STUDIES ON THE FORAMINIFERA OF THE SOUTH WEST COAST OF INDIA

THESIS

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By

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CERTIFICATE

This is to certify that this thesis is an authentic record of the work carried out by Shri A. Antony, M.Sc., under my supervision in the University Department of Marine Sciences and that no part thereof has been presented before for any other degree in any University

Dr.C.V.KURIAN
Supervising Teacher

Ernakulam,
Oct. 22, '79.

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I

INTRODUCTION

Foraminifera are shell bearing Protozoa belonging to the class Sarcodina (Rhizopoda) which has a world wide distribution. They are almost entirely marine, though a few live in brackish or fresh water. Except in a few of the simplest types, there is a shell, generally less than a few millimetres in size, either of agglutinated foreign material, or of chitin or calcareous material secreted by the animal itself. Though the shell is external, the animal lives both inside and outside the test. Majority of the foraminiferal species are benthic and a few are planktonic.

The living benthic species of foraminifera number about 4200 in contrast to only about 30 planktonic forms. The total number of fossil foraminifera is estimated to be over 13000 species - (International Dictionary of Geophysics, London, 1969). The oceanographic interest of these marine animals lies in the skeletal structures produced by its members. Their tests commonly accumulate in large numbers on the sea floor where they may constitute more than 90% of the bottom sediment. They are believed to cover the bottom of 36 per cent of the Pacific Ocean, 54 per cent of the Indian Ocean and 67 per cent of the Atlantic Ocean - a total area of 126 million square kilometres (Sverdrup et al, 1961).

Planktonic foraminifera constitute a group of free floating marine protozoans living in ocean waters from the surface to an undetermined depth. They are dominated in the tropical latitudes by the species of Globigerina and its near relatives and the deposited skeletons of planktonic foraminifera are so ubiquitous and abundant that they form an ooze - the globigerina ooze. This is the most wide-spread type of ooze in the Atlantic and Indian Oceans.

These shelled protozoans are apparently one of the oldest known group of animals and have a long and continuous fossil record. The history of fossil foraminifera goes back to the cambrian period. For palaeontological interpretations of the fossil the study of foraminifera in the marine sediment is important.

It was Dujardin (1835) who first demonstrated the zoological position of foraminifera in the Rhizopoda. Before his time foraminifera was considered as a peculiar group of cephalopod molluscs. Eventhough there are a vast number of papers written on this group, very little is known about their protoplasm. So the systematics are only based upon the shell structure. The test may be unilocular or multilocular. When multilocular the shape of the test varies, almost in every imaginable form.

They may be close coiled, elongate coiled, evolute, uniserial, biserial, triserial, globular, spiral or irregular without any definite arrangement. The surface of the shell may be smooth or ornamented.

Foraminifera possess their own characteristic body shape and this is correlated with their particular mode of life. A peculiarity of the body form in foraminifera, whether benthic or planktonic, is the tendency to form a more or less pronounced spherical twist. A broad distinction may be drawn between species which move freely in their environment and those which are fixed and sessile in habit. Planktonic species tend to be ovoid and creeping forms are more or less flattened and spread upon the substratum. Sedentary forms tend to be vasiform, often with a point of attachment drawn out into a peduncle.

During the past 50 years several zoologists have provided valuable data on the life cycle of some species of foraminifera (Le Calvez, 1938; Myers, 1943; Arnold, 1953; Jepps, 1956; Bradshaw, 1957; Buchanan et al, 1960 and Hedley, 1964). The duration of life of foraminifera has been estimated to be varying from three weeks to two years.

From an ecological point of view foraminifera appear to constitute a dynamic population which are constantly adapting themselves to marine environments. Transitions of planktonic forms between warm and cold waters are affected by intermixing of water masses in different localities. The implications of current systems are of considerable interest in this. Sequences of planktonic species in deep sea cores have been used to indicate possible marine conditions during the glacial and interglacial times. These forms also have been used as indicators of marine water masses, both in modern oceans and in ancient seas. The study of transportation of sediments gives a clue relating to the water movements over the bottom.

In an account of the general problems in taxonomy, ecology and biology Ax (1956) pointed out that the first stage in the investigation of a biocoenose is the systematic comprehension of its basic elements. He also highlighted the necessity of the exact comprehensive knowledge of the individual species for all further levels in the investigation of a biotope and its biocoenose. Foraminifera create great problems to general ecologists in their identification. Davis (1927) has stated that one of the biggest tasks confronting any one engaged in ecological survey work is that of getting all the animals identified. As there is scarcity of information on the bionomics, the classification of foraminifera is primarily based on the test morphology.

For more than a hundred and fifty years zoologists and palaeontologists have shared the study of foraminifera. With the rapid expansion of the oil industry palaeontologists took the field of stratigraphical study. The study of the taxonomy and biostratigraphy have broadened the interest of the palaeontologist to include ecology as a means of interpreting palaeontology. The fossil foraminifera laid down in the deposits in the past have often become consolidated into soft lime stone known as chalk. The very large fossil foraminifera Nummulites has been found in the early Tertiary period forming limestone beds in Europe, Asia and Northern Africa.

Foraminifera are widely distributed in marine rocks throughout the geological column and probably no other group of organisms has had such a long continuous history preserved. These shelled protozoans are widely used by geologists as indicators of geologic ages. To reconstitute the geological study of the earth it is required to have information regarding the rate of sedimentation. According to Schott (1935) the average thickness of the marine sediment is 3 km and the rate of sedimentation of globigerina ooze is estimated as 1 mm per thousand years.

Foraminifera ranks first in the constituents of marine sediments. The calcareous shells are subjected to mechanical disintegration and chemical transformation. In applied geology such as exploration for petroleum the study of marine sediments is highly desirable. Adequate knowledge of the conditions of the formation of certain sediments would be helpful in the exploration of oil. The decomposition of buried organic matter using oxygen takes place by chemical action as well as by bacteria. The micro organisms favour the generation of petroleum by reducing the organic matter in the sediments and decomposing it to form petroleum. As petroleum is formed of marine sediments it is important to determine the conditions under which potential oil-bearing sediments are laid down for prospecting the industry. In recent years foraminifera have been much employed in the oil industry in correlating rock strata.

The study of foraminifera in the sediment samples began with the work of d'Orbigny (1826) though our present knowledge of this group in the world oceans is based primarily on the collections made by H.M.S. Challenge The most comprehensive record of foraminiferids in the world oceans is that of Brady (1884) from the samples taken during the Challenger Expedition. Since then a number of papers dealing with this highly variable group have been published. Particular mention could be made of the works of Carter (1880), Murray (1889), Chapman (1895), Philippi (1910), Schott (1935), Phleger (1939; 1951, 1952), Parr (1950), Walton (1955), Parker and Athearn (1959), Boltovskoy (1963, 1970), Bandy (1964) and Bradshaw (1968) who have made contributions to our knowledge on the systematics, distribution and field ecology of foraminifera.

The earliest work on the foraminiferida in the Indian Ocean is that of Moebius (1880) from the Island of Mauritius. The present knowledge of foraminifera in the Indian waters is largely based on the collections made by a few oceanographic expeditions which passed through the Indian waters in the course of their voyage round the world. Special mention may be made of the work of Brady (1884) who gave an excellent account of the foraminifera from the dredgings made by H.M.S. Challenger in the southern Indian Ocean. This was followed by a list of foraminifera obtained from the Bay of Bengal published by Murray (1889). Later Champman (1895) studied the foraminiferal collections obtained by the Royal Indian Marine Survey Ship "Investigator" from the

Arabian Sea, near Laccadive Islands. Dakin (1906) recorded 131 species from the collections taken by Prof. Herdman at Ceylon. Hofker (1927, 1930) published a monograph of foraminifera collected from the Arabian Sea and was followed by Stubbings (1939) who recorded about 300 species and varieties from the same area. Later Gnanamuthu (1943) reported 47 species of foraminifera from the Gulf of Mannar. Other important works on foraminifera from the marginal marine environments of the East Coast of India are those of Rao (1939, 1940), Daniel (1949), Chaudhary and Biswash (1954), Bhatia (1957), Ganapati and Sathyavathi (1958), Ganapati and Sarojini (1959), Chatterjee and Gururaja(1968), Rao (1969, 1971), Vedantam and Rao (1970), Ramanathan (1970, 1975), Pandy et al(1971), Rao and Rao (1972) and Rao (1974).

In recent years, the increasing attention paid by the oil and Natural Gas Commission of India, for finding out oil and gas has accentuated the need for detailed micropalaeontological investigations. The study of the micropalaeontological aspects of foraminifera has been undertaken by many authors with a view to ascertain the precise age of the deposit and to make inter-regional correlations. (See Nutall, 1925, 1927; Davis, 1927;

Rao, 1940; Jacob and Sastri, 1952; Kumar, 1967; Bhalla and Dev, 1974; Bhalla and Abbas, 1975; Bhalla, 1977 and Bhalla and Talib, 1978).

By virtue of the world wide distribution, numerical abundance and diversity of habitats, foraminifera provide a demanding problem to anyone interested in ecology. But all the erly works on foraminifora deal with only systematics and distribution. It should be pointed out that the past two decades have proved to be a relatively ennobling period in the ecological study of foraminifera. But these works are only from a few restricted geological areas around the world.

During the past 25 years much attention has been paid to the study of the ecological aspects of these unicellular organisms from different parts of the world (Walton, 1955; Bandy, 1956; Phleger, 1956; Smith, 1957; Bradshaw, 1957; Nyholm 1957; Uchio, 1960; Loeblich and Tappan 1964; Murray, 1967 and Dusas, 1968). Though our knowledge on the systematics and distribution of the foraminifera in Indian waters is somewhat satisfactory, studies relatd to the ecology of this group are still in its infancy. However some work has been done on the ecological aspects of foraminifera from the East Coast of India (Ganapati and Sarojini, 1959; Vedantam and Rao, 1970 and Ramanathan, 1970).

The earliest works on the foraminifera of the Kerala Coast are those of Kurian (1951, 1953) who recorded a few species from the coastal waters of Travancore and of Sethulakshmi Amma (1958) who described 114 species and varieties from a few stations off Trivandrum. Later Antony (1968) studied in detail the taxonomy and distribution of 164 species and varieties of foraminifera from the continental shelf of Kerala. Recent works on the foraminifera of the Kerala Coast are those of Antony (1968), Rao (1970), Pflaumann (1970), Seibold (1971) and Zobel (1971).

All the above mentioned works mainly deal with the taxonomy and distribution of foraminifera in the continental shelf of the South West Coast of India. But hitherto no attempt has been made to study the ecological aspects of these micro-organisms from the West Coast of India.

The present study is aimed at getting a comprehensive knowledge of the habitat and relationship to environmental factors of the foraminifera in the South West Coast of India. The work comprises studies on the foraminifera of the

Vembanad estuary - a major estuary in the South West Coast of India and the interstitial foraminifera of the sandy beaches of the South West Coast of India. These investigations were undertaken with a view to understand the occurrence, composition, distribution and live-dead ratios of foraminifera in the above areas. An attempt has also been made to correlate the above aspects with the environmental factors such as sediment characteristics and hydrographical parameters like temperature, salinity, dissolved oxygen, pH and nutrients.

II

GENERAL ACCOUNT OF FORAMINIFERA

Most of the works on foraminifera deal with only systematics and geographical and geological distribution and very little is known about the bionomics of this group. As only very little is known about the living content of these acellular animals, most of the work on this group is based on the test. The skeletal elements are usually non-living secretions of free protoplasm. The shell may be composed of elements secreted by the organism or of foreign particles taken up by the animal from its surroundings. The skeleton may be chitinous, siliceous or calcareous.

Chitinous test

A thin flexible transparent test, with a thin chitinous inner layer, represents the most primitive type of the group. The absence or scarcity of ~~scarcity of~~ calcareous material results in the development of purely chitinous test. Little is known about the chemical composition of these elements. In brackish water, the absence or scarcity of calcareous material results in the development of chitinous test which otherwise might have been calcareous. In some forms the inner wall of the test forms chitinous element and foreign materials are present on the outer part. Species with purely chitinous test form only a minor portion of the total foraminiferal species.

Siliceous test

Siliceous tests are developed only in a few forms and found either in brackish water or deep sea, generally in the temperate waters. Siliceous forms mainly belong to the families Silicinidae and Miliolidae.

Calcareous test

The calcareous tests develop directly from the primitive chitinous types. Calcareous tests in young specimens is transparent and glassy. The wall of the shell gets thickened by the advanced growth of the organism. The calcareous deposit of the foraminiferal test is found as the most abundant single deposit in the ocean basins. Calcareous tests are of two types, perforate and imperforate and the former is more primitive. The calcareous cement of the imperforate group is distinctly different from that of those forms which develop perforate calcareous test. In brackish water the calcareous forms become less calcareous as the water grows less saline.

In some primitive groups of foraminifera the test consists of foreign particles cemented together over a chitinous inner layer. The foreign particles consist of sand grains, sponge spicules, calcareous grains, mica and tests of other foraminifera. Many species are very selective in choosing materials for the construction of the test. The purpose of forming the agglutinated test is to have a rigid protecting wall, covering the softer protoplasmic body.

Benthic foraminifera

Most foraminifera are bottom living forms, crawling slowly on the surface of the mud or sand of the ocean botto They are distributed throughout the oceans. The rate of movement in foraminifera is very slow, yet for their small size they cover considerable distance. The speed varies in different species and it ranges from 6 mm to 1 cm per hour (Cushman, 1948). Some species belonging to the families Rotaliidae and Miliolidae are found attaching themselves to other objects like hydroid stems. Planorbulina and Sorites are found attached to eelgrass.

Numerous types of body forms are found in benthic species. Though they are single celled animals, most often the tests are built of many chambers. In multilocular forms new chambers are added in characteristic series and within reasonable limits. The result is a wide variety of patterns.

Benthic foraminifera constitute more than 99% of the total species of the foraminiferids. They are generally included in the size division "microbenthos" with diatoms, bacteria etc. which are usually separated by bacteriological techniques.

Mare (1942) coined the term "Meiobenthos" between microbenthos and macrobenthos. The most widely accepted size limits of meiobenthos, which are determined by the mesh size of the seives used in their separation techniques are 0.5 - 1 mm as the upper limit (Mc Intyre, 1969). However this size grouping has no restricted biological boundaries. The size limit of the foraminifera in the present collection ranges from 0.2 to 1.7 mm. Considering the size variations, it is desirable that majority of this protozoan group may be included in the category "meiobenthos". According to Parker (1959) also foraminifera can be considered under the heading "meiofauna".

Planktonic foraminifera

The planktonic foraminifera consists of only a small fraction of about 1% of the total species. They live most abundantly in the upper 200 metres of water in tropical and subtropical regions and their number decreases in the polar regions. This group is dominated by *Globigerina*, *Globorotalia* and their relatives. Planktonic species live in different environments since they represent different habitats. Considerable shell thickening in planktonic species has been observed as the surface forms adapt themselves to deeper habitats.

Pelagic foraminifera drift with the currents and their preferred habitat seems to be the open ocean, although they probably live to some extent over the more shallow parts of the continental shelf area (Zeigler, 1964) The dead shells fall to the bottom and accumulate in the ocean floor forming the foraminiferan ooze or Globigerina ooze. It is made up chiefly of calcareous shells of planktonic foraminifera. The globigerina ooze is the most widespread type of ooze in the Atlantic and Indian Ocean and it covers most of the floor of the Pacific Ocean. In general it is a deposit of both the warm and temperate seas. It is at depths ranging from 1500 to 2000 fathoms that the globigerina ooze most abundantly and most characteristically develops. As many as 50000 foraminiferal shells may occur in 1 gm of the bottom sample, the majority belonging to the genera Globigerina, Globorotalia and Orbulina. At very great depths the globigerina ooze gives rise to the Red Clay.

Taxonomy

The taxonomy of foraminifera is in a state of extreme confusion (Hoglund, 1947; Bermudes, 1952; Batjes, 1958 and Hedley and Adams, 1974). Owing to the highly overlapping morphological characters and physiologi races in various parts of the world, the determination of relevant forms seems sometimes difficult. Many of the external characters considered to be of taxonomic value, undergo marked changes by the deposition of calcareous material during growth. So even the minute characters have to be examined in detail for identifying the material.

Reproduction

Most foraminifera reproduce once a year in cool environments and more frequently in warmer environments (Murray 1973). Thus the birth rate varies with environmental conditions. The length of life of foraminifera varies from three weeks (*Spirillina vivipara* Myers) to two years (*Elphidium crispum* Linne).

The mode of reproduction in foraminifera is variable among different groups, although it is primarily a cell division. Both sexual and asexual reproductions are observed. In monothalamous forms the reproduction is by binary or multiple fission. In the sexual forms, the protoplasm divides into minute masses, each provided with one or two flagella. The flagellulae are gametes and may form shell while still within the shell of the parent or after becoming free. In dimorphic foraminifera like *Elphidium* alternation of generation occurs—the macrospheric form alternates with the microspheric form.

Growth rate

Very little is known about the growth rate of individual chambers or the length of the time between various stages of the life cycle. Lee *et al* (1961) have suggested that it is difficult to make a clear idea on the critical factors limiting foraminiferal growth on the basis of field study alone.

Food

The normal food of foraminifera consists of a mixed diet of diatoms and phytoflagellates. In deeps they feed on bacteria and detritus.

III

FORAMINIFERA OF THE VEMBANAD ESTUARY

Foraminifera are generally marine and widely distributed in the seas. Although most of them occur in the seas of normal salinity a few live in brackish water or even in fresh water. Foraminifera inhabiting the brackish water environment has been an interesting subject of study in different parts of the world during the past 20 years. Such studies have been carried out chiefly by Bradshaw (1957), Bandy (1964), Murray (1968b, 1973), Nichols and Ellison (1967) and Tapley (1969).

The foraminifera from the estuaries of Indian coasts have attracted comparatively less attention. A pioneer study on the foraminifera in brackish water in India is that of Ramanathan (1969, 1970) who has reported the occurrence of 20 species in the Vellar estuary in Tamil Nadu. Rao and Rao (1976) have contributed to the study of foraminifera in the Kakinada backwaters on the East Coast of India. Antony (1975a) has given a preliminary report on the foraminifera of the Vembanad estuary, on the West Coast. The present investigation was undertaken with a view to study in detail the foraminifera of the Vembanad estuary (a typical tropical estuary on the South West Coast of India) in relation to the environmental parameters.

The Vembanad lake (Fig. I) the largest on the South West Coast of India is located between latitudes 9° 28' and 10° 10' N and longitudes 76° 13' and 76° 31'E. The length of the lake is about 115 km and covers an area of about 235 sq. km. This forms part of a chain of brackish water lagoons and estuaries which stretch parallel to the coast line of Kerala, extending over 325 km in length. The width of the lake varies between 500 m to 12 km. The Vembanad estuary is an open type and it has permanent connection with the Arabian sea by a narrow channel, about 500 m wide, which forms the main entrance into Cochin harbour.

The Vembanad lake is a shallow one; the depth varies from 8-10 m in the lower reaches close to the sea. The upper reaches of the estuary which are close to the fresh water zone are relatively shallower, with depths ranging from 2 - 5 m. The bottom of the estuary is generally muddy.

Six rivers - Periyar, Pamba, Achancoil, Manimala, Meenachil and Moovattupuzha flow into the lake. It also

Fig. 1 Map of the Vembanad estuary showing locations of the stations investigated.

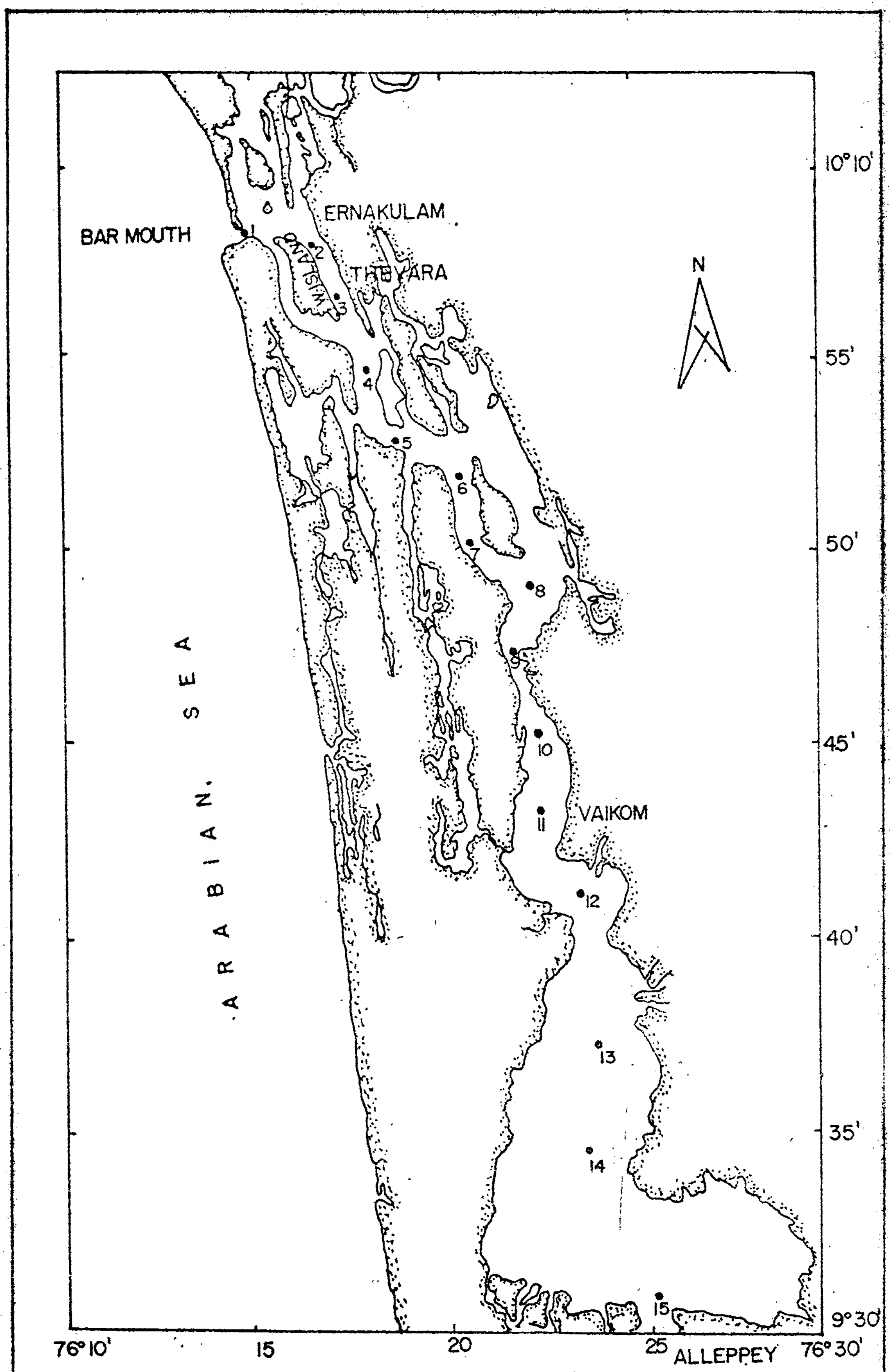

BAR MOUTH
ERNAKULAM
W.ISLAND
THEVARA
N
ARABIAN SEA
VAIKOM
ALLEPPEY
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
10°10'
55'
50'
45'
40'
35'
9°30'
76°10'
15
20
25
76°30'

FIG. 1

receives some canals and tributaries during the monsoon months. The inflow of fresh water into the lake from various sources varies from season to season. The average tidal range of the lake is about 1 m in the lower part of the estuary and it diminishes progressively towards the upper region. The tidal current from the sea into the lake on one hand and the discharge of fresh water from the rivers and their tributaries on the other, mix salt and fresh water and make the lake a typical estuary.

The Cochin gut is adequateenough to transmit the tidal energy and sea salts into the lake. The run-off plus precipitation exceeds evaporation and so it is a positive type of estuary. As it is subjected to long term alterations in salinity and other parameters resulti in seasonal variations, the conditions of the lake become unique for biological and hydrographical investiga

Material and Methods

The study area

A preliminary survey for foraminifera in the Vembanad estuary was conducted taking sediment samples from 125 equidistant sampling stations distributed from Cochin barmouth in the north to Alleppey in the South situated between latitudes 9° 30' and 10° N and longitudes 76° 16', and 76° 25' E. Four samplings were done during the pilot survey in October 1970, April 1971, October 1971 and January 1972. All the samples were subjected to examination and all contained foraminifera, either calcareous or chitinous or siliceous - agglutinated forms. The results of this preliminary observation have been reported earlier by Antony (1975a).

From this study it has been observed that calcareous living foraminifera are found living upto the middle region of the estuary - a distance of about 35 km from the barmouth. No limit of tolerance has been observed in the lake for chitinous and siliceous forms. Based on the results of the preliminary survey on the distribution of foraminifera in the lake, 15 representative stations were chosen for the present study for sample collection at different points in the lake. (Fig. 1, Table 1). Fortnightly collections were made for a period of two years from July 1973 to June 1975.

Field collections

Though different methods are used for representin the living foraminifera such as the number per unit volu

Table 1 List of stations showing the distance from barmouth, locality and depth.

