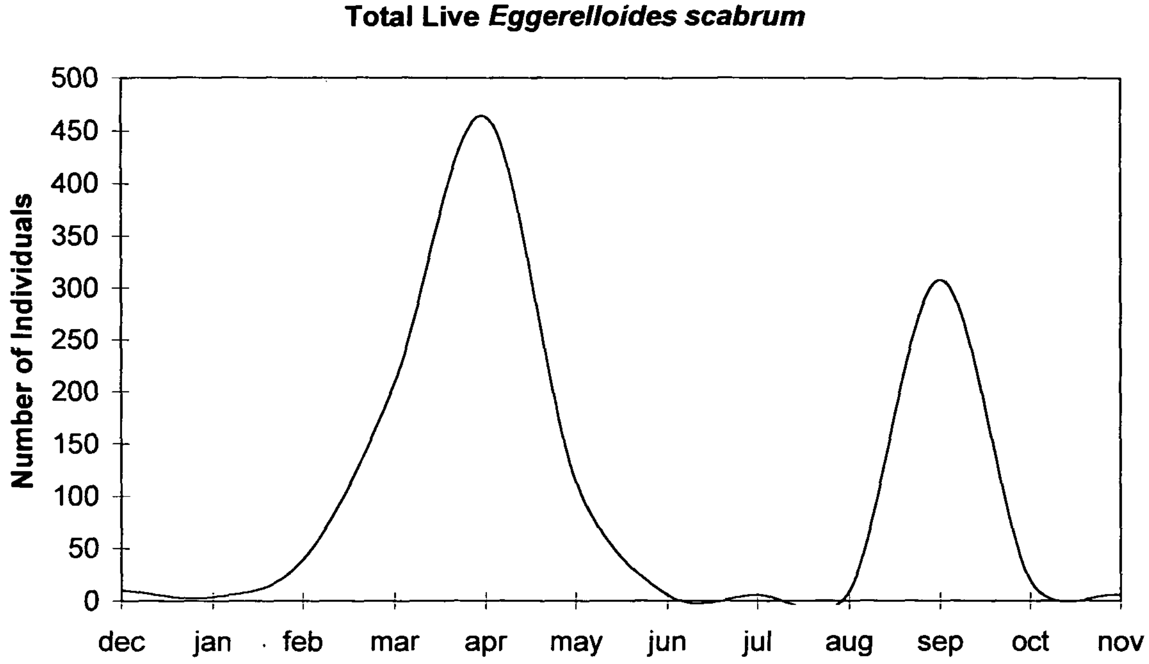


Figure. 8.58. Distribution of *E. scabrum* throughout the year.

It may be that *E. scabrum* does not prefer these conditions (as it shows a preference for hyposaline conditions) or is actively forced out during this period by competition from other species.

Eggerelloides scabrum attains maximum abundance during March at Location 9 and during April for Locations 12 and 15. It is virtually absent at all localities for the rest of the year (with the exception of a small number of *E. scabrum* in May at Location 9). The correlation of *E. scabrum* within the three mud facies is good (Figure 8.59).

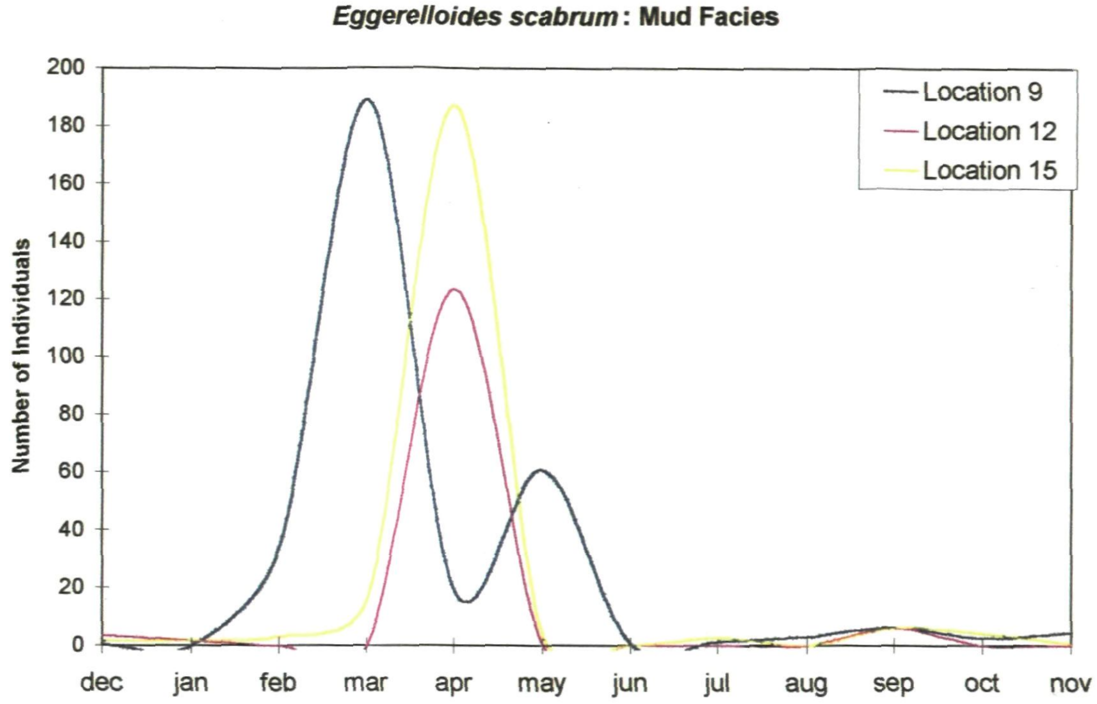


Figure 8.59. Distribution of total *E. scabrum* throughout the year from mud facies.

At mixed sediment locations *E. scabrum* exhibits a different distribution attaining maximum abundance at Locations 4 and 17 during October and Location 18 during May.

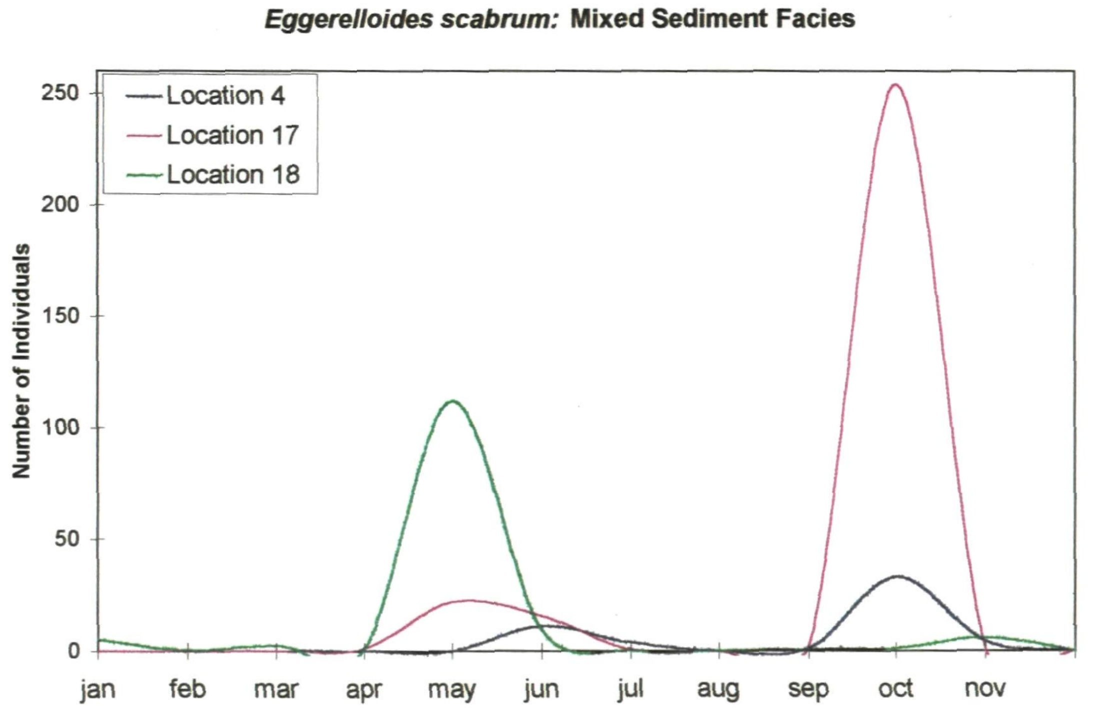


Figure. 8.60. Distribution of total *E. scabrum* throughout the year from mud facies.

Eggerelloides scabrum is rare in sand and gravel facies. It is most abundant at Location 17. In the mud facies *E. scabrum* occurs in spring and in the mixed facies in the autumn (with the exception of Location 18 which peaks in the spring). This pattern of distribution throughout the year and between sites is unusual, and different facies show poor or no correlation. It may be that the food on which it feeds occurs in the autumn at some locations and spring at others, or the effect of competition may suppress *E. scabrum* at various localities and periods during the year. The morphology of this species implies that it is a detritivore (see Chapter 8 Section 8.1 on morphogroups) and probably infaunal. It maybe most abundant between blooms of algae and phytoplankton when detritus from these blooms is most abundant.

Eggerelloides scabrum also exhibits a preference for slightly hyposaline conditions and may reproduce during periods of slightly lower or variable salinities such as winter, spring and late autumn. Reproduction is thought to have occurred during January to March in mud facies and in September in mixed facies. When this species exhibits elevated abundance it is not sustained for more than one month. Its distribution is generally coincident with other species with the exception of Location 9 where it attains high abundance while all other species are in low abundance.

8.14.6. Stainforthia concava **var.** *loeblichi*

The distribution of *Stainforthia concava* var. *loeblichi* is very similar to that of *B. pseudopunctata* and *Q. oblonga* exhibiting three maxima of abundance in February, May and July 9 (Figure 8.61). Over 90% of *Stainforthia concava* var. *loeblichi* is recorded at Location 9, the 3 peaks in abundance correlate well with the general abundance of other species of foraminifera from Location 9.

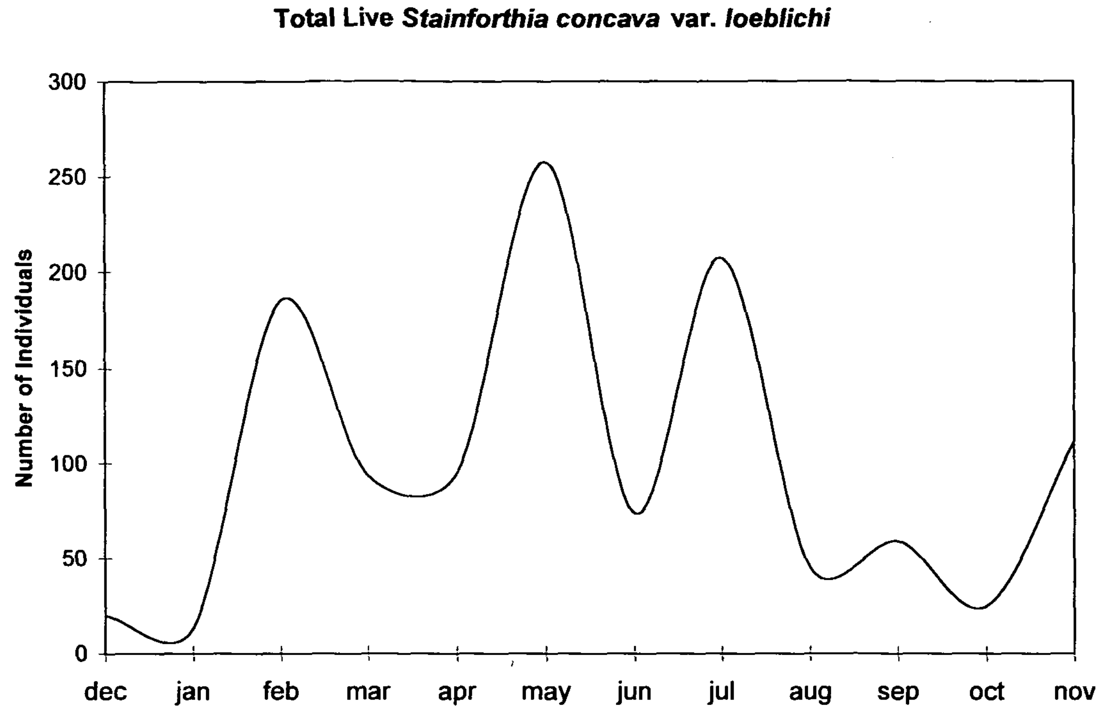


Figure 8.61. Total distribution of *Stainforthia concava* var. *loeblichi* throughout the year.

Stainforthia concava var. *loeblichi* is virtually absent from Location 12, and rare at Location 15 (which shows a maxima of 20 individuals during July). It is very abundant at Location 9, in February, May and July. This is a pattern of abundance observed in many species at Location 9 and must reflect the abundance of food or some other parameter.

In mixed sediments *Stainforthia concava* var. *loeblichi* is quite rare, it is almost absent from Location 17 (Figure 8.63).

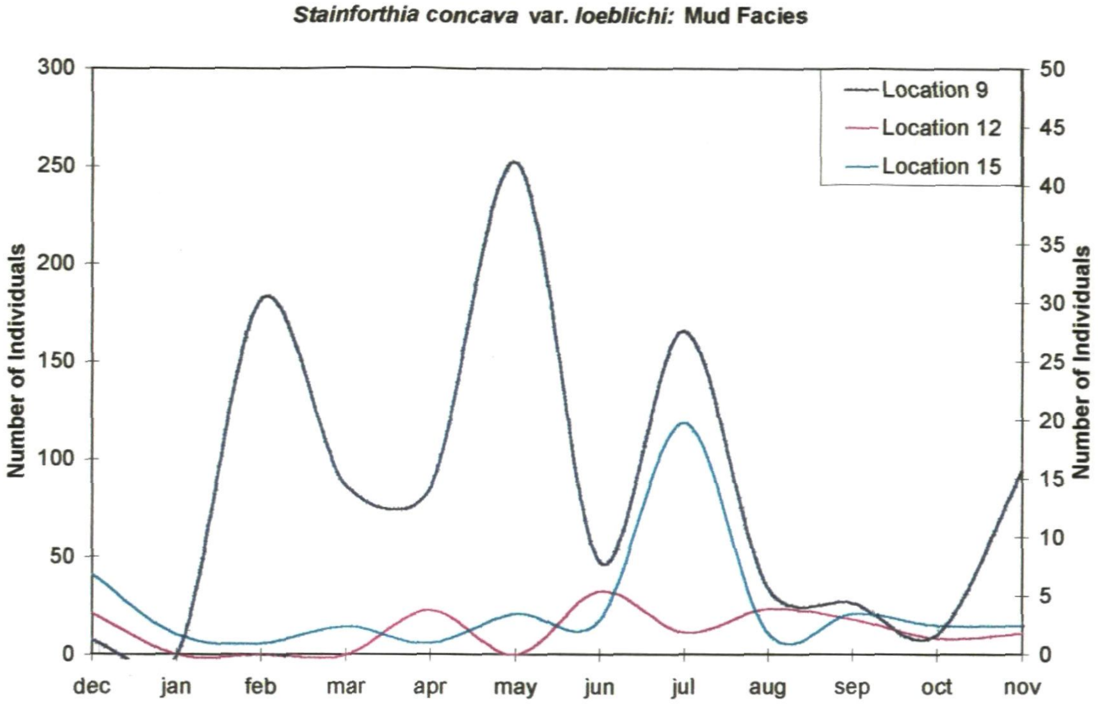


Figure 8.62. Distribution of *Stainforthia concava* var. *loeblichi* from mud facies throughout the year. Note that Location 9 is plotted on the left axis and Locations 12 and 15 on the right axis.

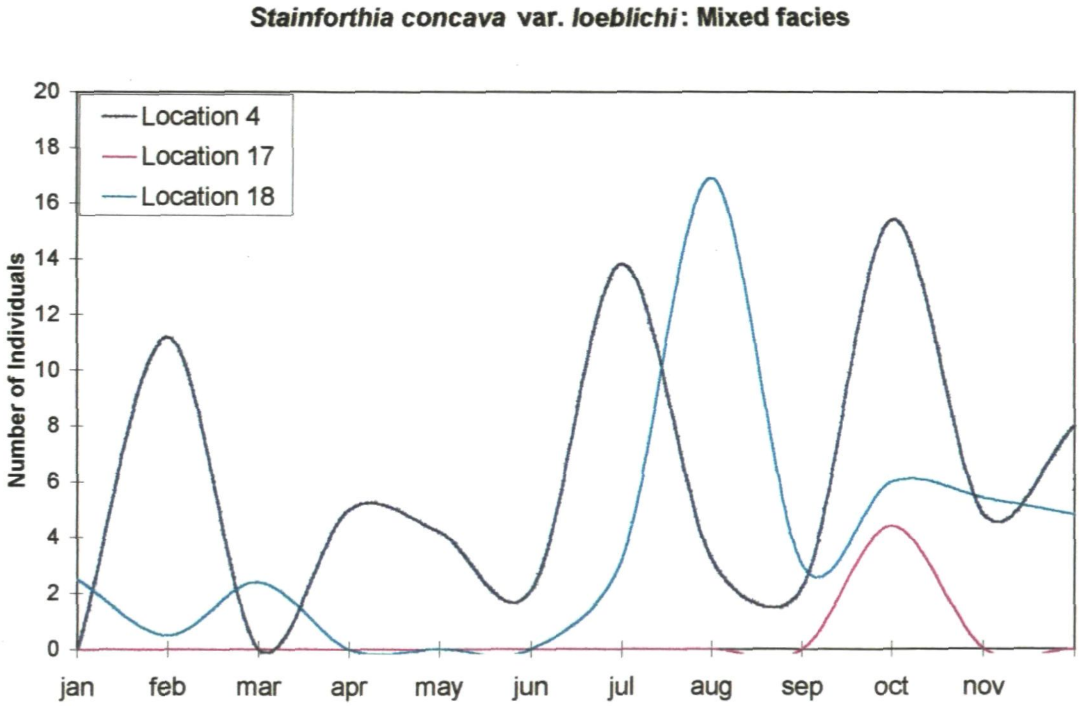


Figure. 8.63. Distribution of *Stainforthia concava* var. *loeblichi* from mixed facies throughout the year.

Reproduction of this species probably occurred in January, March/April, June and perhaps August/September.

As mentioned earlier the greatest number of *Stainforthia concava* var. *loeblichi* occurs at Location 9. Its preference for low energy mud rich facies is clear, as it is absent from sand and gravel facies. The distribution of *Stainforthia concava* var. *loeblichi* is coincident with other species so its distribution is probably the result of greater food availability and other favourable conditions. Its elongate morphology is typical of an infaunal mode of life probably being a detritivore. It has a very similar distribution to *B. pseudopunctata* and *Q. oblonga* which are also detritivores and very abundant at Location 9.

8.14.7. Brizalina spathulata

This species has a flattened tapered morphology. It is a detritivore and probably infaunal. It is most abundant at Location 9 (Breakwater muds), this distribution greatly influences its total distribution. This species was very common from February to August during which three abundance maxima were recorded (February, May and July, See Figure 8.64).

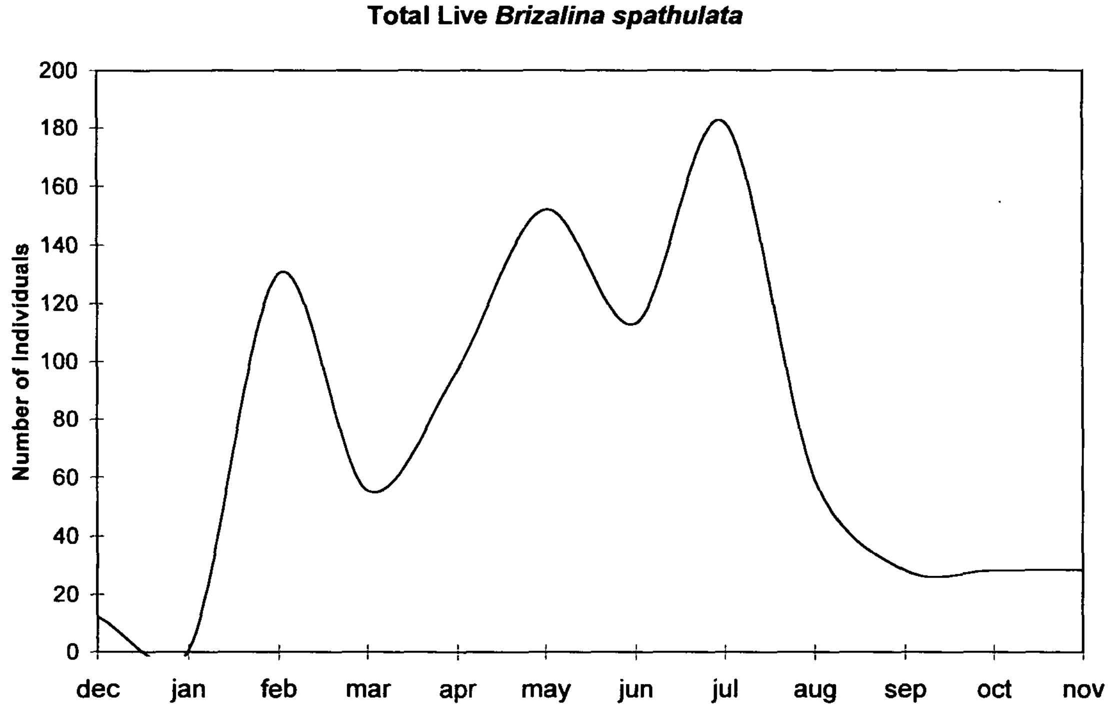


Figure 8.64. The distribution of all *B. spathulata* throughout the year.

Brizalina spathulata is very abundant at Location 9 and rare at Locations 12 and 15. Correlation between these sites is poor although during July they all showed relatively high abundances (Figure 8.65).

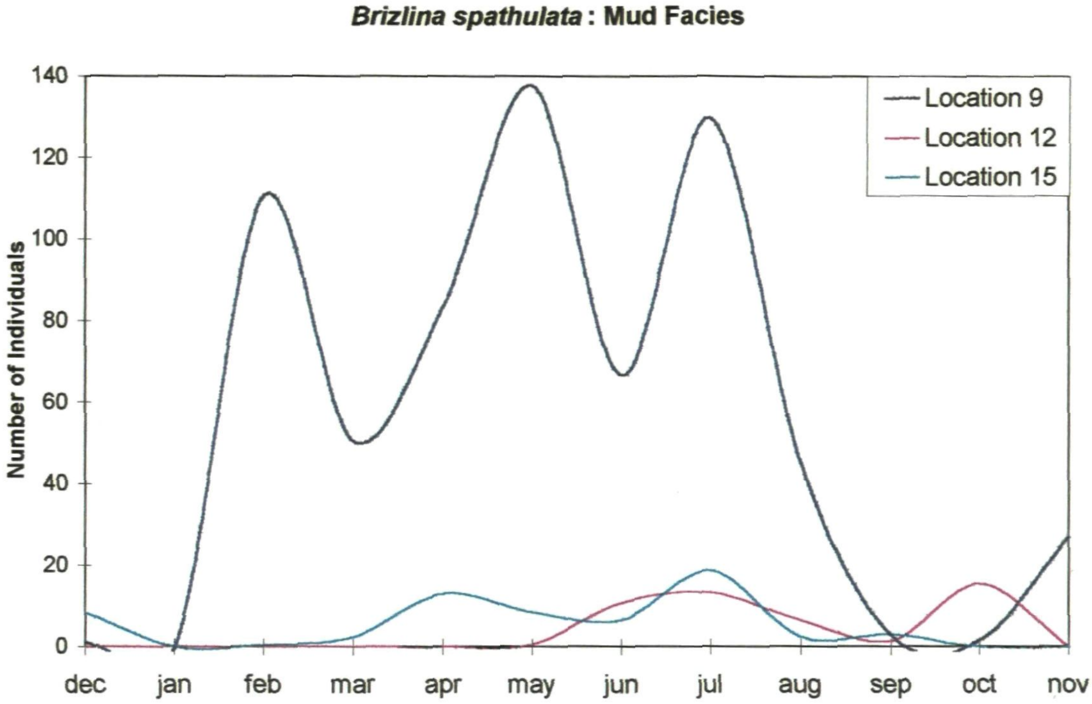


Figure. 8.65. The distribution of *B. spathulata* in mud facies throughout the year.

Brizalina spathulata commonly occurred in mixed sediment facies but was never abundant. The three sites show moderate correlation with each other and the sites of mud facies (See Figure 8.66).

Brizalina spathulata shows a strong preference for normal marine muds as it was very rare in sand and gravel facies and is not abundant in mixed or mud facies with the exception of Location 9. The reason it is only abundant within one mud facies (Location 9) may be due to an intolerance for slightly lower salinity (as at Location 12 and 15). Its trend is coincident with other species and there is no evidence for a high degree of interspecific competition.

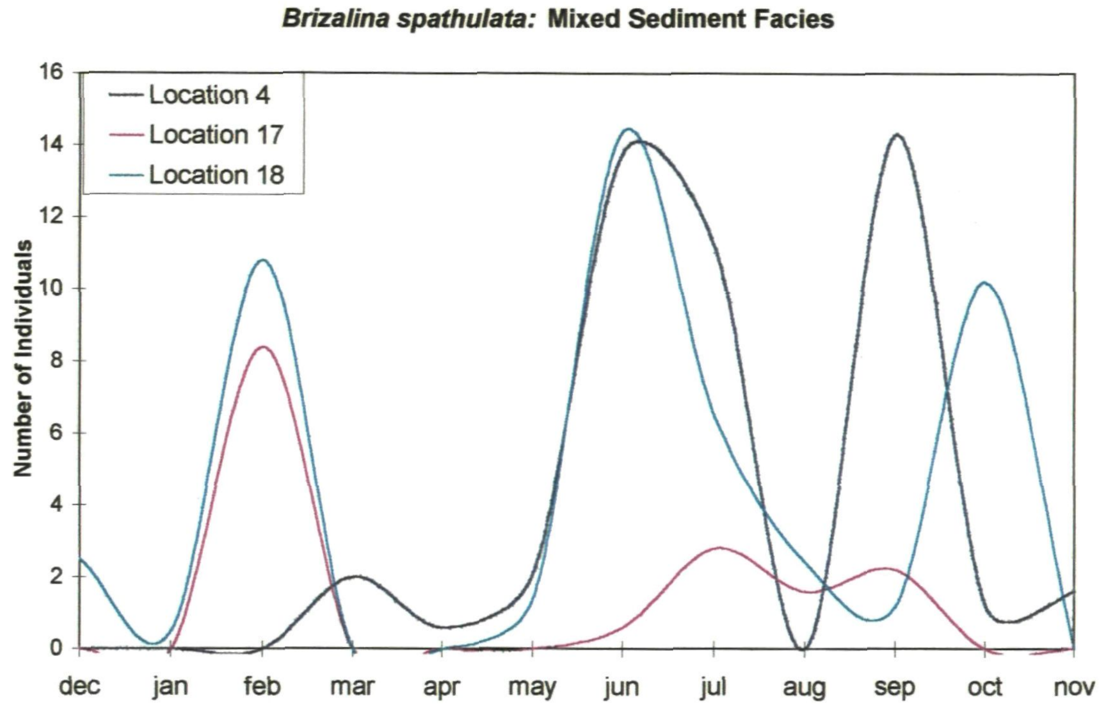


Figure. 8.66. The distribution of *B. spathulata* in mixed sediment facies throughout the year.

8.14.8. *Quinqueloculina seminulum*

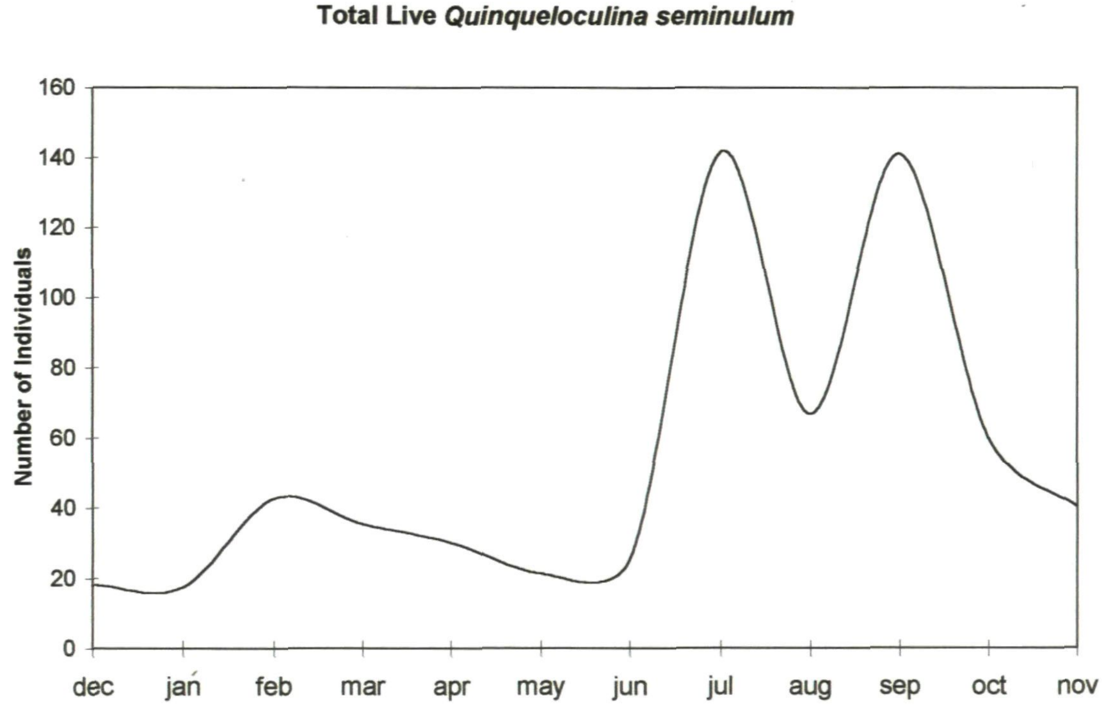


Figure. 8.67. The distribution of all *Q. seminulum* throughout the year.

This species was most abundant in the late summer and autumn, but was present throughout the year. Two abundance maxima occurred in July and September (Figure 8.67).

Quinqueloculina seminulum was recorded in all mud facies and was present throughout the year, but usually in low numbers. It was present in very low abundances at Locations 12 and 15 and for most of the year at Location 9, but it became very abundant at Location 9 during July and August. During these months food may have been more abundant. Reproduction occurred in May/June at Location 9 (Figure 8.68).

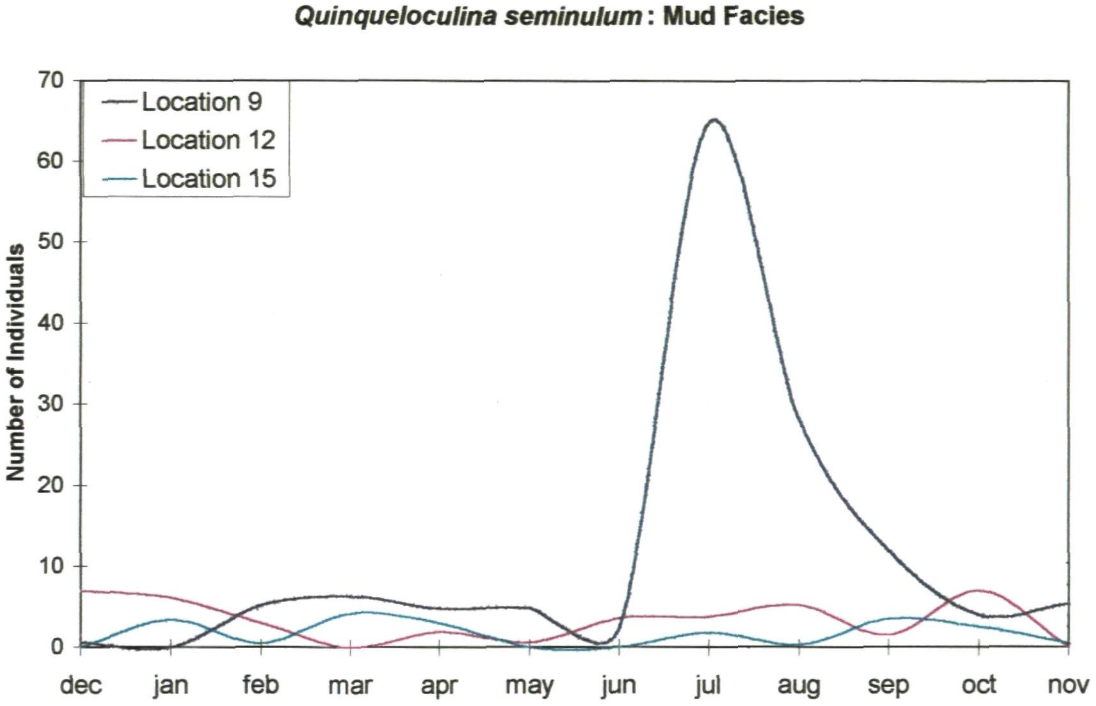


Figure. 8.68. The distribution of *Q. seminulum* in mud facies throughout the year.

Quinqueloculina seminulum is present in low abundance throughout the year at all locations within mixed sediment facies. At Location 17 there was a peak in abundance during September reflecting reproduction during August (maximum sea temperatures), whilst at Location 18 a maximum abundance occurred during July reflecting reproduction in June (rapidly rising sea temperatures). Location 18 correlates well with Location 9 (mud facies).

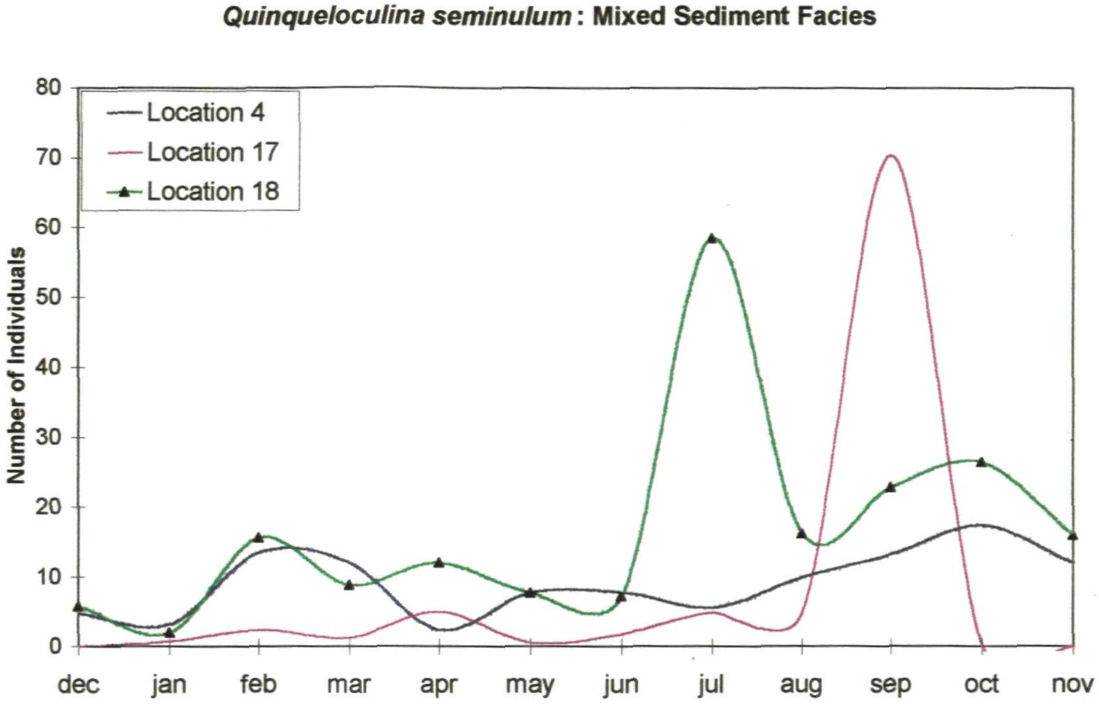


Figure 8.69. The distribution of *Q. seminulum* in mixed sediment facies throughout the year.

Quinqueloculina seminulum is an unusual species within the Sound because it is present within all sedimentary facies in low but consistent abundances. Its fusiform test indicates that it is free living and may be infaunal. Very large rounder specimens occurred within shell gravels while generally more elongate specimens occurred within mud rich facies (although large specimens were also present). This may be a result of age or perhaps ecophenotypical variation. The former morphology may have epifaunal tendencies. This species is most abundant in mixed and mud facies but this may be due to the higher standing crops and productivities of these facies.

8.14.9. *Rosalina williamsoni*

This species was a principal species of the shell gravel facies. Within these facies it exhibited a low abundance throughout nearly all of the year with the exception of August when it reached its maximum abundance (Figure 8.70).

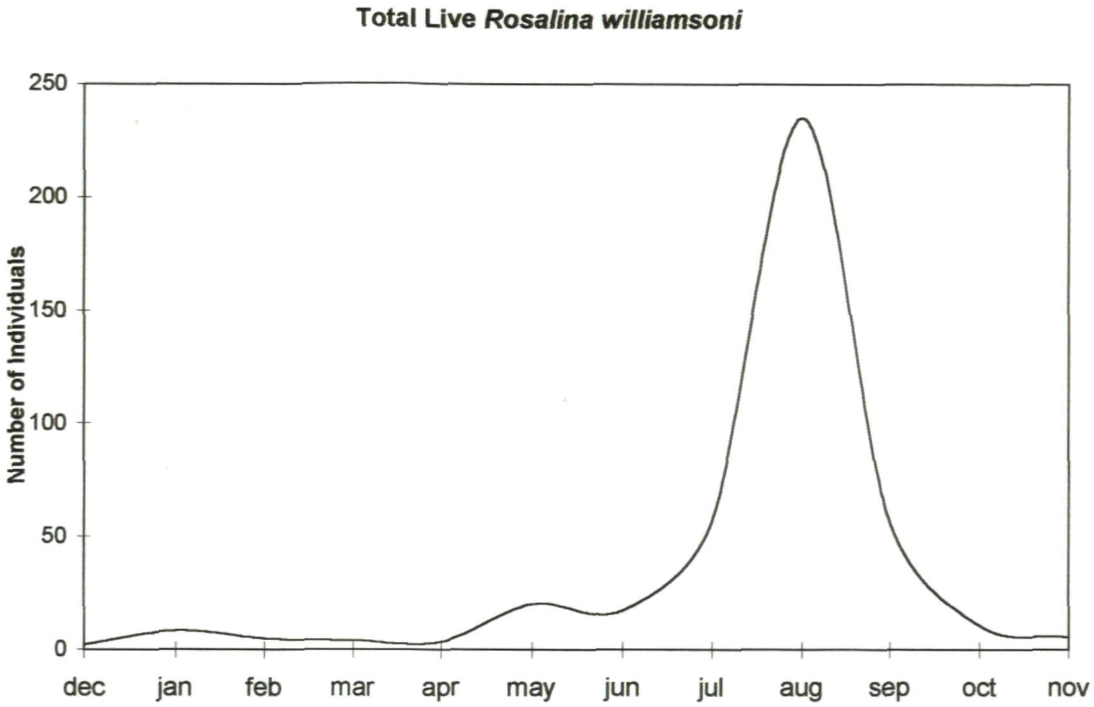


Figure 8.70. Distribution of all *R. williamsoni* throughout the year.

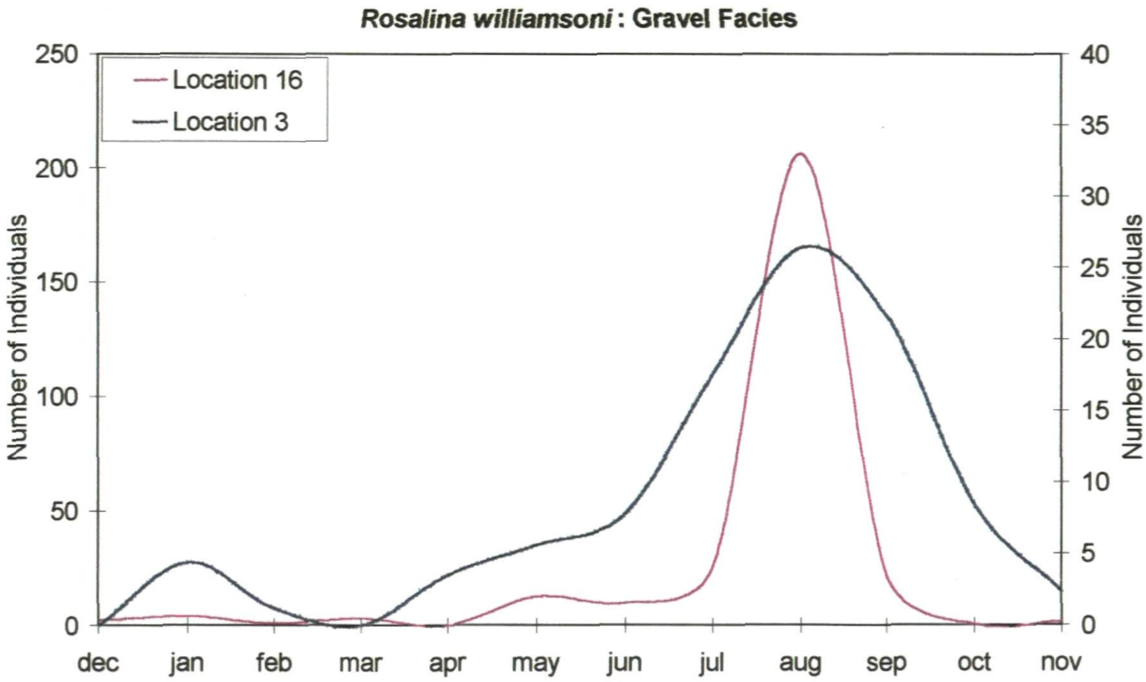


Figure 8.71. Distribution of *R. williamsoni* in gravel facies throughout the year. Note Location 3 (blue) is plotted on the right axis.

Within the two shell gravel sites the temporal distribution of this species were very similar, they differed mainly in magnitude, with over 200 individuals at Location 16 and less than 50 at Location 3 (Figure 8.71).

Rosalina williamsoni has a plano-convex morphology typical of attached foraminifera. This species is very rare in sands and virtually absent from other facies. The species is only abundance in high energy sites with sediment of coarse grain size. Plants and weed are absent from the area hence *R. williamsoni* adheres mainly to sediment grains. This is one of the few species to exhibit maximum abundance in August when sea temperatures where also at there highest, implying that reproduction occurs as sea temperature is rising or has reached 14 °C. It does not reproduce again when sea temperatures attain their maximum. Competition may occur with *Textularia truncata* which is another principal species of shell gravels.

8.14.10. *Textularia truncata*

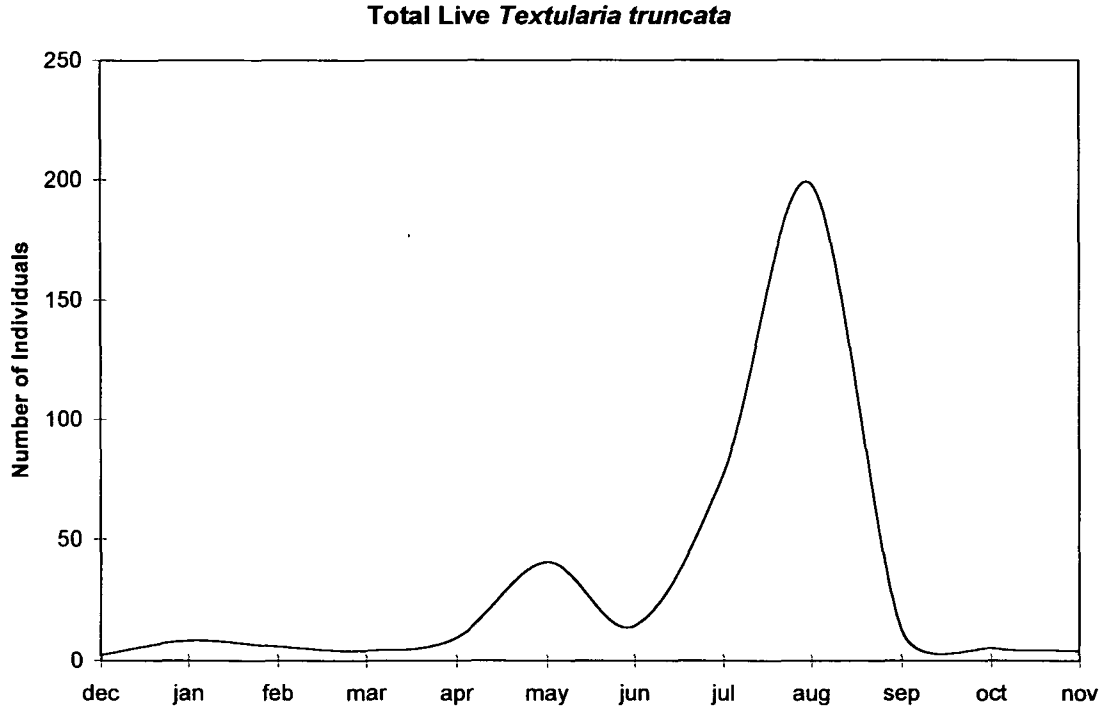


Figure 8.72. The distribution of all *T. truncata* throughout the year.

Textularia truncata was very rare in all facies except the shell gravels. Populations of *T. truncata* began to increase in July and reached a maximum in August, thereafter abundance returned to its usual very low levels. The temporal distribution of this species was very similar to the other shell gravel species *R. williamsoni*. There was a good correlation between the maximum abundance of this species and maximum sea temperatures.

At Location 3 maximum abundance of *T. truncata* was reached during July and August while at Location 16 maximum abundance was attained in August. The exact reason for these slightly out of phase peaks is not known but may result from a slight variation in the abundance of food or perhaps from the population having been modified by predation or competition (Figure 8.73).

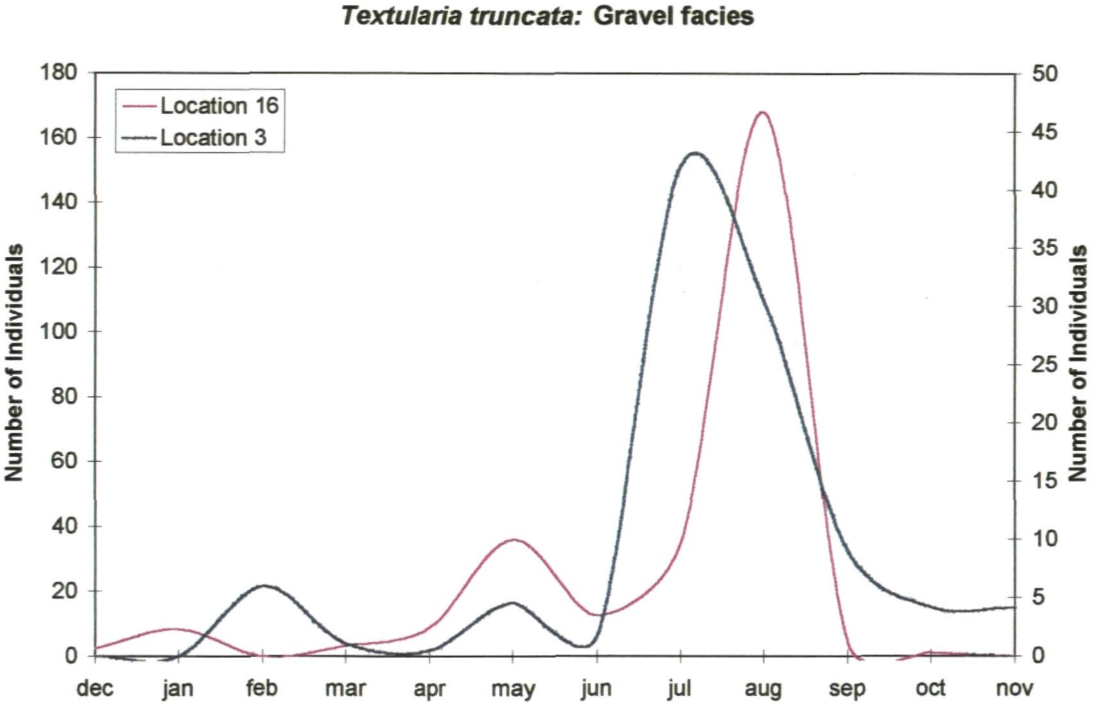


Figure 8.73. The distribution of *T. truncata* throughout the year within shell gravel facies. Note Location 3 (blue) is plotted on the right axis.

Textularia truncata has a strongly tapered, short, wedge-shaped test. This species probably has a clinging mode of life which is well suited to high energy environments. It is very rare in all other facies. Reproduction may be triggered by increasing sea temperatures and the abundance of food. Reproduction occurred in June/July.

This species is less abundant at Location 3 and attains maximum abundance during July (one month earlier than at Location 16). Lower abundance of food may create interspecific competition between *T. truncata* which blooms in July and *R. williamsoni* which blooms in August, hence their maximum populations do not coincide. At Location 16 both species attain there maximum populations in August and achieve greater abundance. This may reflect a high abundance of food thus minimising the affect of interspecific competition.

8.14.11. *Bulimina elongata*

This species was never very abundant within the Sound although it commonly occurred in many samples and facies throughout the year. The total amount of *B. elongata* showed a very variable distribution throughout the year, three peaks in abundance were present in February, April and May (Figure 8.74).

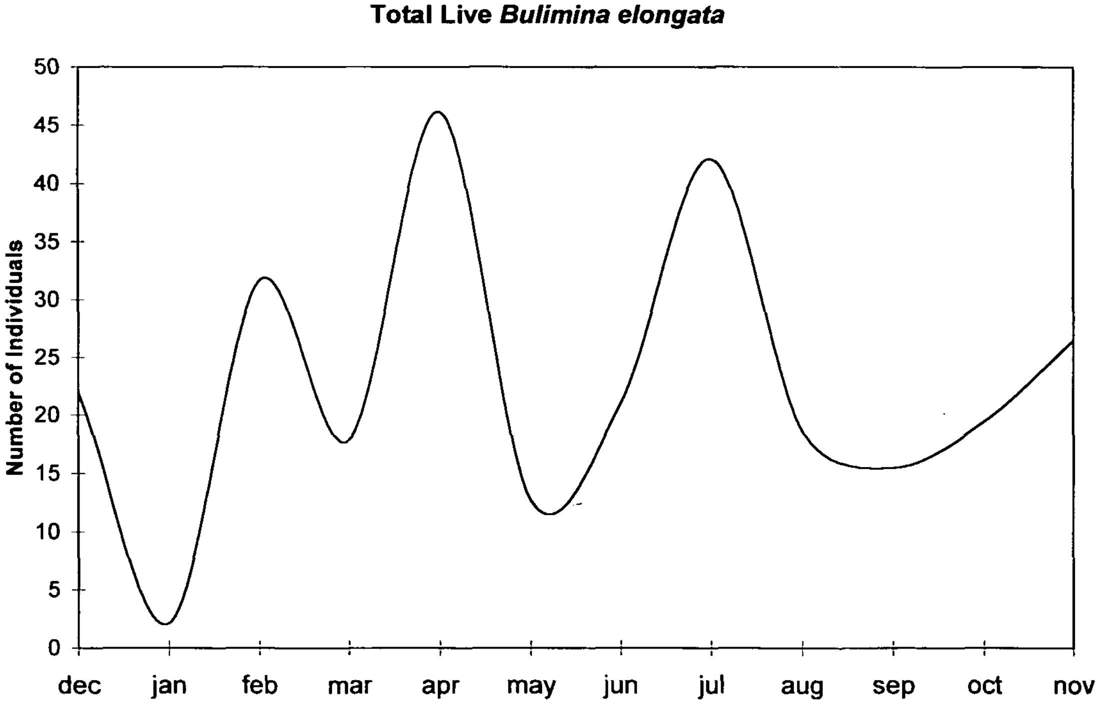


Figure 8.74. The distribution of total *B. elongata* throughout the year.

Although *B. elongata* was present at most locations, it was most common at three locations; two within the mud facies (9 and 15) and one within mixed facies (18). Correlation between these sites was good and showed higher abundances during February, April and July (Figure 8.75). *Bulimina elongata* was most abundant at Location 9 during February to April.

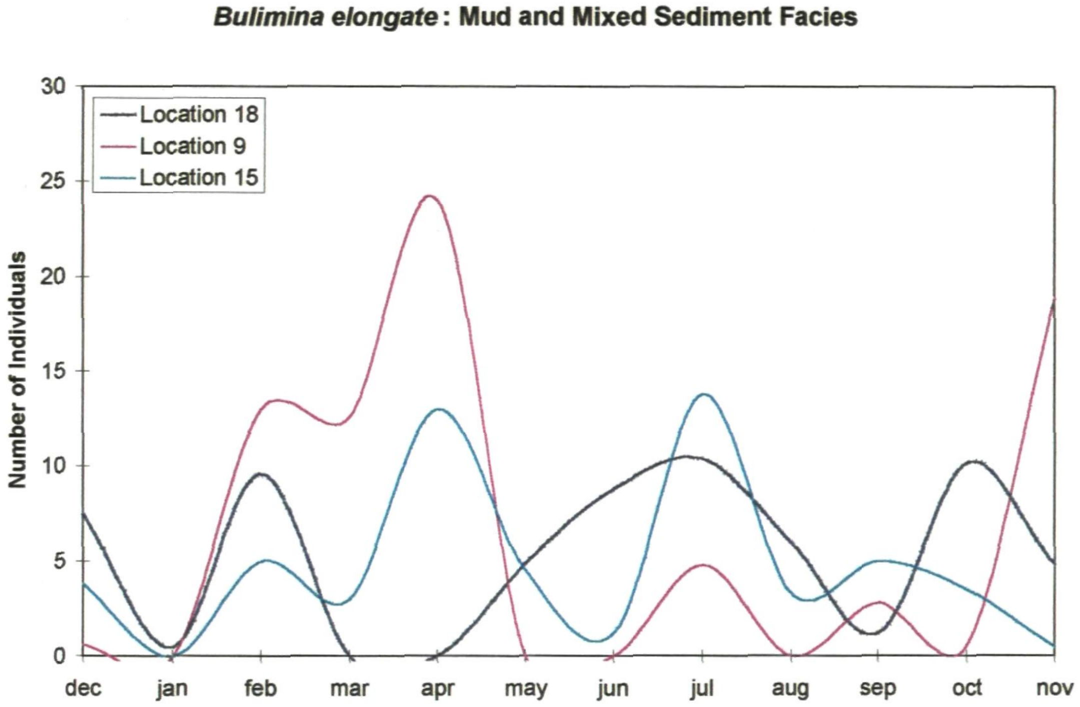


Figure. 8.75. The distribution of *B. elongata* at Locations 9, 15 and 18 throughout the year.

Bulimina elongata has an elongate conical morphology and is probably an infaunal detritovore. Although it is distributed within all facies it showed a clear preference for mud rich facies. Its distribution throughout the year is similar to many other species. Its distribution at Location 9, particularly its near absence during the summer may be due to interspecific pressure. This species was never abundant at any time within the Sound.

8.14.12. *Bulimina gibba*

Bulimina gibba was generally rare within the Sound. It showed a similar distribution pattern to that of *B. elongata*, with peaks in abundance during February (very minor), May and July. These two species differed in the timing of their maximum abundance, *B. gibba's* maximum occurred during May while *B. elongata's* maximum occurred during April.

Bulimina gibba was reasonably abundant only in the mud facies, particularly Location 9 (near the Breakwater). At Location 9 a clear maximum in abundance occurred during May (Figure 8.77).

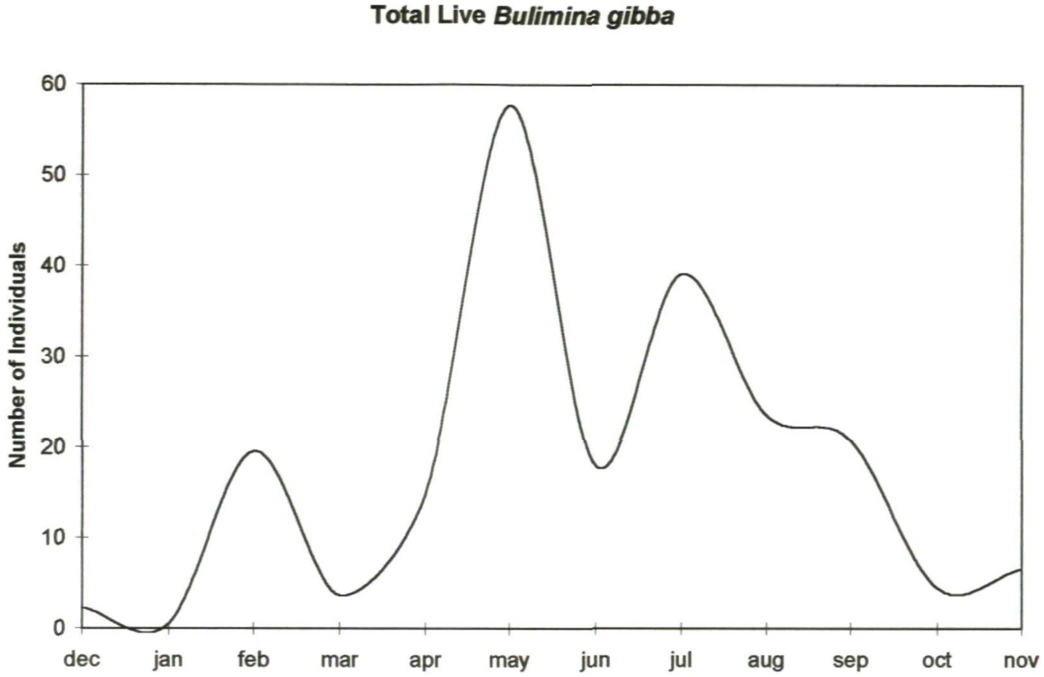


Figure. 8.76. The distribution of all *B. gibba* throughout the year.

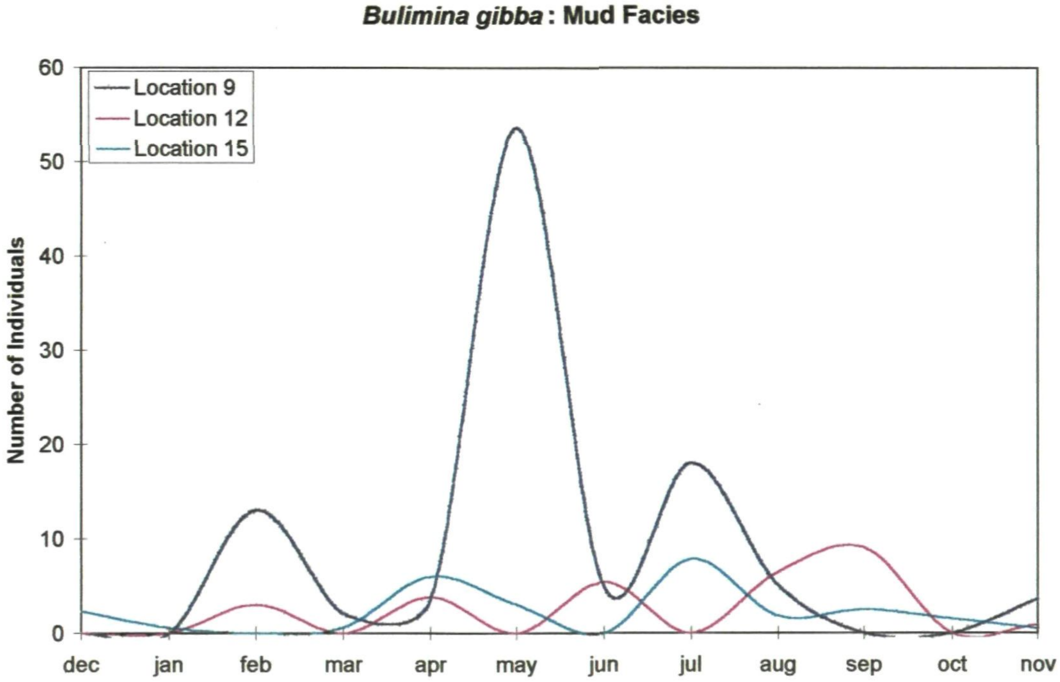


Figure. 8.77. The distribution of *B. gibba* in mud facies throughout the year.

Bulimina gibba is generally rare within the Sound. It shows a preference for mud rich facies and only occurs in reasonable abundance at Location 9. Its rounded conical morphology suggests that it is an infaunal detritovore. Interestingly its distribution at Location 9 does not coincide with *B. elongata* but is out of phase by one month. This pattern may indicate that these species utilise different food types or have different criteria for reproduction. It may indicate that they are not in direct competition or have adopted this strategy to coexist together.

8.14.13. *Elphidium cuvillieri*

This species exhibited low abundances throughout the first half of the year but reached high abundance in July and August before declining in abundance in September. Its maximum abundance was attained in November (Figure 8.78).