Station No.	Depth (m)	Distance from barmouth (km)	Locality
1	8.0	0	Barmouth
2	6.0	2	Ernakulam Chann
3	5.0	5	Thevara
4	4.5	8	Nettor
5	3.5	12	Edacochin
6	4.0	16	Arookutty
7	3.5	20	Perumbalam
8	3.5	24	Paravoor
9	5.5	28	Chempu
10	5.0	32	Thyecttussery
11	2.5	36	Vaikom
12	3.0	40	Vechoor
13	2.0	47	Thottumugappu
14	1.5	53	Ariyad
15	1.5	60	Alleppey

(Parker *et al*, 1959; Phleger, 1964, 1965) and the number per unit weight (Bandy, 1954, 1964; Reiter, 1959; Zaleeny, 1959; Harman, 1964), the present study was carried out on the basis of the unit area.

Sediment samples were taken using a Van-veen grab of 0.05 m^2 surface area. As soon as the grab was hauled up the top plate of the grab was removed and the surface of the deposit was exposed. The surface material having an area of 10 cm^2 and 1 cm depth was taken (Murray 1970). In order to check the reliability of these samples duplicate sample were taken from each station for the analysis of foraminiferal population and the mean values were taken. The sample was preserved immediately after collection in ethyl alcohol or 5-10% neutralised formalin. When formalin was used for preservation a small amount of sodium carbonate was added to the sample to maintain an alkaline solution, since the neutralised formalin becomes acidic with time. This type of sampling method for the study of epifauna upto 2 mm diameter has been suggested by many authors (Phleger, 1951; Mc Intyre, 1969; Murray, 1969, 1970). Besides this a portion of the sediment sample from each station was taken in Polythene bags for determining the organic matter and grain size analysis. The sediment core was split into 1 cm long sections, each of which was collected in a plastic container, by gently releasing the rubber bung, with the core tube held in a vertical position. Two or three samples were taken in this way from each station.

Environmental conditions such as water temperature, salinity, dissolved oxygen, pH and nutrient contents were studied during the period of investigation. Water temperature was measured by using an ordinary centigrade thermometer. Water samples for salinity, dissolved oxygen and nutrients were collected from the surface and near bottom. Surface water samples were collected using an ordinary plastic bucket, and bottom water immediately above the sediment, using a bottom water sampler.

Laboratory analysis

In the laboratory chlorinity of water was estimated using the Mohr Method (Barns, 1959) and salinity calculated using Knudsen's Table. Dissolved oxygen in the water was estimated using the Winkler method (Barns, 1959). Nutrients of the water samples were determined by the methods suggested by Strickland and Parsons (1965). pH was determined using a pH meter.

The preserved sediment samples were washed through a 230 mesh sieve (0.063 mm) for eliminating silt and clay. Tap water was allowed to flow until the mud and other suspended matter were removed from the sample. The foraminifera thus collected included dead as well as living specimens.

The live and dead specimens were separated by adding Rose Bengal stain. The shells which got stained were taken as alive and the others were regarded dead (Walton, 1952). Stained sample was washed clearly to remove the excess stain and dried. Small quantities of the same were spread out evenly on a graph slide and examined under a stereoscopic binocular microscope. Dead shells were separated from the residue by floatation using carbon tetrachloride solution (Cushman, 1948). For ascertaining the numerical strength of the different species all foraminiferal specimens (both living and dead) were counted. Regarding the dead shells it has not been possible to know whether they died a few days or weeks before collection. The foraminiferal shells were picked out from the dry sample with a fine moist brush. The specimens for identification were fixed on a glass slide in a thin layer of gum dissolved in water and allowed to dry. Canada balsam was used for permanent mounting.

As remarked by Hedley and Adams (1974) it is usually difficult to get all species identified owing to the non-availability of literature. However, with the knowledge gained during the last several years in the identification of the local foraminiferal species it has been possible to identify most of the specimens collected. In the present study no new species have been recorded and the taxonomic part has been omitted from the purview of this study. The classification followed in the present study is that of Cushman (1948), but the identification of specimens is based on recent literature by various authors.

Portextural study the sediment samples taken from the grab haul were subjected to the combined sieving and pipette analysis method given by Krumbein and Pettijohn (1938). Known quantities of the dried sediment sample were first dispersed overnight with sodium hexametaphospha solution of 0.025 N. The silt and clay fractions were separated by washing the dispersed sediment through a 230 standard mesh sieve. The coarse fractions retained in the sieve were dried and weighed which gave the weight of material coarser than 0.063 mm. The dried materials were analysed using a set of standard Endicott sieves. The washings collected in a measuring jar of one litre were analysed for silt and clay by pipette method.

Observations

Hydrography

An important feature of the Vembanad estuary is the influence of the south west monsoon which affects the hydrographic conditions of the area in a very remarkable manner. The lake receives the full benefit of the south west monsoon as well as some precipitation from the north east monsoon. The south west monsoon flood causes large inflow of fresh water which affects greatly the fauna inhabiting the backwaters. The hydrographic conditions of the Vembanad estuary are influenced both by the sea and the fresh water.

Based on the influence of monsoon and the associat environmental conditions the year can be conveniently spl into three well defined periods having characteristic hydrographic features. The pre-monsoon period (February-May) is comparatively with very little rain fall and characterised by a fairly uniform high salinity and high temperature, the monsoon period (June-September) is characterised by heavy rain fall and high inflow of river waters into the estuary causing considerable lowering of slinity. The post-monsoon (October-January) period shows an increase in the salinity and temperature values (Balakrishnan, 1957; Ramamirtham and Jayaraman, 1963; George and Kartha, 1963 and Jose Anto, 1975).

Temperature:

The details of bottom water temperature during the period of investigation are shown in Fig. 2. It may be seen that the highest temperature is in April (32.2°C) and the lowest in July (26.7°C). The difference in temperature from the surface water to the bottom is about 1°C in the dry season and it is about 3°C in the monsoon months. The temperature difference between the water at the upper reaches of the estuary and that of the lower reachs is less than 2°C in all the months. The results show that the temperature difference between the bottom water and the sediment never exceeds 0.5°C at any time of observation. The period of south west monsoon coincides with the period of minimum water and sediment temperatures. From June to August-September the temperature gradually decreases and from February to April-May it shows progressive increase. There is also a slight decrease in temperature from October to January.

Salinity:

The salinity of the Vembanad estuary varies from place to place, season to season and surface to bottom. Seasonal changes in salinity are very well marked. June to August is the active period of monsoon. During June-July with the onset of the monsoon there is a sudden fall in salinity throughout the estuary (0.19-3.2‰). Even before the close of the monsoon, sea water begins to penetrate into the estuary. But the intensity of tidal influence is negligible in the upper reaches of the estuary due to the strong seaward flow of fresh water from the rivers. From October onwards the salinity rises uniformly throughout the area due to tidal effects and reaches its maximum in April-May (33.5‰). In the lower region of the estuary, during April-May the conditions are predominantly marine. During this period there is not much difference in salinity values between the upper reaches of the estuary (30.2‰) and the lower reaches (33.5‰). During the period of high salinity there is very little difference in values from the surface water to the bottom, both in the upper and lower reaches of the estuary. But during the other periods the difference in the vertical profile is more pronounced. Except during the flood season the entire lake shows typical brackish water conditions. The values of bottom water salinity are shown in Fig. 2.

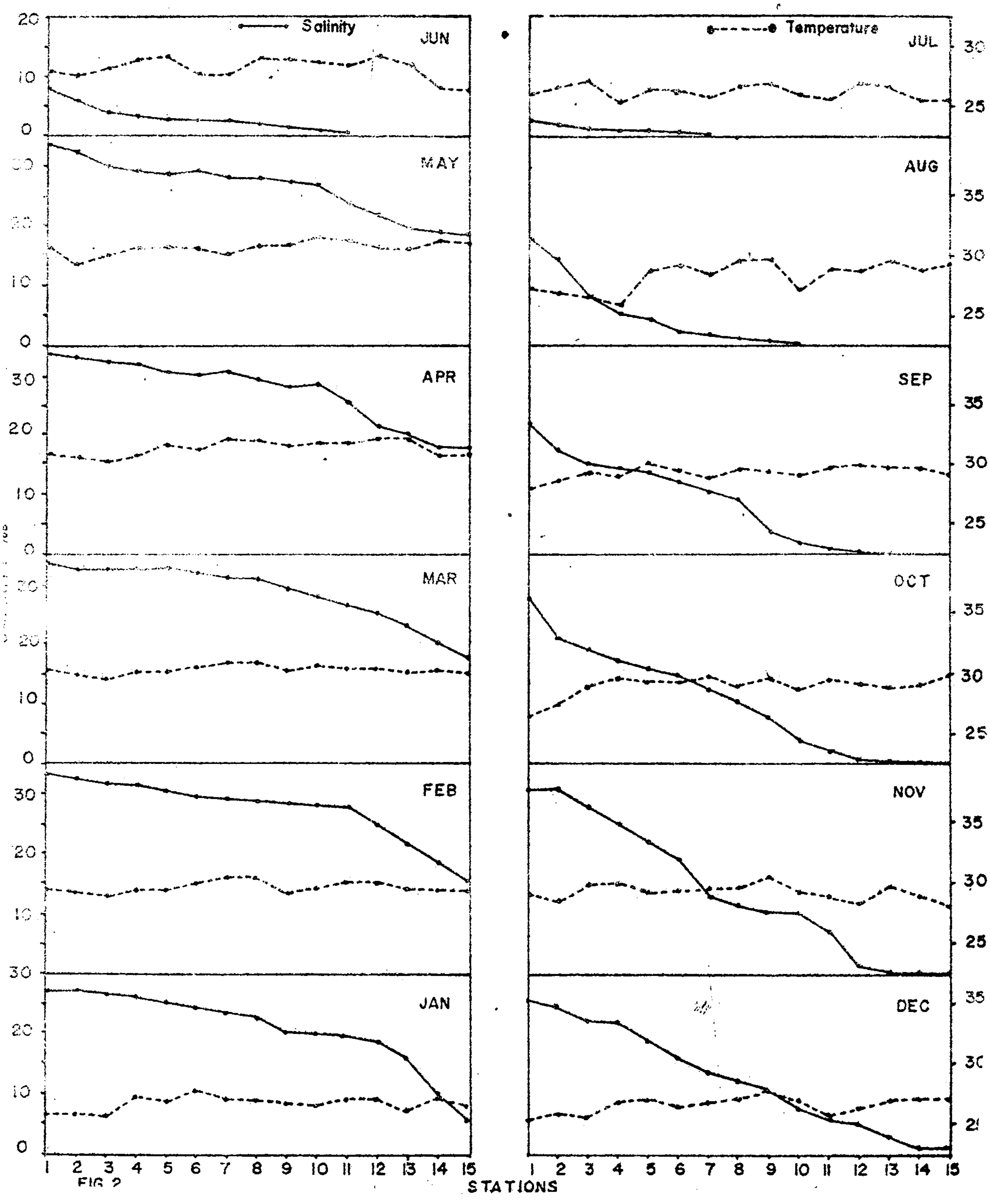
Tides:

The tide of Cochin area is of mixed semi-diurnal type with an average range of 1 m. During November-December high spring tides of 1 m and above occur at the Cochin gut. The tidal range progressively diminishes towards the upper region. During the pre-monsoon and post-monsoon periods the tidal effects can even be noticed at Alleppey (station 1 60 km away from the barmouth. During the flood season the effect of the tidal currents is very much reduced and it is felt only upto Aroor, 12 km south of the gut. Thus the tidal current, responsible for carrying the salt water upstream during the pre-monsoon and the post-monsoon seasons is having very little effect during the monsoon season.

Dissolved oxygen:

Dissolved oxygen content of bottom water varies from 3.2 ml/l at station 1 in January to 6.4 ml/l at

Fig. 2 Monthly mean values of temperature and salinity of the bottom water of the Vembanad estuary during July 1973 to June 1975



Salinity
Temperature
JUN
JUL
MAY
AUG
APR
SEP
MAR
OCT
FEB
NOV
JAN
DEC
STATIONS

FIG 2

station 9 in July. During the monsoon months the winds are fairly strong and it can bring about agitation and increased dissolution of atmospheric oxygen in the surface waters. The increase in fresh water influx is favourable for an increase in dissolved oxygen during the monsoon months. Persistant zonal variations in the dissolved oxygen are displayed from the marine to the fresh water end of the estuary. Oxygen values are always higher in the fresh water zone of the estuary than in the marine region. The changes in the oxygen values seem to be inversely related to the changes in salinity. The values of dissolved oxygen are shown in Fig. 3.

pH:

pH shows variations within the range of 7.0 to 8.4 as shown in Fig. 3. A review of the monthly values of pH shows seasonal fluctuations with the lowest value (7.0) during June-July and the highest (8.4) during March-April months. Zonal variations in pH are seen, always with high values in the lower part of the estuary and lower values towards the upper part. The increase in pH in the pre-monsoon and post-monsoon periods throughout the area and in the post-monsoon period in the marine end shows a favourable ecological condition for marine organisms in the estuary.

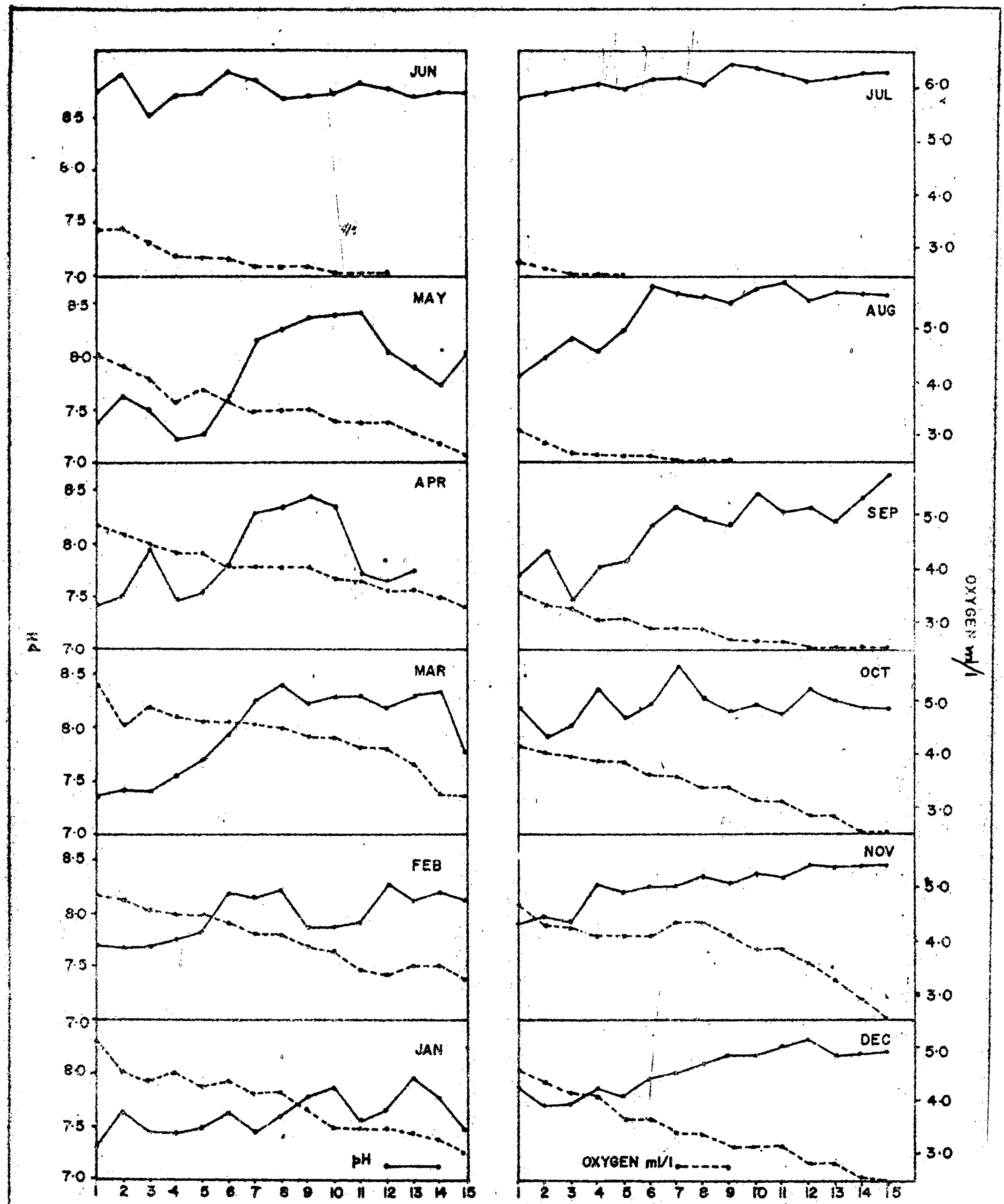

JUN
JUL
MAY
AUG
APR
SEP
MAR
OCT
FEB
NOV
JAN
DEC
pH
OXYGEN ml/l
STATIONS

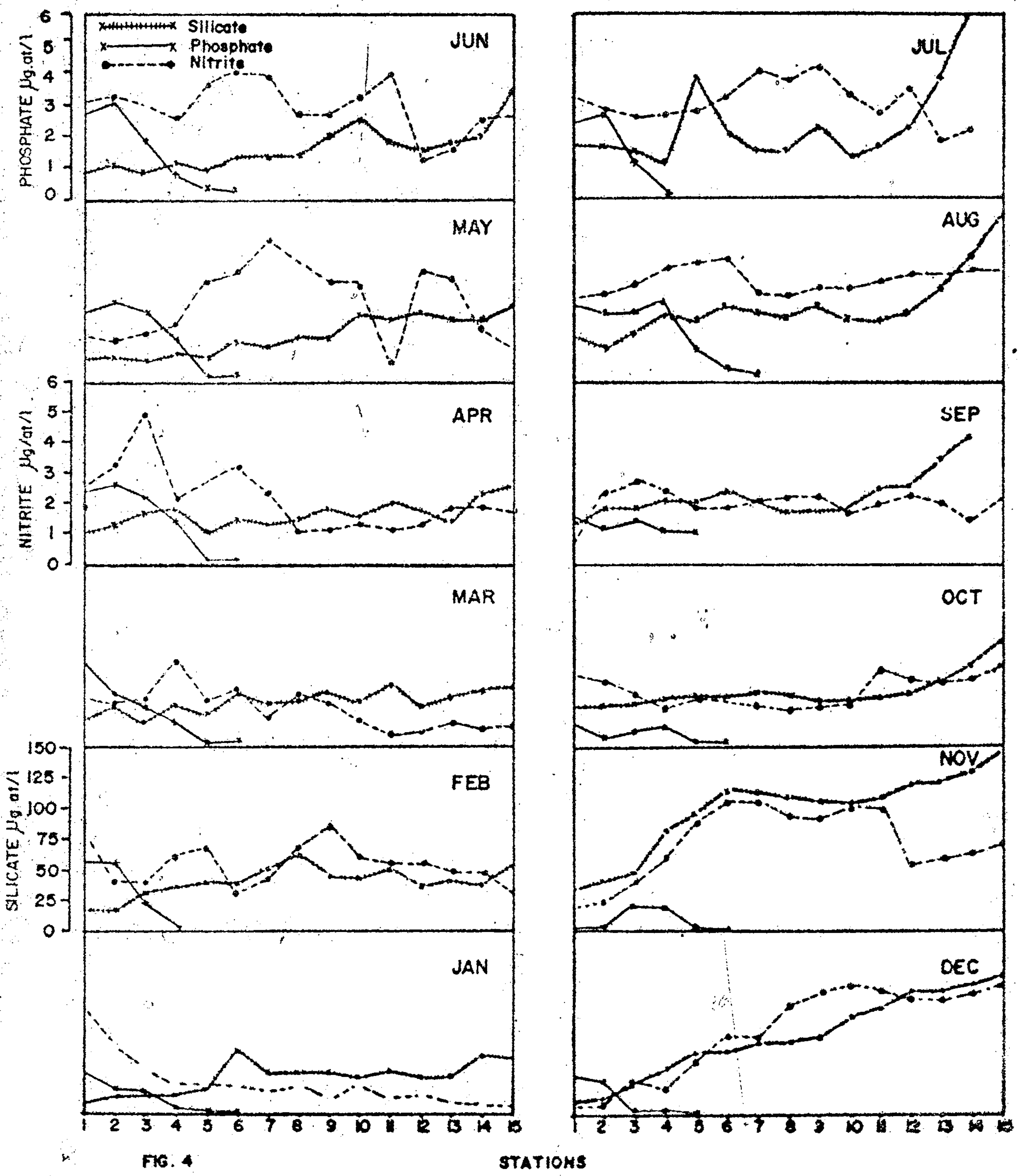
FIG. 3

<u>Nutrients:</u>

The inorganic phosphate concentration in bottom water varies between 0.11 µg at/l and 2.8 µg at/l, the highest value obtained in June-July and the lowest in November. It is significant that high values of phosphate are recorded in the marine zone and the upper half of the estuary marks the least concentration in all seasons. There is considerable variation in the inorganic phosphate content in different months. The maximum phosphate content is observed during the monsoon period and the minimum during the post-monsoon period. Monthly mean values of the phosphate content in the area are given in Fig. 4.

Values of nitrite are given in Fig. 4. Nitrite values are subjected to little fluctuation and range between 0.3 µg at/l in January to 4.8 µg at/l in June. The maximum values are recorded during the monsoon period and the minimum during the pre-monsoon.

Monthly values of silicate are shown in Fig. 4. Silicate content in the Vembanad estuary shows rhythm mainly due to the local precipitation and the river run off. The peak value of silicate in the area was 155 µg at/l and was recorded in July at station 15 and the lowes value was 12 µg at/l recorded in December at station 1.



Silicate
Phosphate
Nitrite
PHOSPHATE μg.at/l
NITRITE μg/at/l
SILICATE μg.at/l
JUN
JUL
MAY
AUG
APR
SEP
MAR
OCT
FEB
NOV
JAN
DEC
STATIONS

FIG. 4

During the monsoon period high concentrations of silicate are recorded. After a decline during the pre-monsoon another peak of silicate enrichment in the estuary occurs during October to December period.

Currents:

The water currents normally appear to be tidal in origin except during June-July when there is monsoon flood. The incoming and outgoing of tidal currents are observed throughout the lake, although they vary in intensity with reference to seasons. During high tide vertical variations in salinity are observed especially towards the barmouth region of the estuary. This is caused by the surface currents of outgoing fresh water and the running of incoming seawater under the surface water.

Substrate

The details of the composition of the sediments are given in Table 2. From this it is evident that the composition of the sediment varies markedly from station to station and season to season. Sand-silt-clay ratios determined for the sediment show that in 13 stations clay content predominates and it varies between 20 to 66% in the pre-monsoon period, 18 to 49% during monsoon and 21 to 64% in the post-monsoon period. Sand is the next dominant constituent of the substrate at 6 stations which forms 41 to 70% in the pre-monsoon, 40 to 73% in the monsoon and 40 to 80% in the post-monsoon season. At stations 12 and 13 sand comprises 86% and 84% respectively. Silt forms the least dominant constituent of the substrate in all the stations and it ranges from 10 to 41% in the pre-monsoon, 12 to 48% in the monsoon and 11 to 41% in the post-monsoon period. In general the substrate in the Vembanad estuary mainly falls into the category of clayey-sand or sand-silt-clay. Sandy substrate and silty-clayey substrate are found at two stations each.