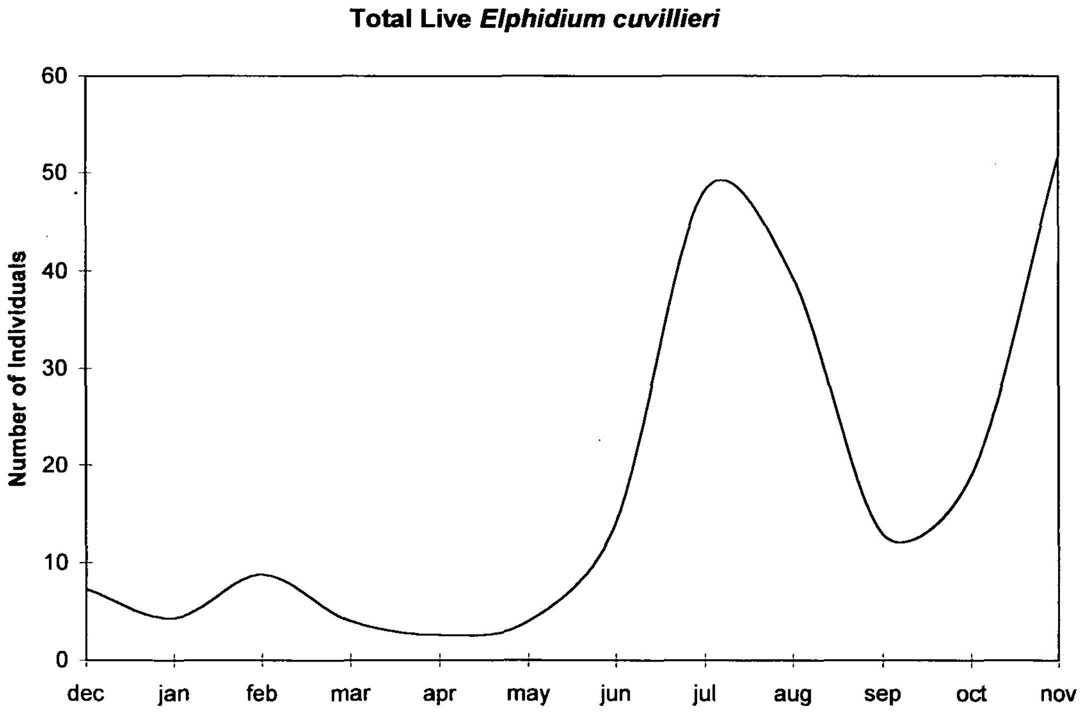
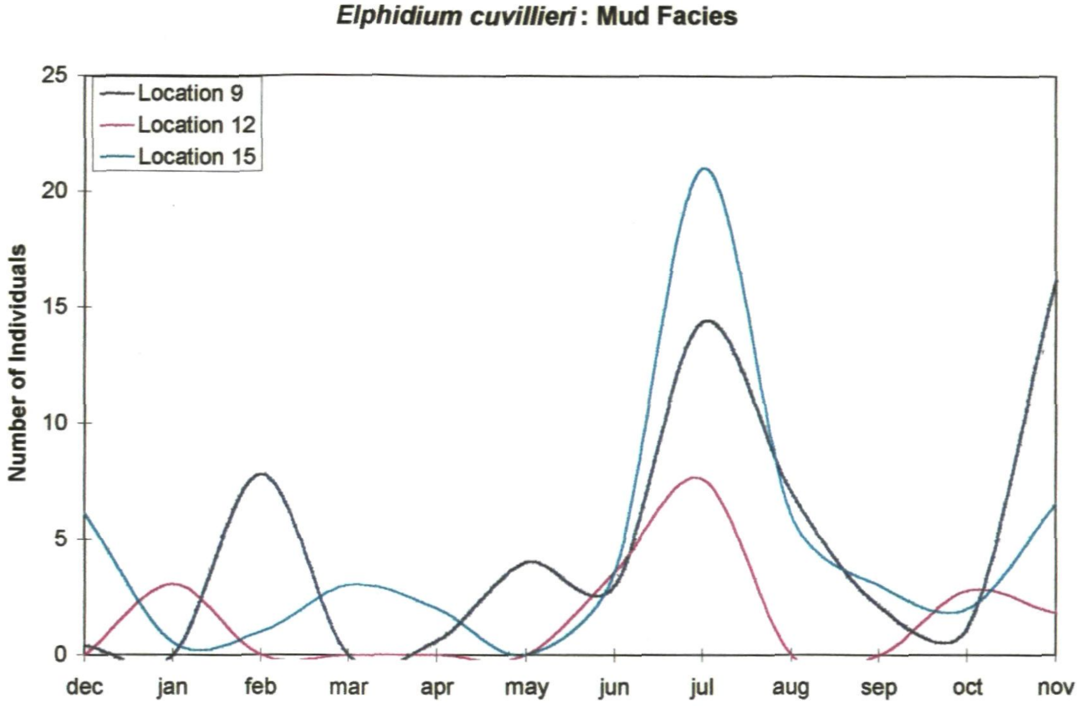


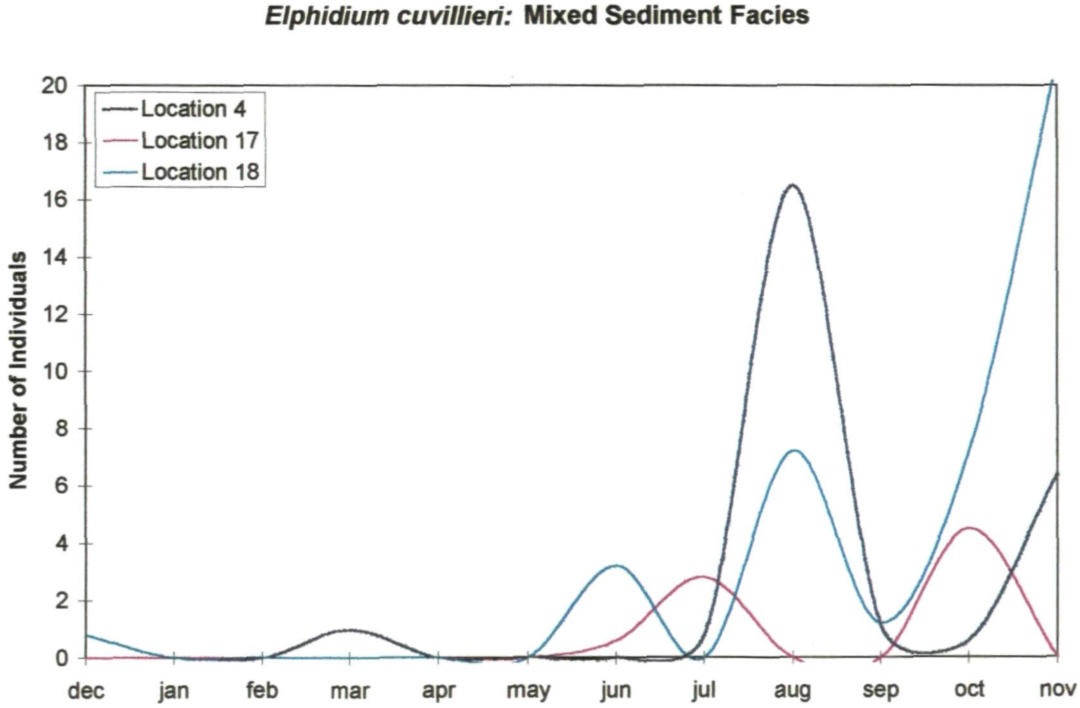
Figure. 8.78. The distribution of all *E. cuvillieri* throughout the year.

Elphidium cuvillieri was present throughout most of the year within the mud facies. This species correlated well in the mud facies, as high abundance is exhibited at all locations in July. Locations 9 and 15 showed an increase in November (Figure 8.79).



***Elphidium cuvillieri*: Mud Facies**

Figure. 8.79. The distribution of *E. cuvillieri* in mud facies throughout the year.



***Elphidium cuvillieri:* Mixed Sediment Facies**

Figure 8.80. The distribution of *E. cuvillieri* in mixed sediment facies throughout the year.

Within mixed sediment sites, only Locations 4 and 18 exhibited reasonable abundance of this species (Figure 8.80). Unlike the mud facies (which peaked in July) a peak in abundance is exhibited in August. Again, one location (18) showed an additional increase in November (its maximum abundance).

Elphidium cuvillieri has a rounded planispiral morphology, which suggests that it may be an infaunal herbivore or detritivore. This species shows an increased population in July and August which correlates well with sea temperature and more generally salinity, but its maximum abundance occurs in November which shows no correlation with salinity or temperature and must certainly be influenced by some other factors, perhaps food or competition.

8.14.14. *Reophax scottii*

This very delicate species was generally rare, being most common from April to July. It exhibited two peaks of relatively high abundance during May and July (Figure 8.81).

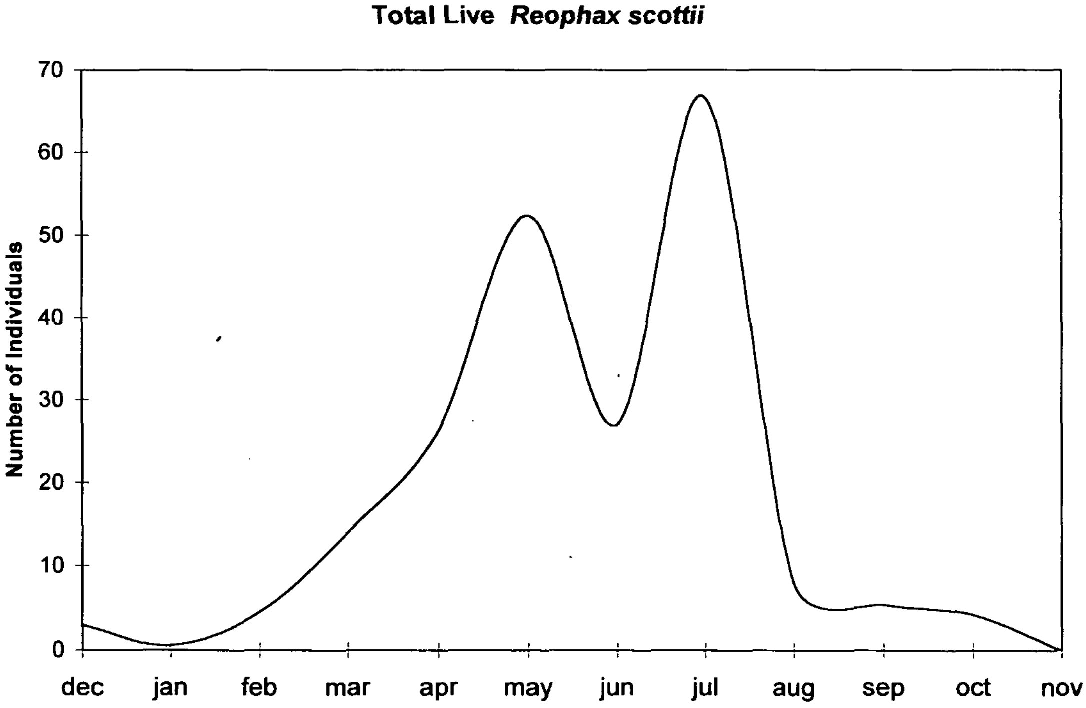


Figure. 8.81. Distribution of all *R. scottii* throughout the year.

Within mud facies *R. scottii* was rare at Location 12 but attained higher abundances at Locations 9 and 15 during May, and Location 9 during July (Figure 8.82). Correlation between sites was moderate to good (excluding Location 12 in which *R. scottii* was too rare to be significant).

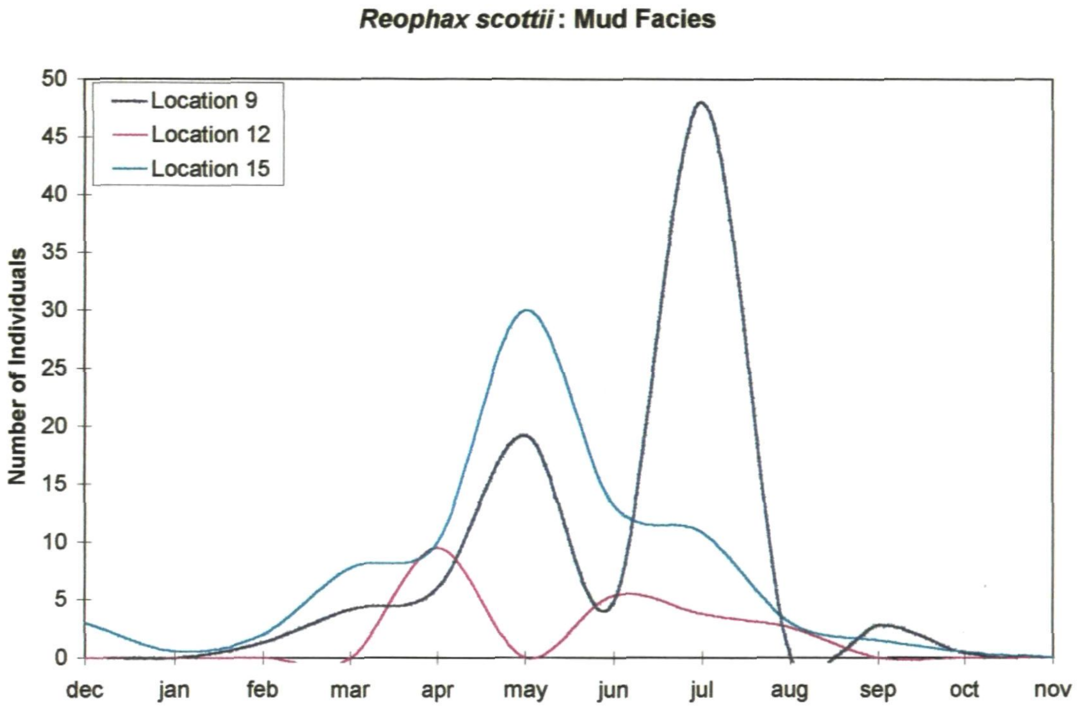


Figure. 8.82. Distribution of *R. scottii* within mud facies throughout the year.

Reophax scottii is absent from sand and gravel facies and it is very rare in mixed sediment facies. This species has a very delicate test and shows a preference for low energy and subsequently mud rich facies. It is most abundant at the lowest energy mud facies of Locations 9 and 15. Reproduction occurred in April and June, the first period may be linked to food and the second temperature induced.

8.14.15. *Nonion depressulus*

This species consistently occurred in very low abundance at a range of sites within the Sound. Its distribution suggests that it is facies independent. It attained a maximum abundance of 88 individuals during July. Reproduction probably occurred during May or June and may have been triggered by rising sea temperatures (Figure 8.83).

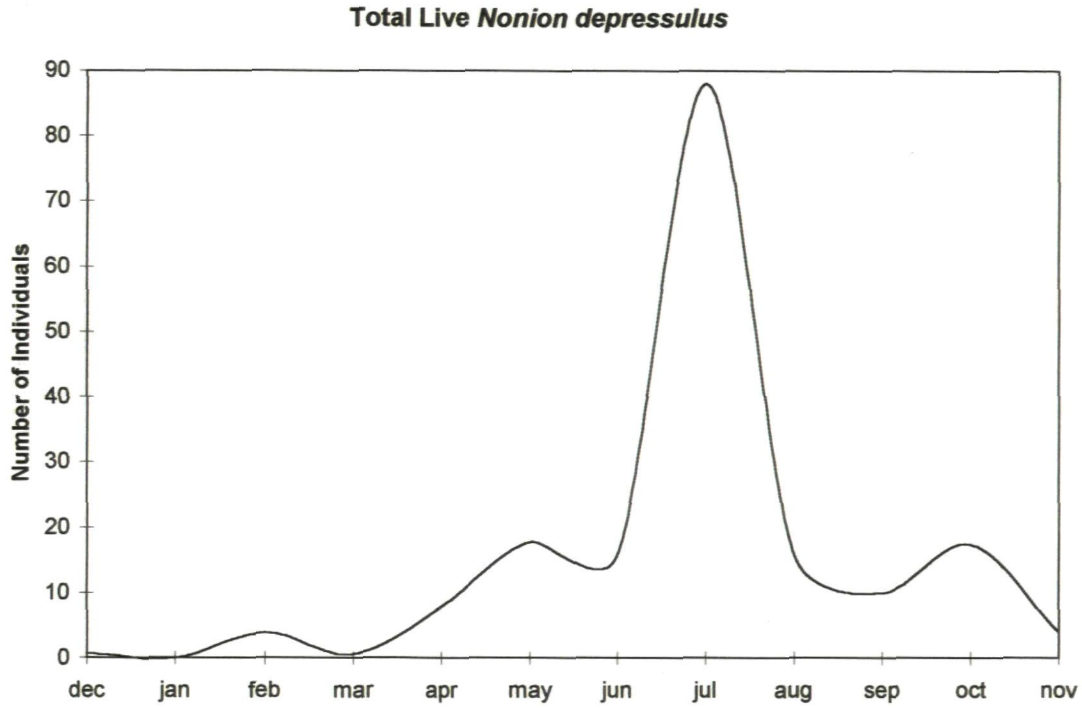


Figure. 8.83. Distribution of all .*N. depressulus* throughout the year.

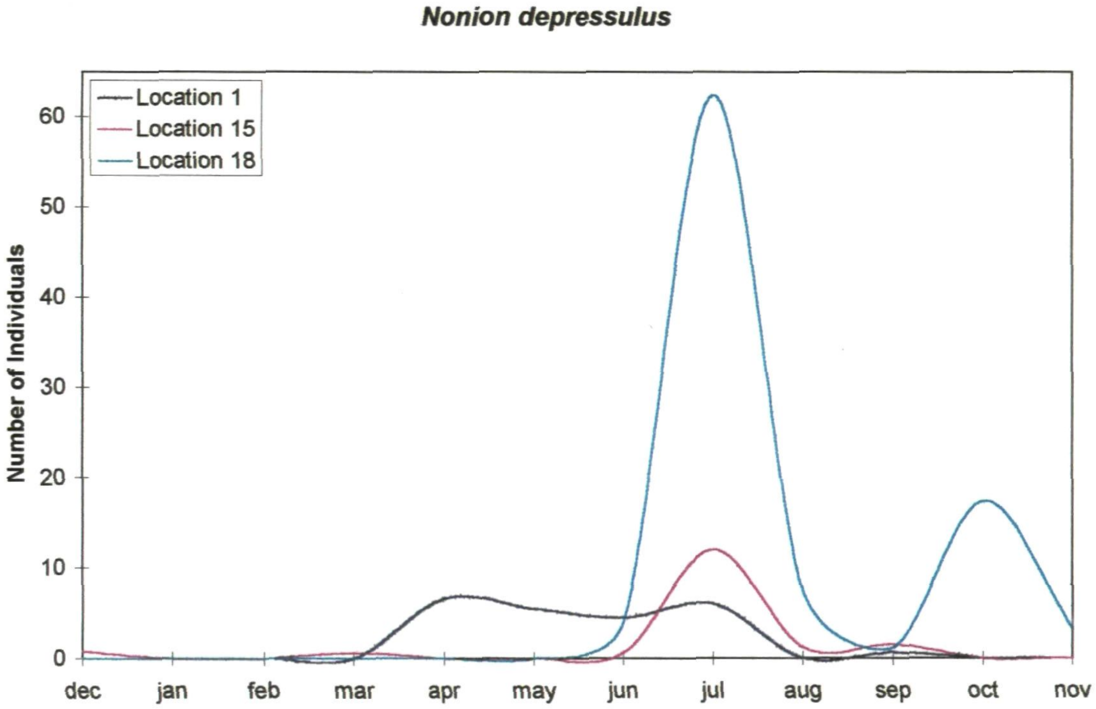


Figure. 8.84. Distribution of *N. depressulus* at Location 1, 15 and 18 throughout the year.

This species occurred within all the sedimentary facies of Plymouth Sound. It did not show a preference for a particular facies being most common at Location 1 (clean sand), Location 15 (mud) and Location 18 (mixed sediment). Large populations of this species were only attained at Location 18 in July (Figure 8.84). This species reproduces in June which is probably linked to increased sea temperatures.

This species has a flattened planispiral morphology with rounded periphery which suggest that it is infaunal and may be a detritivore or herbivore. *Nonion depressulus* was identified as having strong infaunal tendencies within Chapter 4 (on foraminifera depth distribution within cores), this was particularly evident at Location 18 (Withyhedge cores 1994 and 1995), it may be that the observed abundance at this location may have been present in the subsurface at other times of the year or more likely the observed bloom in July may be part of the total bloom which extends down into the subsurface and was not entirely collected with the 'Murray Grab'. Its infaunal habit may be important to its occurrence in other facies. Its rarity may be overstated as a result of the sampling technique employed.

8.14.16. *Ammoscalaria pseudospiralis*

This species was generally rare within the Sound. Its distribution throughout the year showed a rapid increase in abundance during July and elevated abundance during July to November which correlated well with sea temperature which increased rapidly during July and remained high during this period (Figure 8.85).

This species was only present in mud rich facies and only reasonably common at Locations 4 (mixed), 9 (mud) and 18 (mixed). Its distribution within these sites show little correlation with each other. They all however exhibit maximum abundances at the end of the year (Figure 8.86).

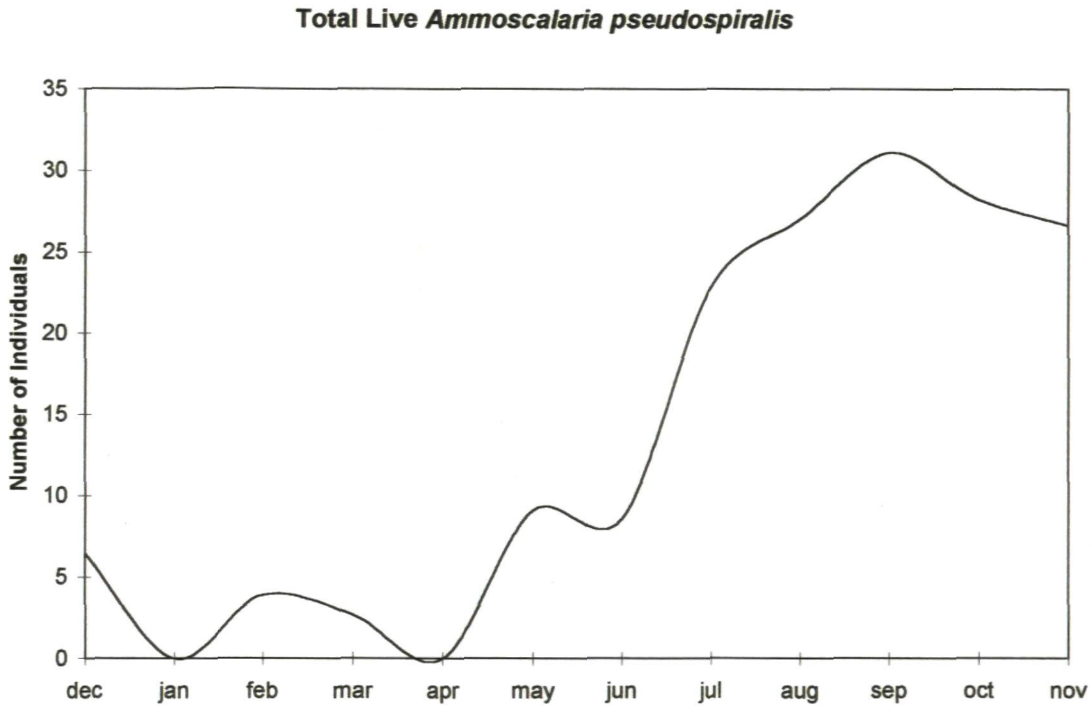


Figure. 8.85. Distribution of all *A. pseudospiralis* throughout the year.

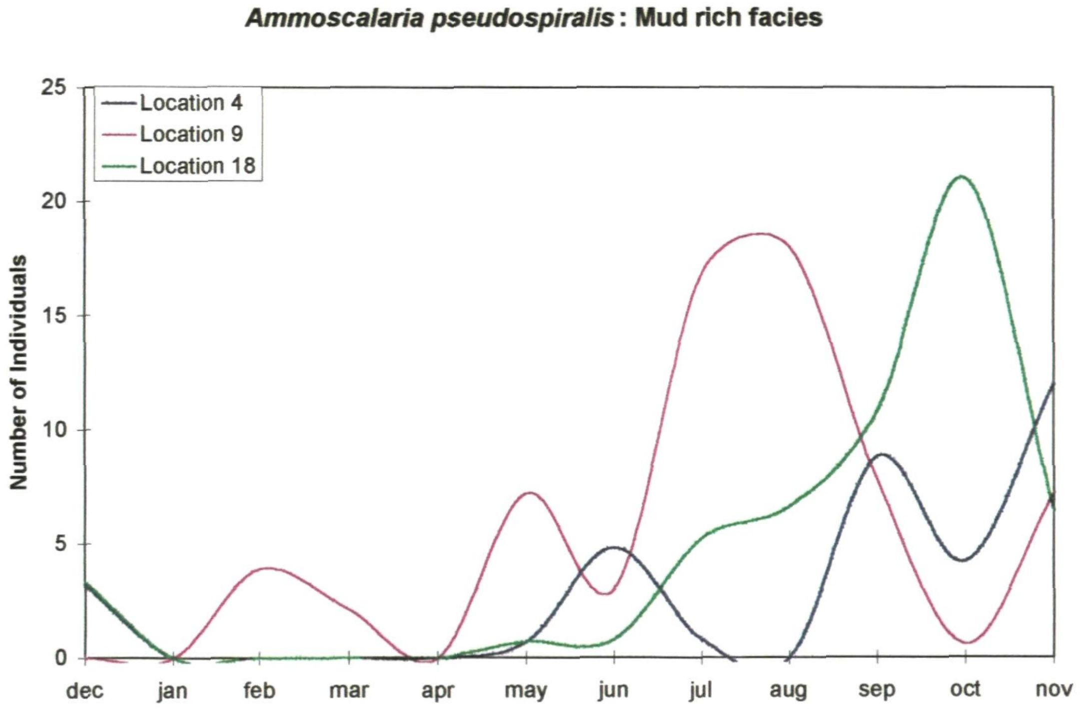


Figure. 8.86. Distribution of *A. pseudospiralis* within various facies throughout the year.

Ammoscalaria pseudospiralis showed a strong preference for low energy mud-rich facies. Its extreme rarity at Location 12 and 15 may be due to this species being strictly stenohaline. Its elevated abundance from July to November and its initial increase in abundance during July suggest that this species distribution and reproduction and strongly related to high temperatures and normal salinity.

8.14.17. *Planorbulina mediterranensis*

Planorbulina mediterranensis was virtually absent during the first half of the year. It increased slowly in abundance during June and July but increased rapidly during August where it attained its maximum abundance before declining rapidly in September (Figure 8.87).

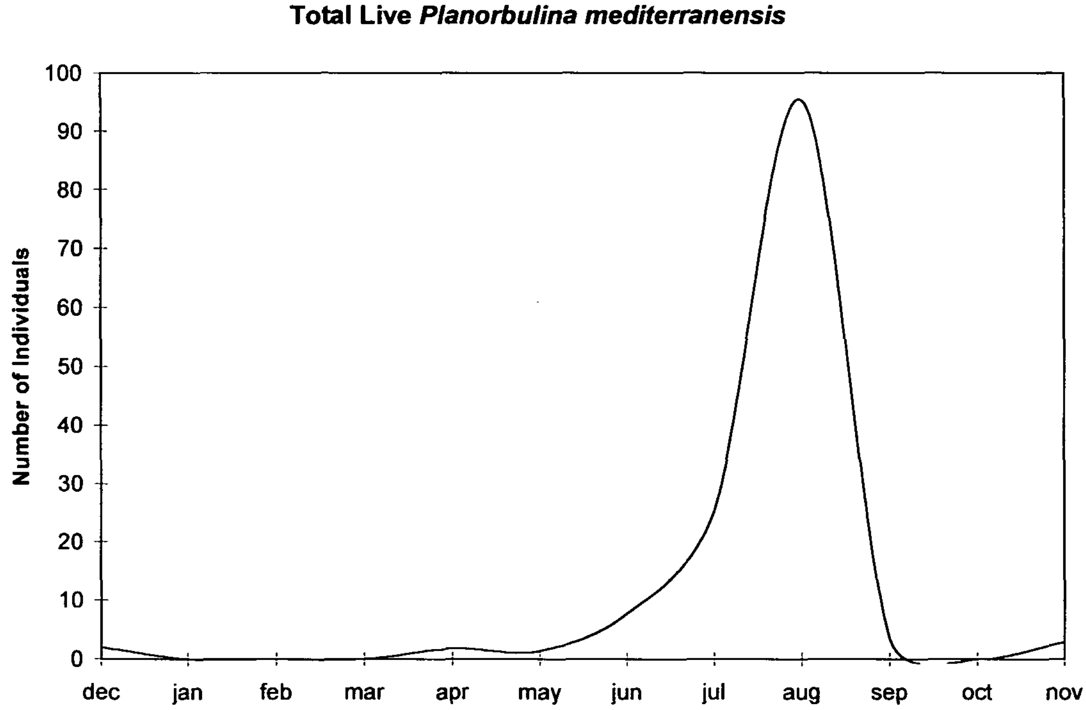


Figure. 8.87. Distribution of all *P. mediterranensis* throughout the year.

This species was common only in shell gravel facies and only abundant in August. Both shell gravel sites correlate perfectly. *Planorbulina mediterranensis* was also present at Location 1 (a sand facies outside the Breakwater) where maximum abundance was attained in July (Figure 8.88).

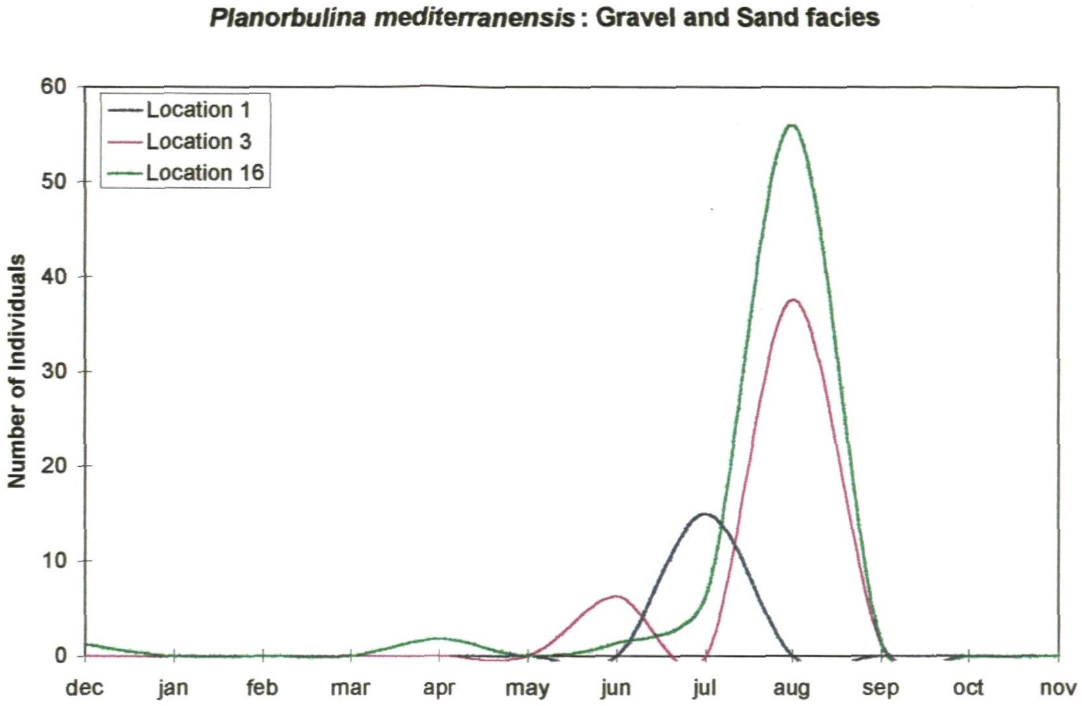


Figure. 8.88. Distribution of *P. mediterranensis* within gravel and sand facies throughout the year.

Planorbulina mediterranensis shows a strong preference for high energy clean facies. It was present as isolated individuals within most facies but was only common within shell gravel facies. It was also present (as more than isolated individuals) within the fine sands outside the Breakwater. Its occurrence within the shell gravels correlated well with other shell gravel species (*T. truncata, R. williamsoni* etc.). Its abundance in July (Location 1) and August (Locations 3 and 16) suggest that the occurrence and reproduction of this species is strongly influenced by high sea temperatures.

8.14.18. *Cribrostomoides jeffreysii*

Abundance of *C. jeffreysii* was very low during the first half of the year. It increased rapidly during July and attained a maximum during August thereafter it declined rapidly (Figure 8.89).

Cribrostomoides jeffreysii was most common in the shell gravels but its distribution within this facies was quite different between the two sites. It was most abundant at Location 16, where populations of *C. jeffreysii* were very small attaining their maximum in August. At Location 3 *C. jeffreysii* was present between July and October but remained rare. Within the mud facies of Location 9, *C. jeffreysii* was very rare but it increased in abundance during July (Figure 8.90).

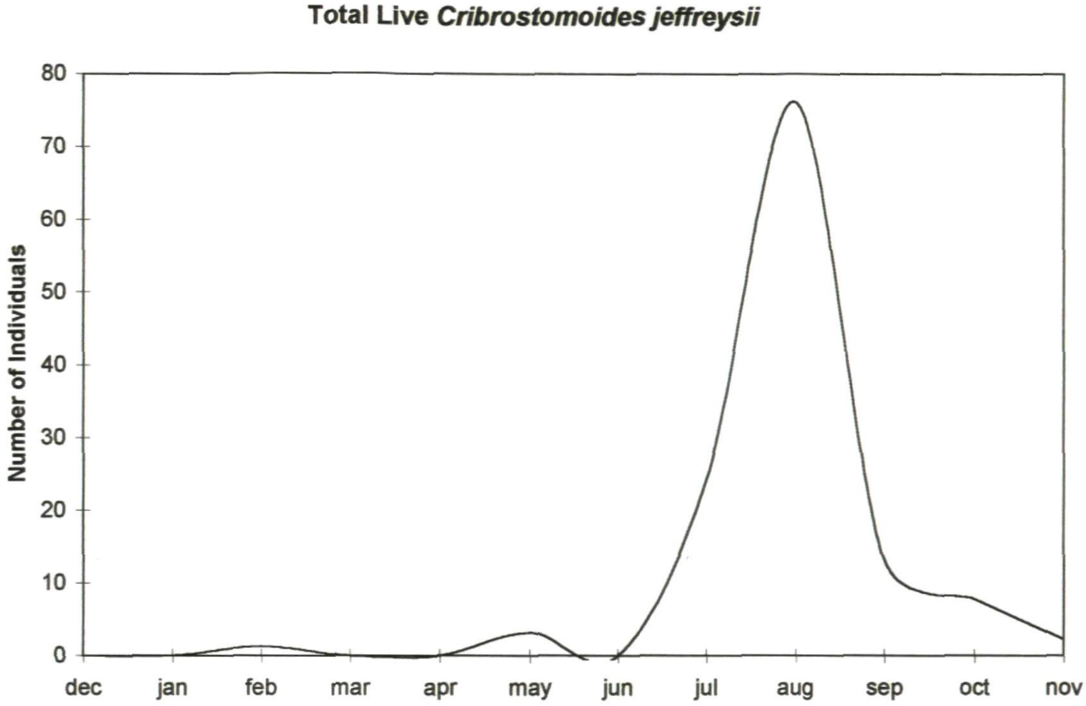


Figure. 8.89. Distribution of all *C. jeffreysii* throughout the year.

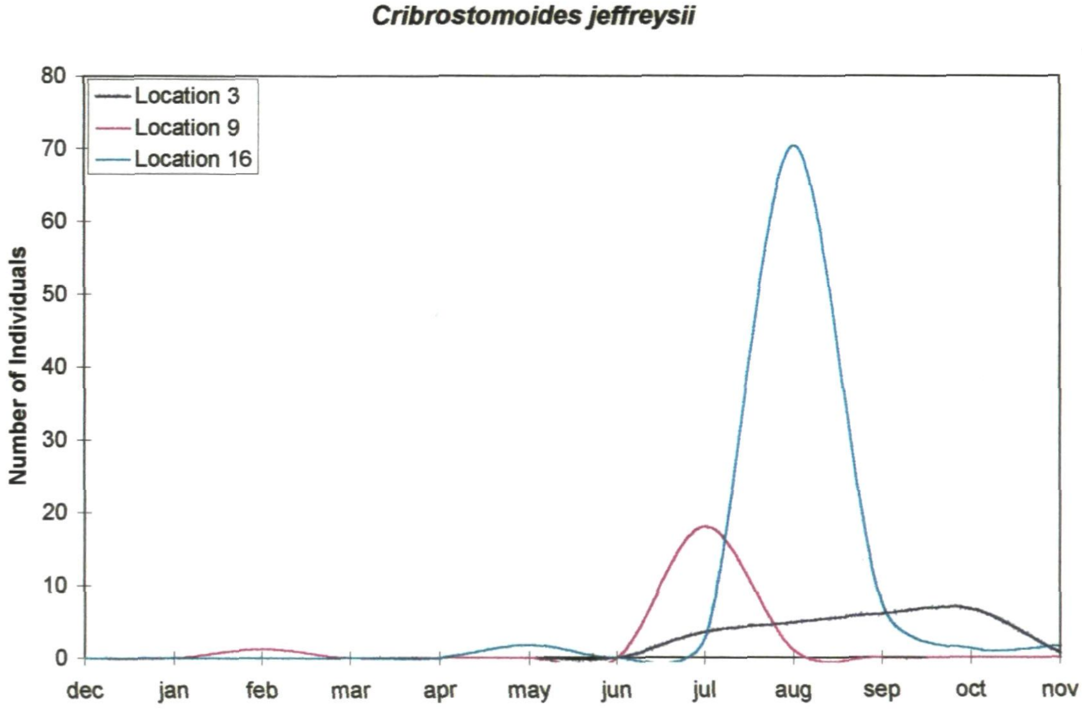


Figure. 8.90. Distribution of *C. jeffreysii* within gravel and mud facies throughout the year.

Cribrostomoides jeffreysii is generally absent or very rare within the Sound. It shows a preference for high energy environments and was reasonably abundant within the shell gravels during the late summer. Its pattern of distribution within the two shell gravel sites are different and may reflect modification of the population due to different amounts of food, competition and perhaps predation (less favourable conditions at Location 3). Its clinging mode of life is appropriate for turbulent high energy environments such as the shell gravel sites. Its occurrence within the mud facies of Location 9 in July is quite unusual. It may be that individuals were transported there by storms or currents but it is more likely that during July when food was very abundant at Location 9, this species briefly colonised the area. The distribution of *Cribrostomoides jeffreysii* correlates very well with increased sea temperatures and stable salinities.

8.14.19. *Quinqueloculina lata*

This species was common in the dead assemblage (Chapter 9) but rarely observed living (stained). Its distribution throughout the year exhibited three peaks in abundance during May, July and November (Figure 8.91).

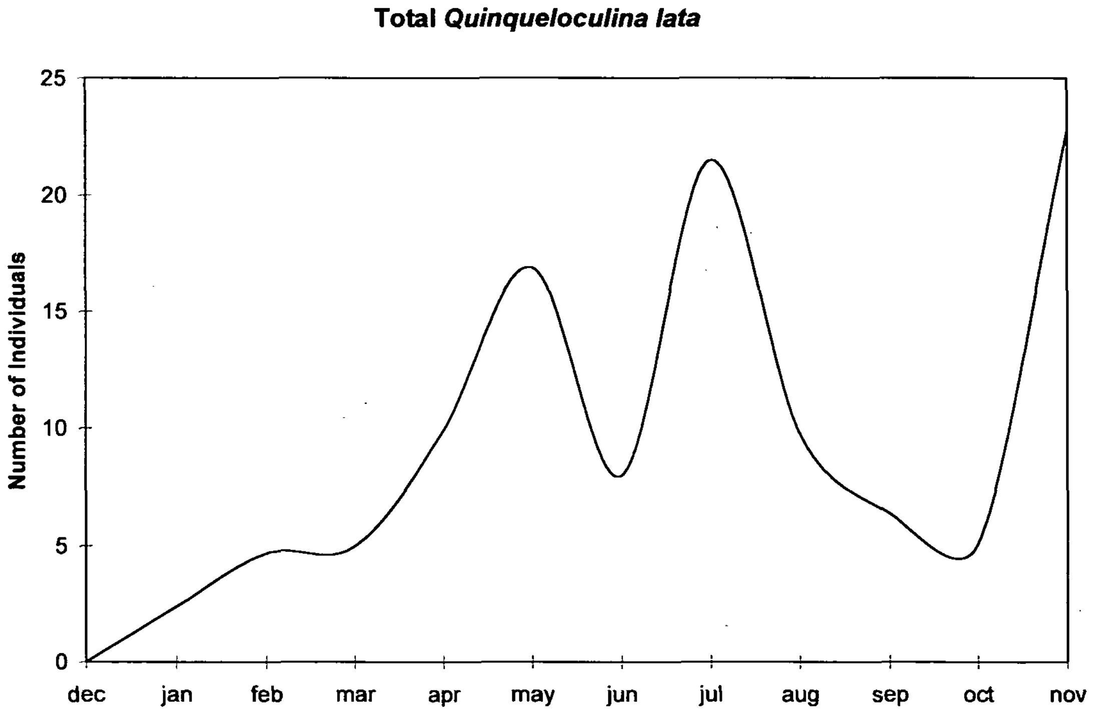


Figure. 8.91. Distribution of all *Q. lata* throughout the year.

Although present in many sandy sediments it was most abundant at Locations 8 and 17 (Location 17 was usually a clean sand but was sometimes silty). There is no correlation between these two sites (Figure 8.92).

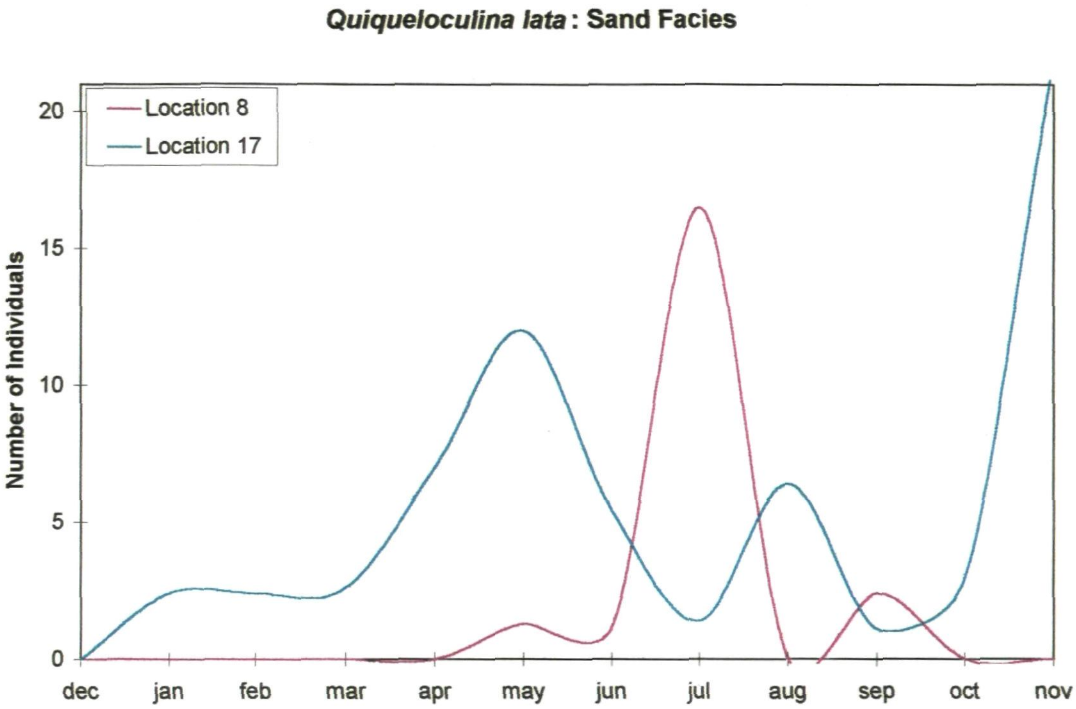


Figure. 8.92. Distribution of *Q. lata* within gravel and mud facies throughout the year.

Quinqueloculina lata shows a distinct preference for sandy sediments but it is generally rare within all sediment types. This species seems to colonise areas which have generally low abundances of foraminifera. Its fusiform test is well suited to a free living mode of life, and probably actively collects food and may be either infaunal or epifaunal.

8.15. DISCUSSION

The twelve locations sampled within the Sound exhibit a wide range of temporal distributions (standing crop and production), diversity and abundance of foraminiferal assemblages. The factors which affect the foraminiferal assemblages are usually divided into abiotic (traditionally recorded by geologists) which usually comprise parameters which are relatively easy to detect and measure (in the modern environment) and biotic factors (often recorded by biologists and ecologists) comprise parameters which require more time and effort to record often involving longer observations and are often not absolute (i.e. a number or figure). The abiotic and biotic factors which affect the distributions of foraminifera are shown in Table 8.38. The interaction of all, or many, of these factors result in the observed assemblages. Many of the mentioned parameters also influence the food of foraminifera and may therefore be of indirect importance.

Biotic	Abiotic
Food (abundance and type)	Temperature
Competition	Salinity
Predation	Depth
Reproduction	Type of substrate
Symbiosis	Energy (waves, tides & currents)
Disease	Sunshine
	Turbidity
	Pollution
	Oxygen
	Eh and pH

Table 8.38 Biotic and abiotic parameters which may affect the distribution and abundance of foraminifera.

The distribution of foraminifera exhibit a high degree of variation. Foraminiferal abundance often rapidly increases and decreases. Increases may be prompted by a range of factors but can only occur through reproduction and to a lesser extent immigration. Decreases are the result of mortality mainly the result of reproduction and to a lesser extent, burial, predation, disease and depletion of food. Hence reproduction will initially cause abundance to fall before increasing. Several phases of reproduction and mortality will result in a series of undulating high and low abundances.

8.15.1. Depth, Temperature and Salinity

These variables were recorded at each site on a monthly basis. The depth ranged at the 12 sites from 4 m (Mean High Water) at Drake's Island to approximately 18 m (Mean High Water) inside the Breakwater and eastern Sound. These variations in depth are relatively small and probably do not affect the foraminiferal assemblages significantly. Depth is usually inextricably related to other parameters such as dissolved oxygen, pressure, temperature, salinity, sediment type, etc.. Depth itself is probably of little consequence as a parameter on its own (Reiss and Hottinger, 1984) and because of this, and the small depth range of sample sites within the Sound, depth is not believed to be a direct influence on the foraminiferal assemblages of Plymouth Sound.

Many species have optimum temperatures for reproduction (Murray, 1991). A certain minimum temperature may have to be exceeded before reproduction can occur. Apart from reproduction, temperature can effect foraminifera in many other ways. Schnitker (1974) was able to produce at least 5 different forms of *Ammonia beccarii* by varying the temperature at which cultures where grown. Low temperatures may cause species to grow slowly but attain a larger size (Bradshaw, 1955). Higher temperatures may cause a preference in coiling directions in some foraminifera (e.g. dextrally in *Bulimina* Collins, 1989). Boltovskoy *et al.* (1991) concluded that, in general, lower temperatures result in larger individuals, due to a period of prolonged growth before conditions suitable for reproduction occurred.

Temperature may also effect bacteria, algae and phytoplankton (on which foraminifera feed). These organisms then become abundant and are in turn followed by an increase in abundance of foraminifera which feed on them. In this way temperature is indirectly influential. Walton (1955) described the maximum abundance of foraminifera from California as occurring in June and August. The June abundance was linked to phytoplankton, while the August bloom to optimum sea temperature.

Sea temperatures began to rise significantly in May and June. The very low abundance of many species in May and June such as *A. beccarii batavus* (Figure 8.44), *E. crispum* (Figure 8.48), *S. concava* var. *loeblichi* (Figure 8.61), *Q. seminulum* (Figure 8.67), *Bulimina gibba* (Figure 8.76) and many other species is probably temperature induced reproduction, the progeny of which create the large populations seen in July. In fact most species reproduce during this period.

The August temperature maximum coincides with another significant abundance low seen in many species which corresponds to a second temperature induced reproduction which is reflected in large populations in September.

Although foraminifera and temperature exhibit a good degree of correlation during the summer, many other significant foraminiferal reproductive events occur during the winter or early spring (February and April) before sea temperatures had began to increase and often when they were at there lowest. These events are the result of other parameters.

Sea temperatures and salinity are recorded a few centimetres above the sea bed. The temperatures of Plymouth Sound are very similar to published temperatures (Maddock and Swann, 1977). Temperatures vary markedly throughout the year but show uniform spatial distribution across Plymouth Sound, consequently all locations are plotted on the same temperature chart.

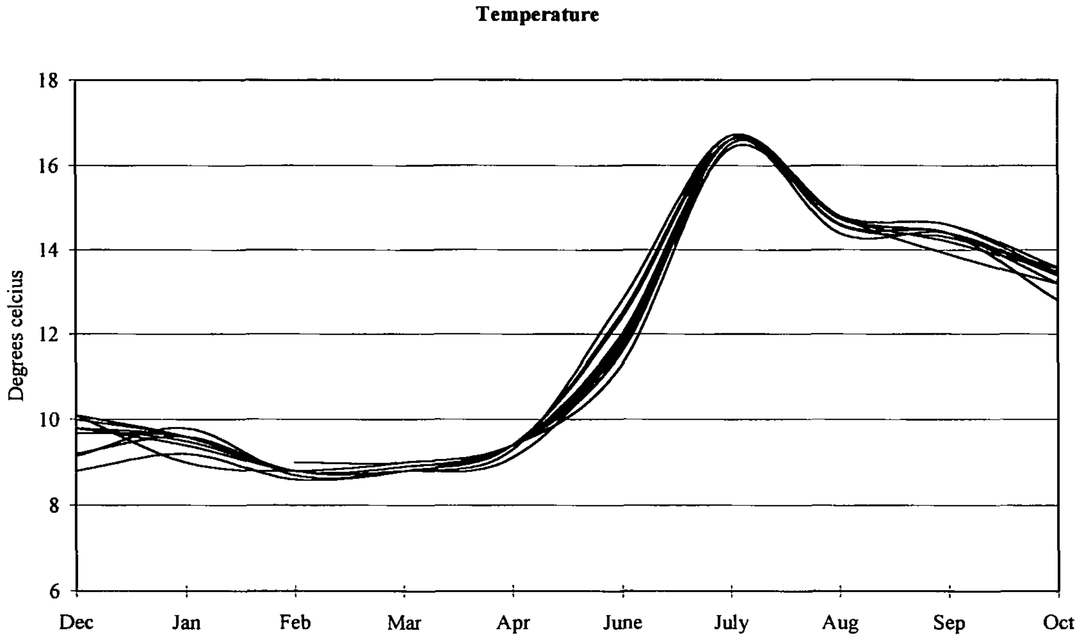


Figure 8.93. Bottom water sea temperatures from the 12 locations in Plymouth Sound, throughout the year.

The thermal cycle of the Plymouth Sound water mass is of rapid warming and slow cooling (Figure 8.93). Sea temperatures were low from December to April but began to rise in June. Temperatures rose sharply in July and reaching a maximum of over 16 °C in August. Temperatures fell slightly in September, October and November. December and January probably represent periods of more rapid cooling.

Salinity and $CaCO_3$ are closely linked, as are temperature and depth. Normally areas of low salinity also have low levels of $CaCO_3$. This is particularly evident in marshes where salinity is low and the foraminiferal fauna is dominated by agglutinated foraminifera. When salinity falls below the normal growth range of a species, the individuals generally become smaller, thinner walled and less ornamented (Forti & Röttger, 1967; Wright, 1968). However, Bradshaw (1961) found that the euryhaline species *Ammonia beccarii* increased its size in low salinity conditions. Again, this probably represents a period of prolonged growth before conditions suitable for reproduction occurred.

Several authors (Hofker, 1971; Brasier, 1975; Wang *et al.*, 1985) have reported that foraminifera living in low salinity conditions have tendencies to become deformed and this is true within the Plymouth Sound area. The largest number of deformed tests were observed within the Plym Estuary, which also has the lowest and most variable salinity; the number of deformed tests was not in excess of 1% of the total live assemblage.

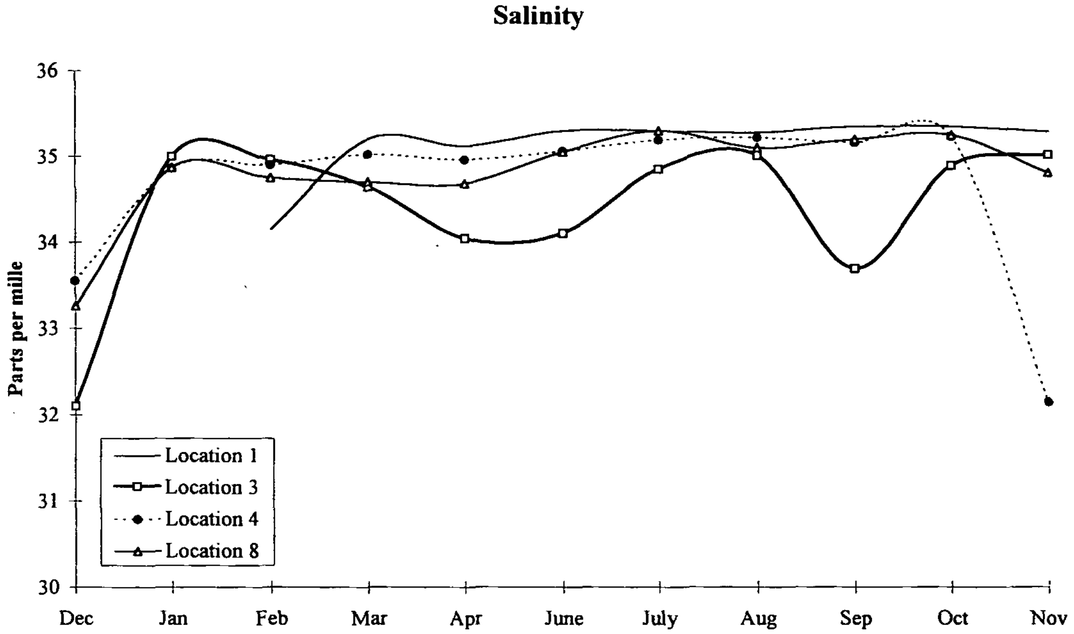


Figure 8.94. Salinity at Locations 1, 3, 4 and 8. Salinity was generally lowest during December 1993 and November 1994.

Poag (1978) studied several species from estuaries and concluded that in conditions of near optimum temperature and salinity, foraminifera were thinly calcified, had few chambers and were small. In conditions approaching the limit of tolerance, foraminifera were larger and had more chambers. He attributed this to delayed reproduction which results in the production of a larger test.

Salinity within the Sound exhibits a moderate to low variability from site to site spatially (Figures 8.94-8.96).

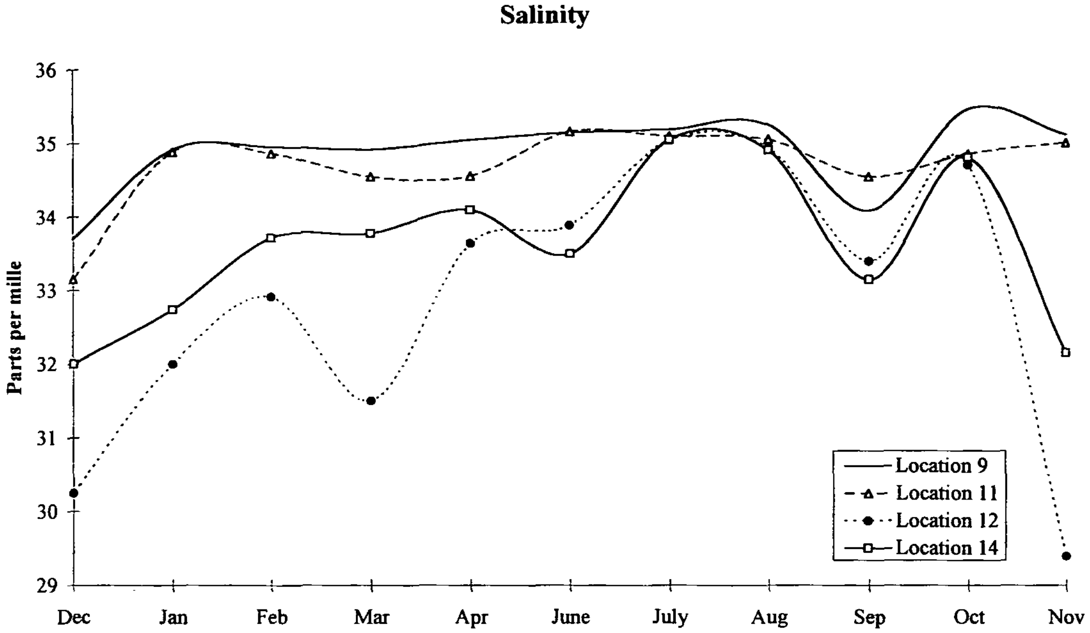


Figure 8.95. Salinity at Locations 9, 11, 12 and 14. Salinity is generally lowest during December 1993 and November 1994.

Salinity ranged from 29‰ to 35‰ at locations within the Sound throughout the year (Figures 8.94, 8.95 and 8.96). Most localities showed lower salinities in December 1993 and/or November 1994. Location 12 (Barn Pool) and 14 (Drake's Island) exhibit the most variable salinities although Location 12 exhibited the lowest salinities. Other locations show normal, relatively stable salinities throughout most of the year (January to October). Even at the most hyposaline locations, salinity did not vary very much and remains close to normal marine salinity (34‰ to 35‰).

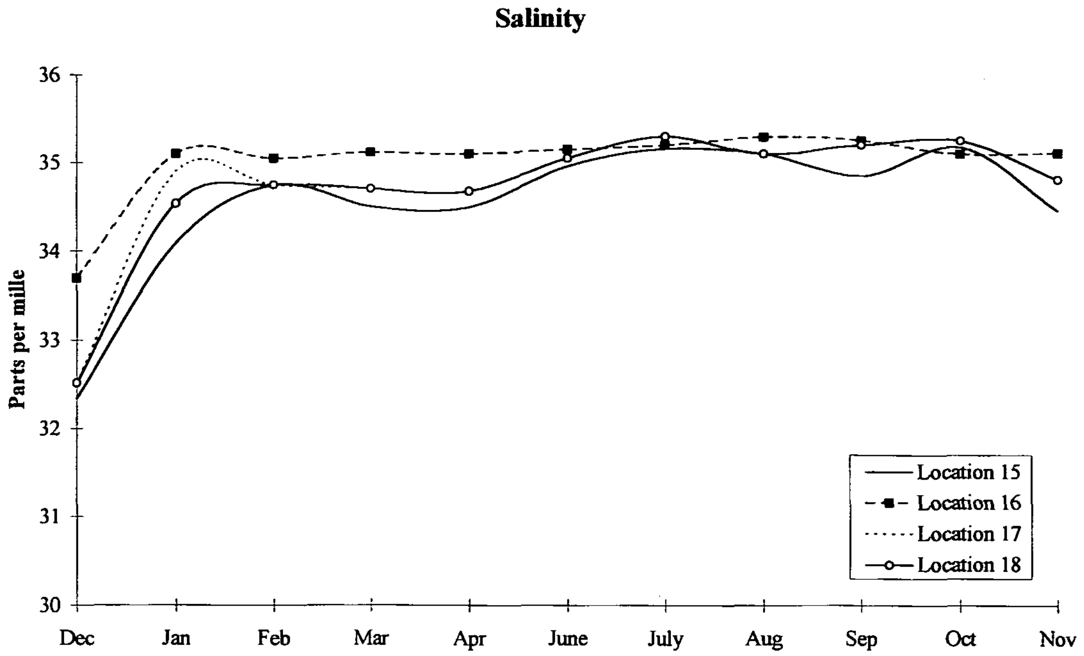


Figure 8.96. Salinity at Locations 15, 16, 17 and 18. Salinity was generally lowest during December 1993 and November 1994.

Salinity and temperature exhibit a reasonable correlation; both were high during the months from July to October (Figure 8.97).

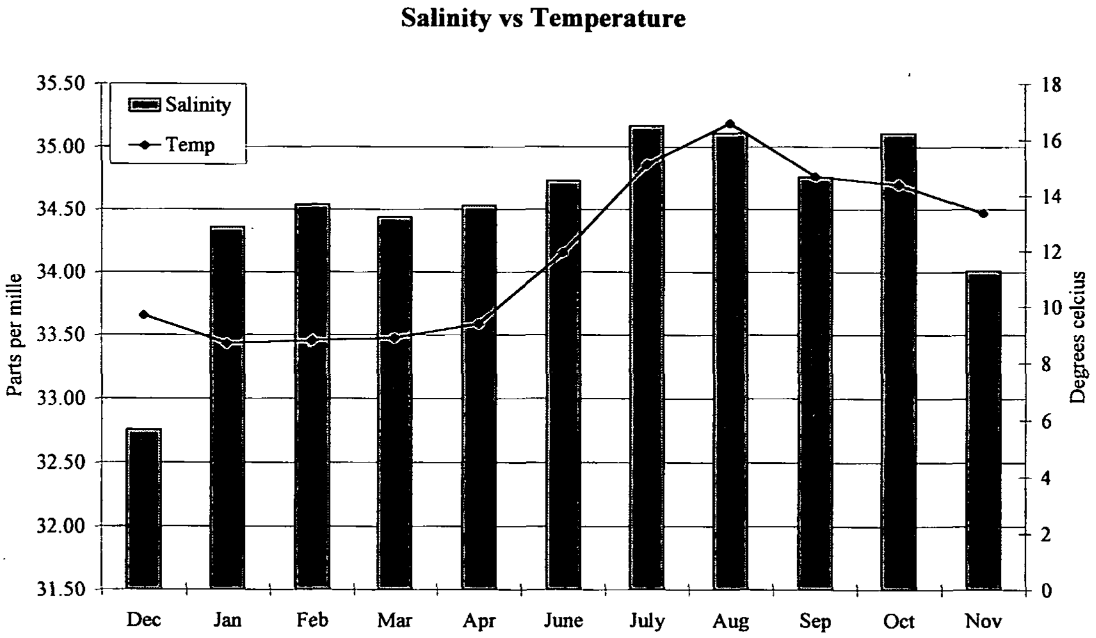


Figure 8.97. Average salinity compared to temperature throughout the year in Plymouth Sound

8.15.2. Correlation between foraminiferal distributions and salinity (temporally).

Salinity was generally stable throughout the year only being lower during December 1993 and November 1994. Salinity can be highly variable from day to day, measuring salinity once a month is not ideal. Few conclusions can be drawn from salinity data and its relationship to foraminiferal populations. At Location 12 during March very low salinities coincide with very low abundance of foraminifera, but when salinity is low in September, foraminiferal abundance reaches a maximum.

Salinity may effect primary production (food abundance and type), the absorption of mineral salts ($CaCO_3$), osmotic and metabolic processes, etc. which subsequently effect foraminiferal assemblages.

8.15.3. Correlation between Distribution of Foraminifera and Salinity (Spatially)

Salinity in the northern Sound (into which the Plym and Tamar rivers drain) is very slightly, but distinctly, lower than the rest of the Sound (average salinities are 1‰ or 2‰ lower than other areas of the Sound). These lower salinities result in the different composition of the foraminiferal assemblages.

Site	Salinity	Number of principal species	species name	% abundance of principal species
Location 12	32.88	1	*A. beccarii batavus*	83
Location 14	33.63	1	*A. beccarii batavus*	68
Location 3	34.39	4	*T. truncata*	22
Location 15	34.54	2	*A. beccarii batavus*	66
Location 4	34.66	2	*E. crispum*	49
Location 11	34.70	1	*E. crispum*	61
Location 18	34.72	2	*A. beccarii batavus*	50
Location 17	34.75	3	*A. beccarii batavus*	51
Location 8	34.82	2	*A. beccarii batavus*	36
Location 9	34.89	3	*B.pseudopunctata*	38
Location 16	35.01	2	*R. williamsoni*	30
Location 1	35.03	2	*E. crispum*	40

Table. 8.39. Average yearly salinity at each location and yearly sum of species abundance (%). Salinity shows an inverse correlation with species dominance .

Assemblages are dominated by one or two species (low species evenness) and slightly lower diversity. *Ammonia beccarii batavus* is very common and is usually dominant at these locations. In the rest of the Sound where salinity is close to, or normal (34‰ to 35‰), species evenness is greater and assemblages are often composed of 2-3 principal species. The relationship between salinity and species dominance is shown in Table 8.39 and graphically in Figure 8.98.

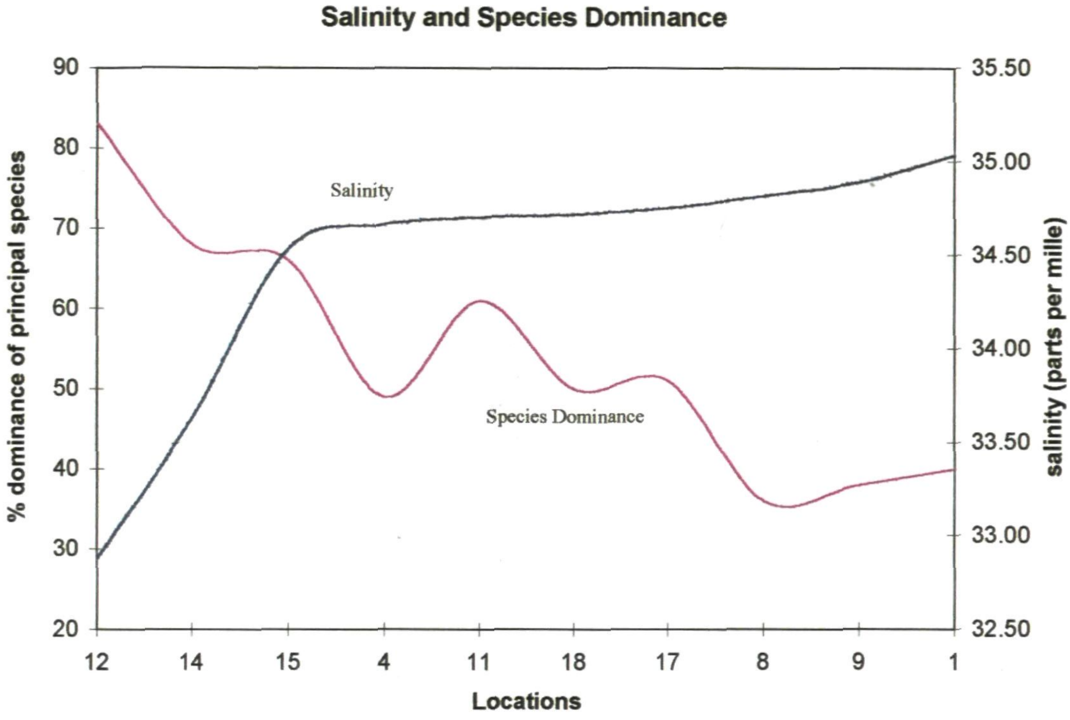


Figure 8.98. Comparison between the dominance (%) of the principal species (in red) against average yearly salinity (in blue).The shell gravel locations have not been included because of their very different species composition and structure.