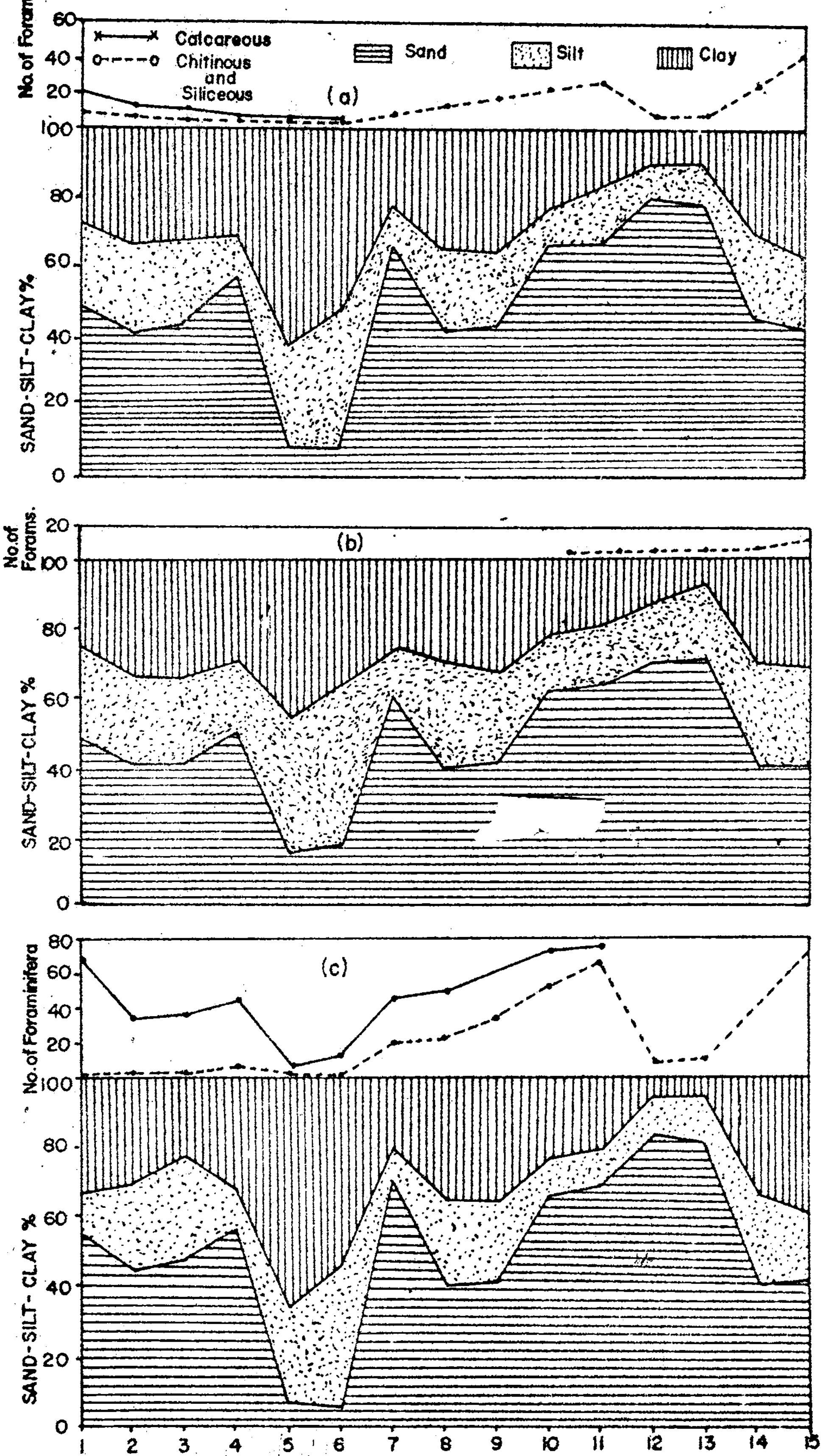
Though the percentages ofsand-silt-clay composition vary slightly from season to season the sediment type is not changing. Near the barmouth area(station 1) the sediments are clayey sand. The substrate of station 2 and 3 (Ernakulam Channel and Thevara) are of sand-silt-clay type. Clayey-sand occupies station 5 and silty-clay station 6. Again a stretch of clayey-sand occurs south of Perumbalam (station 7). The sediments at Peravoor (station 8) and Chembu (station 9) are of sand-silt clay. Further south at Thaikattucherry (station 10) and Vaikom (station 11) the sediments are again of clayey-sand type. The deposits are sandy at station 12 (Vechoor) and 13 (Thottumugappu). Near Aryad (station 14) the sediments are sand-silt-clay which is followed by clayey-sand deposit at Alleppey (station 15).

Based on the texture of the sediment type the region under investigation can be differentiated into the following major sedimentological divisions viz. (1) the mud dominant regions of the southern and northern ends of the estuary, (2) a sandy zone in the central region and (3) two scattered zones, one a stretch of silty-clay deposit zone extending between stations 5 and 6 and another with sand as the dominant fraction extending from station 12 to 13.

A perusal of Fig. 5 shows that there are seasonal variations in the sand-silt-clay content of the sediment. During the monsoon period sand is comparatively less in the southern and northern ends of the backwaters than in the other seasons, with a corresponding increase of silt fraction throughout the area. During this period in the middle region the proportion of clay also decreases due to the increase in the silt content. In the post-monsoon period sand proportion is less than that in the pre-monsoon throughout the area except in the barmouth region. In the upstream area the clay content shows an increase during this period than in the pre-monsoon season and the silt fraction is more downstream than in the pre-monsoon season The minimum value of silt content is observed during the pre-monsoon period throughout the backwaters.

Table 2 Sand, silt and clay content (%) of the bottom sediments in the Vembanád estuary (Mean values of April, July and December 1974 and 1975).

St. No.	April Sand	April Silt	April Clay	July Sand	July Silt	July Clay	December Sand	December Silt	December Clay	Sediment type (Shepard, 1954)
1	55.51	12.69	31.80	48.34	24.96	26.70	46.54	25.76	27.70	Clayey sand
2	43.45	25.82	30.73	41.35	26.35	33.30	40.35	26.35	34.30	Sand silt clay
3	48.24	29.96	21.70	42.12	23.20	33.68	42.52	23.00	33.48	Sand silt clay
4	57.94	10.15	31.95	50.84	20.15	29.05	55.80	12.25	31.95	Clayey sand
5	06.03	28.17	65.80	15.03	36.18	48.79	08.23	26.07	63.70	Silty clay
6	05.56	41.74	52.70	12.56	48.50	38.34	06.56	40.74	53.70	Silty clay
7	70.00	09.25	20.75	60.20	15.15	24.65	65.10	12.25	22.65	Clayey sand
8	39.96	27.64	35.40	40.10	32.54	32.40	40.76	28.74	35.50	Sand silt clay
9	41.45	23.25	25.30	42.45	28.35	30.20	41.35	22.35	36.30	Sand silt clay
10	67.52	09.88	22.60	65.52	12.78	21.70	65.62	10.78	23.60	Clayey sand
11	68.53	09.87	21.60	67.53	12.67	18.80	65.23	12.27	21.50	Clayey sand
12	86.00	09.90	04.10	70.70	17.70	12.10	12.70	11.00	10.10	Sand
13	83.42	12.23	04.35	73.42	19.13	07.95	78.42	13.33	09.25	Sand
14	41.68	24.52	33.80	40.58	28.62	30.80	44.58	25.62	30.80	Sand silt clay
15	42.32	19.10	38.58	41.32	26.20	32.48	42.32	21.10	36.58	Clayey sand



Calcareous
Chitinous and Siliceous
Sand
Silt
Clay
(a)
No.of Forams.
SAND-SILT-CLAY %
(b)
No.of Forams.
SAND-SILT-CLAY %
(c)
No.of Foraminifera
SAND-SILT-CLAY %
STATIONS

FIG. 5

General distribution of foraminifera

In the present study the foraminiferal community as a single entity is dealt with and an attempt has been made to understand their occurrence and dominance of each species within the community. The foraminifera in the Vembanad estuary appear to vary according to estuarine conditions. The general distribution of species shows that the lower reaches of the estuary, particularly near the barmouth is characterised by calcareous species. Calcareous forms decrease in number in relation to the decreasing influence of the sea water and they are completely absent in the upper reaches of the estuary. The siliceous and chitinous foraminifera are dominant in the upper reaches of the estuary where fresh water conditions prevail. They occur very rarely in the marine zone and their number increases with the decreasing influence of marine environments towards the upper parts of the estuary.

Of the 10 calcareous genera recorded, Rotalia, Elphidium and Quinqueloculina are represented by the largest number of specimens. Together they account for about 85% of the total calcareous species while each of the other genera is represented by only a few specimens. A relatively large number of foraminifera belongs to the family Rotaliidae. Ammonia beccarii (Linne), the most dominant species in the lower half of the estuary forms about 50% of the total foraminiferal population in the area. Other species which are widely distributed in the marine zone are Elphidium crispum Linne, E. craticulatum (Fichtel and Moll) Quinqueloculina seminulum (Linne), Rotalia calcar d'Orbigny, Discorbis rosacea (d'Orbigny), Cibicides lobatulus (Walker and Jacob) Nonion boueanum Hade and Nonion sloanii d'Orbigny. Rest of the species occur in low concentrations in the area.

Though the chitinous and siliceous species are dominant in the upper half of the estuary, not all the species are equally distributed in the area. Of the 11 species, Miliammina fusca (Brady), Trochammina inflata (Montague) and Saccammina sphaerica Sars occur in abundance in the upper reaches. Of these three dominant species Trochammina inflata is abundant in the middle region of the estuary and they account for about 60% of the total fauna in that area. Miliammina fusca shows the highest population in the upper most end (station 15) forming about 55% of the total fauna. Saccammina sphaerica also seems to be dominant in the upper region (stations 11-15) constituting about 20% of the foraminiferal fauna. Other major species distributed in the area are Trochammina nitida Brady, Ammobaculites foliaceous Brady, Ammobaculites taylorensis Cushman and Waters and A. dilatatus Cushman and Bronnimann. Though these species are common throughout the estuary their number decreases towards the lower reaches. In some of the stations in the upper half they account for about 10% of the total population. The lowest number of specimens forming less than 10% of the total fauna belongs to the species Reophax scottii Chaster and R. gattella Hoglund in the upper zone. The species Textularia agglutinans d'Orbigny and T. conica d'Orbigny constitute less than 10% of the total population in the middle and lower regions of the estuary.

In addition to the 32 species recognised from the stuarine environment some other species are also found as live specimens in the barmouth area (station1). But their occurrence appears to be restricted to this area only and that too in the high saline conditions of the barmouth region during the pre-monsoon period and they are never found living in samples from other stations. Since the occurrence of these species is restricted to the barmouth area in a high saline condition (about 30‰ S) and their number is negligible in the area, it is obvious that these species are characteristic of marine habitat and have only very little tolerance capacity in the estuarine environment.

Numerical density

The results of the survey conducted for two yers reveal that the foraminiferal fauna in the estuary is rich numerically. But the total number of live foraminifera present in the sample shows considerable variations. In order to have an overall picture of the distribution of the foraminifera in the estuary, monthly mean values of the total population and other ecological factors have been determined. The details of the numerical density at different stations are given in Fig. 6. It shows that the number of individuals per (10 cm^2 surface sediment varies from 8 to 80 in the pre-monsoon months, 5 to 42 in the post-monsoon period and 0 to 11 in the monsoon months.

Analysis of the live populations from different months reveals that the largest live population occurs throughout the estuary in the pre-monsoon months. In the post-monsoon period a medium density of population exists throughout the estuary. But the live population is less in the monsoon months.

When the total number of live specimens are taken into account stations 11 and 15 record the highest values with concentrations of 80 and 78 individuals respectively. Similar high density of total individuals is observed at stations 10 and 1 with the values 74 and 65 respectively. Stations 9, 8, 7, 14, 4, 3 and 2 support relatively large populations with 63, 48, 46, 42, 43, 38, and 34 living specimens respectively. At stations 6, 13 and 12 the samples contain a maximum of 14, 13 and 8 specimens respectively. The least value of live specimens is observed in station 5 with only 6 individuals. The monthly average of live specimens in the three seasons are given in the Table 3.

Species composition:

Bottom samples of the Vembanad estuary yielded 32 species of live foraminifera representing 16 genera

Table 3 Seasonal variations in monthly mean values of living foraminifera in the Vembanad estuary, during July 1973 - June 1975 (per (10 cm)^2 sample)

Station	Seasons								
	Pre-monsoon			Monsoon			Post-monsoon		
	Cal.	Sil.	Total	Cal.	Sil.	Total	Cal.	Sil.	Total
1	63	2	65	-	-	-	21	4	25
2	32	2	34	-	-	-	14	3	17
3	35	3	38	-	-	-	8	3	11
4	36	7	43	-	-	-	3	2	5
5	5	3	8	-	-	-	3	2	5
6	11	3	14	-	-	-	3	3	6
7	25	21	46	-	-	-	-	10	10
8	26	2[illegible]	48	-	1	1	-	12	12
9	32	31	63	-	3	3	-	18	18
10	21	53	74	-	5	5	-	22	22
11	12	68	80	-	6	6	-	28	2[illegible]
12	-	8	8	-	2	2	-	5	
13	-	13	13	-	2	2	-	7	
14	-	42	42	-	8	8	-	24	
15	-	78	78	-	11	11	-	42	

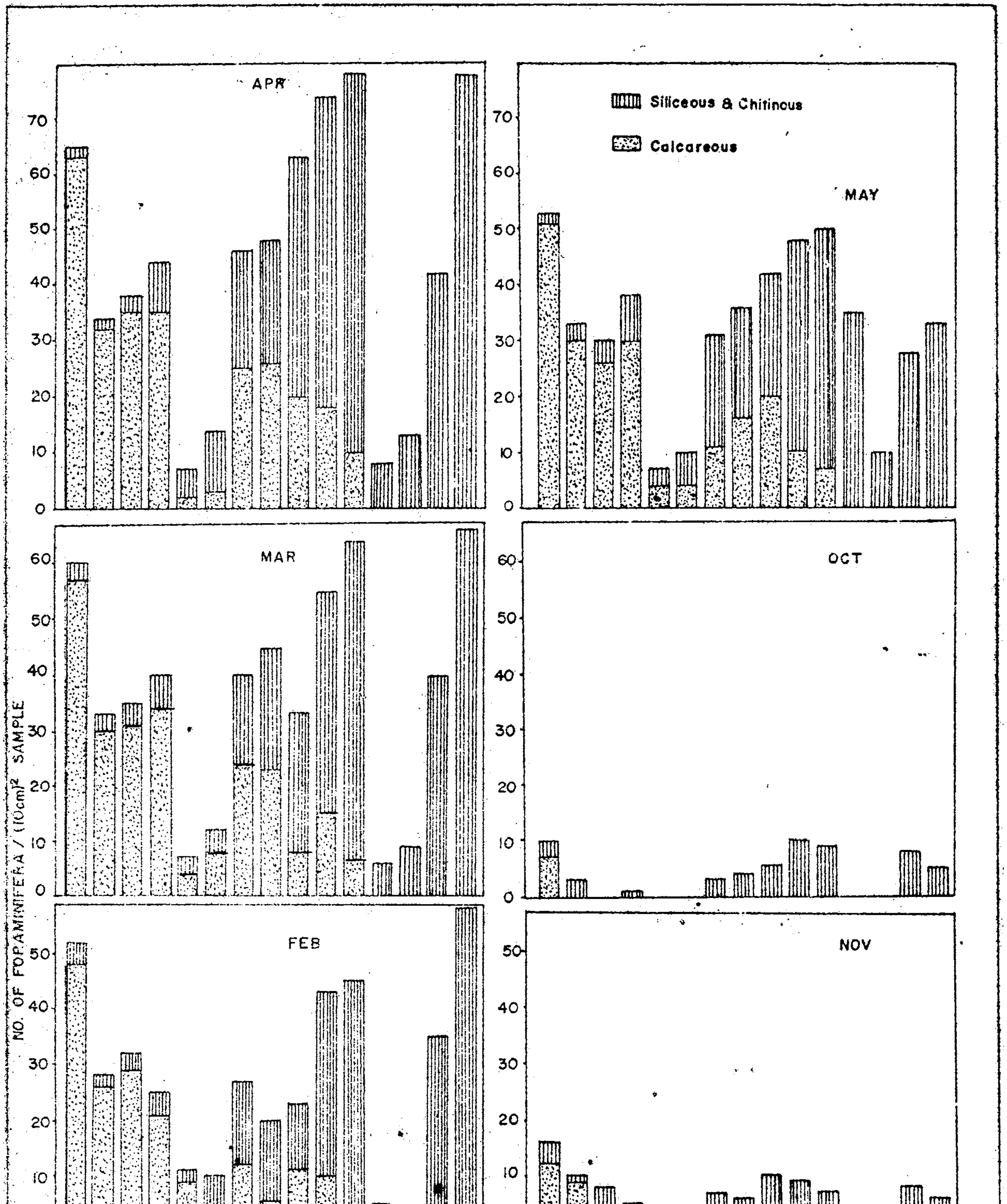
Cal. Calcareous
Sil. Siliceous

in 12 families. The collections include calcareous, chitinous and siliceous specimens; the major portion (66%) of the assemblage being calcareous. All of them are benthic, living on sandy, clayey and silty substrates. The calcareous foraminifera is composed of species with imperforate or perforate tests. The perforate group has the largest number of families (5) and most genera (8) and species (17). The imperforate family Miliolidae has only 4 species in 2 genera. The classified list of foraminifera is given in Table 4.

Arenaceous-Agglutinated Foraminifera:

Arenaceous-agglutinated specimens consist of chitinous and siliceous tests composed of foreign particles bound together with cement. In the most earlier groups of foraminifera, the primitive chitinous tests are developed. The test of this primitive forms is of chitin and the foreign material is added on the outer portion. Truly chitinous tests are developed only in a few groups particularly in the families Saccamminidae and Silicinidae.

Family Saccamminidae is represented by a single species which occurs widely in the upper part of the area. Family Reophacidae with 2 species forms the



APR
MAY
MAR
OCT
FEB
NOV
JAN
DEC
Siliceous & Chitinous
Calcareous
NO. OF FORAMINIFERA / (10cm)² SAMPLE
STATIONS

FIG. 6

Table 4 Classified list of foraminifera collected from the Vembanad estuary

Family	Saccamminidae
Subfamily	Saccammininae
Genus	*Saccammina* Sars
	Saccammina sphaerica Sars
Family	Reophacidae
Subfamily	Reophacinae
Genus	*Reophax* Montfort
	Reophax scottii Chaster
	Reophax catella Hoglund
Family	Lituolidae
Genus	*Ammobaculites* Cushman
	Ammobaculites foliaceous (Brady)
	A. taylorensis Cushman and Waters
	A. dilatatus Cushman and Bronnimann
Family	Textulariidae
Genus	*Textularia* Defrance
	Textularia agglutinans d'Orbigny
	T. conica d'Orbigny
Family	Silicinidae
Genus	*Miliammina* Herron Allen and Earland
	Miliammina fusca (Brady)

Family			Trochamminidae
	Subfamily		Trochammininae
		Genus	_Trochammina_ Parker and Jones
			Trochammina inflata (Montague)
			T. nitida (Brady)
Family			Miliolidae
	Subfamily		Miliolinae
		Genus	_Quinqueloculina_ d'Orbigny
			Quinqueloculina agglutinans d'Orbigny
			Q. seminulum (Linne)
			Q. bicornis (Walker and Jacob)
		Genus	_Triloculina_ d'Orbigny
			Triloculina oblonga Montague
Family			Nonionidae
		Genus	_Nonion_ Montfort
			Nonion boueanum Hade
			N. scaphum (Fichtel and Moll)
			N. sloani d'Orbigny
		Genus	_Elphidium_ Montfort
			Elphidium crispum (Linne)
			E. advenum Cushman
			E. macellum (Fichtel and Moll)
			E. craticulatum (Fichtel and Moll)
Family			Camerinidae
		Genus	_Operculina_ d'Orbigny

	Operculina granulosa Leymerie
	Operculina complanata (Defrance)
Genus	*Operculinella* Yabe
	Operculinella cumingii (Carpenter)
Family	Buliminidae
Subfamily	Virgulininae
Genus	*Bolivina* d'Orbigny
	Bolivina nobilis Hantken
	B. striatula Cushman
Family	Rotaliidae
Subfamily	Discorbinae
Genus	*Discorbis* Lamarck
	Discorbis orbicularis Terquem
	D. rosacea d'Orbigny
Subfamily	Rotaliinae
Genus	*Rotalia* Lamarck
Genus	*Rotalia* (*Ammonia*) *beccarii* (Linne)
	Rotalia calcar d'Orbigny
Family	Amphisteginidae
Genus	*Amphistegina* d'Orbigny
	Amphistegina lessonii d'Orbigny
Family	Anomalinidae
Subfamily	Cibicininae
Genus	*Cibicides* Montfort
	Cibicides lobatulus (Walker and Jacob

least representative in this group occurring very rarely in the collections. Lituolidae represented by 3 species have been recorded from the middle stations. Textulariidae represented by 2 species have a moderate occurrence at the lower section of the estuary. Relatively large number of chitinous foraminifera belongs to the family Silicinidae and the single species *Miliammina fusca* (Brady) out-number all the other chitinous species at the fresh water end. Family Trochamminidae includes 2 species and has its maximum intensity in the middle region of the estuary. The species *Trochammina inflata* (Montague) constitutes more than 50 per cent of the total agglutinated foraminiferal fauna.

Calcareous forms:

The majority of foraminiferal fauna has calcareous tests. There are two types of calcareous tests, imperforate and perforate. Imperforate group is the most primitive, which is often referred to in the literature as porcellanous. Species belonging to the family Miliolidae are with chitinous inner wall, showing their arenaceous ancestral character. The perforate calcareous forms are referred to as hyaline.

Calcareous imperforate group is represented by 4 species in 2 genera belonging to the family Miliodidae. Specimens of this group are common at the lower sector of the estuary.

The majority of the species belongs to the calcareous perforate group. This group includes 17 species in 8 genera and 5 families. Among these, family Rotaliidae is the best represented and it includes 4 species in 2 genera. Numerically *Ammonia beccarii* is the most predominant species in the lower reaches of the estuary and it forms more than 50 per cent of the total population in the area. Family Anomalinidae is represented by a single species which is common in the lower part of the estuary. Family Nonionidae comprises the most varied group in number of species with 2 genera and 7 species. Numerically they are second in abundance at the marine end. Individuals of this group amount to about 20 per cent of the total population in the area.

Distribution of dead shells:

Both the living and dead specimens were counted from all the stations and the numerical abundance is shown in Fig. 7. In order to have an overall pattern

Fig. 7 Distribution of live and dead specimens of foraminifera at different stations in the Vembanad estuary (mean values of April 1974 and 1975 are taken)

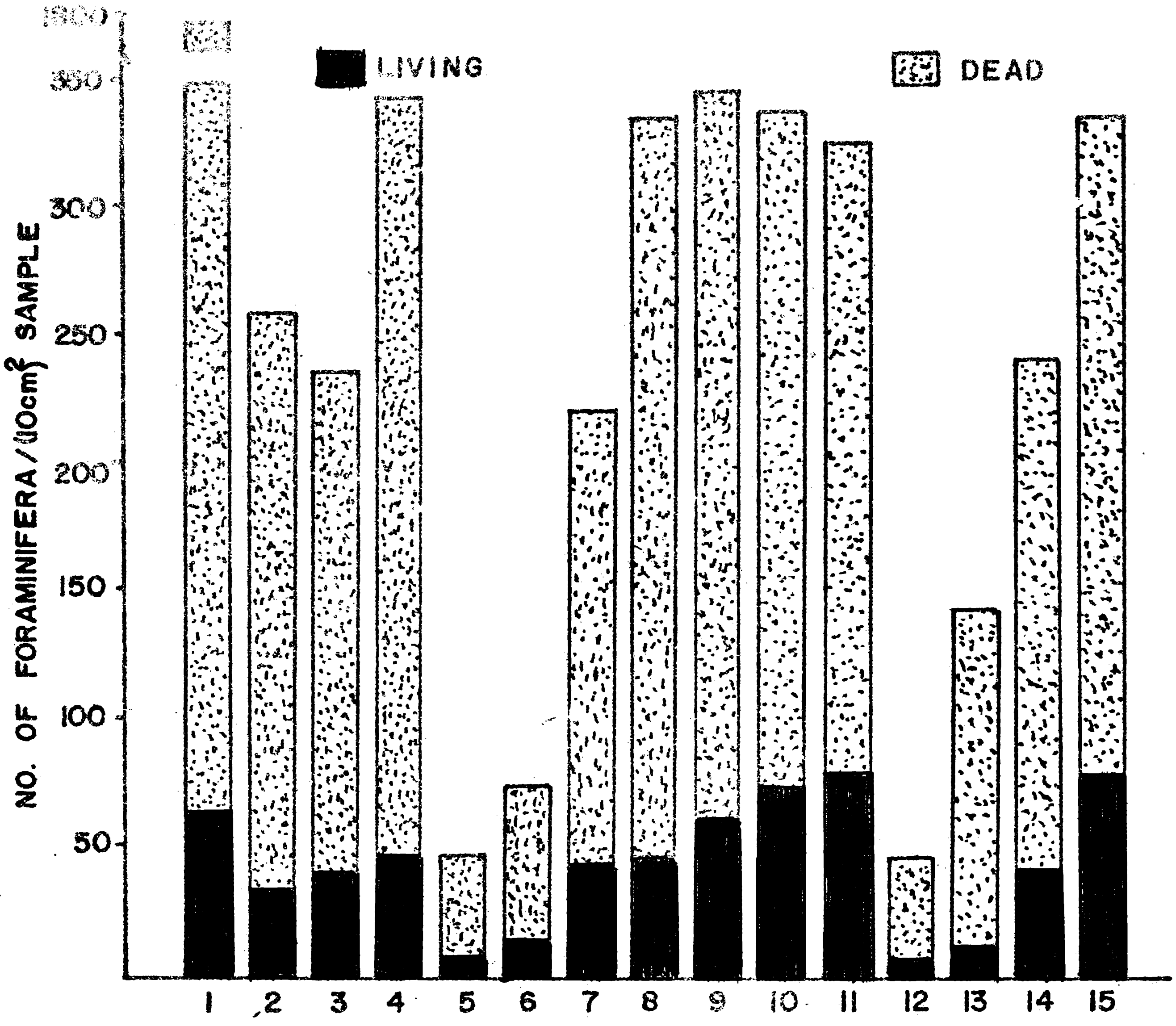

LIVING
DEAD
NO. OF FORAMINIFERA / 10cm² SAMPLE
1800
350
300
250
200
150
100
50
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
STATIONS

FIG. 7

of occurrence of the dead specimens, monthly mean values of the three seasons are given. Only the total number of dead shells at each station was noted and the dead individuals of the same species was not counted separately, as done for the living specimens.

The distribution of the calcareous and siliceous specimens varies according to the zonal divisions in the estuary. Empty tests of calcareous forms are dominant in the marine zone. Dead shells of all the estuarine species have been found in the lower part. The barmouth area (station 1) is characterised by the presence of the dead shells of all the marine forms in addition to the estuarine species. In general the number of marine forms decreases in relation to the decreasing influence of sea water and they are completely absent in the upper part of the estuary. Relatively large number of dead shells of the calcareous foraminifera belongs to the family Rotaliidae. When the living specimens of Rotalia beccarii are seen upto a distance of 35 km (station 11) from the barmouth, the dead shells of this species are found at a distance of 46 km from the barmouth i.e. the empty tests of A. beccarii are distributed upstream 11 km beyond the limit of living specimens. However they are not found living beyond station 11 and the dead shells are abundant in the assemblage.