Even within the relatively small body of water of the Sound, which exhibits small salinity variations spatially, the affect of this variation is marked and distinct on the composition and structure of the foraminiferal assemblages.

8.15.4. Species which are more common in the northern Sound (Hyposaline)

Ammonia beccarii batavus is very dominant in the mud facies of the northern Sound (83% at Location 12 and 66% at Location 15). At Location 9, a mud facies in the southern Sound, it is abundant (30%) but does not dominate the assemblage. This trend is also present within sand facies where *A. beccarii batavus* accounts for 68% of the assemblage at Drake's Island in the northern Sound but only 40% of the assemblage south of the Breakwater (Location 1) which is strictly stenohaline.

Eggerelloides scabrum is common in mud and mixed sedimentary facies throughout the Sound; it is rare in sands and almost absent in gravels. Within the mud facies of the northern Sound it accounts for 3 to 5% of the assemblage and is the third most common species (See Tables 8.21 and 8.27). In the mud facies near the Breakwater it remains an important subordinate species accounting for 2% of the assemblage but is the seventh most common species (in terms of abundance, see Table 8.15) hence it shows a slight preference for slightly lower salinity. *Eggerelloides scabrum* shows a less clear trend in mixed sediments, being rare at Locations 4 and 18 and very common at a Location 17 which is geographically very close to Location 18, although it has a less silty sedimentology.

Quinqueloculina oblonga shows a preference for hyposaline salinities in sand facies but the opposite trend in mud and mixed sediment facies.

Several species show a preference for stenohaline conditions, particularly *Ammoscalaria pseudospiralis* which occurs in mud rich facies (including mixed sediments). It is very rare at Locations 12 and 15 in the northern Sound (1 and 6 specimens respectively) but accounts for 1% (34 and 67 individuals respectively) of assemblages at Location 4 (mixed sediment in the Southern Sound) and the Location 9 (mud facies near the Breakwater).

Elphidium crispum is common in sandy and mixed sediments. In sand facies it is very common outside the breakwater (40%) but rare at Drake's Island near the mouth of the Tamar (1%). It has a very variable distribution at other sand locations within the Sound which is probably the result of the nature of these locations (perhaps a variable abundance of food). In mixed sediments it accounts for 49% of the assemblage at Location 4 (southern Sound) and 20% and 30% at less marine areas on the eastern Sound (Locations 17 and 18 respectively).

Stainforthia concava var. *loeblichi*, *B. pseudopunctata*, *B. variabilis* and *B. spathulata* all have very similar distributions, being common in mud facies (no clear trend is observed in mixed sediments where they are generally rare). Together they account for 53% of the assemblage near the Breakwater. In the mud facies of the northern Sound (Locations 12 and 15) they account for 3% and 5% of the assemblages respectively. This difference in distribution is unlikely to be entirely the result of salinity but is probably significantly influenced by salinity.

Many species do not exhibit a preference for hyposaline or normal marine conditions. The most abundant of these are *E. cuvillieri*, *Q. seminulum*, *N. depressulus*, *R. scottii* and *C. obscura*. Many other species are not abundant enough for their preference if any to be determined.

8.15.5. Grain size of sediment substrate and its relationship to energy

In areas of relatively shallow water the energy imparted through waves and currents (including tides) is intrinsically linked to the type of substrate, in particular the type of sediment. The sediment type and composition is also influenced by the source and abundance of sediment (an area of high energy in which coarse sediment is not present will not be characterised by coarse sands and gravels). In Plymouth Sound a wide range of sediment grain size and composition are present.

Unlike many other biotic and abiotic parameters the type of substrate, in particular sediment substrate (as opposed to rock or plant) and the effect on species and assemblages which live in and on the sediment have been poorly documented (Boltovskoy *et al.*, 1991). The effect on individuals living within/on different substrates is also poorly documented although Haake (1971) noted a species of *Textularia* became broader and more robust within coarse sediments. Kaminski *et al.* (1988) and Sturrock (1982) noted that the role of substrate is very important in determining which species will be present. While some foraminifera preferentially select particles of a specific size, many agglutinated foraminifera use whatever materials are available for the construction of their tests, subsequently coarsely agglutinated forms occur in coarse grained sediments and vice versa (Slama, 1954; Hada, 1957).

Hendrix (1958) and Wetmore (1987) both observed that thick walled, robust species and individuals are more common in coarse substrates than in fine substrates and this may be due to specific and phenotypical adaptation. Poag and Tresslar (1981) recognised foraminiferal associations with either rocky substrates or mud/sand substrates. Medioli and Scott (1978), Kitazato (1984) and Langer (1993) found that the morphologies of individuals varied according to whether on rocky, sediment or epiphytal substrates.

As mentioned above a sediment substrate is intrinsically linked to the energy it receives (depending on the availability of sediment), which in turn is closely linked to other related factors important for foraminifera such as the amount of organics present, food (type and quantity), stability of the substrate, oxygen, Eh and pH (Trask, 1939).

Foraminiferal assemblages from similar sediment types (muds for example) show a higher degree of similarity than from other types of sediments (compared to gravels). Foraminifera from all the localities within the Sound are treated statistically and grouped according to the degree of similarity of the assemblages which also reflects the various sediment types. The data are shown as dendrograms using a Bray-Curtis similarity index and Multi Dimensional Scaling maps (MDS).

8.15.6. Dendrograms and MDS Plots

Four different sedimentary facies and associated foraminiferal assemblages are delineated using both dendrograms and MDS plots:

Gravels
Sands
Mixed Sand and Mud
Muds

Cluster and MDS analysis are used in conjunction, to illustrate the similarities and differences between the sites sampled. Cluster and MDS analysis are generated on the primer statistical package and the data has not been transformed. Analysis were carried out on live foraminifera for each month of sampling and the total live foraminifera for the entire sampling period. The relationship between sites from month to month may vary greatly, due to abundance of foraminifera, diversity and species composition. For these reasons the sum of all sites over one year may provide a more accurate and stable picture of site relationship and similarity

Mixed sediments (muds and mixed sand) and muds are often very closely related. This is probably because there is no natural division (it is a gradational division) between these two sediment types, the presence of silt and clay create very different physico- chemical conditions. It is believed that once a certain percentage of clay and silt is present the addition of more clay and silt has little effect on the physico-chemical conditions. A plot of total yearly live foraminifera clearly shows the relationship between foraminiferal assemblage and sediment type (Figures 8.99, 8.100 and 8.101).

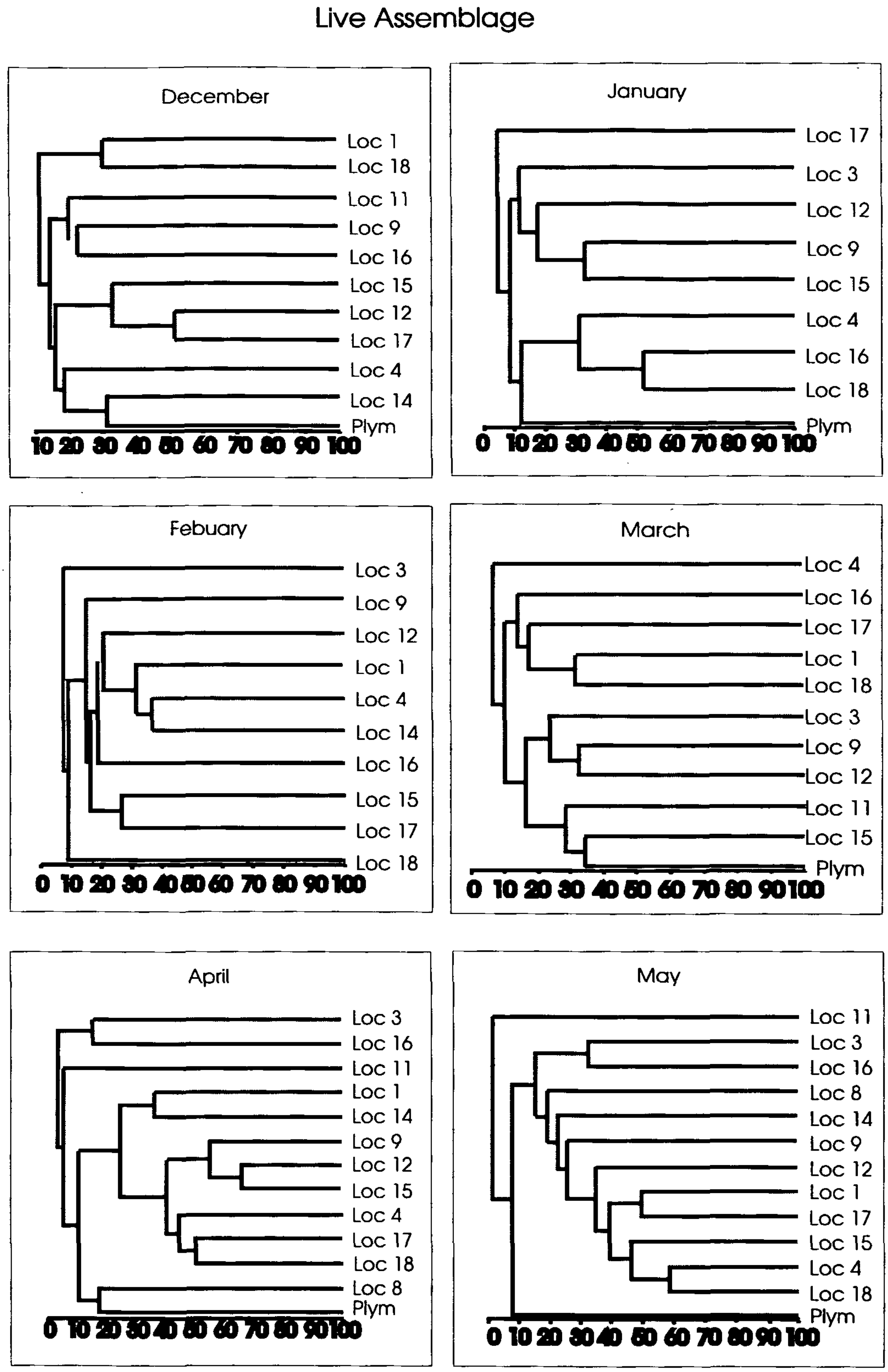


Figure 8.99. Dendrograms of all samples for the first six months (December 1993 to May 1994). The degree of similarity can be read on the X axis labelled 0-100 (0 = no similarity, 100 = total similarity). Similarity of assemblages from the same facies is poor to good.

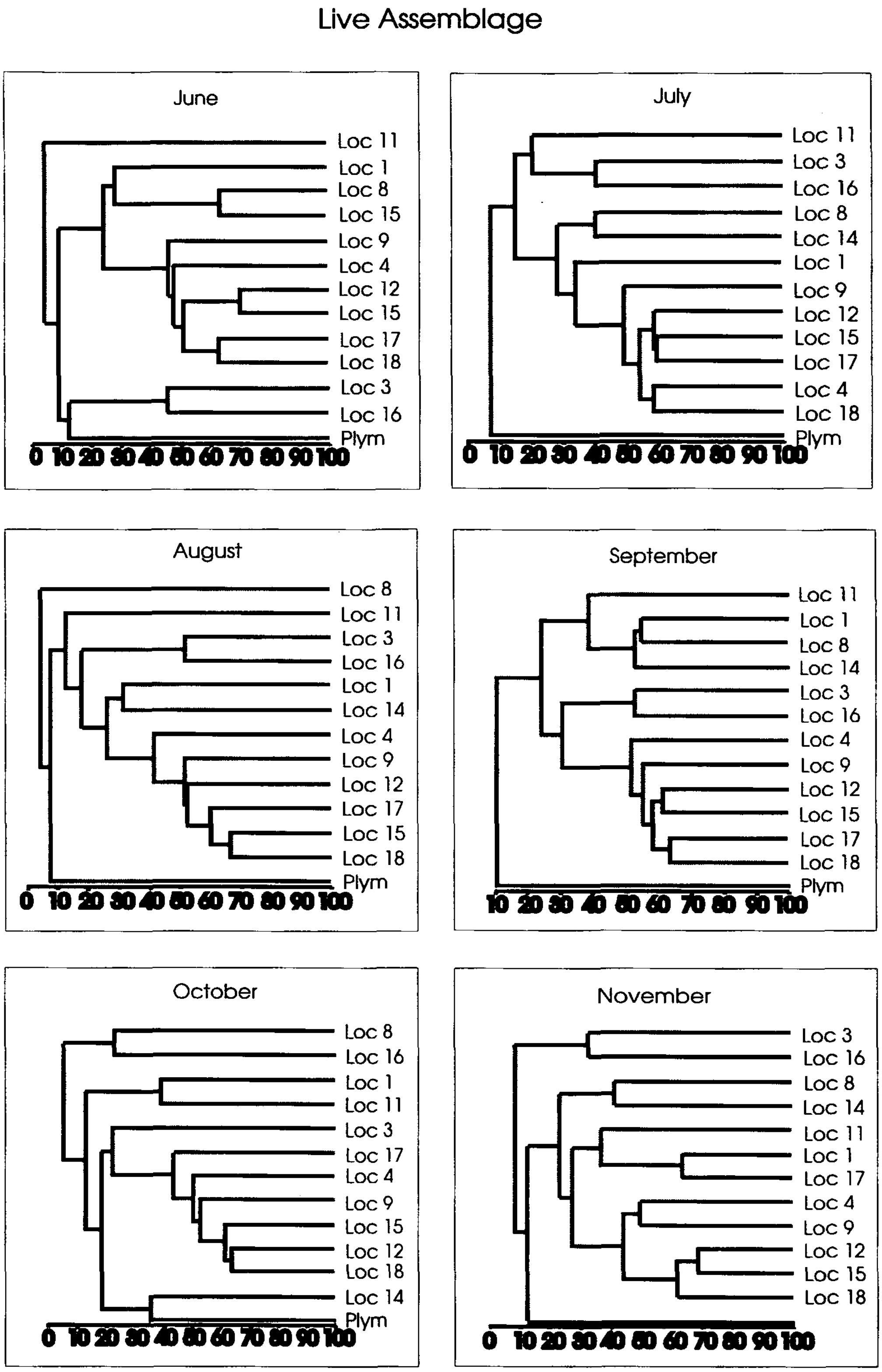


Figure 8.100. Dendrograms of all samples for the last six months (June 1994 to November 1994). The degree of similarity can be read on the X axis labelled 0-100 (0 = no similarity, 100 = total similarity). Similarity of assemblages form the same facies is poor to good.

The degree of similarity or dissimilarity can be seen and quantified on the dendrograms by the length of the branches of the dendrogram. The numbered (0-100) axis allows quantitative comparison of the similarity of foraminiferal assemblages throughout the year.

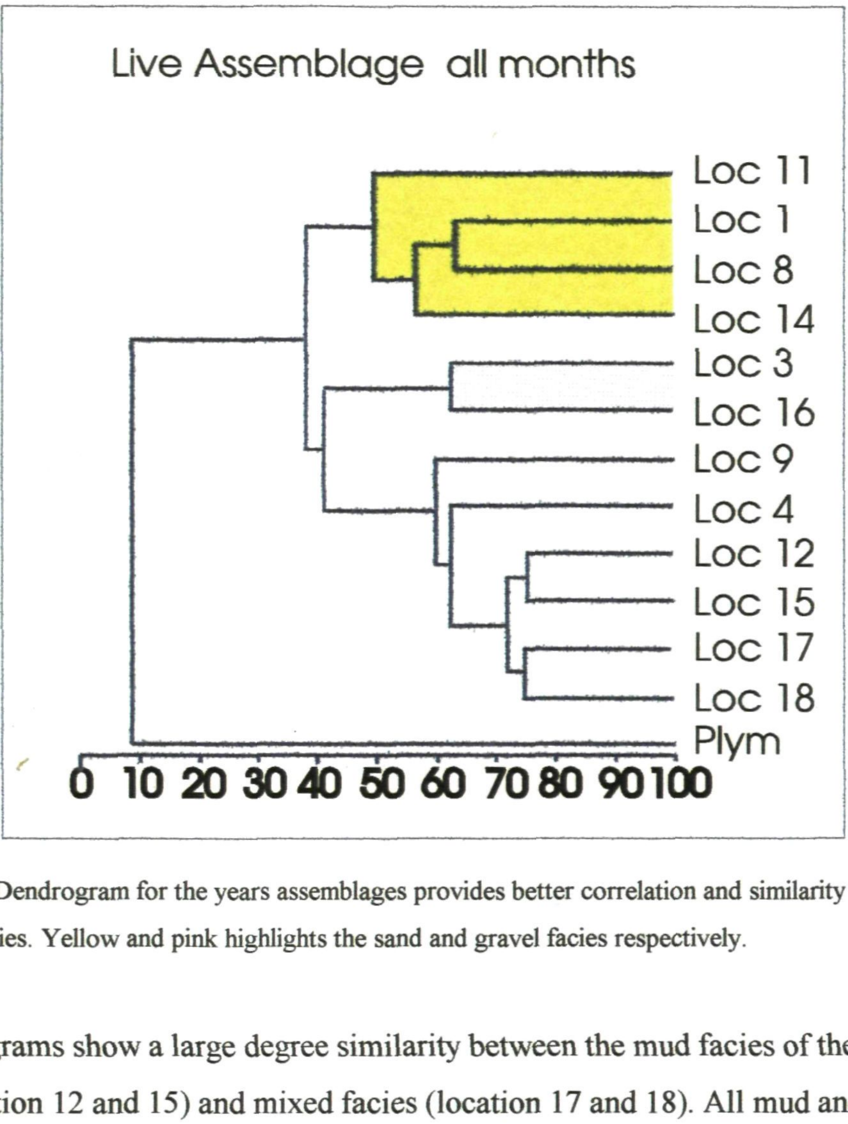


Figure 8.101. Dendrogram for the years assemblages provides better correlation and similarity between sites of the same facies. Yellow and pink highlights the sand and gravel facies respectively.

The dendrograms show a large degree similarity between the mud facies of the northern Sound (location 12 and 15) and mixed facies (location 17 and 18). All mud and mixed facies show good similarity. The two gravel sites show moderate similarity, with the sand facies (Locations 1, 8, 11 and 14) being least similar to each other.

8.15.7. MDS Maps

The Multi Dimensional Scaling plot or map is generated in a similar way to the dendrogram (the most similar facies/faunas plotted closest together). The data is plotted in a 2 dimensional form (areas rather than lines), with most similar the sites being plotted closest,

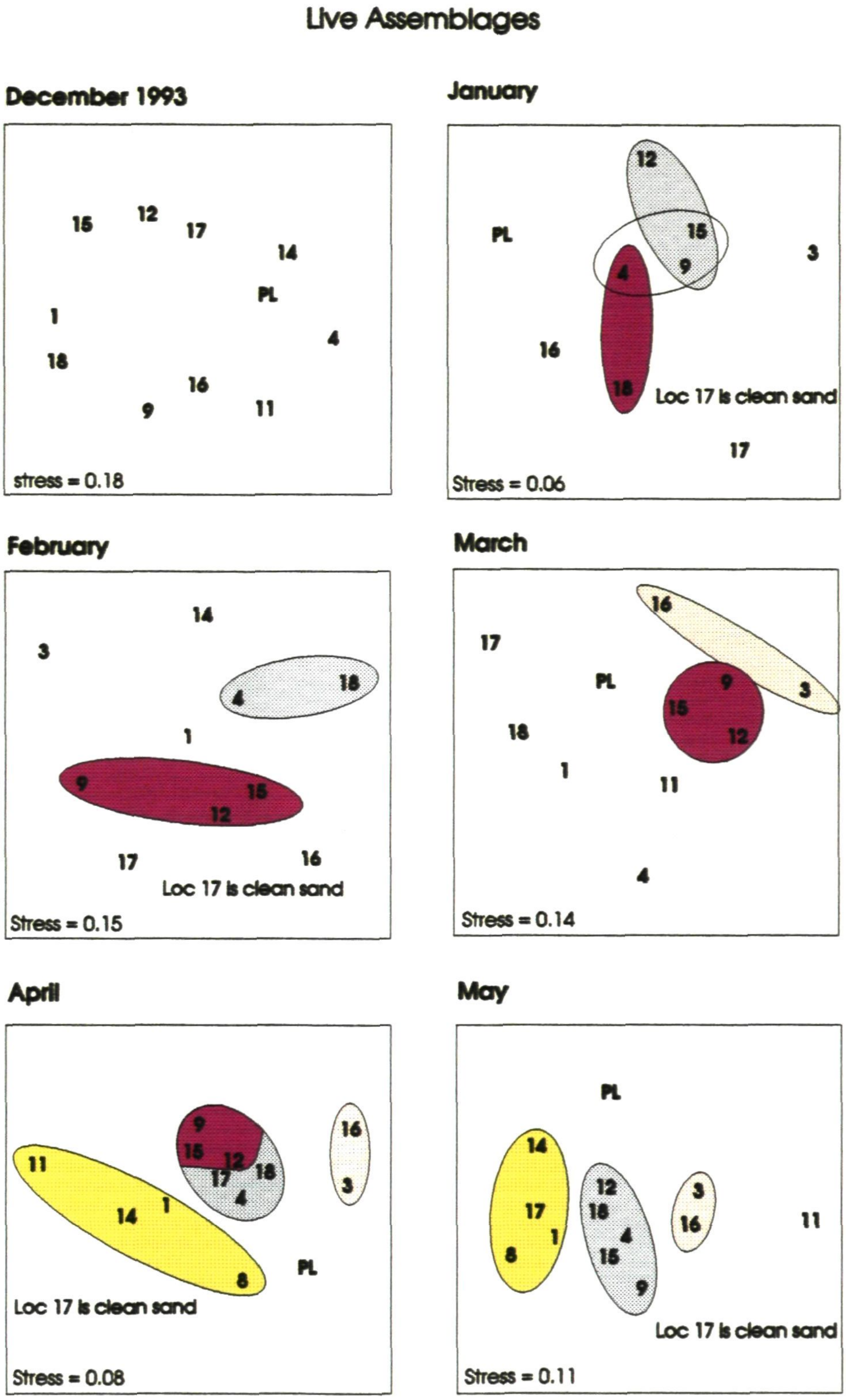


Figure 8.102. MDS maps of the first six monthly assemblages (December 1993 to May 1994) at all locations within the Sound. With the exception of mud and mixed facies the sediment facies form distinct and separate units. The higher the stress the more poorly a correlation was made by the statistical package (stress below approx. 0.2 or 0.3 is regarded as being low)

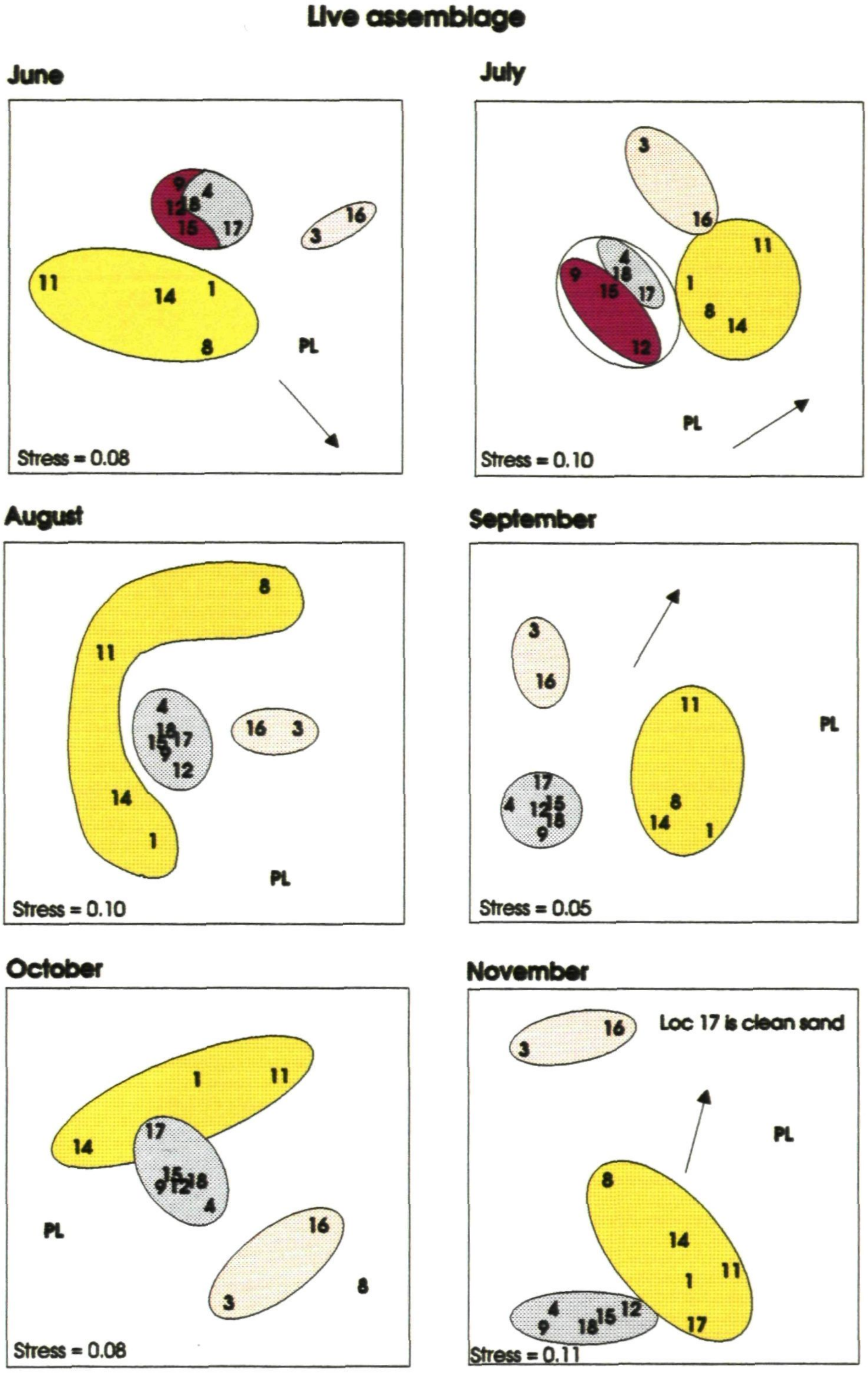


Figure 8.103. MDS maps of the last six monthly assemblages (June 1994 to November 1994) at all locations within the Sound. With the exception of Mud and mixed facies the sediment facies form distinct and separate units. The direction of increasing sediment grain size is shown by an arrow where appropriate.

and dissimilar being furthest apart. Sites of closest similarity often form clusters which can be grouped, these groups normally delineate sedimentary or faunal facies. Because a MDS map has been generated for each month (Figures 8.102 and 8.103), clusters and groups cannot be identified for all months (as foraminifera where absent or sparse at periods during the year). Figure 8.104 shows all foraminifera throughout the year and hence gives a more complete and clear picture.

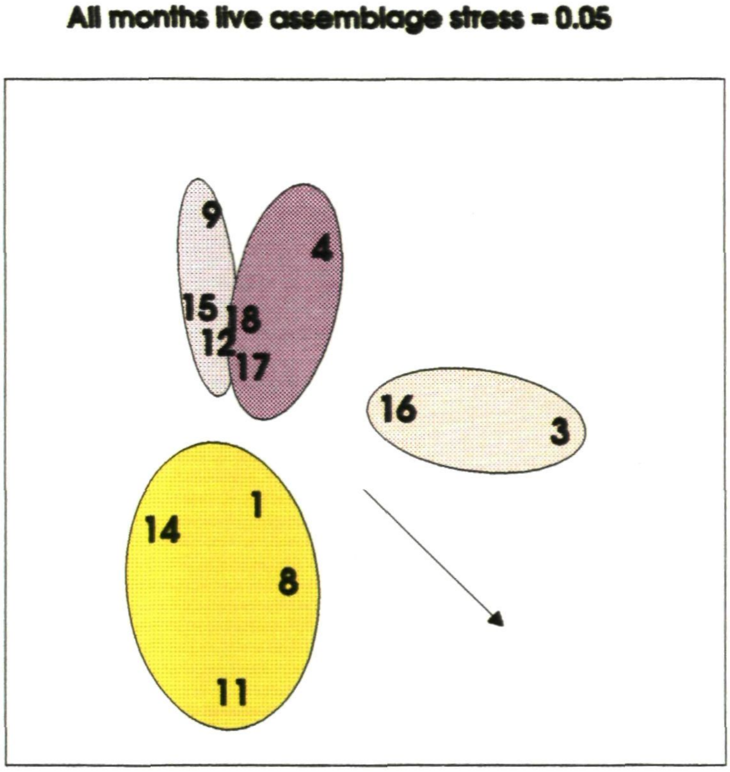


Figure 8.104. The yearly MDS map shows a very distinctive association between sediment type and foraminiferal assemblages. The mixed (purple) and mud (mauve) facies show a high degree of similarity. Sand shown in yellow and gravel in pink

Sandy sediments exhibit a wider range of foraminiferal variation, which can be seen in the MDS plots and within the dendrograms. Muds and mixed sediments form two groups which are very similar and sometimes inseparable. These two fine grained sediments have distinct foraminiferal assemblages. The gravels form a very distinctive group with foraminiferal assemblages which are most unlike the assemblages from other sediments.

8.15.8. Species list for the sediment groups

Below are species lists for the four main sediment types in order of abundance and species which are absent from the sedimentary facies.

8.15.8.1. Gravels

Gravels (Locations 3 & 16)	**Abs.**	**%**
Textularia truncata	384	26
Rosalina williamsoni	387	27
Quinqueloculina spp.	107	7
Planorbulina mediterranensis	113	8
Cribrostomoides jeffreysii	107	7
Miliolinella subrotunda	67	5
Miliolinella circularis	42	3
Textularia earlandi	27	2
Quinqueloculina seminulum	23	2
Brizalina pseudopunctata	17	1
Patellina corrugata	15	1
Ammonia beccarii batavus	11	1
Bolivina pseudoplicata	13	1
Haynesina germanica	10	1
Quinqueloculina cf. *lata /seminulum*	9	1
Spirophthalmidium acutimargo var. *emaciatum*	9	1
Clavulina obscura	9	1
Massilina secans	8	1
Brizalina spathulata	8	0
Elphidium cuvillieri	7	0
Technitella legumen	7	0
Asterigerinata mamilla	5	0
Nonion depressulus	6	0
Quinqueloculina williamsoni	4	0
Fissurina marginata	5	0
Cibicides pseudoungerianus	4	0
Bulimina gibba	4	0
Psammosphaera bowmani	5	0
Technitella sp2 (ear bud form)	4	0
Quinqueloculina lata	3	0
Elphidium crispum	4	0
Eggerelloides scabrum	3	0

Absent
Spiroplectammina wrightii
Adelosina normal
Adelosina ribbed
Ammonia beccarii limnetes
Ammoscalaria pseudospiralis
Ammoscalaria runiana
Amphicoryna cf. *scalaris*
Astacolus crepidulus
Genus 1
Brizalina variabilis
Buccella frigida
Cibicides lobatulus
Genus 2
Cornuloculina balkwilli
Cornuspirella diffusa
Dentalina spp..
Elphidium gerthi
Elphidium margeritaceum
Elphidium williamsoni
Fissurina lucida
Fissurina orbignyana
Fursenkoina fusiformis
Genus 3
Gaudryina rudis
Globulina gibba var. *myristiformis*
Jadammina macresens
Lagena laevis
Lagena lyellii
Lagena perlucida
Lagena semistriata
Lagena substriata
Lagena sulcata
Lagena sp.
Lamarckina haliotidea

Lenticulina crepidula	3	0
Reophax moniliformis	2	0
Quinqueloculina aspera II	2	0
Cyclogyra involvens	1	0
Quinqueloculina bicornis	2	0
Globulina gibba	2	0
Fissurina quadrata	2	0
Buliminella elegantissima	2	0
Quinqueloculina cf. *cliarensis*	1	0
Brizalina striatula	2	0
Lagena clavata	2	0
Trifarina angulosa	2	0
Elphidium earlandi	2	0
Technitella teivyense	1	0
Deuterammina (Lepidodenterammina) ochracea var. *sinuosa*	2	0
Bulimina elongata	1	0
Bulimina marginata	1	0
Lenticulina orbiculatis	1	0
Lagena gracilis	1	0
Quinqueloculina aspera I	1	0
Reophax fusiformis	1	0

Lagenammina cf. *arenulata*
Miliammina fusca
Nodosaria pyrula
Nonionella sp.
Nonionella turgida var. *digitata*
Oolina hexagona
Oolina melo
Oolina squamosa
Parafissurina malcomsoni
Pateoris hauerinoides
Polymorphina cf. *novangliae*
Pyrgo depressa
Pyrgo williamsoni
Quinqueloculina sp. 5
Quinqueloculina aspera III
Quinqueloculina auberiana
Quinqueloculina mediterranensis
Quinqueloculina oblonga
Quinqueloculina oblonga var. *lata*
Quinqueloculina cliarensis
Reophax scottii
Rosalina globularis
Rosalina anomala
Siphogenerinoides sp.
Spirillina runiana
Spirillina wrightii
Spirillina vivipara
Spiroloculina excavata
Spiroloculina grata
Spiroloculina rotunda
Spiroloculina sp.
Stainforthia concava var. *loeblichi*
Textularia sagittula
Deuterammina (Deuterammina) rotaliformis
Remaneica helgolandica
Paratrochammina murrayi
Uvigerina sp.
Vaginulina linearis.

Table 8.39. On the left a species list showing the species which were recorded with shell gravel facies throughout the year in absolute (Abs.) and percentage (%) abundance. The right column shows a list of species recorded within the Sound but were not recorded within shell gravel facies.

The characteristic species living in, and on, the shell gravels (which are rare or absent in other sediment types) are *T. truncata, R. williamsoni, P. mediterranensis, C. jeffreysii, Q. cliarensis, M. subrotunda, M. circularis, P. corrugata* and large rounded fusiform specimens of *Q. seminulum.* Very rare species, which almost only occur in the shell gravels, are *R. moniliformis, Technitella legumen, Technitella* sp. 1, *T. teivyense* and *Deuterammina (Lepidodeuterammina) ochracea* var. *sinuosa.*

Species which are usually very common within Plymouth Sound but are rare within the shell gravels are *A. beccarii batavus, E, crispum* (most species of *Elphidium* are absent) and *E. scabrum.* Many species of nodosarids are absent (particularly those belonging to *Lagena, Dentalina, Oolina, Amphicoryna* and *Fissurina*). Also absent are species belonging to the genera *Spiroloculina, Pyrgo* and *Spirillina.* Surprisingly, many species of *Quinqueloculina* are also absent (as miliolids are usually common in moderate to high energy environments).

8.15.8.2. Sand

Sand (Locations 1,8,11&14)	Abs.	%
Ammonia beccarii batavus	310.4	34.0
Elphidium crispum	245.2	26.8
Quinqueloculina lata	75.4	8.2
Nonion depressulus	33.5	3.7
Quinqueloculina seminulum	28.4	3.1
Eggerelloides scabrum	21.4	2.3
Planorbulina mediterranensis	17.5	1.9
Brizalina pseudopunctata	15.6	1.7
Quinqueloculina oblonga	15.4	1.7
Psammosphaera bowmani	15.2	1.7
Miliolinella circularis	13.5	1.5
Bulimina elongata	13.3	1.5
Textularia truncata	12.6	1.4
Quinqueloculina spp.	11.7	1.3
Quinqueloculina williamsoni	9.6	1.1
Massilina secans	9.2	1.0
Cibicides lobatulus	7.2	0.8
Elphidium cuvillieri	6.3	0.7
Haynesina germanica	5.2	0.6
Rosalina williamsoni	4.9	0.5
Quinqueloculina aspera I	3.8	0.4

Absent
Adelosina ribbed
Ammoscalaria pseudospiralis
Ammoscalaria runiana
Amphicoryna cf. *scalaris*
Astacolus crepidulus
Genus 1
Bolivina pseudoplicata
Brizalina striatula
Brizalina variabilis
Buccella frigida
Bulimina gibba
Bulimina marginata
Cibicides pseudoungerianus
Genus 2
Cornuloculina balkwilli
Cornuspirella diffusa
Cribrostomoides jeffreysii
Lenticulina crepidula
Lenticulina orbiculatis
Dentalina sp.
Elphidium margeritaceum

Elphidium earlandi	2.6	0.3
Textularia sagittula I	2.6	0.3
Globulina gibba	2.5	0.3
Reophax fusiformis	2.5	0.3
Buliminella elegantissima	2.2	0.2
Quinqueloculina aspera II	2.2	0.2
Adelosina normal	2	0.2
Brizalina spathulata	1.7	0.2
Stainforfia concava var. *loeblichi*	1.6	0.2
Spiroplectammina wrightii	1.5	0.2
Clavulina obscura	1.5	0.2
Ammonia beccarii limnetes	1.3	0.1
Uvigerina sp.	1.3	0.1
Asterigerinata mamilla	1.2	0.1
Pateoris hauerinoides	1.2	0.1
Quinqueloculina cf. *cliarensis*	1.2	0.1
Elphidium gerthi	1.1	0.1
Pyrgo depressa	1.1	0.1
Cyclogyra involvens	1	0.1
Genus 3	1	0.1
Quinqueloculina bicornis	0.9	0.1
Pyrgo williamsoni	0.7	0.1
Nonionella sp.	0.6	0.1

Elphidium williamsoni
Fissurina lucida
Fissurina marginata
Fissurina orbignyana
Fissurina quadrata
Fursenkoina fusiformis
Gaudryina rudis
Globulina gibba var. *myristiformis*
Jadammina macresens
Lagena clavata
Lagena gracilis
Lagena laevis
Lagena lyellii
Lagena perlucida
Lagena semistriata
Lagena substriata
Lagena sulcata
Lagena sp.
Lamarckina haliotidea
Lagenammina cf. *arenulata*
Miliammina fusca
Miliolinella subrotunda
Nodosaria pyrula
Nonionella turgida var. *digitata*
Oolina hexagona
Oolina melo
Oolina squamosa
Parafissurina malcomsoni
Patellina corrugata
Polymorphina cf. *novangliae*
Quinqueloculina sp. 5
Quinqueloculina aspera III
Quinqueloculina auberiana
Quinqueloculina cliarensis
Quinqueloculina mediterranensis
Quinqueloculina oblonga var. *lata*
Quinqueloculina cf. *lata/seminulum*
Reophax moniliformis
Reophax scottii
Rosalina globularis
Rosalina anomala
Siphogenerinoides sp.
Spirillina runiana
Spirillina wrightii

Spirillina vivipara
Spiroloculina excavata
Spiroloculina grata
Spiroloculina rotunda
Spiroloculina sp.
Spirophthalmidium acutimargo var. *emaciatum*
Technitella teivyense
Technitella legumen
Technitella sp. 2 (ear bud form)
Textularia earlandi
Trifarina angulosa
Deuterammina(Lepidodeuterammina) ochracea var. *sinuosa*
Deuterammina (Deuterammina) rotaliformis
Remaneica helgolandica
Paratrochammina murrayi
Vaginulina linearis

Table 8.40. On the left a species list showing the species which were recorded with sand facies throughout the year in absolute (Abs.) and percentage (%) abundance. The right column shows a list of species recorded within the Sound but were not recorded within sand facies.

Sandy sediments are typified by *A. beccarii batavus* and *E. crispum*. Characteristic species of sandy sediments are *Q. lata, N. depressulus, Q. seminulum, E. scabrum, P. bowmani* and *B elongata*. All of the *Elphidium* species are present within sand facies.

Species which are absent from sands are most or all of the nodosariid species (particularly those belonging to *Lagena, Dentalina, Oolina, Amphicoryna* and *Fissurina*) together with species belonging to *Spiroloculina*, *Pyrgo, Deuterammina, Paratrochammina, Remaneica, Technitella* and *Spirillina* and some species of *Reophax* and *Buliminella*. Surprisingly, many species of *Quinqueloculina* are also absent from the sandy facies.

8.15.8.3. Mixed Sediments

Mixed sediments (Locs 4,17&18)		
Ammonia beccarii batavus	6539	43
Elphidium crispum	5316	35
Quinqueloculina seminulum	1086	7
Eggerelloides scabrum	488	3
Quinqueloculina oblonga	398	3

Absent
Spiroplectammina wrightii
Adelosina normal
Adelosina ribbed
Amphicoryna cf. *scalaris*
Genus1

Brizalina pseudopunctata	172	1
Stainforfia concava var. *loeblichi*	119	1
Nonion depressulus	113	1
Brizalina spathulata	112	1
Quinqueloculina lata	102	1
Ammoscalaria pseudospiralis	93	1
Bulimina elongata	87	1
Elphidium cuvillieri	74	0
Quinqueloculina aspera I	41	0
Bulimina gibba	37	0
Rosalina williamsoni	34	0
Textularia truncata	31	0
Textularia sagittula	30	0
Quinqueloculina sp.	29	0
Brizalina variabilis	28	0
Quinqueloculina auberiana	23	0
Buliminella elegantissima	20	0
Quinqueloculina sp. 5	19	0
Reophax scottii	18	0
Globulina gibba	18	0
Fissurina lucida	16	0
Massilina secans	16	0
Psammosphaera bowmani	15	0
Cornuspirella diffusa	14	0
Nonionella sp.	13	0
Quinqueloculina aspera II	13	0
Bolivina pseudoplicata	12	0
Textularia earlandi	11	0
Lagena semistriata	11	0
Quinqueloculina mediterranensis	10	0
Quinqueloculina cliarensis	9	0
Elphidium williamsoni	8	0
Quinqueloculina cf. *cliarensis*	8	0
Clavulina obscura	8	0
Planorbulina mediterranensis	7	0
Uvigerina sp.	6	0
Bulimina marginata	6	0
Quinqueloculina oblonga var. *lata*	6	0
Miliammina fusca	6	0
Lagena clavata	5	0
Miliolinella subrotunda	5	0
Haynesina germanica	5	0
Quinqueloculina williamsoni	5	0

Cibicides lobatulus
Genus 2
Elphidium earlandi
Elphidium gerthi
Elphidium margeritaceum
Fissurina orbignyana
Fissurina quadrata
Fursenkoina fusiformis
Gaudryina rudis
Globulina gibba var. *myristiformis*
Lagena laevis
Lagena lyellii
Lagena perlucida
Lagena substriata
Lagena sulcata
Lagena sp.
Lamarckina haliotidea
Lagenammina cf. *arenulata*
Nodosaria pyrula
Oolina hexagona
Oolina melo
Oolina squamosa
Parafissurina malcomsoni
Patellina corrugata
Pateoris hauerinoides
Pyrgo williamsoni
Quinqueloculina cf. *lata/seminulum*
Reophax fusiformis
Rosalina anomala
Spirillina runiana
Spirillina wrightii
Spirillina vivipara
Spiroloculina rotunda
Spiroloculina sp.
Spirophthalmidium acutimargo var. *emaciatum*
Technitella sp. 2 (ear bud form)
Deuterammina (Deuterammina) rotaliformis
Remaneica helgolandica
Paratrochammina murrayi
Vaginulina linearis

Lenticulina crepidula	4	0
Lenticulina orbiculatis	4	0
Quinqueloculina aspera III	4	0
Spiroloculina excavata	3	0
Polymorphina cf. *novangliae*	3	0
Dentalina sp.	3	0
Reophax moniliformis	3	0
Cornuloculina balkwilli	2	0
Rosalina globularis	2	0
Pyrgo depressa	2	0
Technitella teivyense	2	0
Cyclogyra involvens	2	0
Cibicides pseudoungerianus	2	0
Ammonia beccarii limnetes	2	0
Technitella legumen	2	0
Cribrostomoides jeffreysii	1	0
Brizalina striatula	1	0
Miliolinella circularis	1	0
Lagena gracilis	1	0
Nonionella turgida var. *digitata*	1	0
Quinqueloculina bicornis	1	0
Asterigerinata mamilla	1	0
Fissurina marginata	1	0
Trifarina angulosa	1	0
Deuterammina (Lepidodeuterammina) ochracea var. *sinuosa*	1	0
Genus 3	1	0
Jadammina macresens	1	0
Spiroloculina grata	1	0
Siphogenerinoides sp.	1	0
Ammoscalaria runiana	1	0
Astacolus crepidulus	1	0
Buccella frigida	1	0

Table 8.41. On the left a species list showing the species which were recorded with mixed sediment facies throughout the year in absolute (Abs.) and percentage (%) abundance. The right column shows a list of species recorded within the Sound but were not recorded within mixed sediment facies.

Mixed sediments are characterised by *A. beccarii batavus* and *E. crispum*. Other species which are characteristic of such sediments are *Q. seminulum, E. scabrum, Q. oblonga, Stainforthia concava* var. *loeblichi, A. pseudospiralis, M. secans* and *E. cuvillieri*. Many species of nodosariids are present. Virtually all of the *Quinqueloculina* species are represented in these sediments.

Species which are not present are most of the technitellids and deuteramminids. Several species of *Lagena, Oolina* and *Fissurina* are not represented. Attached and clinging forms are mostly absent or rare.

8.15.8.4. Mud

Mud (Locations 9,12 & 15)	**Abs.**	**%**
Ammonia beccarii batavus	9894	43.6
Brizalina pseudopunctata	5261	23.2
Quinqueloculina oblonga	2130	9.4
Stainforfia concava var. *loeblichi*	1065	4.7
Brizalina spathulata	767	3.4
Eggerelloides scabrum	680	3.0
Elphidium cuvillieri	644	2.8
Brizalina variabilis	410	1.8
Quinqueloculina seminulum	198	0.9
Bulimina gibba	193	0.9
Reophax scottii	190	0.8
Bulimina elongata	159	0.7
Elphidium crispum	108	0.5
Bulimina marginata	79	0.4
Pyrgo depressa	75	0.3
Ammoscalaria pseudospiralis	74	0.3
Textularia earlandi	62	0.3
Quinqueloculina cf. *cliarensis*	57	0.2
Ammonia beccarii limnetes	46	0.2
Cristellaria orbiculatis	45	0.2
Brizalina striatula	44	0.2
Nonionella turgida	43	0.2
Quinqueloculina mediterranensis	30	0.1
Nonion depressulus	29	0.1
Fissurina lucida	28	0.1
Cornuspirella diffusa	24	0.1
Cyclogyra involvens	23	0.1
Bolivina pseudoplicata	21	0.1
Bulimina elegantissima	21	0.1
Cribrostomoides jeffreysii	20	0.1
Psammosphaera bowmani	20	0.1
Vaginulina sp.	15	0.1

Absent
Spiroplectammina wrightii
Adelosina normal
Adelosina ribbed
Ammoscalaria runiana
Cibicides pseudoungerianus
Genus 2
Cornuloculina balkwilli
Elphidium williamsoni
Gaudryina rudis
Globulina gibba var. *myristiformis*
Jadammina macresens
Lagena semistriata
Lagena sulcata
Lagena sp.
Lamarckina haliotidea
Lagenammina cf. *arenulata*
Miliammina fusca
Miliolinella subrotunda
Oolina melo
Oolina squamosa
Parafissurina malcomsoni
Pyrgo williamsoni
Quinqueloculina williamsoni
Quinqueloculina cf. *lata/seminulum*
Rosalina globularis
Rosalina anomala
Spirillina wrightii
Spirillina vivipara
Spiroloculina grata
Spiroloculina rotunda
Spiroloculina sp.
Spirophthalmidium acutimargo var.

Amphicoryna cf. *scalaris*	14	0.1
Dentalina sp.	14	0.1
Quinqueloculina aspera III	13	0.1
Clavulina obscura	11	0.0
Lagena gracilis	11	0.0
Reophax fusiformis	11	0.0
Haynesina germanica	11	0.0
Quinqueloculina sp.	9	0.0
Genus 3	9	0.0
Uvigerina sp.	9	0.0
Astacolus crepidulus	8	0.0
Trifarina angulosa	8	0.0
Siphogenerinoides sp.	8	0.0
Lagena substriata	6	0.0
Spiroloculina excavata	6	0.0
Quinqueloculina oblonga var. *lata*	5	0.0
Genus 1	5	0.0
Fissurina orbignyana	5	0.0
Oolina hexagona	5	0.0
Lagena clavata	5	0.0
Fursenkoina fusiformis	5	0.0
Rosalina williamsoni	5	0.0
Globulina gibba	4	0.0
Textularia sagittula	4	0.0
Quinqueloculina cliarensis	3	0.0
Elphidium earlandi	3	0.0
Buccella frigida	3	0.0
Elphidium gerthi	3	0.0
Lenticulina crepidula	3	0.0
Nodosaria pyrula	3	0.0
Quinqueloculina sp. 5	2	0.0
Cibicides lobatulus	2	0.0
Nonionella sp.	2	0.0
Planorbulina mediterranensis	2	0.0
Patellina corrugata	2	0.0
Asterigerinata mamilla	2	0.0
Fissurina quadrata	1	0.0
Massilina secans	1	0.0
Quinqueloculina lata	1	0.0
Spirillina runiana	1	0.0
Miliolinella circularis	1	0.0
Quinqueloculina aspera I	1	0.0
Polymorphina cf. *novangliae*	1	0.0

emaciatum
Technitella teivyense
Technitella legumen
Technitella sp. 2 (ear bud form)
Deuterammina (Lepidodeuterammina) ochracea var. *sinuosa*
Deuterammina (Deuterammina) rotaliformis
Remaneica helgolandica
Paratrochammina murrayi

Fissurina marginata	1	0.0
Lagena perlucida	1	0.0
Quinqueloculina aspera II	1	0.0
Elphidium margeritaceum	1	0.0
Lagena laevis	1	0.0
Lagena lyellii	1	0.0
Reophax moniliformis	1	0.0
Quinqueloculina auberiana	1	0.0
Quinqueloculina bicornis	1	0.0
Pateoris hauerinoides	1	0.0
Textularia truncata	0	0.0

Table 8.42. On the left a species list showing the species which were recorded with mud facies throughout the year in absolute (Abs.) and percentage (%) abundance. The right column shows a list of species recorded within the Sound but were not recorded within mud facies.

The mud facies show the highest diversities of all sediments. They are characterised by *A. beccarii batavus* and to a lesser extent *B. pseudopunctata*. Abundant and characteristic species are *Q. oblonga, Stainforfia concava* var. *loeblichi, B. spathulata, E. scabrum, Q. seminulum, Bulimina gibba, B. marginata, R. scottii* and all species of *Pyrgo*. Rare species which occur mostly or only in mud facies are *Nonionella turgida* var. *digitata, Cornuspirella diffusa, B. elegantissima, C. obscura, Uvigerina* sp., *Siphogenerinoides* sp., *Fursenkoina fusiformis* and several unidentified species of agglutinated foraminifera (Genus 1, 2 and 3). Almost all species found living within the Sound are present (live) within mud facies, particularly species belonging to the nodosarids.

Species not found living in mud sediments belong mainly to the genera *Deuterammina, Remaneica, Paratrochammina, Technitella, Spiroloculina* and *Spirillina*. Most other species absent from the mud facies occurred extremely rarely within the Sound (one or two live specimens).

8.15.9. Comparison of Foraminiferal Assemblages from Different Sedimentary Facies: Diversity and Production

The type of substrate significantly influences the composition, production and standing crop of foraminiferal assemblages. The only worthwhile way to identify subtle trends in composition, structure, production, etc., is to compare different assemblages within similar substrates.

The total yearly production of foraminifera at all the locations has been calculated and compared. The four basic sediment groups have distinct production rates for their localities (See Figure 8.105). Production in clean sandy sediments is the lowest of all groups. Production is in the order of 100 to 200 (per 100 cm^3) foraminifera per year from these areas. Low production may be due to the low amount of available food in the area. The unstable nature of clean sands provides a difficult habitat for foraminifera to survive in, due to the constant risk of burial particularly during storms (Myers, 1942a). Attached and clinging forms of foraminifera are rare. This may be because there are no large shell fragments or vegetation for these foraminifera to attach themselves to securely. Although one location (8) has been identified as having a significant allochthonous element, it is not believed that the transportation of foraminifera into or out of the sites studied has significantly altered the productivity values. Myers (1942a) believed that most individuals did not move laterally very far during their life span.

Production rates for clean shell gravels are low to moderate and range from approximately 200 to 700 (per 100 cm^3) foraminifera per year. This sediment is produced by a very high energy environment. The amount of available food is again probably low and the unstable nature of the sediment creates difficult conditions for most foraminifera. Many of the species present at these locations are attached or clinging forms which are well suited to such high energy environments. The absence of weed or other epiphytal substrates indicates that foraminifera are attached mainly to shell and rock fragments in such areas.

Foraminiferal production for mixed sediments (sands, silts, and clay with occasional pebbles) is high, in the order of 2000 foraminifera (per 100 cm^3) per year or more. Location 17 has a lower productivity because on several occasions only clean sands were retrieved (by grab sampling) from this area; it lies between the clean sands and mixed sediment group. The higher rates of production are a result of the greater availability of food and, perhaps, a higher degree of stability.

Foraminiferal production for sediments dominated by silt and clay range between 1000 to 7000 foraminifera (per 100 cm^3) per year and are comparable to mixed sediment production rates with the exception of Location 9 which is much higher. Production is high in mud facies because of the availability of abundant of food. The substrate is stable in such sediments and disturbance through storms is less frequent and disruptive.

Production rates of for sands, gravels and mixed/muddy sediments can be clearly distinguished but mixed and muddy sediments have very similar production values. The site locations within each sediment group have been arranged with the most hyposaline on the left and stenohaline (normal marine) on the right. It is clearly seen that production within each sedimentary facies is higher in the more marine conditions (See Figure 8.105).

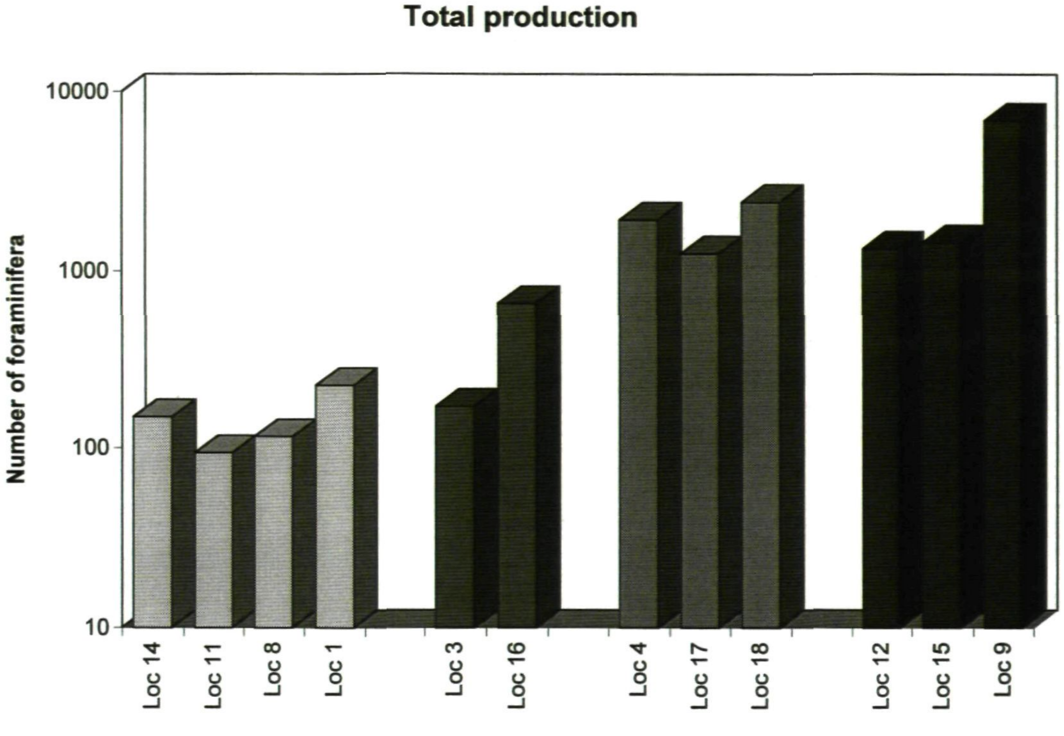


Figure 8.105. Production rates for various sedimentary facies; from left to right sands, gravels, mixed sediments and muds. Within each facies a general gradient of increasing abundance to the right (normal marine) is present.

Diversity of the foraminiferal assemblages from the various sediment groups is distinct (see Figure 8.106). Sands facies typically exhibit 20 to 30 species throughout the year. Gravels have a moderate diversity with 30 to 50 species. Mixed sediments and muds show very similar values with between approximately 40 to 70 species for mixed sediments and 40 to 80 species for muds. Again the most hyposaline locations within each sediment group are plotted on the left and most marine on the right. Diversity is generally lower in the slightly hyposaline conditions of the northern Sound.

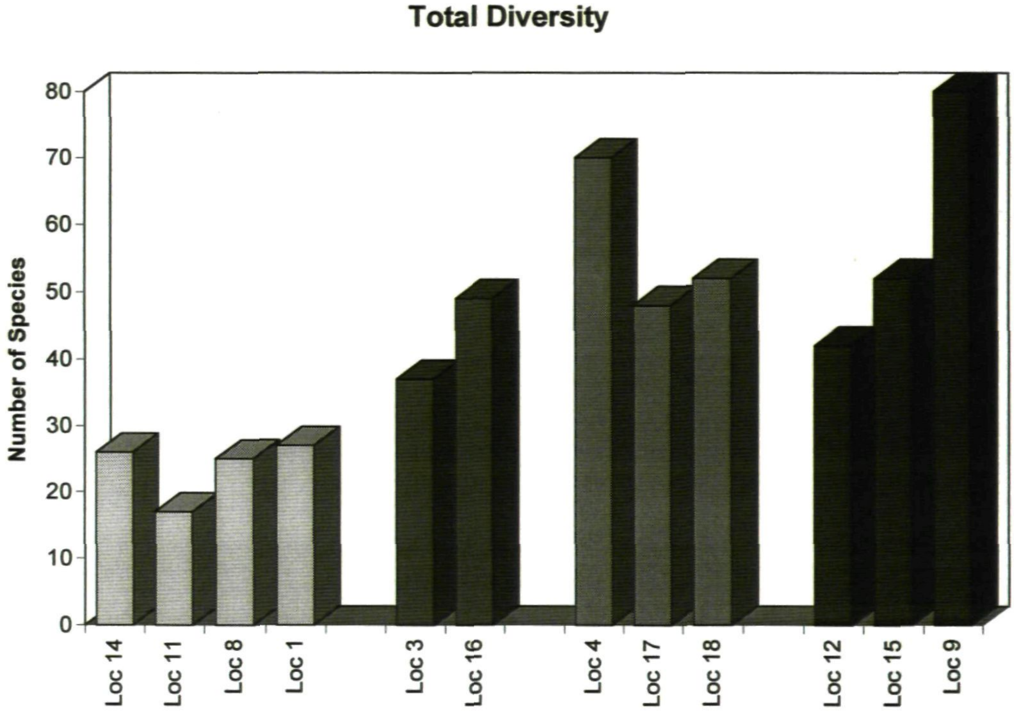
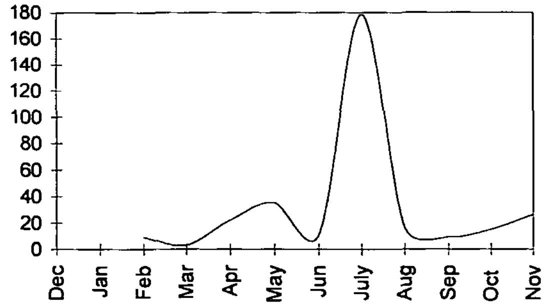
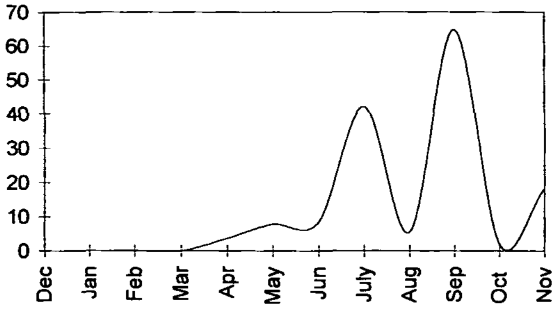


Figure 8.106. Foraminiferal diversity of various sedimentary facies: from left to right sands, gravels, mixed sediments and muds. Within each facies a general gradient of increasing diversity to the right (normal marine) is present.