Dead shells of chitinous and siliceous species are scarce in the lower estuary while they form the characteristic sediment of the upper part. The dead specimens in this area are dominated by the species *Miliammina fusca* and *Saccammina sphaerica*. Empty tests of *Trochammina inflata* and *Ammobaculites dilatatus* are dominant in the middle region of the estuary. Other chitinous and siliceous species are, found rarely. As regards the chitinous and siliceous forms the total dead specimens range from 8 to 78 at stations 12 and 15 respectively.

Live-dead ratios:

The number of living specimens and dead shells varies from a minimum of 5 and 40 respectively at station 5 and to a maximum of 65 and 1800 respectively at station 1 per sample. The low values of dead shells are found at stations 6, 12 and 13 where the number of dead shells are 75, 40 and 130 respectively. The number of living specimens at these stations are 14, 8 and 13 respectively. An average of 260 dead specimens are found in other stations. Distribution of the live - dead ratios of foraminifera is given in Fig. 7.

Absolute abundance:

The concept of absolute abundance of live foraminiferal population has been introduced by many workers like Bandy (1954, 1964), Bandy *et al* (1964, 1965), Harman (1964), and Mc Glasson (1959). All of them have given the number of specimens by unit weight of the surface sediment. In the case of these microorganisms it is difficult to express their live population in biomass, by taking the live weight of the animals, as it is not easy to separate all the specimens from the sediment. The method used by Phleger (1960) i.e. the number of foraminifera in a unit area of $(10\ cm)^2$ is followd in the present study for estimating the absolute and relative abundance of living foraminiferal assemblage. This method of quantifying living foraminifera in a unit area of $(10\ cm)^2$ has been used by many of the recent workers also (Bradshaw, 1968; Murray, 1968 b; Rao and Rao, 1976; Albani 1978).

The absolute abundance of the live foraminifera is shown in Fig. 6. On the whole the foraminiferal fauna in the estuary is rich numerically in the pre-monsoon season and poor in the monsoon season.

From June to September calcareous forms are absent throughout the estuary. The chitinous and siliceous forms are also relatively few during these months. The low absolute abundance in the monsoon months affects the corresponding relative abundance of species, making the latter not so reliable when used in comparison with other seasons that have higher foraminiferal concentrations and relatively more number of species.

The total standing crop in the area never exceeds 80 specimens (station 11) per $(10\ cm)^2$ sample throughout the year. The highest concentrations are found in the middle section of the estuary. From the middle region there is a gradual decrease in the total number of individuals towards the lower part. Stations 5 and 6 in the lower half and stations 12 and 13 in the upper half have the lowest absolute abundance. Stations 1 to 4 are characterised by the presence of calcareous species and stations 14 and 15 are noted for the chitinous and siliceous forms. Thus the area of investigation shows marked variations in the absolute abundance of foraminiferal populations.

Foraminifera in general, particularly the calcareous species shows seasonal variations in their absolute abundance. The pre-monsoon period supports the highest population throughout the estuary and the monsoon period the lowest concentration. In the monsoon period no calcareous living forms are seen and the chitinous and siliceous specimens are very poorly represented. The seasonal fluctuations in the diversity of foraminiferal population are more pronounced in the marine end of the estuary than in the fresh water end. The fauna shows its minimum density in June-July months when the living calcareous foraminifera are completely absent. Calcareous forms begin to appear in the lower reaches of the estuary from October onwards and in the middle region from December onwards and attain the maximum population in April-May. The fauna does not reveal significant variations in their absolute abundance in March, April and May.

The results of the investigation show that there is great diversity in the genera and species, at various stations. Of the total 16 genera recognised in the area the maximum value (13) is observed at station 1 and the minimum (2) in station 12. High values of 8 to 11 genera are noticed at stations 2 to 11 except at station 5 where only 3 genera are found. The values are found to be in a decreasing order from the uppermost area downwards upto station 12 and the corresponding values are 5, 5, 3 and 2 at stations 15, 14, 13 and 12 respectively.

Species diversity:

For measuring the species diversity a rare fraction curve is plotted following the methodology advocated by Sanders (1968). The rare fraction curves obtained for the foraminifera from all the 15 stations are given in Fig. 8. The mean values of the standing crop during April 1974 and 1975 are taken for preparing the figure. The fact that the fauna is variable with both the number of species and individuals of each species in the sample is clearly evident. A comparison of the number of individuals with the number of species gives an idea of the variety of the foraminiferal populations at different stations. The pattern of distribution is found to be quite different from one station to another. The largest number of species is found at station 1. The lowest species diversity is noted at station 15 though the number of individuals at this station is more. From

Fig. 8 Rare fraction curves showing the species diversity at 15 stations in the Vembanad estuary (mean values of April 1974 and 1975 are taken)

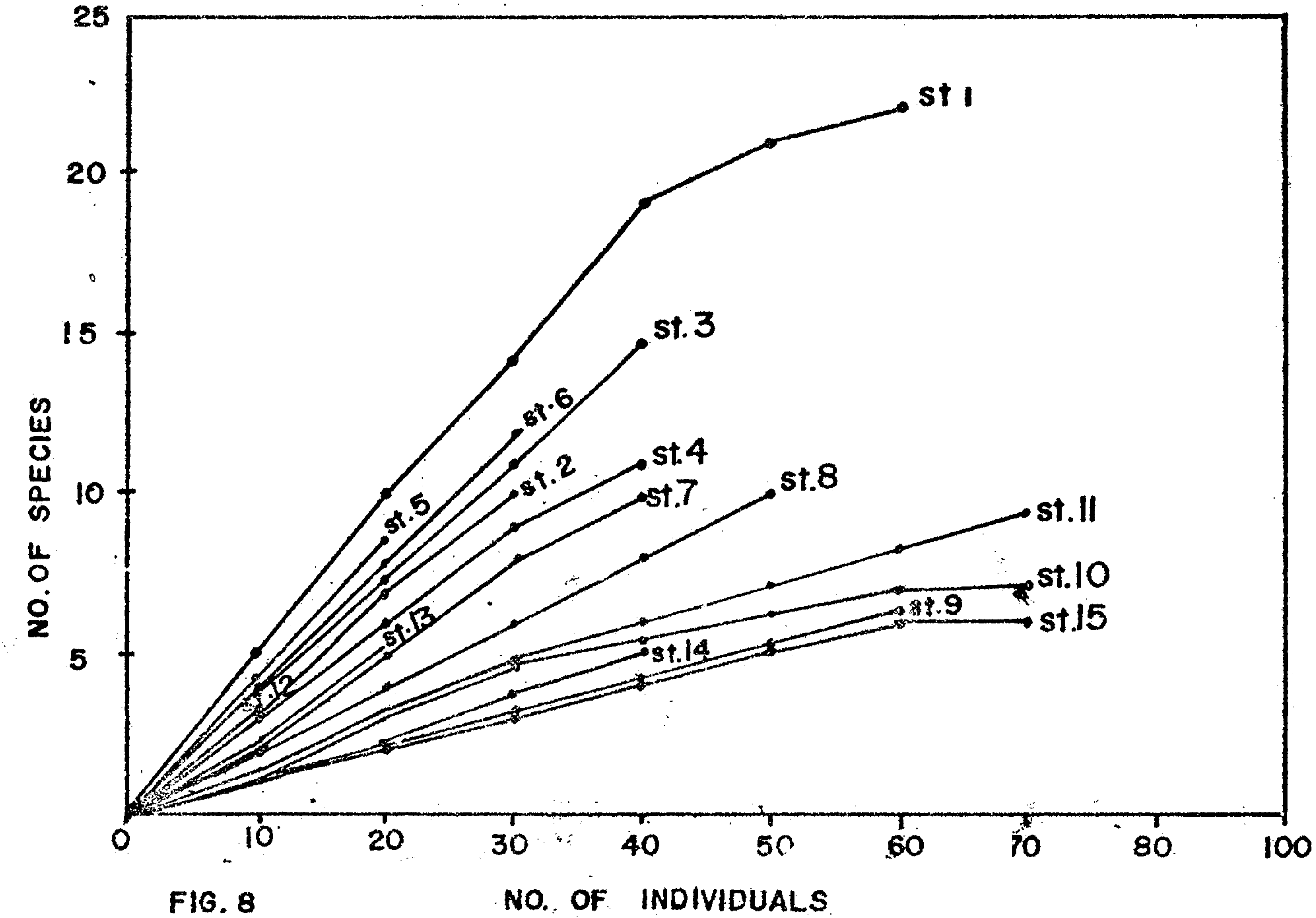

st 1
st. 3
st. 6
st. 4
st. 2
st. 7
st. 8
st. 5
st. 13
st. 12
st. 11
st. 10
st. 9
st. 15
st. 14
NO. OF SPECIES
25
20
15
10
5
0
10
20
30
40
50
60
70
80
100
NO. OF INDIVIDUALS

FIG. 8

Fig. 8 it is evident that the low species diversity is noted at stations in the upper reaches of the estuary (stations 11 to 15) and high species diversity at stations in the lower reaches of the estuary (stations 1 to 8). This could be directly attributed to the presence of large number of calcareous marine forms present in the lower half of the estuary. Since the foraminiferal fauna in the lake, especially in the lower section shows seasonal fluctuations according to environmental changes the population density and the species diversity are not constant.

Species dominance:

All the species are not equally distributed throughout the estuary. Of the 32 species only 4 species - *Ammonia beccarii*, *Saccammina sphaerica*, *Miliammina fusca*, and *Trochammina inflata* - are dominant in the estuary. The calcareous species *A. beccarii* constitutes a maximum of 70% of the total population at station 6 and a minimum of 20% of the population at station 10 and its occurrence is restricted to the lower half of the estuary. The species *S. sphaerica* and *M. fusca* constitute upto

65% of the total individuals at the stations of its occurrence in the upper reaches of the estuary (stations 11 to 15). The middle region (stations 10 and 11) is dominated by T. inflata which forms 60% of the total population at these stations. In general more than 50% of the total foraminiferal population in the estuarine complex is formed mainly by these four dominant species.

Relative abundance:

In the area under investigation there is a conspicuous segregation of species into restricted areas. The calcareous species are found restricted to the lower half of the estuary and chitinous and siliceous species are found in the upper region, though some are also found in the lower part in few numbers. The highest concentrations of total individuals are found at stations 1, 10,11 and 15 and the lowest concentrations at stations 5, 6, 12 and 13. The highest number of species (22, 12, 13 and 15) are found at stations 1, 2, 3 and 4 respectively and the lowest concentrations of 3, 4, 2 and 3 are found at stations 5, 6, 12 and 13 respectively.

Stations 14 and 15 are also represented by 5 and 6 species respectively. The concentrations of individual species show a marked increase at stations towards the lower part of the estuary. The distribution of species at 8 stations is shown in Table 5.

Vertical distribution:

Altogether 24 samples were taken for the study of the vertical distribution of the foraminifera. It was observed that in all the samples foraminifera were confined to the ~~top~~ upper 1 cm surface sample. A detailed analysis of the population revealed that more than 90% of the total fauna were found in the upper layer during all the seasons. Only a few species like Ammonia beccarii, Elphidium crispum and Quinqueloculina seminulum were found as deeper penetrants and these species were recorded upto 2 cm depth. It was interesting to note that A. beccarii was found to penetrate still deeper and were observed upto 3 cm depth.

The vertical distribution of foraminifera is correlated with seasonal environmental changes. The post-monsoon period when the salinity is lower than that of the pre-monsoon period the foraminifera are seen to occur a little deeper. This seasonal difference in the vertical distribution is more pronounced in the species A. beccarii.

Discussion

Environmental factors

Study of the ecology of foraminifera has experienced difficulties owing to overlapping morphological characters. Many of the characters considered to be of taxonomic value undergo marked changes in the varying ecological conditions. It is obvious that only a coordinated study involving foraminifera from the marine conditions as well as from estuarine environment may be the right approach to synthesise information and to clarify the morphological and ecological problems. The results obtained in the present study, through the field investigation have proved that the variations in the chemical and physical properties of water in the area influence the distribution of the foraminiferal species. The effect of environmental factors have strong control in the assemblages of foraminiferal population.

According to Krebs (1978) the distribution of a species is controlled by that environmental factor for which the organism has the narrowest range of adaptability or control. Therefore the hydrographical studies are important to interpret the potential and realise the niches of different foraminiferal species with respect to varying ecological conditions. The present investigations on the physical and chemical parameters of the environment are discussed below.

Temperature:

For the area under investigation as a whole the pattern of variation of temperature is bimodal. A similar type of oscillation of temperature has been noticed by other workers also (Balakrishnan, 1957; Ramamirtham and Jayaraman, 1963, George and Kartha, 1963). During March-April the atmospheric temperature is high and there is practically no rainfall. This results in high water and sediment temperatures during this period. June-July can be considered as the active period of the south west monsoon. It can be seen that from the beginning of the monsoon, the temperature shows a decrease. During this period the sediment temperature shows a fall of about 0.5°C. The slight decrease in temperature during the post-monsoon period may be due to the drop in the atmospheric temperature. After this period the atmospheric temperature steadily increased and the pattern is reflected in the sediment and water temperature.

The difference between the hot and cold seasons is very great in cold countries, whereas a more even temperature condition prevails in the tropics. So acclimatisation to seasonal variations of temperature is easier in the tropics than in the temperate regions.

Considerable attention has been devoted by many workers on the correlation between temperature and the distributional pattern of foraminifera. The range of tolerance (the lower limit and the upper limit) of temperature for tropical species is greater than temperate species (Arnold, 1974). So in the geographic distribution of foraminifera temperature is known to be an important ecological factor. Bradshaw (1961) by conducting experiments, showed that the reproduction in foraminifera occurred only within a narrow temperature range different for each species. He pointed out that eventhough foraminifera reached maturity, it would reproduce only if the temperature condition was favourable. According to him foraminifera reproducing at low temperature have more chambers and a greater mean size than those which reproduce at high temperatures. Bradshaw (1961) has shown that <u>Ammonia beccarii</u>

reproduces at an optimum temperature between 25 and 30°C. Majority of the foraminiferal species are poikilothermic. Some are eurythermal (having a wide tolerance) while others are stenothermal (having a narrow tolerance) as stated by Murray (1973). Based on the control of temperature on foraminifera he has has defined five critical temperatures viz. (1) maximum temperature for survival (2) maximum temperature for successful reproduction (3) optimum temperature (4) minimum temperature for successful reproduction and (5) minimum temperature for survival. In the area under investigation the maximum temperature recorded is 32.2°C and the minimum 26.7°C. This shows the annual range of variation in temperature in the area is 5.5°C and the temperature values are within the range of tolerance of all the species. Murray (1973) has suggested that the range of temperature for the reproduction of the tropical foraminifera is between 25-35°C. In general the foraminiferal abundance follows the same trend as the temperature. But it is difficult to determine the effect of temperature on each species based on field observation. Since the temperature does not go lower than 26.7°C and higher than 32.2°C in the course of the year it does not seem to be a local limiting factor in the occurrence of these animals in the locality.

Salinity:

Among all the hydrographical factors studied salinity is found to be the most fluctuating factor in the area. The salinity pattern in the estuary is considerably influenced by rivers and rain-fall. Most of the time in the year brackish water conditions prevail in the estuary. The maximum salinity is recorded in April-May (30-33.5‰). This period is dry with less rainfall. With the onset of the south west monsoon the flood water discharged from the rivers causes a steep decline in salinity during June-July. During this period very low saline conditions (0.15-3.0‰) prevail in all the stations. The influence of intermitant rain can again be seen during September-October, when the area is under the influence of the north-east monsoon. From October onwards the salinity gradually increases to reach an annual peak in April-May.

The salinity conditions in the area is as follows: In June-July the conditions of the entire lake is oligohaline (salinity 0.15-5‰). From October to December the same condition is observed in the upper end of the estuary. During this period polyhaline conditions (salinity 12–30‰) prevail in the middle region. Euryhaline conditions (salinity 30–33.5‰) are seen from November to May in the lower part while polyhaline conditions (salinity 16–30‰) are noticed in the middle region. During this period mesohaline (salinity 5–19‰) and oligohaline conditions are recorded in the upper part.

Fig. 9 shows that the foraminiferal assemblage follows the same trend as that of salinity. Generally populations are abundant at stations with salinity ranging from 15–33.5‰. Agglutinated species appear to thrive in limnetic to mesohaline conditions that prevail in the upper reaches of the area. In the lower reaches of the estuary where polyhaline to euryhaline conditions occur, calcareous species are found. Extreme variations in salinity seem to control the distribution and abundance of foraminiferal species in different water bodies.

Since the fluctuations in other ecological parameters are not so significant, salinity can be considered as the most potent factor affecting the life

Fig. 9 Monthly variations (mean values) of the 4 dominant species of foraminifera in the Vembanad estuary in relation to salinity during July 1973 to June 1975

a <u>Ammonia beccarii</u> at station 1

b <u>Trochammina inflata</u> at station 10

c <u>Miliammina fusca</u> at station 5

d <u>Saccammina sphaerica</u> at station 15

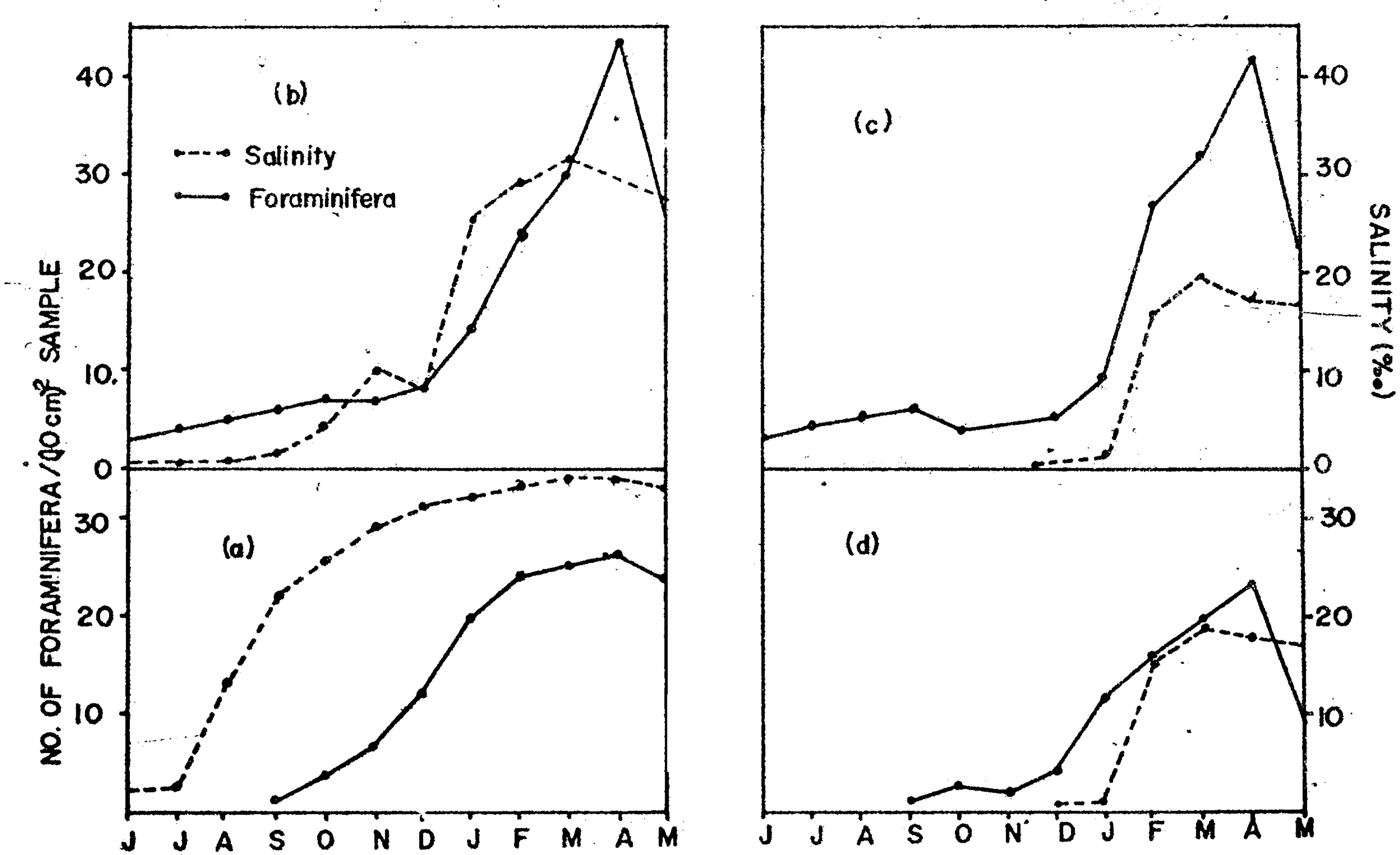

(b)
Salinity
Foraminifera
(c)
(a)
(d)
NO. OF FORAMINIFERA/(10 cm)² SAMPLE
SALINITY (‰)
J J A S O N D J F M A M
J J A S O N D J F M A M

FIG. 9

of foraminifera in the estuary. Reviews on the effects of salinity on marine organisms are available in the works of Robertson (1957), Moore (1958), Remane and Schlieper (1958), Nicol (1960), Prosser and Brown (1961), Kinne (1971) and Vernberg and Vernberg (1972). Studies on the effects of salinity on foraminifera have been reported by Bradshaw (1961, 1968), Bussa (1968), Nichol and Norton (1969) and Murray (1973). Changes in salinity affect the osmosis of marine forms. It is generally assumed that foraminifera are isotonic with sea water, and they are therefore described as poikilosmotic. Fresh water species are hypotonic to their environment and are described as homoiosmotic. Brackish water forms can fall into either category.

As regards the estuarine foraminifera, species that are restricted to marine conditions are stenohaline and others that tolerate hyposaline or brackish water conditions are euryhaline. Majority of foraminifera are believed to be stenohaline, i.e. they will tolerate only small changes of salinity. Only a few species of foraminifera are euryhaline and these are found in the estuarine environment. The majority of hyposaline species include chitinous and siliceous forms and these are mainly confined to low saline conditions. They occur rarely in the normal saline water.

Changes in salinity affect the density of water and its osmotic effect on the foraminifera. In low saline conditions these shelled protozoans are unable to maintain the pseudopodial reticulum outside the shell. Consequently they do not live in hyposaline waters. So salinity is the most important limiting factor in the occurrence of the foraminifera in the estuary.

As pointed out by several observers, the penetration of foraminifera into the estuarine complex is a characteristic feature of the tropics. An interesting fact regarding the foraminiferal fauna in the estuary is the occurrence of numerous adaptations in the mode of life of animals of marine origin, which survive to facilitate their life in the changing environment. The different species show varying degrees of adjustment in their tolerance in the brackish environment.

Murray (1968b) used the method of comparing the range of salinity conditions with the occurrence of species at each locality in an estuary. The foraminifera that have invaded the Vembanad estuary show a clear preference to certain salinity conditions in the pattern of their distribution (Table 6). The foraminifera in the Vembanad estuary can be divided into four groups following Murray (1973) based on the lowest salinities to which they survive.

1. Stenohaline marine forms: Stenohaline marine species have restricted their occurrence in the barmouth area and are not transported into the estuary in living condition. There are true stenohaline marine calcareous species which are transported from the sea to the barmouth of the estuary (station 1). These foraminifera live only in association with high salinity conditions above 30‰. The following species are included in this category.

Amphistegina lessonii d'Orbigny

Elphidium excavatum Terquem

Elphidium translucens Natland

Spirillina vivipara Ehrenberg

Planorbulina mediterranensis d'Orbigny

Cancris auriculus (Fichtel and Moll)

Rotalia venustra Brady

Discorbis globularis (d'Orbigny)

Discorbis allomorphinoides (Reuss)

Discorbis vilardeboana d'Orbigny

Nonionella hantkeni Cushman and Applin

Cribrononion delicatulus Bermudez

Truncatulina haidingerii d'Orbigny

Hanzawaia strattoni Applin

Peneroplis pertusus (Forsk)

Quinqueloculina costata d'Orbigny

Triloculina tricarinata d'Orbigny

Bolivina vadescens Cushman

2. Marine forms able to tolerate small variations in salinity: Of the 21 calcareous species recorded from the estuary 4 species have acclimatised to a salinity of about 28‰. These species are distributed in stations 1 to 3 extending to a distance of 6 km from the barmouth. The tolerance limit of these 4 species seems to be slightly narrower than the other species. The species included in this category are Operculina granulosa Leymerie, O. complanata (Defrance), Operculinella cumingii Carpenter and Discorbis orbicularis d'Orbigny.