8.15.10. Patterns of Production and Standing crop

The sum of all foraminiferal standing crops from all locations within the Sound are added together to produce a general pattern of foraminiferal distribution throughout the year. Four peaks, or maxima of standing crop, are observed in February, April/May, July and September. July represents the absolute maximum in standing crop and productivity of foraminifera throughout the year (see Figures. 8.107 & 8.108)


Location 1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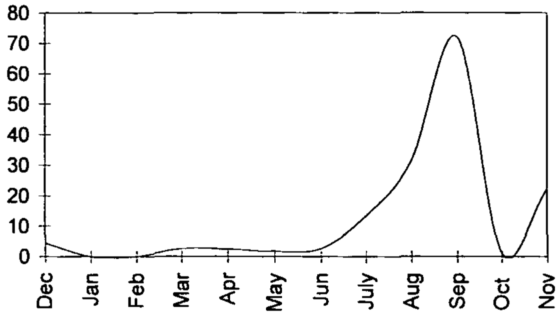
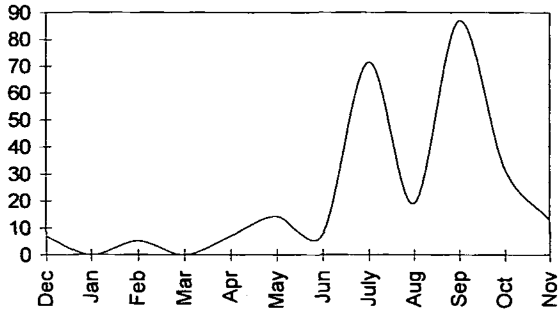
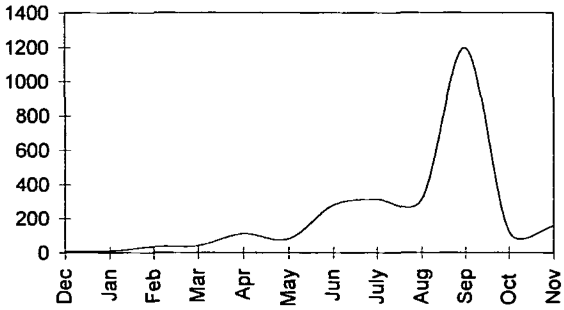
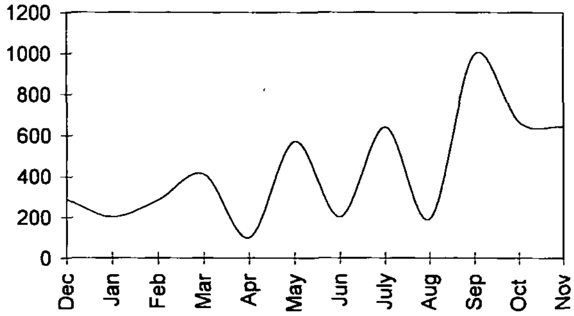
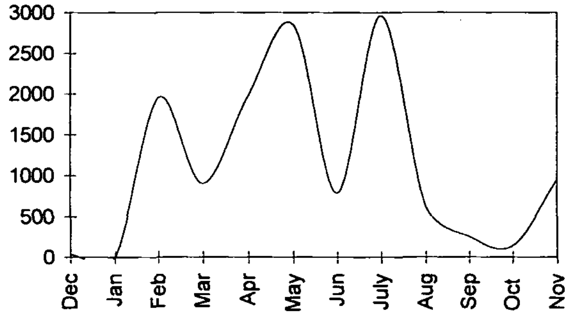
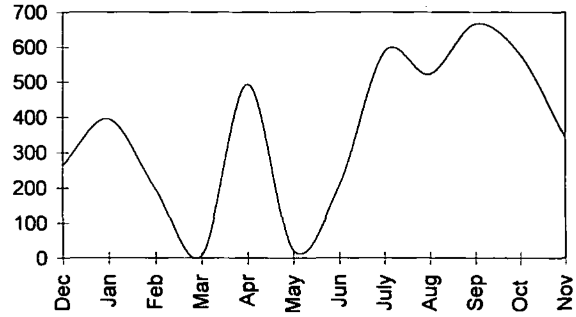

Location 11


Location 14


Location 17


Location 4


Location 9


Location 12

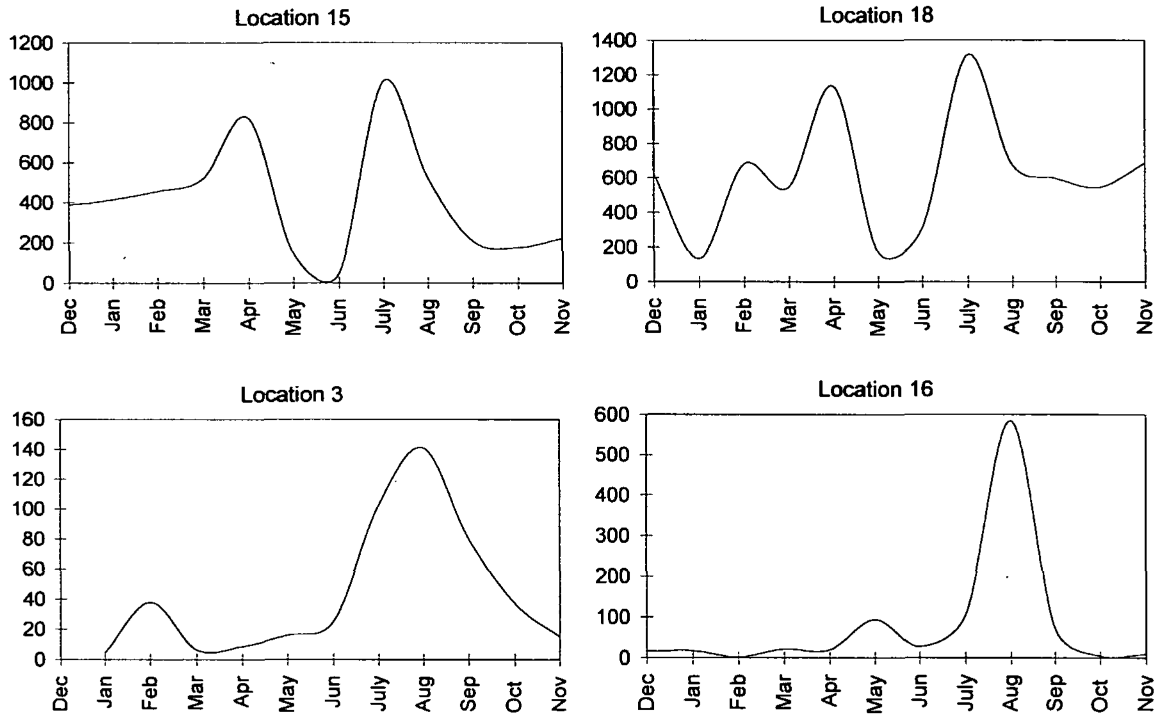
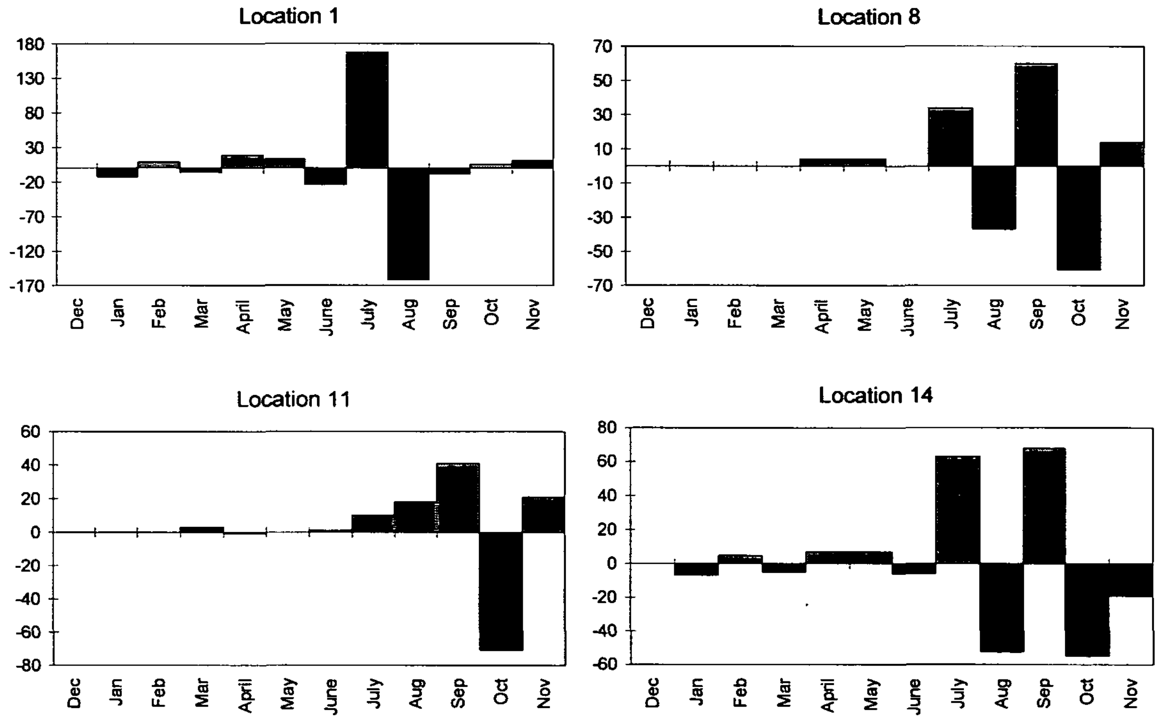


Figure 8.107 The distribution of total live foraminifera at the twelve sample locations throughout the year December 1993 to November 1994. Y axis = number of individuals.



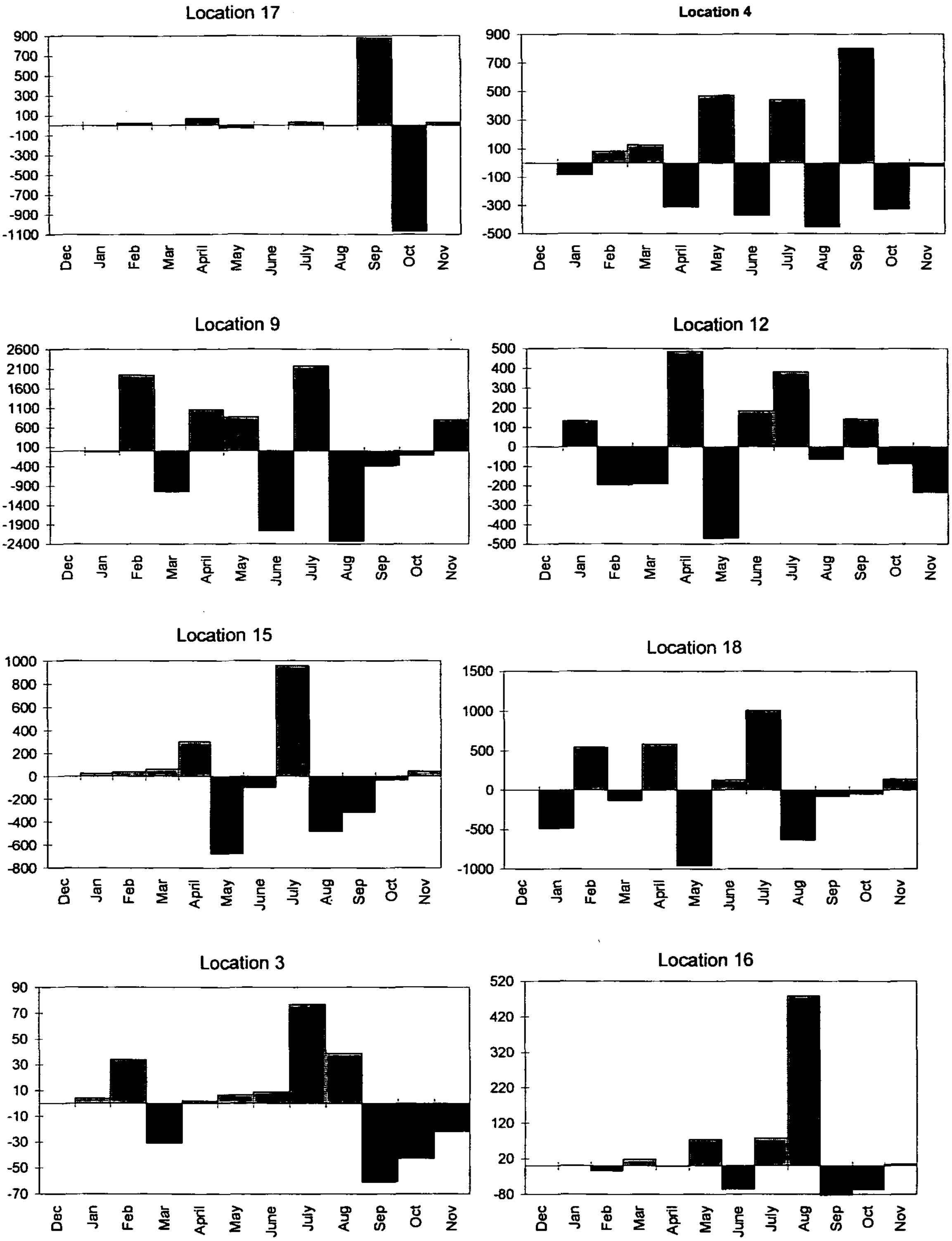


Figure 8.108 Production (pale grey) and mortality (dark grey) of foraminifera at the twelve sample locations throughout the year December 1993 to November 1994. Y axis = number of individuals.

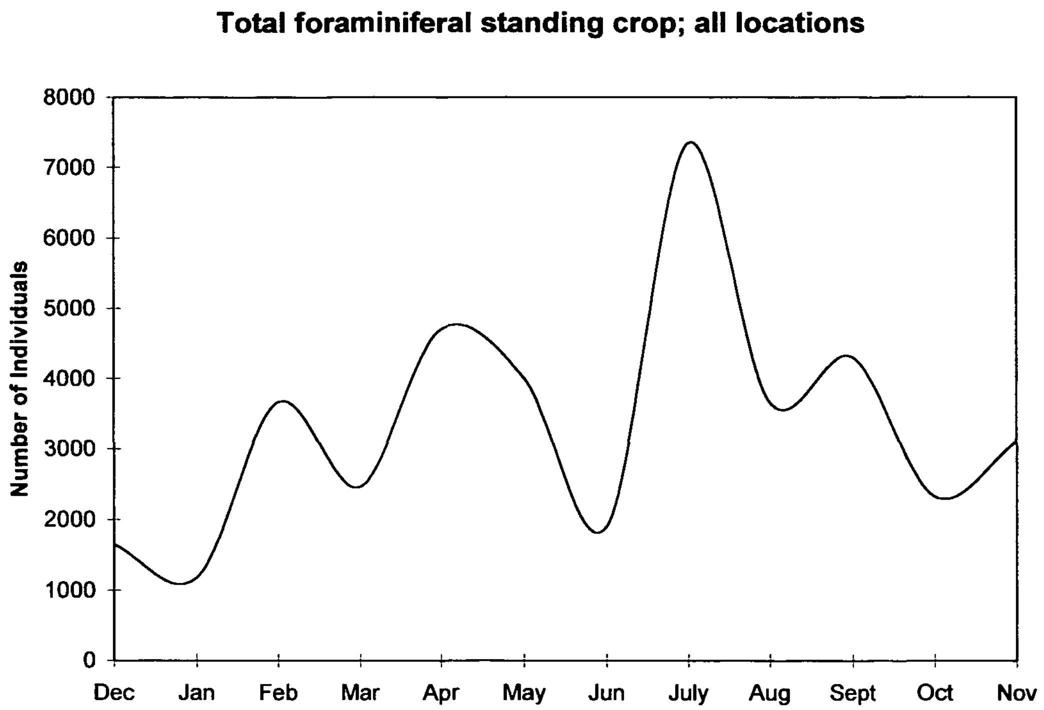


Figure 8.109. Standing crop of foraminifera for Plymouth Sound as a whole.

8.15.11. Comparison of standing crop for all sites

As can be seen from Figures 8.107 & 8.108, standing crop and production for the twelve locations within the Sound show considerable variation. During January only Location 12 exhibits a peak in abundance. During February, Location 3 (shell gravel), Location 9 (mud) and Location 18 (mixed sediment), show maxima of abundance and production. Locations 12, 15 and 18 show a peak in April. Location 4 shows a peak in May while Location 9 shows a broad peak encompassing both April and May. The higher abundances exhibited in April and May are restricted to muddy or mixed sediment sites.

The month of June represents low abundances at all the locations within the Sound. This period probably reflects the most significant reproduction event during the year (and the subsequent mortality of the parents resulted in the observed low abundance), sea temperatures were rising rapidly from the winter and spring low of 9°C and had reached 12°C in June. Sea temperature began rising rapidly during May and perhaps the slightly delayed reproduction may be due to the development of phytoplankton and other food organisms from May. It is unlikely that low levels of food caused the foraminiferal low abundance in June as many conditions were near optimum (sea temperature, salinity day length etc.). During July high abundances of foraminifera are observed at Locations 1, 8, 14 (sand), 9, 12, 15 (mud), 4, 18, (mixed) and as part of a broader peak, Location 3 (shell gravel). August represents low abundance for most sites within the Sound with the exception of Location 12 (mud) which exhibits a minor reduction in abundance although abundance remains high. Location 3 and 16 (shell gravels) exhibit maximum abundances during this month. Nonetheless the low August abundance probably represents another phase of reproduction explaining why many locations exhibit increased abundance in September [Locations 1, 8, 11, 14 (sand), 4, 17 (mixed) and 12 (mud)]. Location 12 continues to increase in abundance reaching a maximum in October. No other locations exhibit a peak in abundance in October.

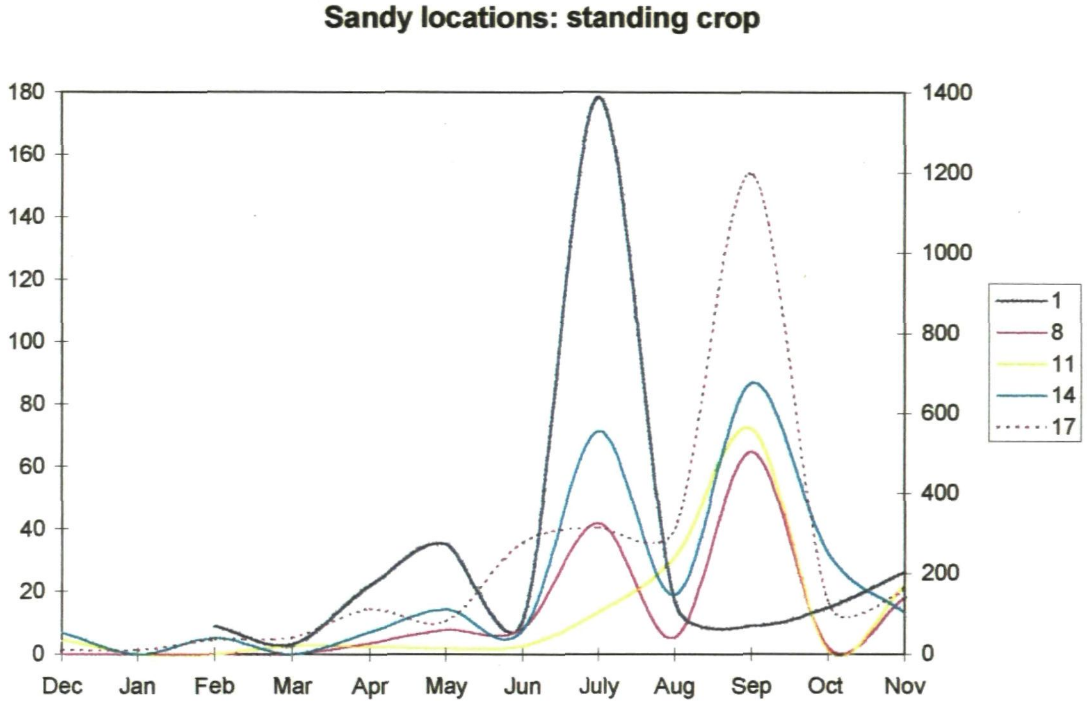


Figure 8.110 Standing crop pattern of locations within sand facies. A high degree of similarity of style and timing are exhibited.

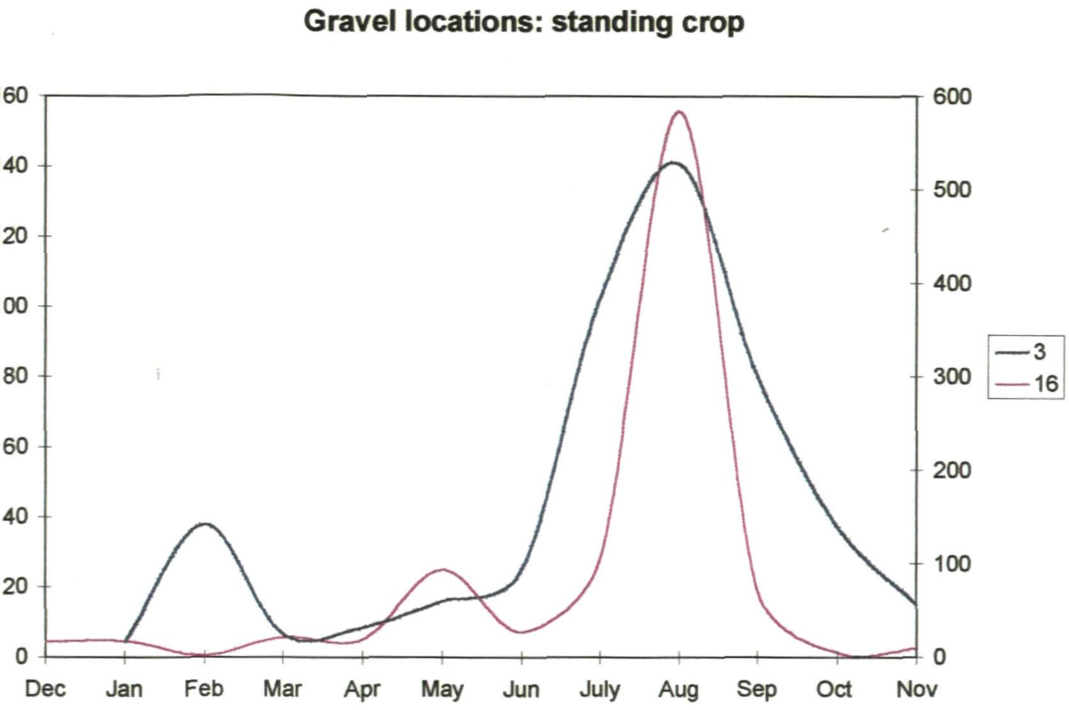


Figure 8.111 Standing crop pattern of locations within gravel facies. A very high degree of similarity is exhibited.

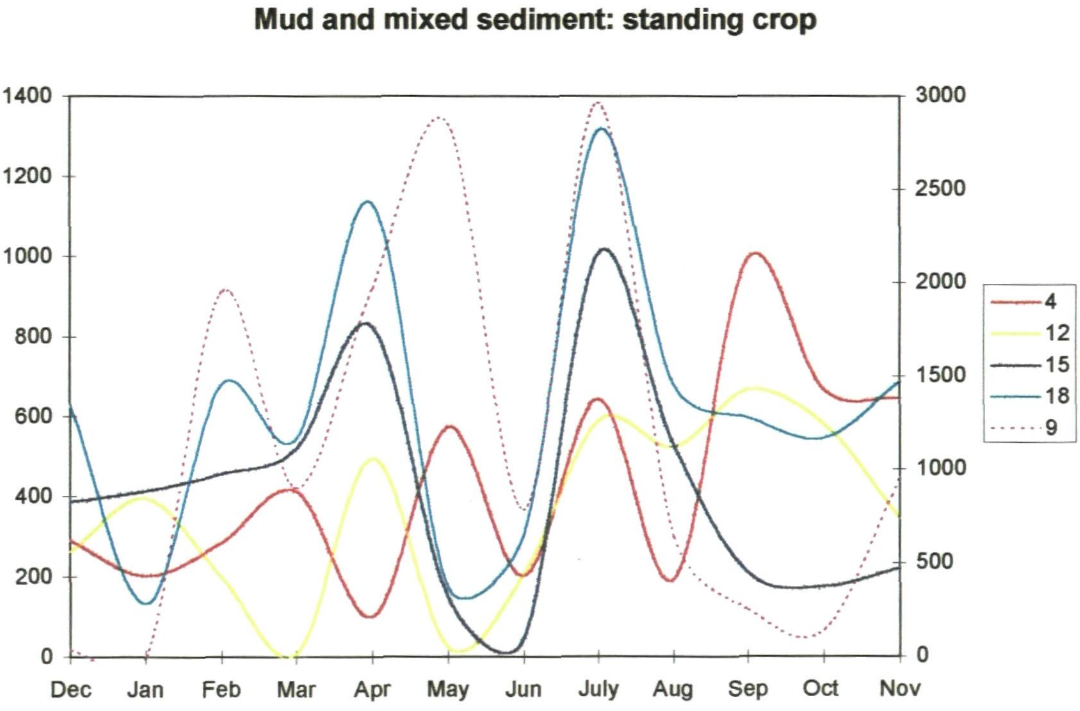


Figure 8.112 Standing crop pattern of locations within mixed and mud facies. A high degree of similarity in style but low degree of correlation is exhibited.

The site locations can be split into two groups on the basis of patterns of standing crop and production. Sand and gravel locations (1, 3, 8, 11, 14, 16, and 17) usually show one or sometimes two peaks in abundance throughout the year and one or two cycles of production and mortality (Figures 8.110 and 8.111). This reflects one or two major phases of reproduction which are primarily controlled by sea temperature.

The mixed and mud locations exhibit 2 to 4 peaks in abundance and a similar number of production/mortality cycles throughout the year. Abundance maxima and cycles of production and mortality show a complex series of high and low standing crop and production which do not correlate well between the locations of those facies. The poor correlation between sites within the mud and mixed sediment facies highlights the large degree of variability within these facies. Reproduction occurs at several different periods throughout the year, some of which may be controlled by increased sea temperatures but other periods are related to different parameters. Only mixed and mud facies show significant reproduction during periods of low sea temperatures and variable salinity (Figure 8.112).

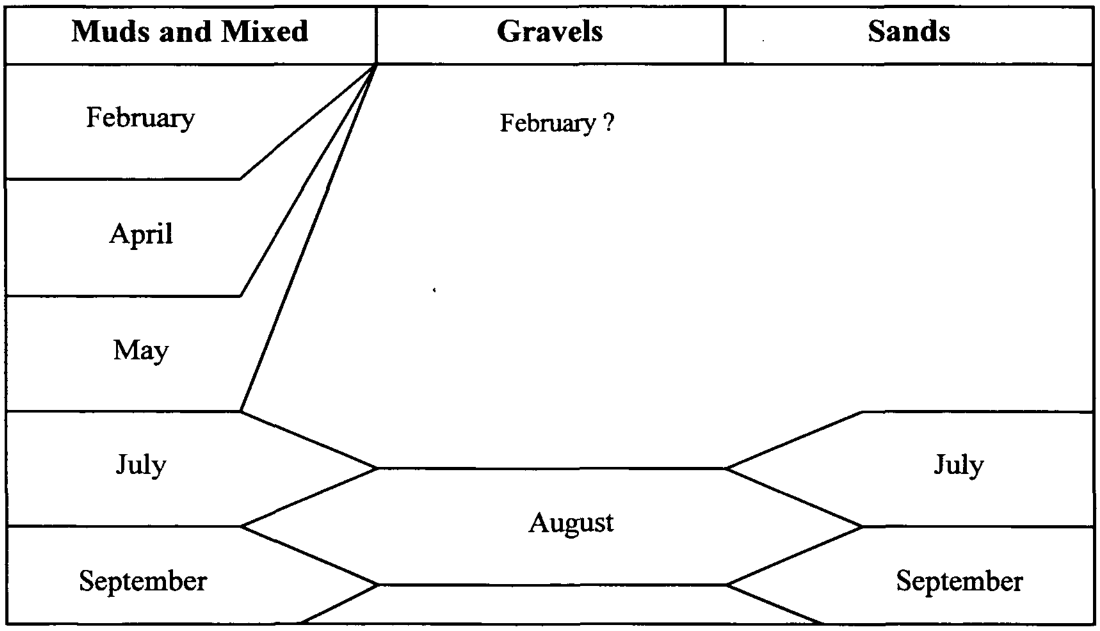


Figure 8.113 Chart showing timing of peaks in standing crop (which are also peaks in production of foraminifera) within the 3 sediment groups throughout the year. The three columns represent the three sediment groups (muds are amalgamated with mixed sediments because they are very similar). A question mark is used in February for shell gravels because only a small peak in abundance was observed.

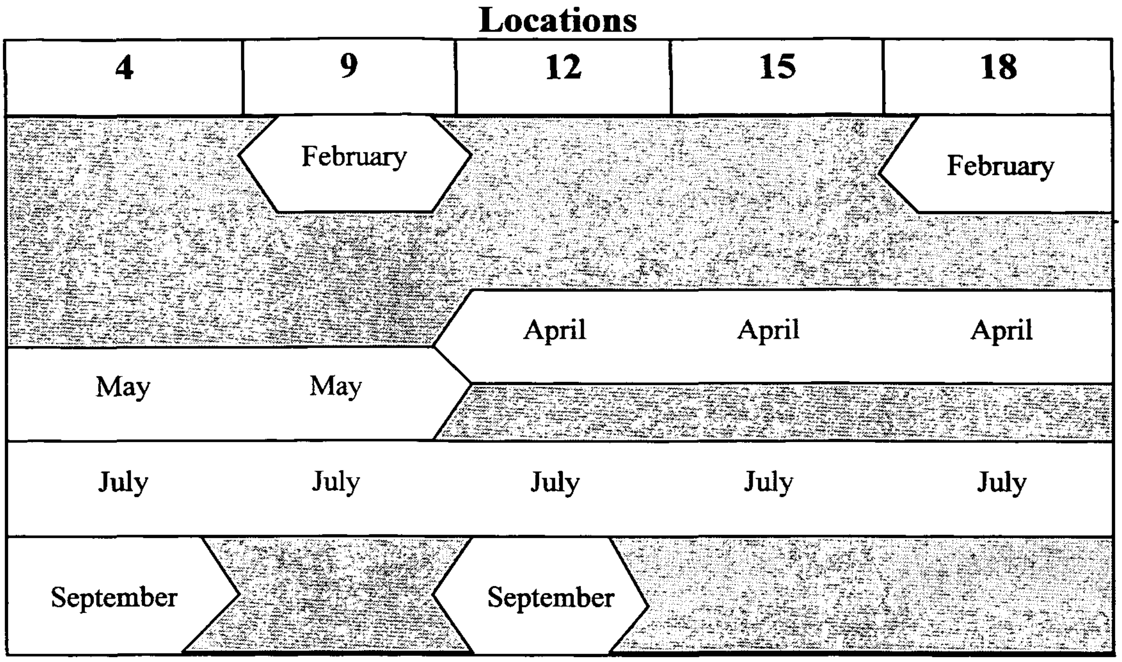


Figure 8.114 Detail of timing of foraminiferal maxima in muddy and mixed sediments throughout the year (December 1992 to November 1993). The locations are shown in columns, the pale areas indicate maxima of foraminifera while the grey area indicate low abundances recorded.

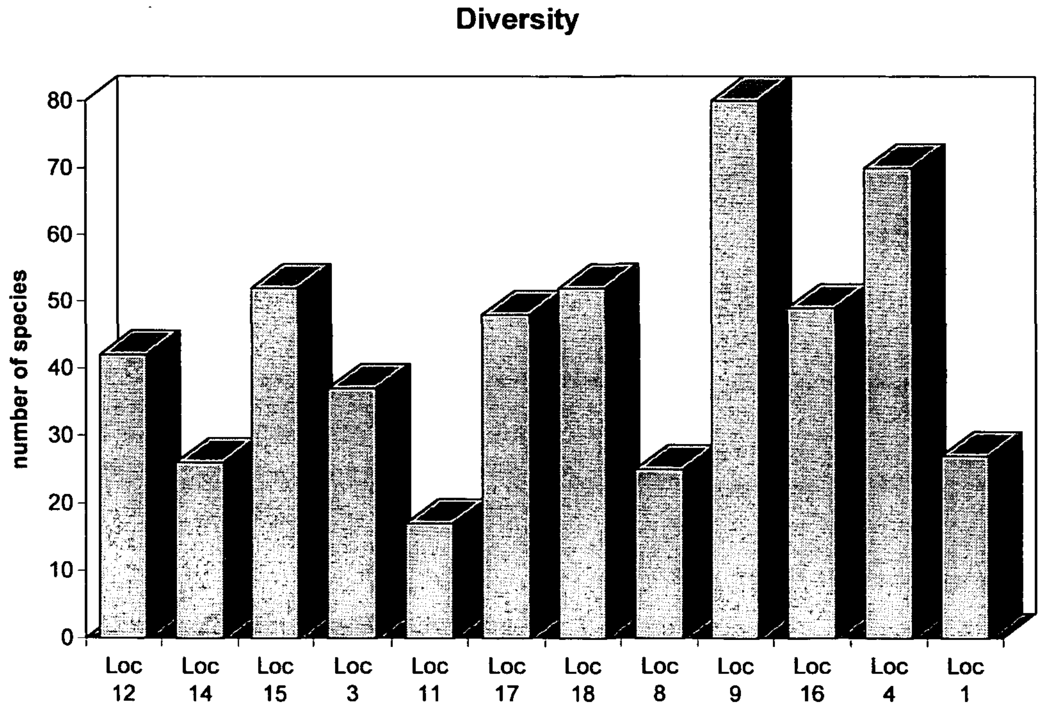


Figure 8.115 Diversity is plotted in order of average salinity (lowest to highest salinity from left to right) at each station. The sediments are not grouped as in Figure 8.106. No clear trend or gradient is observed.

The comparison of foraminiferal assemblages within the same sedimentary facies is emphasised. Comparisons of foraminiferal assemblages between very different facies result in large differences (in faunal composition, production, standing crop, diversity, etc.). which tend to obscure subtle trends within the assemblages such as the effect of varying salinity (see Figure 8.98). In Figure 8.115 the sites have been arranged in order of average salinity to deduce its affect on diversity (irrespective of sedimentary facies), the trend clearly seen in Figure 8.106 is obscured in Figure 8.115 where sediment type was ignored.

8.15.12 Sunshine

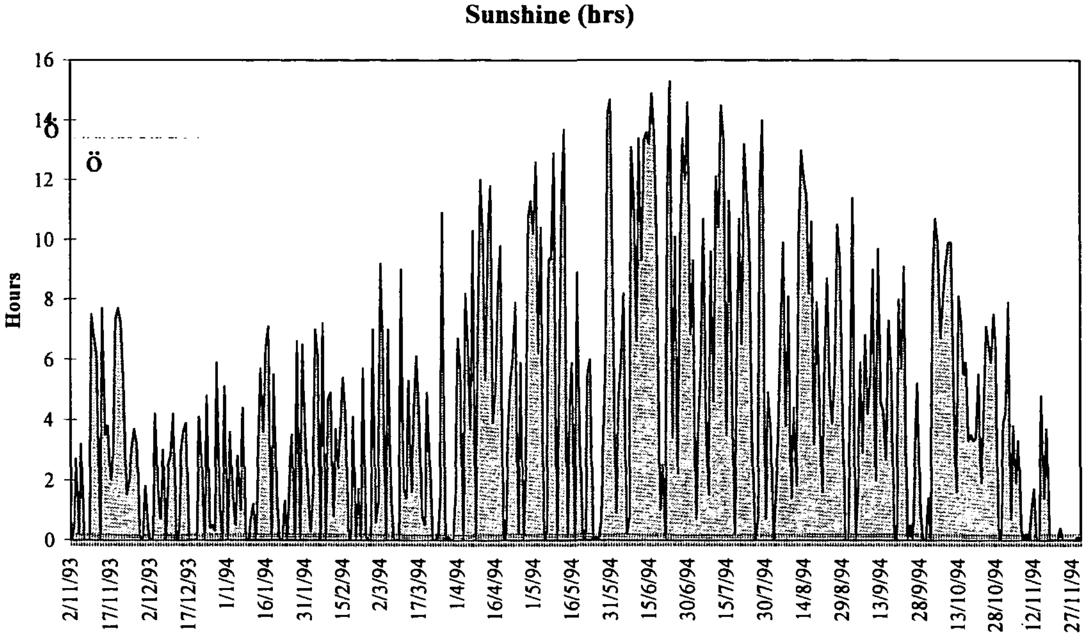


Figure 8.116. Levels of sunshine throughout the year. Note that levels of sunshine are closely linked to day length. NB The data is from the university weather centre and is recorded twice daily. The weather centre is approximately 1 mile from the Sound.

Total hours of sunshine and day length (day light in general) are closely linked. All the sites sampled lie well within the photic zone (although turbidity may be significant in some areas) and the amount of light reaching them is potentially relevant to the foraminiferal assemblages in two principal ways. Firstly, various types of algae which provide food for some foraminifera are directly dependant on light for their growth. The levels and intensity of light probably effect the abundance and speed of growth of algae.

Secondly, foraminifera, which have a symbiotic relationship with algae or harbour algal chloroplasts are through their symbionts, influenced by light intensity and duration. This may effect their rate of growth (Röttger, 1972; Röttger & Berger, 1972; Kuile and Erez, 1984) and general health (Lopez, 1979; Lee, 1980). Levels of sunshine and light intensity are highest in the summer, particularly during the month of June (Figure 8.116) when significant reproduction occurs. Whether this is due to day length (sunshine) or sea temperature or a combination of both is difficult to determine.

8.15.13. Turbidity, Turbulence and Flow

Turbidity is caused by suspended sediment that is agitated by wave, current and tidal energy. The greater the energy from such processes the greater the turbidity and turbulence. For this reason turbidity generally reflects the energy of the site as discussed in Section *8.15.5*. Many sandy and gravel sites probably lie within wave base during storms, particularly at low tide. The muddy sediments are often protected by breakwaters and deeper water hence are usually below wave base. Muddy sites which generally do not receive much wave energy may still be subjected to periods of high turbidity by strong tidal forces (e. g. Location 12 at Barn Pool).

Turbidity may result in detrital food particles passing through the area. Foraminifera which have feeding strategies adapted for catching particles from a flowing current of water are probably well suited to high turbidity. Lipps (1983) describes *E. crispum* feeding in such a way. Generally high levels of turbidity create difficult environments for most foraminifera to live in because of the risk of burial and constant shifting on and through the sediment. Myers (1942a) found that 80% of benthonic foraminifera may be buried and die as a result of storms in Plymouth Sound (presumably mortality is greatest in the unstable and unprotected gravel and sand facies). Palmer *et al.* (1982) conclude that in high flow regimes, foraminifera often retreat into the sediment, thereby reducing the risk of being swept away. Areas of high flow most suit attached or infaunal forms. Poag (1982) recorded specimens of *Webbinella, Elphidium* and *Vasiglobulina* attached to the substrate in areas of high flow. High flow and turbidity may provide adverse conditions (in loose sediment) for algae and bacteria, the main food of foraminifera and hence result in a lower standing crop and production of foraminifera.

Lipina (1961), Medioli & Scott (1978) and Wetmore (1987) conclude that species living in high energy environments often develop tightly coiled tests, with thicker walls and spines.

The robust fusiform *Q. seminulum* found in shell gravels (Locations 3 and 16) are a classic example of phenotypical adaptation, as elsewhere within the Sound they are smaller and less robust. Perhaps the spines that are occasionally observed at the posterior of some *M. secans* (Plate 15, Figure 9) may also be an adaptation to higher energy conditions.

Locations which suffer the highest turbulence and turbidity are the shell gravels (Locations 3 and 16) and many sand facies (Locations 8, 11 and 14) These locations have lower standing crops and production. This may well be at least partly due to the turbulence and turbidity of these locations.

8.15.14. Oxygen

Oxygen is a very important requirement for foraminifera. Foraminiferal literature has several conflicting views Hannah (1994) found that foraminifera, in general, have high oxygen requirements, perhaps 10 times that of naked amoebae. Bradshaw (1961) showed that some foraminifera require very little oxygen to survive. Bernhard (1993) found that some species can survive periods (weeks) of anoxia without adverse effects. The occurrence of very deeply infaunal specimens of *Ammonia beccarii* in poorly oxygenated muddy sediments (Moodley & Hess, 1990) suggests that some species have low oxygen requirements. Some workers believe that foraminiferal occurrences at such depths represent foraminifera which have been displaced by bioturbation or are in a state of metabolic inactivity and not actively feeding (Moodley, 1990) but Bernhard (1993) and Alve & Bernhard (1995) discount this theory. Hannah's (1994) study is the only respiration experiment to be carried out exclusively on temperate, shallow marine foraminifera, including five genera (*Ammonia, Quinqueloculina, Reophax, Elphidium* and *Buliminella*) common to the present study and is taken as being most relevant. Hannah's results suggest that most temperate, littoral or nearshore foraminifera have moderate to high oxygen requirements.

Within Plymouth Sound the sea water is believed to be normally oxygenated in all areas, as it is a shallow, dynamic, well mixed water body which supports a wide range of nektonic and benthonic flora and fauna. The sediment surface at all locations sampled throughout the year always exhibited an oxidised zone. The relatively clean sand and gravel facies has a very diffuse oxidised zone as permeabilities are high and the sediments are yellow or pale in colour. They generally become darker, from pale grey to dark grey, at several centimetres depth; the transition is gradational. Within mud rich facies all sites display a zone of oxidised yellow-brown sediment which generally ranged from several millimetres to perhaps 1 centimetre in thickness. Below this zone the sediment is dark grey or black and represents organic matter which has not been broken down through oxidisation. These depths are probably dysaerobic or anaerobic.

Within the mud rich facies, which have a sharper more distinct zone of oxidised sediment, foraminifera were generally much rarer below the oxidised zone (see Chapter 4&6). All species of foraminifera exhibited their highest abundances (proportionally) within this upper zone of oxidised sediment. In the sand and gravel facies, which exhibited a deep indistinct zone of oxidised sediment, foraminifera were scattered throughout the upper few centimetres. These observations suggest that foraminifera in Plymouth Sound prefer oxidised sediments and probably have reasonably high oxygen requirements. Another explanation may be that their abundance in the oxidised sediment zone may be the result of greater abundance of food, or food which can be easily metabolised (the food organisms themselves probably have an oxygen requirement). Fluctuations of Eh and pH within sediments throughout the year may be due to a fluctuating supply of organic matter (Pearson and Stanley, 1979) which may result in fluctuations of foraminiferal standing crop. This, however, is not believed to be significant as the Sound does not receive very large amounts of organic matter and its shallow, dynamic, nature ensures that it is well oxygenated.

8.15.15. **Pollution**

The effects of pollutants within the environment is highly variable depending on their quantity, nature and the nature of the environment (energy, degree of mixing and oxidation, etc.). Typical pollutants are chemicals, petroleum, heavy metals, sewage and other organic material. The effects of chemicals and metals are undoubtedly very variable and specific to those substances and to individual species. These pollutants, when abundant, probably create stressed conditions for the foraminifera which may result in smaller individuals, aberrant tests and lower diversity and production (Alve, 1991; Sharifi *et al.,* 1991; Yanko *et al.,* 1992). Many other authors have noticed an increased abundance of deformed foraminifera in polluted areas (Watkins, 1961; Lidz, 1965; Wright, 1968; Boltovskoy and Boltovskoy, 1968). High levels of chemical pollutants of various types are probably relatively rare and perhaps localised (near their source). Organic pollution such as sewage is probably far more abundant both in quantity and source. The effects of sewage and other organic pollutants depends on their concentration and the nature of the environment (amount of circulation, oxygenation, energy, etc.). When highly concentrated, few organisms are able to survive. In a less concentrated form, organic materials generally enrich the environment causing greater abundance and dominance of foraminifera but usually lower diversity. *Ammonia beccarii* is seen to flourish in polluted areas (Schafer, 1970; Seiglie, 1971). Species composition is often affected. In environments with small amounts of organic enrichment, foraminiferal abundance and diversity may be slightly higher but species composition and rank remain unaltered (Schafer, 1973; Gray, 1979; Pearson & Stanley, 1979)

Plymouth Sound receives sewage from several sources particularly pipes and gates which discharge along the Hoe and into the estuaries. The strong tidal scour along these regions probably results in the mixing and dispersion of the sewage. Tidal scour is strong enough to remove some or all the sediment along the Hoe as none is present.

An area directly in front of the sewage discharge point (Drake's Island) has a very impoverished fauna but this is unlikely to be entirely due to the sewage contamination because it is several hundred metres away from the discharge point. Many areas of the Sound have very low abundances of foraminifera which suggests that sewage eutrophication is not occurring on a large scale. Even areas of high foraminiferal abundance support only approximately one thousand individuals per 100cm^3. The area of Drake's Island has a high abundance of coal fragments (perhaps a relic of times when coal was transported by boat) and a meagre foraminiferal fauna. Yanko *et al.* (1992) describes how coal pollution may reduce the standing crop and abundance of foraminifera. Aberrant specimens are quite rare within the Sound and, although not quantified, form <1% of the total live assemblage and perhaps occur as one individual per thousand. Aberrant tests can result from a number of other factors discussed in this Chapter. Deformed specimens did not occur specifically at any location but are spread throughout the Sound. Deformities were generally observed within the abundant species which attain moderate to large size such as *A. beccarii batavus* and *E. crispum*. The reason for this is that those species may be more susceptible to deformation or that because they are quite large and abundant, are easily recognised when aberrant.

Reduced levels of food and nutrition can result in irregularities and deformation of the test. Heron-Allen and Earland (1910) observe that when *M. secans* was deprived of food it produced a large number of deformed tests. Boltovskoy (1954,1956) and Murray (1963) conclude that unfavourable food conditions produced various abnormalities. Boltovskoy *et al.* (1991), in the summary of their paper, conclude that rapid environmental changes (physico-chemical) can create deformed specimens. They cite several workers who attributed rapid changes in salinity to the occurrence of abnormal specimens (Bartenstein, 1938; Boltovskoy, 1957a,b; Murray, 1963; Closs and Medeira, 1968; Brasier 1975). Myers (1942b) observes that the chambers of *E. crispum* added in winter were smaller than those added in the summer and this produced a test with an uneven periphery (see Plate 34, Figure 11).

In the Plymouth Sound region deformed tests appear to be most common in the Plym Estuary which may be mainly the result of variable salinity (in the Estuary the area of the channel where salinity fluctuations are greatest exhibited the highest number of deformed specimens).

Recently there have been suggestions that foraminifera (deformed tests) can be used as indicators of pollution but it must be remembered that abnormal/aberrant tests can be produced by a large range of normal environmental parameters common within the natural environment.

Biological Factors Which Influence Foraminifera

8.15.16. Predation

Foraminifera may be selectively preyed upon by other organisms such as nematodes, polychaetes, gastropods, scaphopods and crustaceans or eaten accidentally by indiscriminate deposit feeders such as fish, echinoids, crustaceans, bivalves and tunicates (Lipps, 1983; Murray, 1991). Little is known on the effect and extent of predation on foraminifera (Murray, 1991).

Borings in the tests of foraminifera are often attributed to gastropods (Christiansen, 1964) or nematodes (Lipps, 1983). Gastropods may also account for the damaged tests (scratches and broken edges) of foraminifera (Hickman and Lipps, 1983). Incidental deposit feeders probably consume large numbers of foraminifera. Buzas (1978, 1982) and Buzas and Carle (1979) conducted experiments which demonstrated that large numbers of deposit feeders cause a reduction in the density of foraminifera. Large rays which enter the Oslo Fjord in the summer often obliterate foraminiferal assemblages in localised areas (Christiansen, 1958).

The effect of predation on the foraminiferal assemblages of Plymouth Sound is not known. Predation may have either negligible or major effects upon foraminifera, the effects may be localised in extent, restricted to facies or widespread. It follows that where a large standing crop of foraminifera is present and during large maxima of foraminifera, predators probably also increase in abundance. Foraminiferal tests with large round borings were not observed (in either the live or dead assemblages) although such borings were common in small bivalves and ostracods. Damage, particularly to the periphery of lenticular foraminifera (mainly *E. crispum*), was observed occasionally. The foraminifera were stained red and presumed living at the time of collection. These may reflect damage caused either by the radula of gastropods such as *Olivella* (Lipps, 1983) or by processing of samples over a sieve. Occasionally tests of some miliolids exhibited an interconnected sinuous network of borings which may be attributed to marine fungi or sponges such as

Cliona. Foraminiferal tests from the dead assemblage often exhibited broken chambers and scratching but these are attributed to post-mortem processes.

8.15.17. Disease

The effect of disease on foraminiferal assemblages is not known and little information is available. Seglie (1973) disease in individuals may promote the development of pyrite in living individuals and therefore pyrite may be an indication of disease. Pyrite growth can occur for many other reasons, particularly in anoxic environments. The type and extent of disease, and whether it is intra- or interspecific, could potentially have important ramifications on the populations and assemblages of foraminifera studied, although there is no evidence to suggest that disease has significantly affected the assemblages of Plymouth Sound. Examining the health of foraminifera did not fall within the aims of this study (although deformations of the test were noted when observed). Disease may be important in highly stressed conditions due to rapid fluctuation of abiotic and biotic variables and pollution (also perhaps when food is scarce). Generally disease is not expected to have a major effect on foraminiferal assemblages in Plymouth Sound.

8.15.18. Food

*8.15.18.1.*Herbivory

Foraminifera exploit many different feeding strategies and food types. Many foraminifera actively or passively feed on various types of algae and bacteria from the substrate. Most littoral foraminifera feed on pennate diatoms, small chlorophytes and bacteria (Lee, 1980). Several factors may influence feeding; age and size of the food organism and the age and size of the foraminifera. It must be remembered that juveniles and adults may feed on different food types. It is known that *E. crispum* selects food according to its size (Murray, 1963). The concentration of food affects feeding rates (Lee *et al.*, 1966) and feeding strategies (Lipps, 1983). Lipps (1983) observed *Rosalina* feeding actively or passively depending on whether food was abundant or sparse. The type of food can influence the rate of growth of an individual and hence the population or assemblage of foraminifera. Some foraminifera (e. g. *Q. lata*) can grow up to three times faster when fed on a diet of different species of algae (Muller and Lee, 1969). A diet of bacteria appears to be important to maintain reproduction (Muller and Lee, 1969; Muller, 1975), although Lee *et* *al.* (1970) imply that low numbers of bacteria are optimal for foraminiferal reproduction in littoral environments.

Several of the most important foraminiferal species within the Sound are herbivores and may be effected by the above factors. Many littoral or near shore foraminifera are bloom feeders, feeding and reproducing slowly when food is scarce but when the food source blooms and is very abundant, foraminifera grow and reproduce rapidly (Lee *et al.,* 1966). This may be reflected in the sharp size increases of some of the foraminiferal populations. Myers (1942b) documents a similar pattern of scarcity followed by rapid increase in abundance, with *E. crispum* whose reproduction and pattern of abundance is closely linked to blooms of phytoplankton. The abundance and distribution of plant foods (various algae) probably dictates the pattern of distribution of the herbivorous foraminifera.

8.15.18.2. Detritivory

This is usually a food type exploited by foraminifera living below the photic zone (Murray, 1991) or infaunal species of foraminifera (Lipps, 1983). Foraminifera usually feed on detritus of plant or animal origin and or bacteria. It has been observed that many suspected detritivores (see Table 8.1 of the morphogroups) a) increase in abundance as herbivores increase, b) increase in abundance during the late stages of a herbivorous bloom, c) increase in abundance after a herbivorous bloom. Detritivores may clean up waste food and bacteria (detritus) during the later stages and after a bloom of herbivorous foraminifera. Within the Sound many common and abundant species are potentially detritivores, their mainly coincidental distribution with herbivores suggest that they (potential detritivores) are omnivorous [Lipps (1983) suggests that this is common] or that the detritus has a similar distribution to algae. Detritivores may be more common in mud facies.

8.15.18.3. Suspension feeding

One species of foraminifera (*Cornuspirella diffusa)* which occurs within the Sound in mud or mixed sediment facies has a morphology typical of a suspension feeder. As only one species is identified with this feeding strategy, it is not considered important in influencing the overall patterns of distribution.

8.15.18.4. Other feeding strategies

These include omnivory (many species of foraminifera are probably omnivorous at sometime Lipps, 1983) and parasitism/cannibalism, although very little is known about this feeding strategy and how it may affect patterns of distribution. Plate 3, Figure 1 may show an example of parasitism. Haynes (1981) suggests that species with long tube-like necks such as *Lagena* may be parasitic. It is possible that some species of foraminifera may be able to absorb dissolved organic material directly (Delaca *et al.,* 1981; Delaca 1982) but there is no evidence to suggest that this occurs within Plymouth Sound.

Foraminiferal blooms in the winter and spring may well be related to the abundance of food organisms.

8.15.19. **Symbiosis**

Foraminiferal symbiosis is the interaction between a variety of algae and foraminifera. It can be a very important process as a number of species of foraminifera obtain part or all of their nutrition from such associations. Symbionts may provide a small amount of the species nutrition such as in several species of *Archaias* which receive less than 10% of their carbon requirements from symbionts (McEnery and Lee, 1981), whereas *Heterostegina depressa* can obtain all of its nutritional requirement from symbionts (Röttger, 1972; Schamaljohann and Röttger, 1978). Symbiotic interactions affect species composition and distribution within a community (Lipps, 1983). All symbionts harboured by rotaliine, perforate, species of foraminifera are diatoms, while four different algal classes are associated with porcellaneous, imperforate foraminifera (Leutenegger, 1984).

Three species of foraminifera which commonly occur within Plymouth Sound are known to harbour symbionts. *Haynesina germanica* and *Elphidium williamsoni* (Lopez 1979) are rare within the Sound but very common in the Plym Estuary and have been discussed in Chapter 4. *Elphidium crispum* is very common within the Sound and its association with symbionts has been well documented (Leutenegger, 1984; Lee *et al.* 1988; Lee & Lee, 1989; Lee & Anderson, 1991). The effect on the distribution and abundance of *E. crispum* depends on whether individuals of this species are harbouring symbionts, the numbers being harboured and, as a result, the amount of nutrition they are providing. There is a direct positive correlation between algal symbionts and light levels (Leutenegger, 1984; Lee, 1992). Symbiont-bearing species may be expected to attain highest abundance and productivity during periods of maximum light intensity and duration (early summer, specifically the month of June). Symbiont-bearing species may also be abundant during periods of low food availability when other species are scarce. At several times during the year specimens of *E. crispum* show a prominent green stain, which may reflect the food type recently consumed or be algal chloroplasts. *Ammonia beccarii batavus,* although not documented as harbouring symbionts, also has a green colouration at various times throughout the year.

8.15.20. **Reproduction**

Reproduction occurs as the result of a plexus of interacting favourable conditions with abundance of food being probably one of the most important, this however may be linked to increased sea temperatures. The increase in abundance of a particular species or assemblage can only be a result of immigration or reproduction. Myers (1942a) believes that most foraminifera live and die within a small area (of about one metre). For large scale immigration to occur, foraminifera must be abundant in adjacent areas. When foraminiferal abundance increases from low levels, reproduction accounts for the majority of the increase. Reproduction may occur at one time only during the year or at several times. The former is typical of sand and gravel foraminiferal assemblages, while the latter is typical of mud-rich foraminiferal assemblages. Myers (1942b) calculates that *E. crispum* can potentially increase its population size forty-fold during a single reproductive event. Under optimum conditions, reproduction will result in small individuals with fewer chambers (Poag, 1978). Reproduction may be temperature controlled for many species and the temperature may influence whether sexual or asexual reproduction occurs. Haman (1969) recorded 3 foraminiferal blooms throughout the year in spring, autumn and winter (January). This third bloom, during the time of coldest temperatures, was attributed to sexual reproduction. Myers (1943) states that in temperate regions foraminifera usually reproduce during the warmer summer months. The same author (1942b) established that *E. crispum* reproduced only during March in Plymouth Sound. An advantage of asexual reproduction is that phenotypical adaptations and inherited symbionts are passed on to the new generation.

Boltovskoy and Lena (1969), Forti and Röttger (1967) and Closs and Madeira (1968) all record winter blooms of foraminifera which were attributed to sexual reproduction

8.15.21. Competition

Competition for food, other resources and/or space may be inter-specific, affecting the individuals of two or more species, or intra-specific and only affecting the individuals within one species. Inter-specific competition potentially affects all the species within an assemblage. Species which are less suited, or adapted to the environment may be actively suppressed or excluded (being unable to gain adequate food, space or other resources) by the more successful species. Active take-over through competition is typified by one species growing in abundance while another declines in abundance at the same time. This is believed to have occurred in the Plym Estuary (Chapter 3, Figure 3b) where *Haynesina germanica* actively suppresses *Elphidium williamsoni* and *A. beccarii batavus*. The effect of active take-over of one species should not be confused by passive take-over where one species declines because of environmental conditions and another more adapted species fills the vacant area or niche although these two types of take over are often difficult to differentiate. Within the Sound, interspecific competition may manifest itself as some foraminifera respond rapidly to increased food supply only to be later out-competed by other species which are better able to utilise low food levels. Many species feed more slowly or quickly and have different diets according to the presence or absence of other species of foraminifera (for a detailed account see Lipps, 1983).

Intraspecific competition occurs within one species and may be the result of a population which has out-grown its resources or is confined to a small area, in which case individual foraminifera compete for space, food and other resources. If competition is severe it will result in mortality or emigration and hence reduced population size. Lipps (1983) states that different species respond differently to overcrowding. Some consume more food whilst others less. In an assemblage where one species feeds on a particular food type when it is depleted or reduced in abundance that species will decline in abundance as a result of intraspecific competition while other species will be unaffected. In an assemblage composed of many species, competition is unlikely to be totally intra- or inter-specific but usually a combination of the two.

Competition between foraminifera and non-foraminiferal meiofauna of a similar size may also occur. No information is available on this subject, both generally or from within the study area.

8.15.22. Rate of Growth

Although large scale increases in the number of individuals are usually the result of reproduction, few juveniles were observed throughout the year. At various periods some juveniles of a particular or several species were observed but these usually account for perhaps 10% of the assemblage, even though the assemblage may have grown in size by a factor of 10. It would be expected that approximately 90% of the individuals would be the latest generation and hence juveniles. The paucity or lack of obvious juvenile forms of many species suggests that, initially at least, growth is rapid so that within approximately two weeks these individuals may be sub-adult or adult in appearance/size. *Elphidium crispum* is known to grow at the rate of one chamber per day during at least the first week (C. J. Manley *pers. comm.*) and attain a 400μm diameter 3 weeks after sexual reproduction (Myers, 1942b).

8.16. Conclusion

The observed foraminiferal assemblages result from many interrelated factors and parameters. It is unlikely that any single factor entirely influences the observed distributions but rather a range of factors to varying degrees. Isolating which factors/ parameters are most important is difficult due to their interrelated nature (i.e. as temperature increase so may food organisms). This situation is further complicated by the absence of data for many variables (biotic parameters were not within the aims and scope of this study and other parameters could not be measured satisfactorily).

Of the most important parameters, sedimentary facies (and associated factors) has the greatest effect on the composition and structure of the foraminiferal assemblages. Within the relatively small area of Plymouth Sound the nature and composition of assemblages are very different between some facies particularly the shell gravel facies.

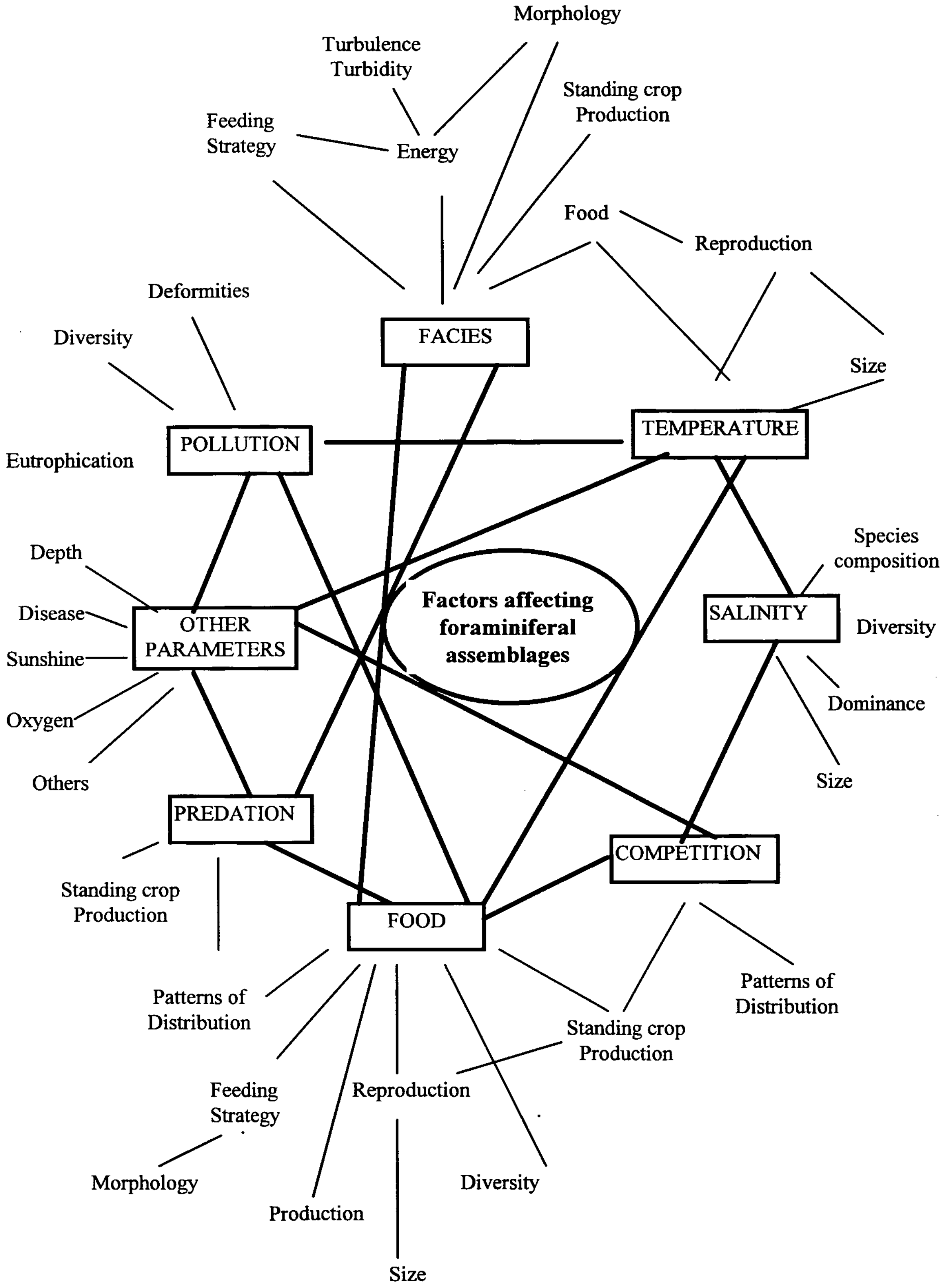


Figure 8.117. Diagram showing some factors and parameters which influence and create the observed assemblages and how they are interrelated. These are the natural features onto which must be added the man-made sampling errors and other difficulties.

The high energy received by these facies undoubtedly strongly influences morphology and feeding strategies of foraminifera which create many of the faunal differences of such assemblages.

The increase in sea temperatures in May/June and the maximum sea temperatures in August is probably the single most important factor influencing the patterns of foraminiferal distribution throughout the year. How sea temperatures effect the abundance and availability of food is not known although it is suspected that food may be closely related to temperature. The high foraminiferal abundance from mixed and mud facies during the winter and spring may be related to food abundance because reproduction is to some extent dependant on the availability of food (Wefer, 1976). Few sites show a sustained and constant standing crop, rather the pattern of standing crop and production exhibits sharp swings from high to low abundance and production. As the food type of foraminifera is variable and its abundance throughout the year is unknown it can only be inferred from other studies (Myers, 1943; Murray, 1973). The abundance of food is likely to be strongly related to sedimentary facies and would seem to be most abundant in mud-rich facies and least abundant in sand facies. The former, therefore, support larger assemblages, have high productivity and are more diverse. The wide range of food is reflected within the range of foraminiferal morphologies and feeding strategies. The mud-rich facies support a wider range of detritivores which are proportionally more abundant in such facies. The interaction of herbivores and detritivores is generally coincidental but detritivores sometimes occur slightly after the beginning of a herbivorous bloom. This may be related to a trend which is commonly observed; high abundance but low diversity followed by lower abundance but higher diversity. The high abundance/low diversity period may reflect predominantly one food type (diatoms for example) one or more species of herbivores are very abundant during this period. After this period, diatoms are depleted but still present as are the herbivores which feed on them. As a result of this bloom, detritus may be more abundant and so detritivores become more abundant causing an increase in diversity whilst abundance is not as high as during the herbivorous bloom.

Salinity exhibits small to moderate variations spatially within the Sound. The average difference between the most hyposaline and stenohaline sites is 1‰ or 2‰. Nonetheless, when sites are compared within the same sedimentary facies, a distinct difference is seen in species composition, diversity and species dominance. Several species show a preference for hyposaline conditions (*A. beccarii batavus, E. scabrum* and *Q. oblonga)*, whilst others show a preference for stenohaline conditions (e.g. *E. crispum, S. concava* var. *loeblichi, B. pseudopunctata* and *A. pseudospiralis*)and others do not show any preference (*E. cuvillieri, N. depressulus, Q. seminulum* and *R. scottii*). No clear correlation exists between salinity and temporal patterns of distribution. Low salinity is sometimes reflected by low foraminiferal abundance but at other times by high foraminiferal abundance.

Active competition which forces certain species to decline in abundance while others increase in abundance is rarely, if ever, observed. This type of competition is probably not very important. Intraspecific competition is probably more important (during periods of foraminiferal decline) particularly because of the fluctuating food supply. The effects of competition (including other organisms) is to increase the fluctuating and variable distribution of foraminifera throughout the year.

Little is known of predation of foraminifera within the Sound hence its effects on the foraminiferal assemblages are difficult to interpret. The same is true of other parameters such as disease, oxygen, Eh & pH and pollution.

- Sediment facies are the most important factor influencing the species composition and diversity of an assemblage (this is because the facies influences many other important factors such as food, oxygen etc.)

- Temperature (and its effect on food) is the most important factor in controlling the temporal patterns of distribution and the occurrence of reproduction

- Food may be of equal importance in controlling patterns of distribution through reproduction in the winter and spring particularly in mud and mixed sediment facies.

- Salinity subtly influences the structure and diversity of assemblages

- Predation and competition may play an important role in temporal distribution of foraminifera

- Many other factors and parameters undoubtedly effect the assemblages but their role is largely unknown.