Table 6 Lowest salinities in which various species of live foraminifera were collected from the Vembanad estuary during July 1973 - June 1975 and the nature of salinity tolerance reported by different authors

Species	Salinity	Nature of salinity tolerated	Author
Saccammina sphaerica Sars	Fresh water	Fresh water Hyposaline	Murray 1973
Reophax scottii Chaster	5.0	Hyposaline	Murray 1973
Reophax catella Hoglund	7.5	Hyposaline	-
Ammobaculites foliaceous (Brady)	8.0	Hyposaline	Schafer 1969
Ammobaculites taylorensis Cushman and waters	7.0	Hyposaline	Murray 1973
Ammobaculites dilatatus Cushman and Bronnimann	8.5	Hyposaline	-
Textularia agglutinans d'Orbigny	21.5	Hyposaline Normal marine	Albani 1978
Textularia conica d'Orbigny	22.5	Normal marine	Albani 1978
Miliammina fusca (Brady)	Fresh water	Fresh water Hyposaline	Boltovskoy and Lena 1971
Trochammina inflata Montague	Fresh water	Fresh water Hyposaline	Ramanathan 1970
Trochammina nitida (Brady)	5.0	Hyposaline	-
Quinqueloculina agglutinans d'Orbigny	26.0	Hyposaline Normal marine	Wright 1968
Quinqueloculina seminulum (Linne)	23.5	Hyposaline Normal marine Hypersaline	Murray 1973
Quinqueloculina bicornis d'Orbigny	25.5	Hyposaline Normal marine Hypersaline	Murray 1973

Species	Salinity	Nature of salinity tolerated	Author
Triloculina oblonga (Montague)	26.5	Hyposaline Normal marine	Forti and Roettger 1967
Nonion boueanum Hade	25.5	Normal marine	Murray 1973
Nonion scaphum (Fichtel and Moll)	26.0	Normal marine	-
Nonion sloani d'Orbigny	24.0	Hyposaline Normal marine	Albani 1978
Elphidium crispum (Linne)	24.0	Hyposaline Normal marine Hypersaline	Murray 1973
Elphidium advenum Cushman	24.0	Hyposaline Normal marine Hypersaline	Murray 1973
Elphidium macellum (Fichtel and Moll)	24.0	Hyposaline Normal marine Hypersaline	Albani 1978
Elphidium craticulatum (Fichtel and Moll)	24.0	Normal marine Hypersaline	Levy 1971
Operculina granulosa Leymerie	28.0	Normal marine	Murray 1973
Operculina complanata (Defrance)	28.0	Normal marine	-
Operculinella cumingii (Carpenter)	28.0	Normal marine	-
Bolivina nobilis Hantken	26.0	Normal marine	-
Bolivina striatula Cushman	25.5	Normal marine	Murray 1973
Discorbis orbicularis (d'Orbigny)	26.5	Normal marine	-
Discorbis rosacea (d'Orbigny)	26.0	Normal marine	-
Rotalia (Ammonia) beccarii (Linne)	19.5	Hyposaline Normal marine Hypersaline	Murray 1973
Rotalia calcar d'Orbigny	26.0	Normal marine	
Cibicides lobatulus (Walker and Jacob)	24.0	Normal marine	Murray 1973

3. Moderately euryhaline forms: Nine calcareous marine species are typical euryhaline forms which constitute the important migrants from the sea to estuary. They are acclimatised to a salinity as low as 26‰. These species are never found penetrating beyond station 6, 16 km from the barmouth. The following species are included in this group. *Quinqueloculina bicornis* d'Orbigny, *Q. Agglutinans* d'Orbigny, *Triloculina oblonga* Montague, *Nonion scaphum* Fitchtel and Moll, *N. boueanum* Hade, *Bolivina nobilis* Hantken, *B. striatula* Cushman, *Rotalia calcar* d'Orbigny and *Discorbis rosacea* d'Orbigny.

4. Highly tolerant euryhaline forms: Eight species are found to occur in the part of the estuary with a low salinity of about 24‰, 28 km (station 9) from the barmouth. They are *Quinqueloculina seminulus* Linne, *Nonion sloani* d'Orbigny, *Elphidium crispum* (Linne), *E. advenum* Cushman, *E. macellum* Fichtel and Moll, *E. craticulatum* Fichtel and Moll, *Cibicides Lobatulus* Walker and Jacob and *Ammonia beccarii* (Linne). Of these 8 species *A. beccarii*, the major inhabitant of the continental shelf region of Kerala is found to

penetrate inwards and persists upto a distance of 35 km from the barmouth (station 11) in salinity as low as 19.5‰. It is to be noted that this species differs from all others in that in the estuarine conditions it possesses a rigid arenaceous periplast for withstanding the adverse environmental conditions in the estuary. While the 7 species included in this category are true euryhaline forms, A. beccarii is euryhaline as well as hyposaline in the area. Murray (1973) also has considered A. beccarii as euryhaline and hyposaline. The highly tolerant euryhaline species in the estuary are most often encountered as true estuarine forms.

Regarding the salinity tolerance of chitinous and siliceous species in the estuary all of them are euryhaline forms. They often tolerate lower salinity, some persisting even in fresh water conditions. The chitinous and siliceous species also show various adaptations in their mode of life in the estuary. Miliammina fusca (Brady) and Saccammina sphaerica are found associated with the fresh water end of the estuary where the salinity is below 15‰. These two species which prefer low salinity conditions are permanent inhabitants of the upper end of the estuary. *Trochammina inflata* Montague, the dominant species in the middle region of the estuary prefers a medium salinity of about 15 to 20‰. The remaining chitinous and siliceous species are distributed in the middle and upper parts of the estuary in salinity conditions below 20‰. These forms are found rarely in the high saline condition of the lower part of the estuary. When compared to the calcareous species, chitinous and siliceous forms are the true brackish water foraminifera which are capable of surviving the wide fluctuations of salinity in the estuary.

The distribution of foraminifera in the Vembanad estuary shows that the majority of the calcareous species found in the coastal waters are stenohaline and they occur only in normal marine conditions. Some euryhaline and hyposaline species are found to penetrate into the estuary and survive there. The sudden decrease in the salinity in the estuary as a consequence of freshwater flow during the monsoon period, kills the calcareous euryhaline forms and only the chitinous and siliceous hyposaline species survive.

Dissolved oxygen:

As shown in Fig. 3 dissolved oxygen shows distinct seasonal fluctuations. During the south west monsoon high values of dissolved oxygen (5.7-6.4 ml/l) are recorded. Dissolved oxygen comes down to a minimum of 3.2 ml/l in September near the barmouth. Relatively high oxygen content in the pre-monsoon season may be due to the increased photosynthetic process. The usual inverse relationship between dissolved oxygen and salinity is also noted.

The availability of dissolved oxygen for reproduction is considered as one of the important ecological factors which controls the foraminiferal productivity in an area (Lee 1974). It has been suggested that the lower limit tolerated by most foraminifera is 1-2 ml/l oxygen. They do not live in anoxygenic conditions. According to Bradshaw (1968) dissolved oxygen is not considered as a limiting factor for the growth of foraminifera. Oxygen content of the bottom water in the present investigation area does not seem to act as a limiting factor as regards the occurrence of these organisms.

pH:

A review of the monthly values shows that higher values of pH are more favourable for high concentration of foraminifera. In the area under investigation the pH is maintained alkaline during the pre-monsoon and post-monsoon periods. The hydrogen ion concentration in the monsoon period is low and it coincides with the lowest concentration of chitinous and siliceous species and the complete absence of calcareous species. Murray (1973) has shown that the range of pH from 7.5 to 8.3 is generally found acceptable for marine calcareous foraminifera. A lowering of pH below this range may cause the dissolution of the tests. But it has been suggested that this dissolution of the tests of the living specimens does not harm the animal because new shells are secreted by the animals on return to the favourable, more alkaline conditions. Boltovskoy (1964) noticed the death of calcareous foraminifera in pH of 7.0. In the area under study from July to September all calcareous forms perish when the pH becomes low. So, in the Vembanad estuary pH is one of the factors that influence the distribution of foraminifera.

Nutrients:

The benthic organisms are dependent on the fertility of the overlying water for their food supply, and factors which control the phytoplankton population in any area are likely to have an indirect influence on the abundance of the benthic fauna. There is considerable evidence for assuming that the nutrient concentration may be a limiting factor in the plankton production (Moore et al, 1952; Ramanathan, 1970; Murray, 1973). The changes in the phytoplankton concentration may influence the benthic foraminiferal population in an area (Murray, 1973). Ramanathan (1970) found that in the Vellar estuary the enrichment of the foraminiferal population is correlated with high phytoplankton production.

The primary production values reported from the Cochin backwaters by Qasim et al (1969) show the daily gross production as 0.5 to 1.5 gc/m^2, daily net production as 0.35 to 0.88 gc/m^2 and 24 hour net production as 0.12 to 0.58 gc/m^2. These values clearly indicate that the area is highly productive.

Nutrients coming from the rivers may be utilised by phytoplankton which in turn serves as food for other organisms. So there is relationship between nutrients and photosynthetic plankters which form the food of foraminifera.

Relationship between foraminifera and substrate

The distribution of foraminifera in relation to the substrate has been studied by various authors (Leoblich and Tappan, 1953; Reiter, 1959; Todd, 1961; Todd and Low 1967,'71; Ramanathan, 1969, 1970, 1975; Vedantam and Rao, 1970; Murray, 1973 and Albani, 1978). Some workers have established a correlation between the foraminiferal fauna and the substrate; but some others failed to discover any relationship between the two. In the present study foraminifera appear to be directly related to the substrate characteristics. According to Leoblich and Tappan (1953) the character of the bottom is the most important factor in the distribution of foraminifera. They have reported that muddy substrate contains fewer foraminifera, probably because of lack of oxygen, for the decaying organic matter consumes the supply of oxygen. When the mud is mixed with sand the foraminiferal population increases, for here the heterogeneous bottom allows a better supply of oxygen so that many foraminifera are present. Lee (1974) studied the correlation between the foraminifera and the nature of the substrate in the Mission Bay Marsh, California and determined that the species Elphidium crispum, E. advenum, Quinqueloculina seminulum, Trochammina inflata and Ammobaculites dilatalus are correlated with sand-silt-clay substrate. Phleger (1970) suggested that Ammonia beccarii, Elphidium advenum, Quinqueloculina seminulum and Trochammina inflata are common in fine grain-size sediment mixed with clay. According to Nichols and Ellison (1967) who studied the foraminifera of the Rapphannock estuary in Northern Virginia, an admixture of sand and mud has very rich foraminiferal fauna. Similar results have been reported by Murray (1968b) who worked on the foraminifera from the estuarine environments. Ramanathan (1969, 1975) who worked on the foraminifera of the Vellar estuary discovered that pure clay or pure sand support the minimum number of foraminiferal fauna and silty-clayey-sand give the maximum population. According to him clayey-sand substrate also gives a fairly rich fauna. Rao (1968) who studied the foraminifera of the Gulf of Cambay suggested that where the sediment is muddy the fauna is extremely poor. Rao and Rao (1974) who worked on the foraminifera from the Chipurupalle stream have not established any specific correlation between foraminifera and bottom sediment. Brooks (1967) reported that the species Ammonia beccarii, Elphidium crispum and E. advenum show little substrate preference.

The sediment sample from stations 1,4,7,10,15 and 11 with clayey sand support the maximum foraminiferal population with the corresponding value of 65, 43, 46, 74, 78 and 80, specimens respectively. The least amount of silt (10 to 25%) is found at these stations. Samples from stations 2,3,8,9 and 14 where the texture is sand-silt-clay type also has rich foraminiferal fauna. The number of specimens at these stations are 34,38,48,63 and 42 respectively. The highest value of clay content is seen at stations 5 and 6 and this silty-clay substrate yields very poor fauna in the abundance of species and specimens. The number of specimens at these stations are 8 and 14 respectively. The highest value of 29% and 42% of silt content is found at these stations. The highest percentages of sand occur at stations 12 and 13 and this sandy substrate supports the least foraminiferal standing crop with the values 8 and 12 respectively.

Thus the character of the bottom substrate appears to have a considerable effect on the foraminiferal fauna inhabiting the area. The highest value of living population is found in localities where the bottom is with fine to medium sand, mixed with low percentage of mud. Where the percentage of mud increases above 40% the foraminiferal population decreases. Regarding the silt content, foraminifera are numerically low in the localities where the bottom sediment is with high percentage of silt. Localities with coarse sand deposit also have relatively lesser number of foraminifera. In general areas with clayey sand or sand-silt-clay yield maximum foraminiferal population. It is possible that the admixture of sand and clay sediment may make the substrate less compact and this paking of the sediment is found favourable to the occurrence of foraminifera. Silty clay supports the least population. The scarcity of foraminifera in the muddy substrate may be due to the decline of oxygen caused by bacterial decomposition in the area. But in the present study no specific correlation could be established between the calcareous foraminifera and the sandy substrate because the distribution of these forms is limited to the lower half of the estuary where there is no pure sandy substrate. For the chitinous and siliceous forms the correlation between the population and the nature of the substrate is evident.

In the Vembanad estuary though the living foraminiferal population shows correlation with the substrate, it mainly reflects the pattern of the water characteristics prevailing in the area. According to Albani (1978) salinity and sediment type are the two most important characteristics in the distribution of foraminifera. In the case of salinity it varies seasonally and geographically, and consequently these ecological variations in the lake are reflected in the occurrence and distribution of the living benthic foraminifera. In the present area, as the occurrence of foraminifera is much dependent on the behaviour of the water characteristics, the sediment characteristic is only a second major factor in the distribution of foraminifera.

<u>Organic matter in the sediment:</u>

Organic content in the sediment of the investigation area varies from 0.9%. (station 12) to 2.2% (station 6) by weight of dry sediment. It is relatively high in the area during the pre-monsoon period than in the other seasons. The physical characteristics of the sediment influence the accumulation of organic matter in the sediment. It is seen that silty clay sediments have higher content of organic matter while sediments with higher sand content have less organic matter content. Areas with sand-silt-clay sediments also have a relatively high proportion of organic matter. The high percentage of organic content in the fine grained sediment may be attributed to the land humus associated with the detrital sediment brought in to the estuary by rivers. But how much of the organic matter is readily utilizable by these microorganisms is not known.

Depth:

The depth of the area under investigation varies from 1.5 to 8 m and the depths at the different stations are shown in Table 1. Station 1 is the deepest and the stations 14 and 15 are the shallowest. Depth is influenced by tides and floods and the differences due to these factors vary from 1 to 2 m. Many parameters like hydrographic pressure, light penetration, temperature, pH, oxygen content etc. are related to depth. However these parameters effect only in deeper areas. Loeblich and Tappan (1953) have shown that depth is of some importance in the distribution of foraminifera in the deeper areas of the sea. Funnell (1967) has pointed out that in shallow waters, depth is probably not a limiting factor for the distribution of foraminifera. According to Murray (1973) individual species of foraminifera does not appear to be controlled directly by depth alone. In the study area where the depth variations are too limited, the distribution of foraminiferal population, station-wise does not show any relationship with depth.

The foraminiferal fauna

Species dominance and relative abundance:

Walton (1964) introduced the method of species dominance of foraminifera which he defined as the percentage occurrence of the most common species in a foraminiferal population. According to him highly variable environments are dominated by few species whereas stable environments are characterised by many species. The marine end of the Vembanad estuary is characterized by the presence of many species whereas the fresh water zone is inhabited by only a few species which occur in large numbers. Species dominance is always controlled by the number of species in an assemblage, the more species present, the lower is the percentage occurrence of each species.

The distributional pattern of foraminifera in the Vembanad estuary shows that the greatest absolute abundance of certain species is found in some areas while the greatest relative abundance of certain other species (as percentage of total population) is found in other areas. This latitudinal segregation of species seems to be based on their tolerance capacity. From the barmouth towards the interior there is decrease of the calcareous species and towards the fresh water end there is increase of the chitinous and siliceous species.

The relative abundance of various species in the area during the two years shows seasonal variations. The high absolute abundance during the pre-monsoon period affects the corresponding relative abundance of species. The relative abundance in the monsoon months is less while the other two seasons show higher foraminiferal concentration and larger number of species. The distribution pattern reveals a steady increase in the number of species in the marine end from the post-monsoon months to the monsoon months.

Since all the species are not equally distributed throughout the estuary the foraminiferal assemblage can be differentiated into four groups, based on the relative abundance of species in the locality. Group 1 includes species that are abundant, forming more than

60% of the total individuals, at least during any month in an year. This group comprises greater part of the total foraminiferal population in the area, especially during the pre-monsoon period. Ammonia beccarii, Trochammina inflata, Miliammina fusca and Saccammina sphaerica are the most abundant species. Group 2 consists of species that are of common occurrence and each constitute 20-60% of the total population. The common species are Trochammina nitida, Quinqueloculina seminulum, Q. bicornis, Elphidium crispum and E. advenum. Frequent species that are scattered throughout the area are Ammobaculites taylorensis, A. foliaceous, Quinqueloculina agglutinans, Elphidium craticulatum, Nonion boueanum, N. sloani, Bolivina striatula, Rotalia calcar, Discorbis rosacea and Cibicides lobatulus. These species are categorised into the 3rd group which constitutes 5-20% of the total population. The species included in this group have a rather haphazard occurrence in the area. The remaining 13 species that are found rarely and whose concentrations are less than 5% of the total population are included in the 4th group. Certain calcareous species of this group are confined to the marine zone and certain chitinous species are confined to the fresh water zone of the estuary.

<u>Faunistic divisions</u>:

A convenient basis of classification of animals living in an environment of variable features like the brackish water is necessary to estimate the ecological divisions of the area. Many authors have classified euryhaline animals into different groups, based on the lowest salinites to which the marine animals penetrate and survive. Redeke, (1922, 1933) suggested a classification of the brackish water animals into oligohaline, mesohaline and polyhaline groups: the first, oligohaline representing the least saline region adjoining the fresh water, the second, mesohaline region forming the middle zone of the estuary and the last polyhaline region connecting the estuary into the sea. He pointed out that these differences in the salinity are reflected in the composition of the fauna.

Based on the various biotopes shown above the Vembanad estuary can be divided into 3 different zones - the lowest part connected with sea, an upper part subjected to the greatest fresh water influence and the middle part in between the two. In the lower part the most dominant species is <u>Ammonia beccarii</u>. Various species belonging to the family Rotaliidae, Nonionidae and Miliolidae are the other common forms in the area. The lower reaches of the estuary can be considered as the polyhaline region. The upper part of the estuary where Miliammina fusca and Saccammina sphaerica inhabit in abundant numbers can be considered as the oligohaline region of the estuary. The mesohaline region or the middle part of the estuary is dominated by Trochammina inflata. This is the zone where the fresh water forms of the upper reaches and the marine forms of the lower reaches meet. In the present investigation area the division of the three regions, according to Radeke's method cannot be strictly followed, since the sudden outbreak of the monsoon flood would result in quick changes from the polyhaline to oligohaline conditions. So demarcations of the animal community exclusively on salinity basis is not strictly applicable in the area during the monsoon season.

In the present study the details of the numerical density of foraminifera at different stations show that some selected species are dominant within the community. The 4 dominant species, each constituting 20-50 per cent of the total fauna at different stations are Ammonia beccarii, Miliammina fusca, Saccammina sphaerica and Trochammina inflata. As regards T. inflata its maximum occurrence is found to be 60 and 55 per cent of the total community at stations 10 and 11 respectively. At stations 12, 13 and 14, 50-60 per cent of the total fauna are constituted by M. fusca and at stations 13 to 15, 20 to 25 per cent of the fauna is formed by S. sphaerica. A. beccarii, the most dominant species in the lower reaches of the estuary shows the highest numerical density constituting 50 to 60 per cent of the total fauna.

Seasonal fluctuations in the density of fauna are observed at all the stations. The fauna shows the minimum density during June-July. From October onwards the faunal density gradually increases and reaches the peak during April-May. Such short term seasonal fluctuations are noted at all the stations. Values of the monsoon period are not comparable with those of the other two seasons because of the complete absence of calcareous foraminifera throughout the area. The siliceous and chitinous fauna also shows fluctuations in the fresh water zone during this period. The interesting feature observed is the abnormal occurrence of the above mentioned 4 species in certain restricted areas which may be correlated to the varying environmental conditions. The distribution of these foraminifera with corresponding salinity in different months is shown in Fig. 9.

In order to define areas of varying environmental conditions based on the percentage of occurrence of dominant species, the method adopted by Johnson and Albani (1973) and Albani and Johnson (1976) is followed here. Based on the percentage occurrence of abundant species the investigation area can be divided into three different biotopes. The biotopes are mainly controlled by the influence of fresh water from the rivers and their tributaries and the sea water by the influence of tidal currents. The distance from the barmouth is another controlling factor. In the upper part of the estuary, the conditions appear to be more variable with freshwater scouring, especially during the monsoon flood. The boundaries between different biotopes are not distinct because of the preferential pattern of tidal flow towards both the directions in the estuary.

Biotope 1. (Ammonia beccarii biofacies): The marine zone is characterised by the presence of Ammonia beccarii and the area of this species extends from station 1 to 11 corresponding to a distance of 35 km from the barmouth. This biotope consists of A. beccarii as the most predominant species amounting to more than 50 per cent of the total population. A beccarii biotope can be divided into three sub-zones based on the other accessory species that have high frequency in the area. The first sub-facies is the area near to the barmouth, from stations 1 to 4. All the 21 calcareous species recorded from this area are found to tolerate varying salinities of 28 to 33.5‰. This sub-zone extends from the barmouth to a distance of 9 km interior. Besides A. beccarii the following species have high frequencies in the area - Quinqueloculina seminulum, Elphidium crispum, E. macellum, E. craticulatum, E. advenum, Nonion boueanum, Nonion sloani, Rotalia calcar, Cibicides lobatulus and Discorbis rosacea.

In the second sub-facies the calcareous species are found to occur further inwards upto a distance of 28 km from the barmouth. The species that are found in this zone can withstand salinity as low as 24‰. In addition to A. beccarii the following species have high frequencies in this area - Quinqueloculina seminulum, Nonion sloani, Elphidium craticulatum, E. crispum, Rotalia calcar, Discorbis rosacea and Cibicides lobatulus.

In the third sub-facies, A. beccarii is the only calcareous species present during the pre-monsoon period. The siliceous species Trochammina inflata is dominant than A. beccarii at stations 10 and 11, but among the 21 calcareous species recorded in the estuary only A. beccarii is seen to penetrate and persist upto a distance of 35 km from the barmouth. A maximum occurrence of 12 per cent of the total population of this species is seen at station 11 during April-May months. The lowest limit of salinity tolerance of A. Beccarii in the area is found to be 19.5‰.

Biotope 2. (Trochammina inflata biofacies): This forms the biofacies of Trochammina inflata. This single species is the dominant form in the middle section of the estuary and it accounts for 25 to 60 per cent of the total fauna from stations 8 to 11. Though T. inflata is widespread throughout the estuary, their percentage of occurrence is less than 15 of the total fauna in the other stations. In the barmouth and in the uppermost two stations they are found very rarely. This species occurs throughout the year but is more abundant in the pre-monsoon season. It is significant to note that the T. inflata biotope is in the middle region of the estuary where the salinity ranges from 15 to 25‰. Other siliceous forms - Ammobaculites dilatatus, A. tayloreneis, A. foliaceous, Trochammina nitida are the accessory forms that occur in low frequencies in the region. The calcareous species Ammonia beccarii is another accessory form of the T. inflata biofacies during the pre-monsoon season.

Biotope 3. (Miliammina fusca - Saccammina sphaerica biofacies): In the upper zone of the estuary (Stations 12 to 15) only chitinous and siliceous forms occur. Miliammina fusca constitute 50 to 65 per cent and Saccammina sphaerica 15 to 25 per cent of the total population at stations 12 to 15. Of these two characteristic species of the fresh water zone M. fusca is more abundant than *S. sphaerica*. This species is found decreasing in number from the upstream end downwards and are found rarely in the lower part. *S. sphaerica* has its maximum number (23) at station 15 and it decreases in number towards the middle region. It is completely absent in the lower part of the estuary. The species that are found as accessory forms in this zone are *Reophax scottii* and *R. cattella*. The species that occur in this biotope are characteristic of low saline water or fresh water conditions.

The composition of foraminifera in each biotope and their characteristics in terms of environmental parameters are shown in Table 7.

Live-Dead ratios

Fig. 7 shows that there is a general direct correlation between the standing crops of foraminifera and the dead shells. As is expected in a region like the Vembanad estuary, which is subjected to high seasonal variations in the ecological conditions there are wide fluctuations in the living and the dead assemblages of foraminifera. During the pre-monsoon months the live specimens have their peak concentration in all the stations. The live specimens decrease in

Table 7 Composition of foraminiferal biotopes and their characteristics in terms of hydrological and geographical parameters in the Vembanad estuary

Zone	Biotope	Subfacies	Biotope characteristics	Stations	Distance from barmouth km	Ranges in salinity	Biotope composition
Marine zone	Biotope 1 (Ammonia beccarii biofacies)	Subfacies 1	Subfacies 1	1 - 4	9	28 - 33.5	Ammonia beccarii with all other calcareous species
Marine zone	Biotope 1 (Ammonia beccarii biofacies)	Subfacies 2	Subfacies 2	5 - 9	28	24 - 33.5	Ammonia beccarii Quinqueloculina seminulum Elphidium crispum E. craticulatum Cibicides lobatulus Rotalia calcar Discorbis rosacea Nonion sloani
Marine zone	Biotope 1 (Ammonia beccarii biofacies)	Subfacies 3	Subfacies 3	10 - 11	35	19.5 - 33.5	Ammonia beccarii
Middle zone	Biotope 2 (Trochammina inflata biofacies)			8 - 11	24-35	15.0 - 25.0	Trochammina inflata Ammonia beccarii Trochammina nitida Ammobaculites tayloronsis A. diatatus A. foliaceous Textularia agglutinans Textularia conica
Fresh water zone	Biotope 3 (Saccammina sphaerica Miliammina fusca biofacies)			12 - 15	36-60	00.5 - 18.0	Miliammina fusca Saccammina sphaerica Reophax cattella R. scottii

number in the post-monsoon period and they show the least value in the monsoon period. During the monsoon months the living specimens are restricted to the upper part of the estuary. These seasonal fluctuations noticed in the number of living specimens are not so prominent in the case of dead shells. The water current may carry empty tests of foraminifera from the barmouth area towards the interior. When compared to the other seasons the action of the tidal current is more in the pre-monsoon season. The presence of empty tests of calcareous species at stations 11, 12 and 13 during the pre-monsoon period may be attributed to the tidal current which carry the shells from the lower part of the estuary to this region. Only at station 1 the occurrence of living and empty specimens shows an irregular pattern in their numbers. The relatively high value of dead shells at this station shows that in the meeting place of the estuary and the sea, most of the marine forms die through rapid changes in the environmental conditions which are beyond the limit of tolerance. The death of marine forms causes the high rate of sedimentation of empty tests at station 1. The dead specimens in the barmouth area includes shells of other marine forms also in addition to the estuarine species.

For assessing the rate of sedimentation, Walton (1955) has introduced a formula viz.

$$\frac{L}{D} = \frac{\text{number of living specimens}}{\text{number of dead specimens}} \times 100$$

Boltovoskoy and Lena (1969) and Murray (1967) have followed this method. In the present study high rate of sedimentation has been observed in the lower part of the estuary than in the upper part. Stations 15, 11, 12 and 14 are with high rate of sedimentation of shells with values 30.5, 30.2, 26.6 and 22.0 respectively. The middle region (stations 7 to 10) also has a relatively high rate of sedimentation with the values ranging from 22 to 26. In the lower part of the estuary (except at station 1) at stations 2 to 6 sedimentation rate ranges from 15 to 19.

According to Murray (1967) the method of assessing the rate of sedimentation helps to compare the annual production with the number of dead individuals. In the sea the calcareous shells deposited by the marine forms remain there for long time without any dissolution or destruction. But dissolution of calcareous shells takes place in the estuary and many shells (including those of living calcareous specimens) are etched.

Murray (1973) has pointed out that the dissolution of calcareous tests is common in the estuary. This is due to the acid action of water and it can be related to the lower proportion of the dead shells in the area. Thus it seems that the changing estuarine environment has its serious effects not only on the living specimens but also on the dead shells. However, in spite of the varying physico-chemical conditions and limit of tolerance of different species in the estuary, there exists a general correlation between the living and dead population.

Vertical distribution

Investigations on the vertical distribution of foraminifera have been carried out by some workers. Myers (1943) has reported that foraminifera can survive buried in the substratum equal to 5 to 7 times the diameter of the test. His studies on *Elphidium crispum* showed that this species bury to a depth of 1-3 cm Buchanan and Hedley (1960) suggested that foraminifera penetrate to the substratum to a depth of 1-2 cm. Boltovskoy (1966) found foraminifera at a depth of 6 cm and according to him sandy sediments are penetrated by these micro-organisms more deeply than muddy ones. This may be attributed to the better aeration of the former substrate than the latter. Frankel (1972) suggested that foraminifera usually occur at the surface of the substratum but some species can penetrate and survive in depths between 1 and 6 cm. Because of this he considered the species like *Ammonia beccarii* as infaunal. The depth distribution of foraminifera in the substrate is related to the type of the sediment (Silter, 1965). The present observations on the vertical distribution of foraminifera and sediment types reveal that in general foraminifera do not prefer a depth greater than 1 cm. The movement of species like *A. beccarii* in deeper layers shows a flexibility in its adaptations to cop with the changing environmental conditions in the area. By moving into the deeper layers of the substrate, the organisms may be getting protection or shelter from slight variations in the environmental conditions. One factor that controls the depth at which foraminifera can survive in the substrate is the thickness of the oxygenated surface layer. This oxygenated surface layer is thinner in the muddy bottom than in the sandy sediment. As foraminifera are epigraphic feeders they always prefer the surface of the bottom and so vast majority of the population occupies the upper 1 cm. Only a negligible proportion of the total fauna has the infaunal habitat and this penetration is only for short periods. In general, foraminifera can be considered as epibenthic.

<u>Food and feeding</u>

The aspect of the food requirements of foraminifera has been explored by several authors (Hofker, 1930, 1931; Sandon, 1932; Cushman, 1948; Hedley, 1958, 1964; Be, 1959, 1960; Nyholm, 1961; Bradshaw, 1961; Lee *et al* 1961, 1966; Murray, 1963, 1973; Ramanathan, 1970). Most of the information on the food of these microorganisms comes from the laboratory experiments. Only few authors have attempted the study on this aspect from field observations.

Lee *et al* (1961) have tried to establish the nutritional requirements of *Trochammina inflata*, *Miliammina fusca*, *Elphidium* spp. *Quinqueloculina* spp. and *Bolivina* spp. by culturing them in the laboratory. He found that the important items of food of these foraminifera are diatoms. But according to him it is difficult to interpret the species preference in the foraminiferal nutrition. Be (1959) from his studies on the feeding habits of foraminifera established that they feed on phytoplankton. According to Bradshaw (1955, 1957, 1961) and Murray (1963) algae and diatoms seem to be the most important food of foraminifera.

Planktonic foraminifera have been found to feed on algae, but at depths the benthic forms must feed by predation, by scavenging on bacteria (Murray, 1973). According to Hedley (1958) some benthic foraminifera seem to be scavengers. Perforated forms such as Elphidium feed on algae and they normally gather it with their pseudopodia and pass it towards the aperture. They form distinct feeding cysts around themselves (Murray, 1963). The type of food organisms of Ammonia beccarii, the most extensively studied species, has been investigated by Bradshaw (1961) and he found algae as the most important item of food for this species. According to him this species also feeds by predation and by scavenging. A. beccarii often gather balls of food which are digested later (Lee et al, 1966). Imperforate forms like Quinqueloculina gather the food in mass near the aperture. The importance of bacteria as a food item was demonstrated by experiments on Quinqueloculina sp. by Lee and Muller (1967). It is believed that bacteria provide some nutritional need which algae alone cannot fulfil. Hofker (1931) recorded foraminifera feeding on detritus. Christiansen (1964) has observed carnivorous feeding by Nonion sp. Buchanan and Hedley (1960) suggested that foraminifera are non-selective feeders which eat any of the microorganisms they can catch. However, they believe that diatoms and other algae particularly chlorophyceans furnish the greater part of the diet of foraminifera. Cushman (1948) suggested that the normal food of foraminifera consists of vegetable matter, diatoms and various other algae. From the interpretations of the different authors mentioned above it can be concluded that the foraminifera require a mixed diet of detritus, bacteria, diatoms and other algae, the most important being the phytoplankton population.

Phytoplankton, being the main source of food of foraminifera controls the density of foraminiferal populations. The observations by Lee et al (1961), Buzas (1969), Murray (1970) and Ramanathan (1970) show that there is correlation between foraminiferal standing crop and phytoplankton food supply. Such relation between phytoplankton and foraminifera is evident in the present study also. In the present study area the highest phytoplankton concentration is seen in the pre-monsoon period. Foraminiferal population density also reaches its peak during this period throughout the area. During the monsoon season, chlorophyll values are low in the estuary. A sudden decrease in the foraminiferal population has been observed in the area during this period. A secondary peak of foraminiferal population is seen during the post-monsoon period, when the phytoplankton is of medium magnitude. In general, the phytoplankton population in the area shows an increase with increasing salinity conditions which coincides with the increase in the foraminiferal population.

According to Ramanathan (1970) and Arnold (1974) the species of the genera Nitzschia, Synechococcus, Coscinodiscus, Skeletonema, Bacillaria, Fragilaria etc. are good food organisms for foraminifera. Arnold noticed that foraminifera feed actively during the decalcifying period in the acid medium. It has been observed that Nitzchia, Cerataulina, Gyrosigma, Synechococcus and Volvox are common in the fresh water zone, Chaetoceros, Bacillaria Pledorina and Pediastrum in the middle region, and Fragilaria, Skeletonema and Coscinodiscus in the high saline region and these form the food of the foraminifera in various regions in the estuary.

Adaptations to estuarine conditions

All the species of foraminifera except a few of the simplest forms secrete the tests, the development of which has a definite sequence. The foraminifera are almost entirely marine animals occurring in waters of normal salinity. But some chitinous species which are believed to be the most primitive type and some genera which have an outer wall of arenaceous layer live in the brackish water having a low salinity than that of normal sea water. Siliceous tests are also reported from the estuarine system and they are secondary in origin. The vast majority are calcareous species which have the test wall of calcareous material.

Several genera of the normal marine calcareous foraminifera, such as Nonion, Elphidium, Discorbis, Bolivina, Rotalia and Cibicides occur in the brackish medium showing their wide range of tolerance to varying ecological conditions. It has been found that these calcareous species exhibit certain range of adaptability against adverse ecological conditions in the estuary.

Encystment:

The average calcium carbonate content of calcareous species of foraminifera is estimated as 96.2 per cent (Murray, 1973). The inorganic materials in the sea are not much variable and consequently do not limit the occurrence of foraminiferal species in the sea. But in the estuary the inorganic materials are washed down into the sea by the fresh water run off. Calcium is probably the most important ion that controls the occurrence of calcareous foraminifera in the estuary. According to Krebs (1978) soft water may contain less than 1 mg/l of calcium while sea water may contain upto 100 mg/l. According to him most of the brackish water animals have well developed external secreting devices which effectively guard against the sudden changes in the ecological conditions, by preventing the passage of water in or out for a certain period. The occurrence of such external covering in brackish water organisms helps the animal to withstand sudden changes from the sea water or fresh water.

Many workers have shown that under adverse conditions some protective cover may be formed in certain species of foraminifera and the individual be practically dormant for a considerable period. In the present observation the formation of the outer protective covering or encystment has been noted in the test of Ammonia beccarii. Specimens of A. beccarii develop an agglutinated covering made up of sand grains and other foreign materials and form a rather firm cyst. May-June period is characterized by the presence of A. beccarii with cysts in the lower part of the estuary. During the post-monsoon season the encysted A. beccarii are found in the middle part of the estuary and a maximum number of 24 specimens in agglutinated covering have been recorded at station 11 during this period. This integument adaptation of foraminifera has been correlated with various environmental changes. In brackish water the physical and chemical characters of the calcareous tests change considerably. The most serious diagnostic change of calcareous forms is the dissolution of calcareous matter by the acidity of water. In calcareous species calcium is exchanged with environmental medium when acidic condition prevails (Mc Enery and Lee, 1970). Decalcification takes place in the brackish water or fresh water (Murray 1967). Murray and Wright (1970) reported that the agglutinated tests can also be destroyed by the dissolution of calcareous cement in the estuarine environment. In fresh water conditions the tests of all calcareous forms are disintegrated completely. In the sea water partial dissolution of shells occurs during low pH and this is indicated by white, opaque, hyaline tests. This decalcification does not harm the specimens because they are able to recalcify the test when the pH increases.

According to Hedgpeth (1957) cemented particles with chitinous walls of the agglutinated tests offer much scope for calcareous foraminifera in the estuarine medium. Boltovskoy (1964) observed that the development of chitinous, agglutinated integument in their normal tests of foraminifera results greater adaptability in the changing ecological conditions. In brackish water areas where the proportion of mineral constituents is relatively small, the marine calcareous species form chitinous agglutinated covering and persists inside. The protective covering helps the organism to withstand the acid action of the estuarine environment. Brady (1884) has stated that in brackish water the supply of earthy salts in solution is smaller than in the open sea and the chemical and physical characters of the shells of such species which survive in the changed conditions are considerably modified. They become less calcareous as the water grows less saline, until eventually a point is reached at which the investment is little more than a chitinous or horny membrane strengthened by the incorporation of minute, siliceous grains. Cushman (1948) has reported that in brackish water it has been found that the absence or scarcity of calcareous material results in the development of purely chitinous tests by some species which otherwise might have a certain amount of calcareous material in their normal tests.

Foraminifera collected from the Vembanad estuary show such integumental adaptations and the external protective covering of the estuarine species is similar to that reported by earlier workers. Another adaptation that has been reported by Lutze (1965) is that certain forms such as Rotalia and Elphidium could outlast unfavourable periods in the estuary by contracting the protoplasm inwards from the outer chambers of the test. This phenomenon is observed in the present study also in forms like Rotalia, Elphidium and Discorbis.

Size and thickness of the test:

Regarding the size of the test it is interesting to note that the specimens collected from the estuary are comparatively smaller in size than those collected from the sea. The average size of specimens of Ammonia beccarii collected from the continental shelf of Kerala is 1.0 to 1.2 mm in diametre. The umbilical area of the test of these specimens in the sea is filled with calcareous material. In the specimens of Elphidium collected from the sea, the wall of the chamber is extended across the preceding surface to form sutural processes, and the umbilical area is filled with calcareous material to form the umbilical plug. These parts of carbonate of lime content in Elphidium are absent in the estuarine specimens. Calcareous tests in the fresh water zone of the estuary are comparatively lesser in size than that of the marine zone of the lower part. Likewise seasonal size differences are also noticed. The specimens collected during the pre-monsoon period are comparatively larger in size than those collected during the post-monsoon months. The largest specimens of A. beccarii collected from the middle region of the estuary (station 11) are about 0.8 mm in diametre and those collected from the marine end (station 1) are about 1 mm in diametre in the pre-monsoon season; the largest specimens collected during the post-monsoon period at station 1 are about 0.8 mm in diameter and those collected from station 11 are only 0.6 mm in diameter. The same pattern of size difference for other species also is observed seasonally and regionally.

Many workers have recorded the size difference of foraminifera in different environmental conditions. Hedley (1964) recorded the size of <u>Elphidium</u> living in the marine area as 60 per cent larger than that of specimens found in the estuarine system. Schnitker (1967) established in <u>Triloculina</u> sp. that the marine forms are larger and thicker than the specimens collected from estuary. Nichols and Ellison (1967) have stated that the size of estuarine foraminifera varies according to environmental conditions related to different areas in the estuary. Levy (1971) has also established that the size of the foraminiferal shells is related to environmental factors while reporting the size differences of <u>A</u>. <u>beccarii</u> from the different environmental conditions.

In brackish water environment the calcareous material is relatively less. So the differences in the size and thickness of the tests can be explained by the fact that the test becomes larger and much thicker in the marine environment by the deposition of calcareous substance from the richer salty water of the marine zone. The tests become smaller in size and less calcareous as it goes towards the low saline region of the estuary where the supply of earthy salts in solution is lesser than in sea water.

As regards the chitinous species *Miliammina fusca* and *Saccammina sphaerica* characteristic of the upper region of the estuary, the specimens are thicker than those collected from the high saline region of the lower part of the estuary. In general chitinous species are comparatively lesser in size in the marine end than in the upper fresh water end. This indicates that the chitinous species develop thicker walls for withstanding the acid action of the fresh water zone of the estuary.

Comparison with the foraminifera of other areas

It would be interesting to compare the foraminiferal fauna of the marginal marine environment of the south west coast of India with that of the estuaries in India and other parts of the world. However such informations from the south west coast of India are scarce. A recent work on the foraminifera of the continental shelf of Kerala Coast is that of Antony (1968). A comparison of the foraminiferal fauna of the Vembanad estuary with that of the adjoining sea reveals that the fauna in the barmouth area is similar to that described from the shallow waters in the sea. While studying the bathymetrical distribution of foraminifera from the continental shelf area Antony has observed that certain species show preference to certain depths. The large sized forms of the families Rotaliidae, Camerinidae, Nonionidae, Miliolidae and Textularidae are characteristic of waters with a depth of less than 25 fathoms. This kind of bathymetrical distribution is particularly noticeable in the case of Ammonia beccarii which is abundant in the continental shelf. The smaller foraminiferal species of the best represented families Lagenidae, Buliminidae and Cassidulinidae occur in samples from depths above 25 fathoms. It is interesting to note that these small sized species are not found in estuarine complex in living condition. The large sized species that penetrate and persist in the estuarine environment are characteristic of shallow waters of the sea.

The typical calcareous species. A. beccarii, Quinqueloculina seminulum, Q. bicornis, Elphidium crispum, E. advenum, E. craticulatum, Cibicides lobatulus, Nonion sloani and Bolivina striatula found in the estuary are common or frequent forms in the continental shelf area.

Murray (1973) has reported the following calcareous species as widely known estuarine forms - Amphistegina lessonii d'Orbigny, Cancris auriculus (Fichtel and Moll), Elphidium translucens Natland, Planorbulina mediterranensis d'Orbigny, Spirillina vivipara Ehrenberg and Quinqueloculina oblonga d'Orbigny. Though these species are found to be widely distributed in the marginal marine environments of Kerala, they are not found living in the estuarine conditions. Regarding the chitinous and siliceous forms the characteristic brackish water species Trochammina inflata, Saccammina sphaerica and Miliammina fusca have not been recorded from the sea. The other chitinous and siliceous species are found rarely in the marine habitat.

As regards the estuarine foraminifera of the other areas Antony (1975b) has given a preliminary account of the foraminifera in the Kayamkulam lake, South West Coast of India. Here also the fauna is a mixed type consisting of calcareous and siliceous species. All the chitinous and siliceous species found in the Vembanad estuary have been recorded from the Kayamkulam lake except Textularia conica d'Orbigny. Among the calcareous forms 6 species viz. Quinqueloculina bicornis, Triloculina oblonga, Elphidium macellum, Operculina granulosa, O. complanata and Operculinella cumingii are not found in the Kayamkulam lake. When compared with the Kayamkulam lake Vembanad estuary appears to be richer in the foraminiferal population except in the barmouth station. In the Kayamkulam lake and the Vembanad estuary the maximum number of specimens found in the barmouth area are 85 and 65 respectively. The general pattern of distribution of the calcareous foraminifera in the Kayamkulam lake and the Vembanad estuary is the same. In both the lakes chitinous and siliceous species are characteristic of the upper region. Another similarity noticed in the distributional pattern of the two areas is the presence of two peaks of abundance in the population, one in the middle region and the other in the upper end. The maximum number of chitinous specimens collected from the Kayamkulam lake is 64 and that from the Vembanad estuary is 76. Among the species collected from the two lakes Ammonia beccarii is the major inhabitant in the lower reaches and it is seen to penetrate inwards and persist upto a distance of 22 km in the Kayamkulam lake and 35 km in the Vembanad lake. The maximum numbers of *A. beccarii* in $(10\ cm)^2$ sample in the Kayamkulam lake and Vembanad estuary are 31 and 27 respectively. In the Kayamkulam lake this species is found to survive a lower salinity of 20.8‰ whereas in the Vembanad estuary it is 19.5‰S. *Trochammina inflata* is the characteristic species of the middle region of both the lakes and *Miliammina fusca* and *Saccammina sphaerica* are the major inhabitants of the upper part. The maximum numbers of *M. fusca* in the Kayamkulam and Vembanad lakes are 24 and 42 respectively and that of *S. sphaerica* are 22 and 23 respectively. As found in the Vembanad estuary the other chitinous and siliceous species occur rarely in the marine end of the Kayamkulam lake.

The effects of the hydrographical parameters that influence the distribution of foraminiferal fauna in both the lakes are more or less similar. In the Kayamkulam lake the bar is closed during the pre-monsoon period and thereby the recruitment of the foraminifera from the sea into the lake by tidal current is prevented. In the Vembanad estuary there is no such barriers to prevent the penetration of the foraminifera into the estuary. But in spite of the more stable ecosystem, with lesser degree of fluctuations in the environmental parameters especially during the pre-monsoon season the Kayamkulam lake supports a comparatively smaller standing crop. The richness of the fauna in the Vembanad estuary may be due to the strong tidal currents for the whole year that favour the penetration of the calcareous marine forms into the estuary.

On the East Coast the distribution of living foraminifera in the Vellar estuary has been reported by Ramanathan (1970). The foraminiferal fauna in the Vellar estuary and in the present investigation area are more or less similar. Ramanathan showed that in the Vellar estuary Ammonia beccarii forms the major constituent of the foraminiferal fauna and that Trochammina inflata and Miliammina fusca appear in considerable amount in the upper part. According to him the other major species that inhabit the marine zone belong to the genera Rotalia, Elphidium, Quinqueloculina and Cibicides. The agglutinated forms belong to the genera *Miliammina*, *Trochammina*, *Textularia* and *Ammobaculites*. It may be noted that *Saccammina sphaerica*, a major inhabitant in the present investigation area has not been recorded from the Vellar estuary. As observed in the Vembanad lake the largest population is found in the summer months and during the flood season all the calcareous forms perish in the Vellar estuary. In general the spacial and seasonal distribution of foraminiferal assemblage in the Vembanad estuary is comparable with that in the Vellar estuary.

The distribution of foraminifera of the Chipurupalle stream in Andhra Pradesh has been studied by Rao and Rao (1976). As in the case of the Vellar estuary, the fauna in the present investigation area has great affinity with that of the Chipurupalle stream. 22 living specis have been recorded from this area. Of these the typical estuarine forms *Ammonia beccarii*, *Quinqueloculina seminulum* and *Miliammina fusca* are the most common and other species are only scarce in occurrene. Other species that are found in both the areas are *Ammobaculites dilatatus*, *Bolivina striatula*, *Quinqueloculina seminulum* and

Triloculina oblonga. The main difference seen in the occurrence of species in the two areas is that *Saccammina sphaerica* and *Trochammina inflata*, the dominant species in the present area have not been recorded from the Chipurupalle stream. The authors have pointed out that *A. beccarii* and *Q. seminulum* reproduce in the stream in favourable ecological conditions. The occurrence of the young ones of *A. beccarii*, *Q. seminulum* and *Elphidium crispum* in the marine end of the estuary indicates that they reproduce there. Similarly the presence of the young ones of the chitinous and siliceous forms in the upper reaches of the estuary indicates that these forms reproduce there.

While studying the bottom fauna of the Chilka lake Patnaik (1971) has observed that the foraminifera are the most dominant micro-benthos in the lake and that they are found distributed all over the area with monthly fluctuations in intensity. According to him the seasonal distribution of foraminifera is directly related to the fluctuations in the salinity of the lake. The maximum number of specimens is reported from the lake during the dry season and the minimum during the flood season. The largest numbers are noticed in the central part of the lake. Specimens of Rotalia and Elphidium are the common forms. The above findings of Patnaik is in agreement with the present observations.

Many of the species recorded in the present collections have been reported from the estuarine environments from other parts of the world also (Parker and Athearn, 1959; Zalesney, 1959; Phleger, 1960; Forti and Roettger 1967; Nichols and Ellison 1967; Wright, 1968; Schafer, 1969; Tapley 1969; Murray, 1968b, 1971; Levy, 1971; Boltovskoy and Lena, 1971 and Albani, 1978). While studying the foraminifera in Miramichi river, Gulf of Lawrence, Canada, Tapley (1969) has observed that Miliammina fusca is the characteristic species in the upper region and Ammonia beccarii in the lower region of the area. The relatively large number of chitinous and siliceous species of foraminifera reported by Nichols and Ellison (1967) from the Rappahannock estuary, Northern Virginia displays the same distribution pattern as in the present investigation area. According to him M. fusca is dominant in the upper stream and A. beccarii and Elphidium spp. are the dominant species in the lower part. Species of the genus Ammobaculites occur in considerable numbers in the fresh water zone of the Rappahannock estuary. Forti and Roettger (1967) have recorded species belonging to the genera Miliammina, Saccammina, Triloculina, Quinqueloculina and Elphidium from the estuarine environments in Brasil. Some species of the family Miliolidae have been reported by Wright (1968) from the brackish waters of Argentina. The foraminifera of the Tarmer Estuary, and Christ Church Harbour in England have been studied by Murray (1965a, 1968a). In both the areas he has recorded A. beccarii and Elphidium spp. as the most dominant forms in the lower part of the area and M. fusca as the dominant species in the upper part. Boltovskoy and Lena (1971) have reviewed the occurrence of M. fusca, T. inflata and S. sphaerica in the fresh water conditions. Thee three species that are known to survive in the fresh water medium are found living in the fresh water zone of the present investigation area also throughout the year. Of these three species T. inflata shows a clear prefernce for a slightly higher salinity medium when compared to the other two species. These three species can be noted as fresh water forms as reviewed by Boltovskoy and Lena (1971).

The total population density of foraminifera determined by Antony (1968) from the continental shelf of Kerala forms 4 to 112 specimens per $(10 cm)^2$ surface sample with an average value of about 50 specimens. According to Murray (1973) the average number of living foraminifera in the surface sediment samples in the sea varies from 50 to 200 per $(10 cm)^2$ and he has pointed out that in certain areas the value ranges from 0 to 4500 per $(10 cm)^2$. The total living foraminiferal density recorded by Rao and Rao (1976) in the Chipurupalle stream has a range of 0 to 37 specimens from a unit volume of 10 ml surface sediment, excluding the exceptionally large population of 250 specimens in the upper end of the estuary during the summer season. Patnaik (1971) determined the foraminiferal standing crop in the Chilka lake with the highest value of 322 specimens per $(10 cm)^2$ sediment sample. According to Nichols and Ellison (1967) the living foraminiferal population ranges from 0 to 41 per 20 ml sample in the Rappahannock estuary and he has recorded a maximum of 500 specimens in

$(10\ cm)^2$ sample. In the present collection the number of individuals in $(10\ cm)^2$ surface sediment sample ranges from 8 to 80 in the pre-monsoon period, 5 to 42 in the post-monsoon period and 0-11 in the monsoon period. This shows that the standing crop in the Vembanad estuary is smaller than those of the marginal marine environments of the adjacent sea. When compared with other estuaries the foraminiferal standing crop of the Vembanad estuary is similar to those of the Chipurupalle stream, the Chilka lake and the Rappahannock estuary.

Regarding the dead shells Rao and Rao (1976) have recorded 16 to 1348 shells per 10 ml sediment sample from the Chipurupalle stream. In the Kayamkulam lake the total number of dead shells recorded by Antony (1975b) is about 30 to 2000 per $(10\ cm)^2$ sample. The distribution of the dead shells in the present investigation area ranges from 40 to 1800 per $(10\ cm)^2$ sediment sample, thereby showing a close similarity with those of Chipurupalle stream and Kayamkulam lake. But the distribution of dead shells in the Vembanad estuary has no similarity with that of the adjacent sea where more than 50,000 dead shells per $(10\ cm)^2$ sample are recorded.

The lower number of the dead shells in the estuaries may be due to the dissolution of dead shells in the estuarine environment by the acidity of water.

From the foregoing account it is evident that some species like *Ammonia beccarii*, *Trochammina inflata*, *Miliammina fusca*, *Quinqueloculina seminulum*, *Elphidium crispum*, *E. craticulatum*, *E. advenum*, *E. macellum* and *Cibicides lobatulus* are enjoying an extensive geographic distribution in estuarine environments. Apart from the above common species, the presence of certain isolated species like *Saccammina sphaerica*, *Rhoopax scotti*, *Ammobaculites tayloreusis*, *Nonion sloani*, *Bolivina striatula*, *Operculinella cumingii*, *O. complanata*, *Rotalia calcar* and *Discorbis rosacea* in different estuaries indicate the variations in the geographical distribution of species.

In general, the distribution of foraminifera in the Vembanad estuary is more or less similar to that reported from other estuaries due to the fact that all the estuarine systems undergo the periodical environmental changes due to the tidal influence on one hand and the fresh water inflow on the other.

Acclimatisation of foraminifera in the estuarine complex

It is universally accepted that fresh water fauna has been derived from ancient marine animals. In the Vembanad estuary marine species of foraminifera have penetrated into the brackish or fresh water, through media of progressively decreasing salinity as found at the meeting place of the estuarine system and sea. Most of the modern brackish water animals are forms which have migrated from the sea. In the Vembanad estuary it is found that along with the fresh water species of foraminifera or brackish water species, the true marine species Ammonia beccarii is capable of surviving in the brackish medium in a low salinity of 19.5‰. This acclimatisation of marine foraminiferal species to frequent changes in salinity, would be a gradual change in their physiology from stenohalinism to euryhalinism and from poikilosmoticity to varying grades of homoiosmotic behaviour depending upon the species and conditions of environment. Thus the estuarine environment has been and continues to be an important route for the migration of the animals from the sea to fresh water.

IV

INTERSTITIAL FORAMINIFERA OF THE SANDY BEACHES OF THE SOUTH WEST COAST OF INDIA

The meeting place of the sea and land is a zone of varying width and this zone is always subjected to wave action and tidal movements. The area between the extreme high water level and the extreme low water level of spring tides is commonly called the intertidal zone and in this zone the space between sand particles is known as interstitial area. The thin film of water present around the particles of sand in the interstitial area is the habitat of many small animals constituting the interstitial fauna. These animals are subjected to adverse environmental conditions like excessive wave action, seasonal and diurnal changes in salinity and temperature and exposure of tidal flats to the sun.

The invertebrate fauna inhabiting the interstitial spaces of the sandy beaches has been a subject of intensive study all over the world (Pennak, 1940; Gauld and Buchanan, 1956; Wieser, 1959; Boaden, 1961, 1963; Macnae and Kalk, 1962; Swedmark, 1964). For the last 20 years a number of papers dealing with interstitial fauna have been published in India. Particular mention may be made of the works of Ganapati and Rao, 1962; Mc Intyre, 1968; Rao and Ganapati, 1968; Trevallion <u>et al</u>, 1970 and Philip, 1972.

The two important groups of protozoans inhabiting the interstitial spaces of the sandy beaches are Foraminifera and Ciliata. Among these two groups, foraminifera are the most common in the beach sand all over the world, comprising living as well as dead representatives.

From the ecological point of view the study of the foraminiferal fauna is important since out of the many species found in the coastal waters only a few are found adapted to the special conditions of the intertidal area.

Because it is easy to collect foraminifera from the sandy coast, greater part of the earlier works has been concerned with the dead shells of foraminifera brought from the shore sand (Williamson, 1958). The study of foraminifera from the sandy beaches has been a subject of great interest in the European coast (Phloger, 1966, 1970; Boltovskoy, 1970; Bandy, 1964; Richter 1964; Evans, 1965; Murray 1965 b, 1971; Hedley et al 1967 and Bradshaw, 1968). The studies on the shelled protozoans of the Indian coast have been initiated by Bhatia (1957) and Rao and Ganapati (1968). But hitherto no attempt has been made to study those micro-organisms from the sandy beaches of the South West Coast of India, in relation to the ecological conditions. The aim of the present work is to investigate the intertidal foraminiferal fauna, their seasonal occurrence, pattern of distribution and abundance along the South West Coast of India.

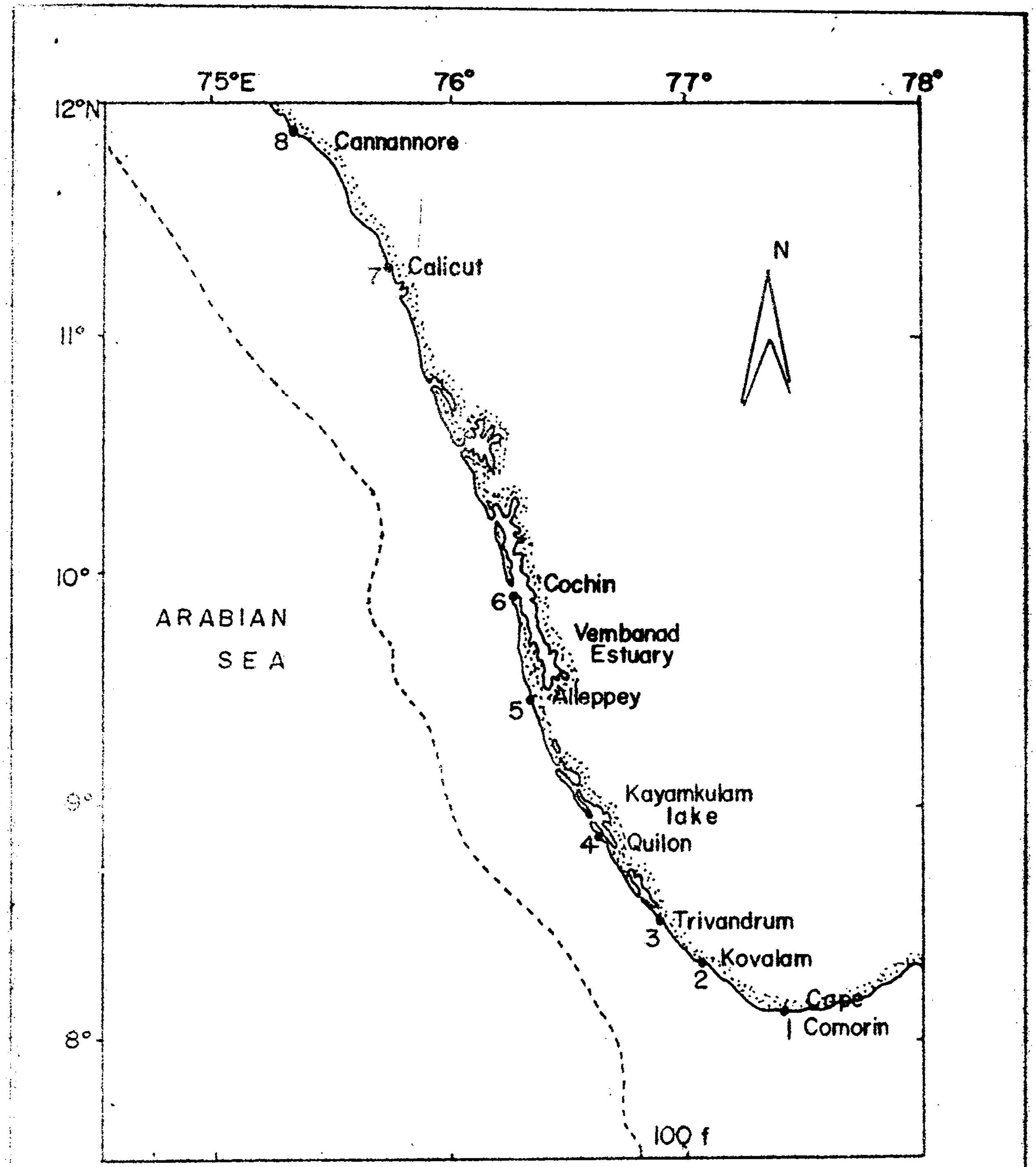
Material and Methods

The study area

The investigation area is the South West Coast of India extending for about 500 km in length situated between latitudes 8° 7'5" and 11° 52'25" N. and longitudes 75° 20'10" and 77° 12'00" E (Fig. 10).

During 1974 - '76 samples were collected from the intertidal area from 8 localities along the coast extending from Cannanore in the north to Cape Comorin

Fig. 10 Map of South West Coast of India showing stations from where samples were collected for the study of foraminifera.



75°E
76°
77°
78°
12°N
11°
10°
9°
8°
8 Cannannore
7 Calicut
N
ARABIAN
SEA
Cochin
6
Vembanad
Estuary
Alleppey
5
Kayamkulam
lake
4 Quilon
Trivandrum
3
Kovalam
2
Cape
1 Comorin
100 f

FIG. 10

in the south (Table 8). Of these 8 localities, monthly collections were taken from the Cochin area to study in detail the occurrence of foraminifera in relation to the ecological parameters of the intertidal area. From each of the other localities only three collections (in April, July and December) were made in an year corresponding to the three seasons of the year.

Field collections

For taking samples, the intertidal zone of the sandy shore has been differentiated into dry and wet zones. The wet zone is the lower region which is submerged by the waves that roll on the shore at frequent intervals; while the upper portion is mostly dry and is submerged only by the rising tides twice a day. Here also the uppermost region is wet by sea water only by the highest tides during full moon and new moon.

In the present study the foraminifera were collected from the wet zone of the intertidal region. Three points were fixed at equidistant intervals - the first one at the highest level of the wet zone,

Table 8 <u>List of stations from where interstitial samples were collected.</u>

Locality	Station No.	Position Long. E.	Position Lat. N.
Cape Commorin	1	77 10' 00"	8 7' 55"
Kovalam	2	77 2' 30"	8 21' 30"
Trivandrum	3	76 55' 15"	8 30' 20"
Quilon	4	76 35' 50"	8 52' 45"
Alleppey	5	76 19' 20"	9 26' 40"
Cochin	6	76 15' 30"	9 58' 12"
Calicut	7	75 43' 00"	11 18' 10"
Cannanore	8	75 20' 10"	11 52' 25"

the third at the lowest level of the receding waves and the second one at the middle of the region in between the first and the third. All collections were taken at low tide only. From each of the three points in the region 250 ml of the surface deposit was taken using a quadrat, 10 cm x 10 cm pushed 2.5 cm deep into the sand. From this 25 ml of the sample was preserved in alcohol for studying living foraminifera. Duplicate samples were preserved from each station for studying living foraminifera and the average number was calculated. The rest of the sample was dried and used for the grain size analysis.

Hydrographic data were recorded from all the stations at the time of collection of samples. Temperature of the atmosphere, sea water and the sand at the three levels of the tidal area were noted. Water samples were collected from the sea and from the intertidal area for the estimation of salinity, dissolved oxygen and pH. The interstitial water was collected by pushing into the soil the end of a specially devised pipette and sucking the water.

Analysis of the samples

In the laboratory the preserved sand samples were stained with Rose Bengal, in the stain for 24 hours and then washed clearly to remove the excess stain and dried. Foraminiferal tests were separated from the sand by floatation in carbon tetrachloride solution. The shells of foraminifera being lighter, floated on the surface of the solution. The surface material was poured through a 63 µ sieve, dried and transferred into a petri-dish. The residual sand was again examined and any foraminiferal tests left were picked and added to the crops. Small quantities of this material was spread on a glass plate and examined under a stereoscopic binocular microscope. The different species were identified and the living and dead populations counted. The grain size of the sand was determined by using standard Endicott sieves (Krumbein and Pettijohn, 1938). Analysis of the water samples was done as described in the earlier part.

Observations

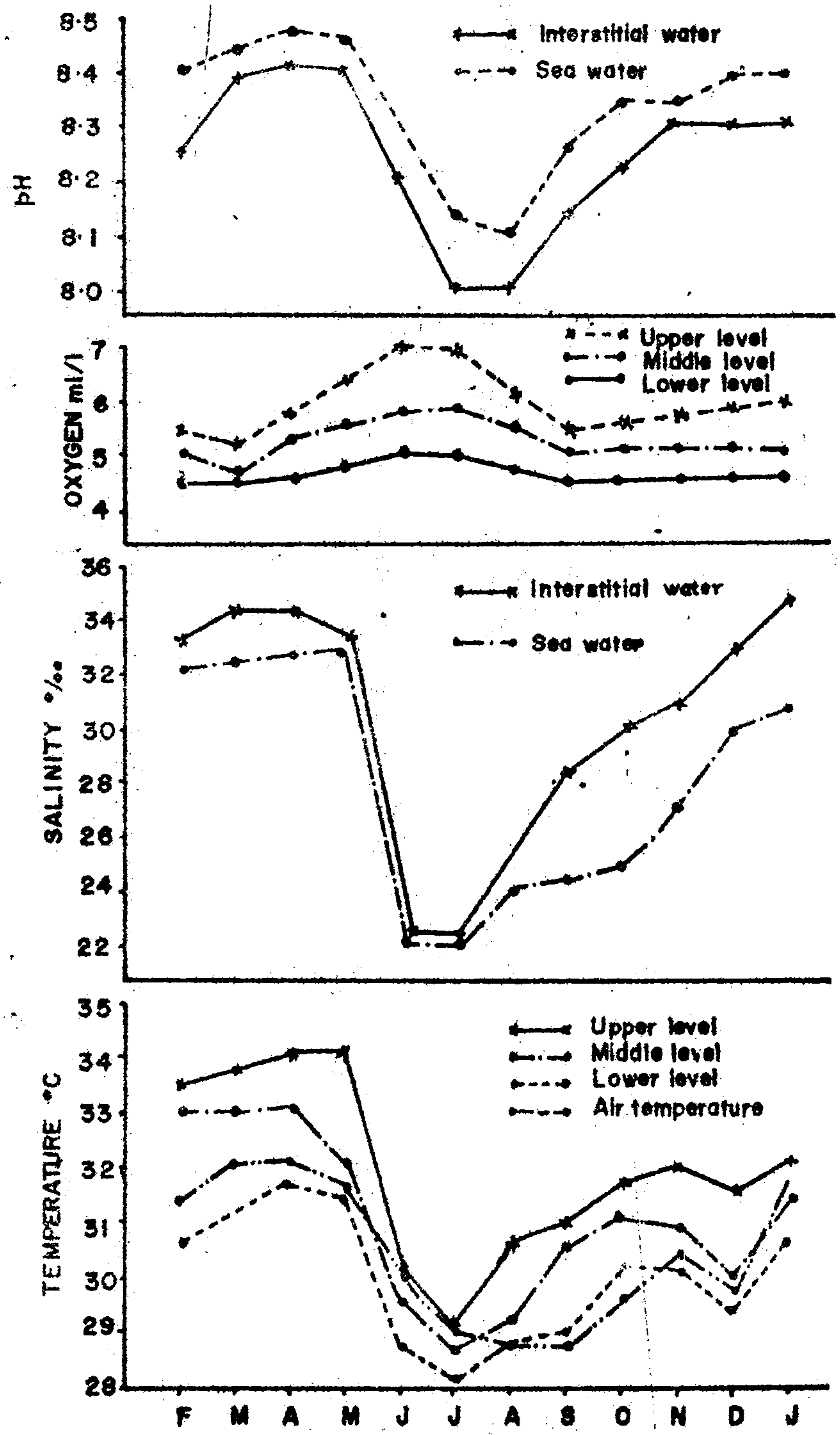
Environmental factors

The animal population in an area is affected by the physico-chemical factors like temperature, salinity, dissolved oxygen and pH. For understanding the ecology of foraminifera the above parameters were studied and the results are given in Fig. 11.

Temperature:

The sediment temperature is one of the most variable factors in the area and it shows seasonal variations. There is little difference between air temperature and surface sea water temperature while there is difference between the temperature of sea water and that of the interstitial water. The temperature of sea water is on an average 0.9°C lower than that of the intertidal sand. For sea water the temperature ranges from 27.5°C in July to 32.0°C in April and for intertidal sand it ranges from 27.0°C in July to 33.1°C in April. Generally the temperature increases from low water mark towards high water mark and it varies according to the time of the day. The temperatures of the sand at the low tide level and the adjacent sea water are more or less the same. The maximum variation in temperature is observed at the upper level, where it ranges from 31.0°C in September to 34.1°C in April. The middle region shows very little difference, since this transect is always wet by the waves and rising tides.

Fig. 11 Monthly mean values of temperature, salinity, dissolved oxygen and pH of the intertidal area at Cochin during 1974 - '76.



8·5
8·4
8·3
8·2
8·1
8·0
pH
Interstitial water
Sea water
7
6
5
4
OXYGEN ml/l
Upper level
Middle level
Lower level
36
34
32
30
28
26
24
22
SALINITY ‰
Interstitial water
Sea water
35
34
33
32
31
30
29
28
TEMPERATURE °C
Upper level
Middle level
Lower level
Air temperature
F
M
A
M
J
J
A
S
O
N
D
J

FIG. II

Salinity:

Based on the variations in salinity and rainfall three seasons are recognised in an year, a pre-monsoon (Feb. - May), monsoon (May - September) and post-monsoon (Oct. - January). The pre-monsoon period is dry with less rain fall and the maximum salinity (34.69‰) is noted during this period. The monsoon is characterised by heavy rain fall and the lowest salinity value (24.36‰) is observed during this period. The salinity of coastal waters is reduced to a minimum of 26.58‰ due to the influx of fresh water from the backwaters and rivers. The post-monsoon period shows an upward trend in salinity eventhough there are fluctuations caused by the north-east monsoon.

The interstitial water shows higher salinity value than sea water during the pre-monsoon and post-monsoon periods, because of the evaporation of capillary water during these dry seasons. But during monsoon the interstitial water shows lower salinity values by the infiltration of fresh water. The salinity values of the interstitial water and the adjacent sea water for different months are shown in Fig. 11.

Dissolved oxygen:

The availability of dissolved oxygen is considered as one of the important factors that controls foraminiferal population. Dissolved oxygen content of the water collected from the interstitial area shows great fluctuations and this is due to the higher wave action and the exposure to changes in atmospheric conditions. The mean values of dissolved oxygen range from 4.4 ml/l (December) to 7.2 ml/l (July). Generally the oxygen values decrease from low to high tide level.

pH:

pH values of the interstitial water are lower than that of sea water. It ranges from 7.7 (July) to 8.4 (April). The pH values recorded at different months are given in Fig. 11.

Tides and waves:

The tides in the area are of the semi-diurnal type and the tidal ebb and flow is one of the factors in the area which determines the width of the inhabitable area of the intertidal zone. The amplitude of tides is variable between seasons and neap tides and the range of the lower low water spring level and higher high water spring level are 0.20 m and 1.05 m respectively. (Indian Tide Table). Strong winds also produce tides which range upto 1.5 to 2 m.

Associated with tide is the phenomenon of wave action which determines the boundaries and slope of the intertidal zone. During the monsoon period the waves wet the sand beyond the high tide mark. The waves and tides determine the exposure of the organisms to desiccation and other environmental conditions of the tidal zone.

Sand grain size:

In all the 8 stations the sand of the intertidal area is a mixture of particles of different sizes. The sand grains are classified as very fine sand from 0.06 to 0.125 mm, fine sand 0.125 to 0.250 mm and medium sand 0.250 to 1 mm (Inman, 1963). Based on the differences in particle size the beach sediment is composed of very fine to medium sand. The percentage weights of sand grains are calculated using the formula by Trask (1932).

Generally the sediment of the intertidal area is predominantly medium to fine sand. A gradation of size variation is seen at the different zones (Fig. 12). In the low water level there is a considerable higher proportion of sand and dead shells. From the data

Fig. 12 Cumulative weight percentage of grain size of sand in three seasons at three tide levels at Cochin during 1974 - '76

a The mean value of the pre-monsoon months

b The mean value of the monsoon months

c The mean value of the post-monsoon months

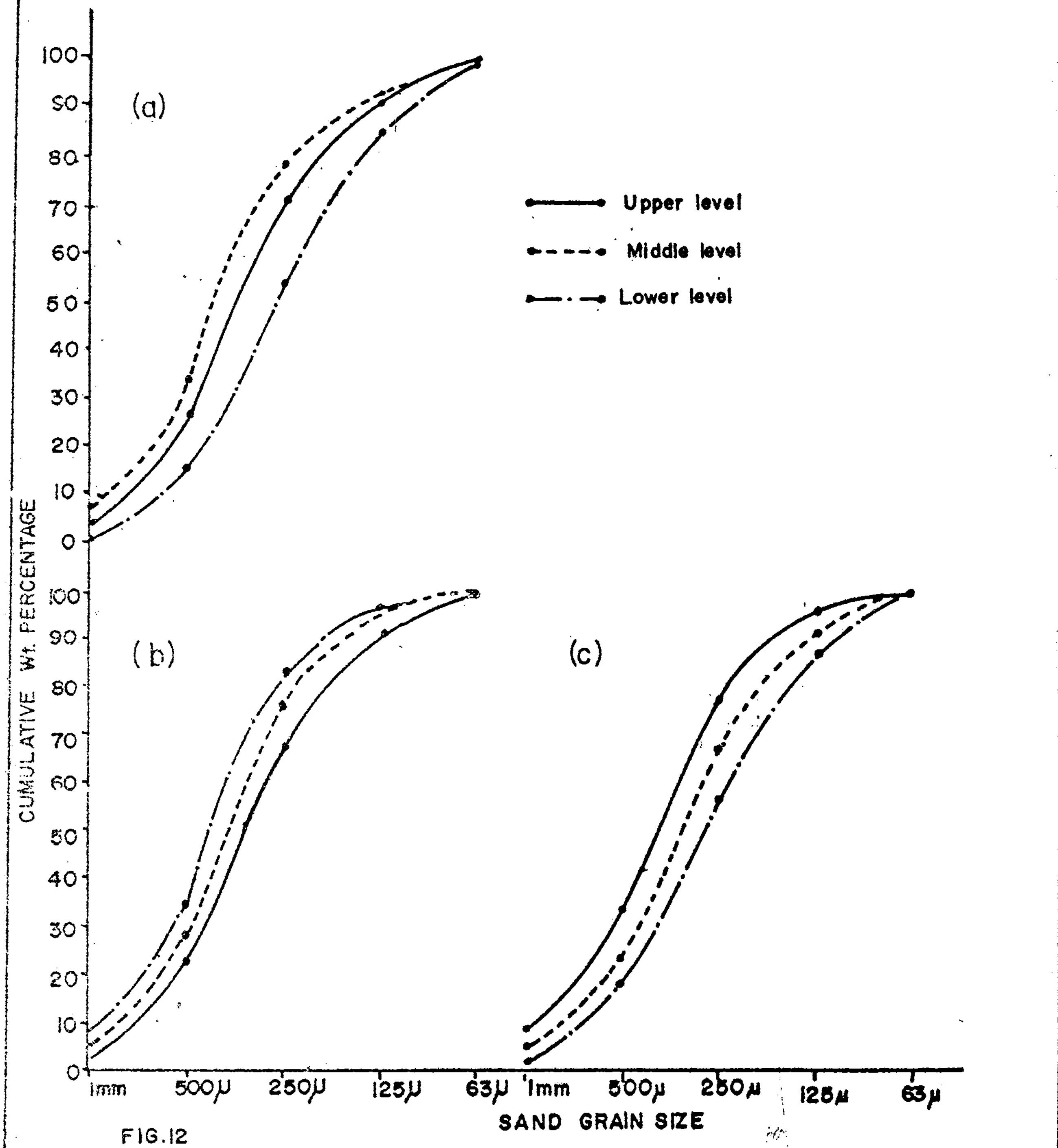

(a)
(b)
(c)
Upper level
Middle level
Lower level
CUMULATIVE Wt. PERCENTAGE
0
10
20
30
40
50
60
70
80
90
100
1mm
500μ
250μ
125μ
63μ
SAND GRAIN SIZE

FIG.12

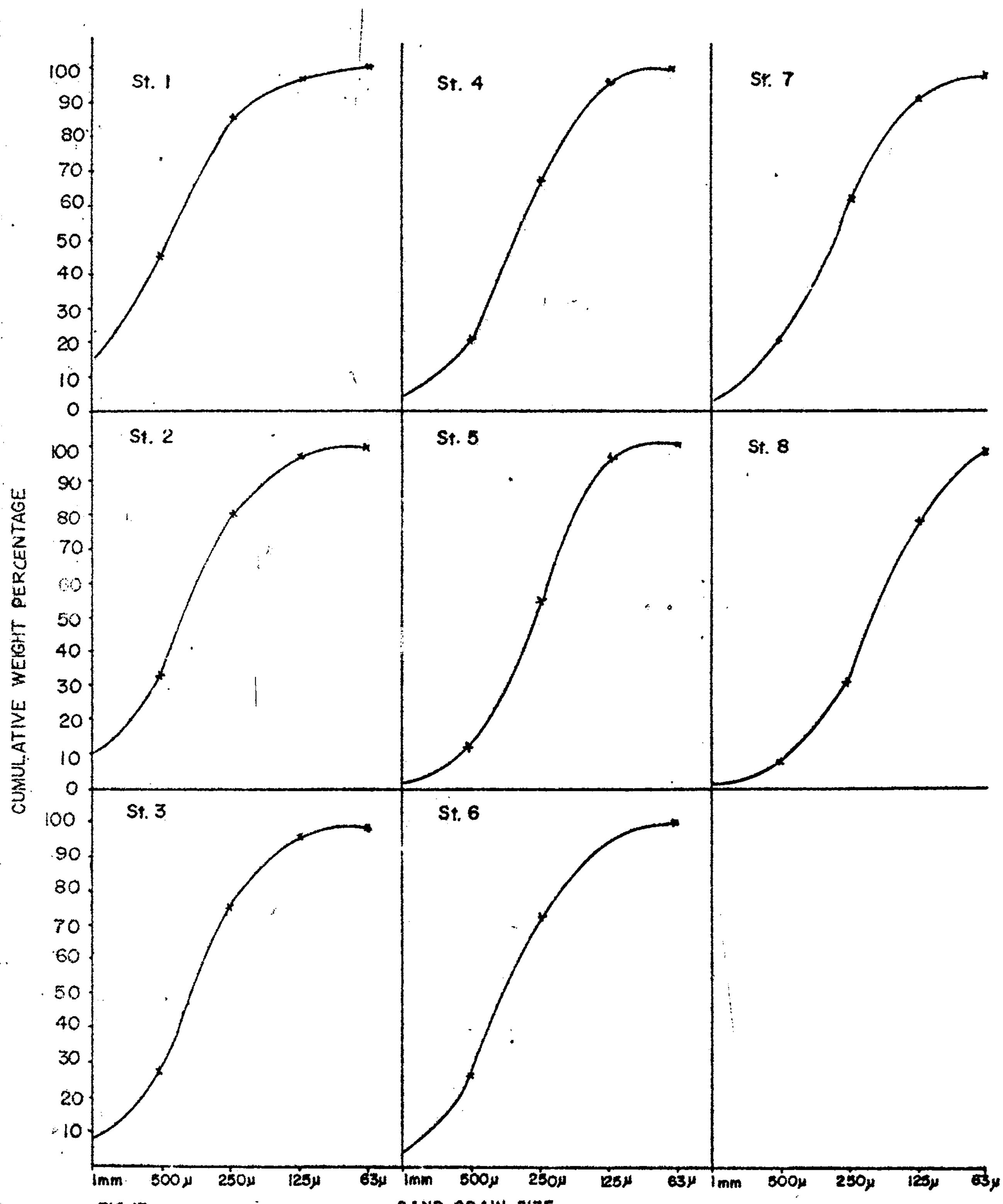
presented in Fig. 13, it is clear that the size of the sand grains differs at the 8 stations. At station 1 the substratum is composed of 14% of very fine sand, 41% of fine sand and 45% of medium sand; while at station 8 it is 69%, 23% and 8% respectively. The percentage compositions of fine sand grains do not vary much in the other 6 areas and at these stations they range from a maximum of 50% at station 3 to a minimum of 42% at station 7. The percentage weight of medium sand varies from 33 at station 2 to 20 at station 8, while the very fine sand composition constitutes a minimum of 20% at station 2 and a maximum of 38% at station 7.

From the data presented it is seen that the size of the sand grains gradually increases from north to south. The substrate of the 3 stations at the southern end is mainly composed of fine to medium sand while the 3 stations at the northern end have very fine sand and fine sand as the major constituent.

Interstitial water:

The irregular shape of the sand grains provides interstices in which water is filled by capillary action.

Fig. 13 Cumulative weight percentage of the grain
size of sand at 8 stations, during 1974 - '76



CUMULATIVE WEIGHT PERCENTAGE
St. 1
St. 4
St. 7
St. 2
St. 5
St. 8
St. 3
St. 6
100
90
80
70
60
50
40
30
20
10
0
1mm
500μ
250μ
125μ
63μ
SAND GRAIN SIZE

FIG. 13

Microorganisms inhabit the inter-spaces that are formed by the imperfect packing of different sized particles. The capillary water is dependent on the nature of the deposit and the tide levels. The percentage of the water content of the surface sand at high water level is less due to evaporation or drainage, but the water content increases with depth. The amount of interstitial capillary water influences the distribution and abundance of the fauna at the upper region and middle region. At the low tide mark the interspaces of sand particles are always filled with water and hence the foraminifera occur in large numbers.

Distribution of foraminifera

Composition of species:

Among the foraminifera occurring in the intertidal area there are living as well as dead specimens and the living species are mainly dealt with in the present study. But, for ascertaining the numerical strength, all specimens including the living and dead are counted. Altogether 17 species of living foraminifera are recorded from the collections.

The number of living specimens in the 25 ml sample analysed varies from 5 to 48. All the 17 species recorded are calcareous forms, and no living chitinous or siliceous form was found. Ammonia beccarii (Linne) is the most predominant form which constitutes more than 50% of the total population in the area. The other common forms found are Quinqueloculina bicornis (Walker and Jacob), Q. seminulum (Linne), Nonion boueanum (Hade), Elphidium crispum (Linne), E. craticulatum (Fichtel and Moll), E. advenum (Cushman), E. macellum (Fichtel and Moll), Discorbis rosacea d'Orbigny and Cibicides lobatulus (Walker and Jacob). Triloculina oblonga (Montague), Nonion sloani (d'Orbigny), Operculina granulosa Leymerie, O. complanata (Defrance), Operculinella cumingii (Carpenter), Rotalia calcar d'Orbigny and Amphistegina lessonii d'Orbigny occur in low frequencies in the area. A classified list of species is given in Table 4.

Altogether six families are represented, but most of the members belong to the families Miliolidae, Rotaliidae and Nonionidae. Of these, except family Miliolidae all are perforate forms. Family Miliolidae includes three species - *Quinqueloculina bicornis* (Walker and Jacob), *Q. seminulum* (Linne) and *Triloculina oblonga* (Montague). In the perforate group, Nonionidae forms the most varied family with two genera and six species - *Nonion boueanum* (Hade), *N. sloani* (d'Orbigny), *Elphidium crispum* (Linne), *_. craticulatum* (Fichtel and Moll). *E. advenum* (Cushman) and *E. macellum* (Fichtel and Moll). The family Camerinidae is represented by two genera and three species - *Operculinella cumingii* (Carpenter), *Operculina granulosa* (Leymerie) and *O. complanata* (Defrance). The family Rotaliidae is represented by three species - *Discorbis rosacea* (d'Orbigny), *Rotalia calcar* (d'Orbigny) and *Ammonia* (Rotalia) *beccarii* (Linne). Each of the families Amphisteginidae and Anomalinidae is represented by a single species, *Amphistegina lessonii* d'Orbigny and *Cibicides lobatulus* (Walker and Jacob) respectively.

Numerical density

In Fig. 14 is presented the total number of foraminifera (both living and dead) as occurs at different stations. The ratios of the total number of living and dead specimens of the three prominent

Fig. 14 Histogram showing the numerical distribution of the total number of foraminifera at 8 localities during 1974 - '76.

Fig. 15 Triangular diagram showing the ratio of the total specimens of the three families Miliolidae, Nonionidae and Rotaliidae at 8 stations

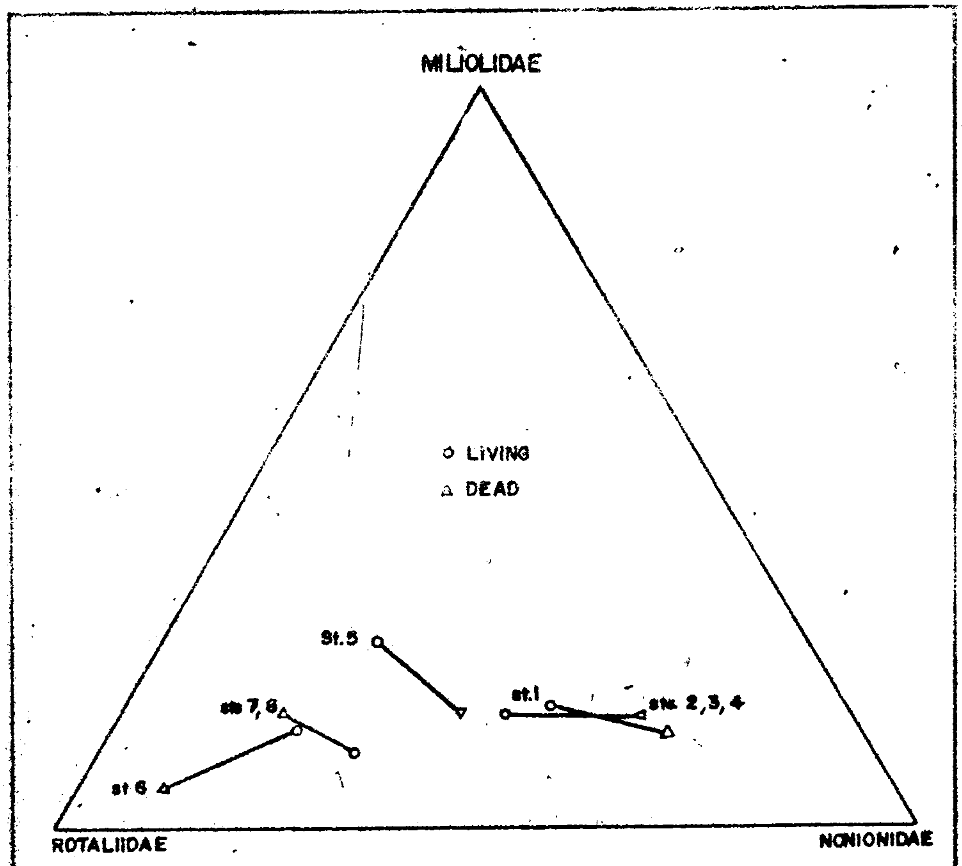

MILIOLIDAE
o LIVING
Δ DEAD
St.5
sts 7, 8
st.1
sts. 2, 3, 4
st 6
ROTALIIDAE
NONIONIDAE

FIG.15

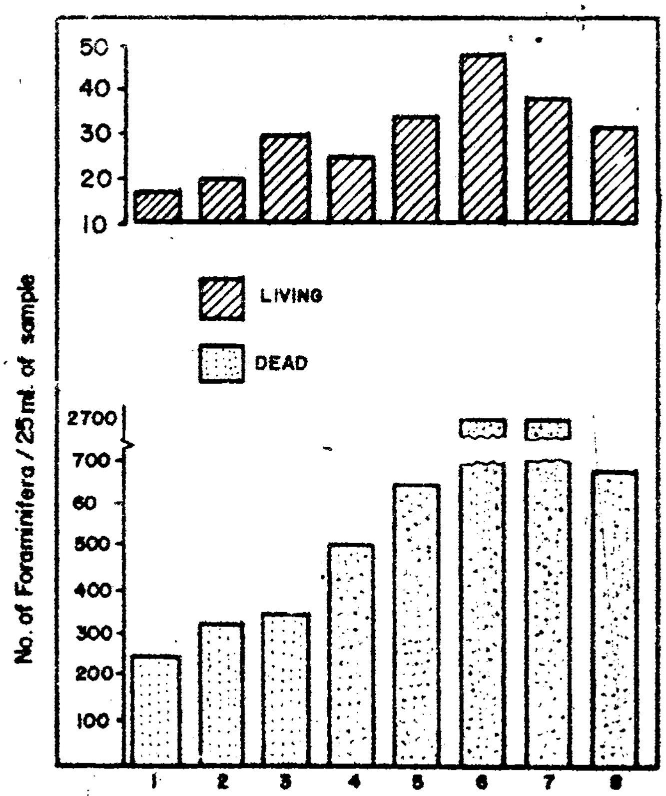

50
40
30
20
10
LIVING
DEAD
2700
700
60
500
400
300
200
100
No. of Foraminifera / 25 ml. of sample
1
2
3
4
5
6
7
8
STATIONS

FIG.14

families Miliolidae, Rotaliidae and Nonionidae at the eight stations are plotted in a triangular diagram (Fig. 15) following Loeblich and Tappan (1964).

Zonal distribution:

The living population in the sample analysed shows considerable variations, seasonally and at the three levels (Table 9). Only Ammonia beccarii is found living at the upper level in June-July months. Elphidium crispum, E. craticulatum and Quinqueloculina seminulum appear at this level from August-September onwards. From January to April all the species are present at this level and the number of living specimens is at its maximum during this period. In the post-monsoon period Q. bicornis, Nonion sloani, Discorbis rosacea and Operculina complanata are not found at this level. The middle zone supports the second abundance in the occurrence of living specimens. Except in the monsoon season all the species are found at this level. In the low water level all the species are found living in the post-monsoon and pre-monsoon periods, but in the monsoon period Elphidium macellum, Quinqueloculina bicornis, Discorbis rosacea, Operculina complanata and Triloculina oblonga are not found alive.

Table 9 Living foraminifera at the three levels of the wet zone of the intertidal region at Cochin in different seasons during 1974 – '76

	Lower level	Middle level	Upper level
Pre-monsoon	All species present	All species present	All species present
Monsoon	Ammonia beccarii Rotalia calcar Elphidium crispum E. craticulatum E. advenum E. macellum Quinqueloculina seminulum Nonion boueanum Cibicides lobatulus Amphistegina lessoni Operculina granulosa Operculinella cumingii Triloculina oblonga	Ammonia beccarii Elphidium crispum E. craticulatum Nonion boueanum Q. seminulum E. macellum C. lobatulus	Ammonia beccarii
Post-monsoon	All species present	All species present	Ammonia beccarii Quinqueloculina seminulum Elphidium crispum E. craticulatum E. advenum E. macellum Nonion boueanum Cibicides lobatulus Amphistegina lessoni Triloculina oblonga Operculina granulosa Operculinella cumingii Rotalia calcar

The total number of living specimens present in the three levels shows considerable variations. The upper level supports the minimum number of living specimens and the population ranges from a maximum of 28 in the pre-monsoon season to a minimum of 8 in the monsoon season. The middle level supports the second abundance in the occurrence of living specimens. At this level the living population ranges from 12 in the monsoon season to 38 in the pre-monsoon period. In the post-monsoon season it is about 25 at this level. The low water level supports the maximum number of foraminifera in all the seasons. The corresponding numbers in the pre-monsoon, post-monsoon and monsoon seasons at this level are 48, 38 and 20 respectively.

Regarding the seasonal occurrence of foraminifera the maximum number is found in the pre-monsoon season and the minimum in the monsoon season at all the three levels. (Fig. 16). The occurrence of living foraminifera with corresponding hydrographic data is shown in Fig. 17.

Regional diversity of species:

The occurrence of foraminifera in all the stations shows the maximum abundance in the pre-monsoon period and hence to study the regional diversity of species the data collected during this season from all the stations are presented in Table 10. The larger forms

Table 10 General pattern of the distribution of foraminifera at 8 stations (mean values of April 1975 and 1976)

Species	Stations							
	1	2	3	4	5	6	7	8
Quinqueloculina bicornis	-	R	R	R	F	F	R	R
Q. seminulum	R	R	R	R	F	C	F	C
Triloculina oblonga	-	R	-	R	-	R	F	F
Nonion boueanum	-	-	R	-	R	F	C	R
N. sloani	-	-	-	-	R	R	F	F
Elphidium crispum	C	F	F	F	R	F	R	R
E. craticulatum	C	C	C	C	R	F	R	-
E. advenum	C	R	F	-	R	R	R	-
E. macellum	R	-	R	-	R	R	F	F
Operculina granulosa	C	C	F	R	-	R	R	-
O. complanata	F	C	R	R	-	R	-	-
Operculinella cumingii	F	F	F	-	R	R	R	-
Discorbis rosacea	-	-	-	R	R	F	R	R
Ammonia beccarii	F	F	R	C	C	C	C	C
A. calcar	-	-	R	R	C	A	C	R
Amphistegina lessonii	-	-	R	R	F	C	-	R
Cibicides lobatulus	-	-	-	R	R	F	C	F

Abundance scale

Rare (R): 1 - 5 individuals in 25 ml sample

Frequent(F): 6 -20 individuals in 25 ml sample

Common (C): > 20 individuals in 25 ml sample

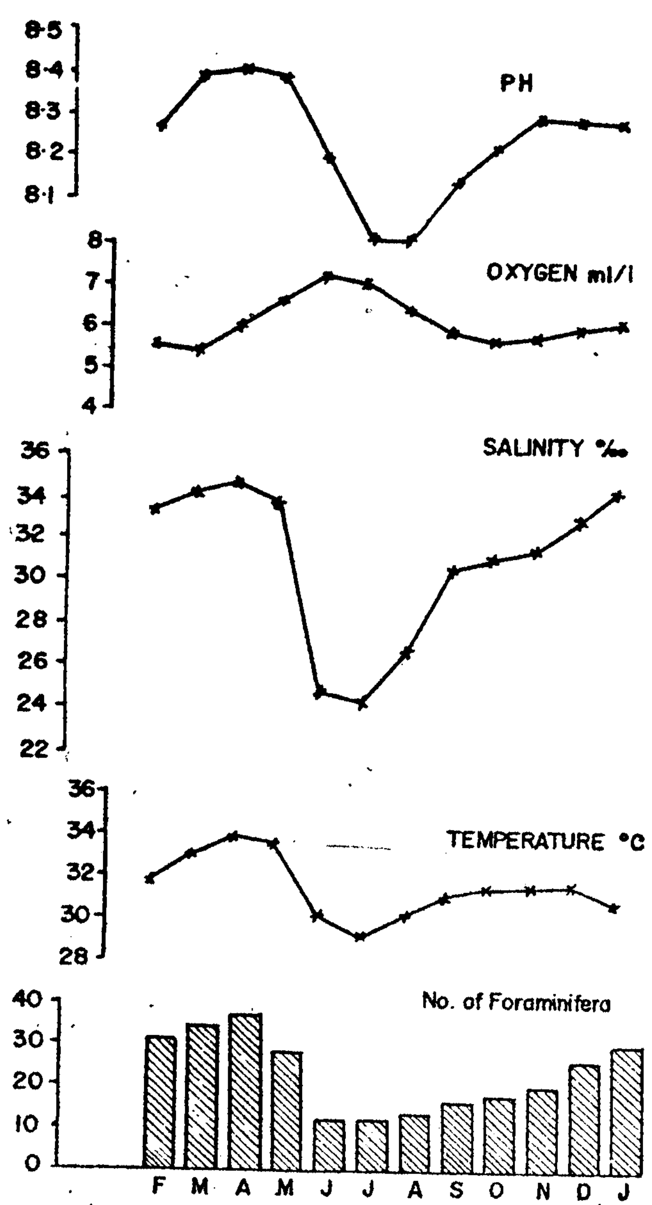
Fig. 16 Monthly mean value of living foraminifera at different levels in 25 cc sample at station 6 during 1974 - '76

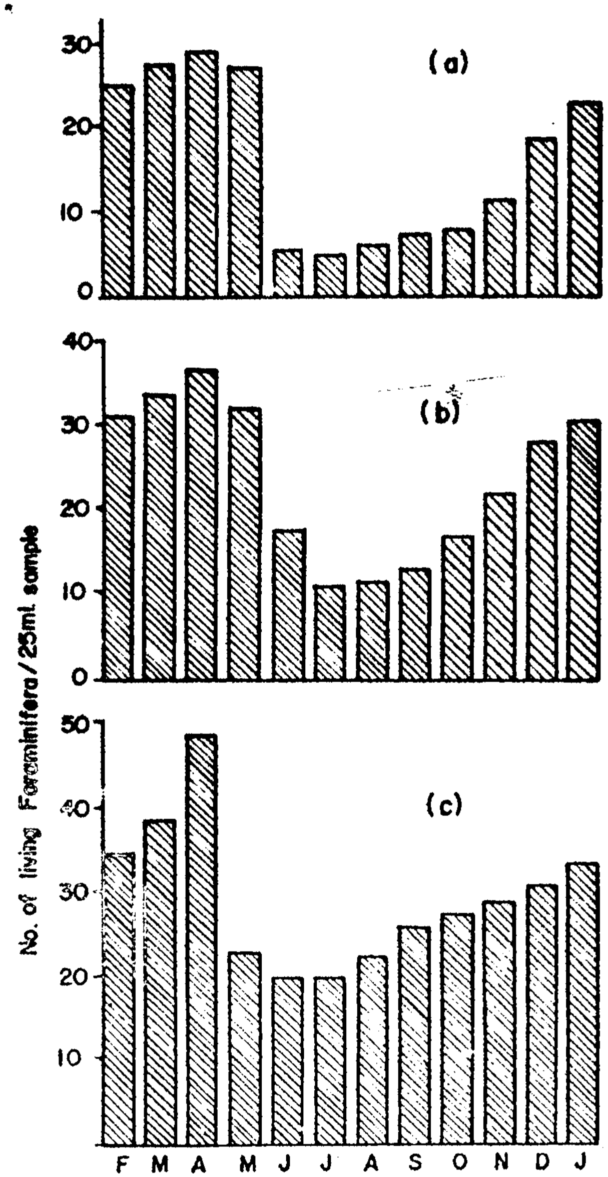
a Upper level

b Middle level

c Lower level

Fig. 17 Monthly mean value of total living foraminifera with corresponding ecological factors at Cochin during 1974 - '76


PH
8·5
8·4
8·3
8·2
8·1
OXYGEN ml/l
8
7
6
5
4
SALINITY ‰
36
34
32
30
28
26
24
22
TEMPERATURE °C
36
34
32
30
28
No. of Foraminifera
40
30
20
10
0
F M A M J J A S O N D J
FIG.17.


(a)
30
20
10
0
(b)
40
30
20
10
0
(c)
50
40
30
20
10
No. of living Foraminifera / 25ml. sample
F M A M J J A S O N D J
FIG. 16

of the families Miliolidae and Camerinidae are dominant in the southern part (stations 1 to 4) while smaller forms of the families Anomalinidae and Amphisteginidae are prominent in the northern part (stations 7 and 8). At station 6, species of the family Rotaliidae form more than 50% of the total assemblage.

Of the 17 species found living in the intertidal area. Ammonia beccarii, Elphidium craticulatum, E. crispum and Quinqueloculina seminulum are the major inhabitants and Nonion sloani, Discorbis rosacea and Triloculina oblonga are rare at all the stations.

At station 1, Operculina granulosa, O. complanata, Operculinella cumingii, Elphidium craticulatum, E. crispum and E. advenum are more dominant than at the other stations. These species are frequent in occurrence at stations 2 to 4 also. At station 6 Ammonia beccarii predominates over all the other forms. All the other species occur in moderate numbers only. Cibicides lobatulus, Nonion boueanum and Triloculina oblonga are the common forms at stations 7 and 8.

Seasonal occurrence of foraminifera at 8 stations

Another feature noticed in the present study is the seasonal variations in the total number of foraminifera collected from the 8 stations. A fairly rich fauna is found at station 6 in all the seasons with the maximum of 2700 and the minimum of 600 numbers occurring during April and December respectively. In July (Monsoon period) the total number at this station is 950. The minimum number occurs at station 1 throughout the year, and it varies as 160 in July, 210 in December and 260 in April. At stations 2,3,4 and 5 the numbers recorded during December (post-monsoon period) are 310, 300, 430 and 510 respectively. At stations 7 and 8 the corresponding values are 640 and 490. In July (monsoon period) the monthly values of the total foraminifera are 280, 300, 400, 450, 950, 500 and 400 at stations 2 to 8 respectively. This shows that the total number of individuals are high during the pre-monsoon season when the living specimens are at their peak of occurrence. The post-monsoon period shows the second abundance in occurrence throughout the area. But in the monsoon period the total number is generally poor when compared to the other seasons. There is a decline in the number of dead shells during the monsoon period when the living specimens are found in lesser numbers. Then a gradual increase in the dead shells is noticed which reaches the maximum in April. Thus a corresponding increase or decrease in the number of dead shells with that of the living specimens is noticed according to seasonal changes.

Live-dead ratios

The number of dead shells shows a decline from the upper level to the low tide level. It varies from 375 to 2700 in the upper region, 300 to 2000 in the middle level and 250 to 1100 in the low tide mark. During pre-monsoon period the ratio of living-dead population at the upper level is 1:65, in the middle mark it is 1:54 and in the low tide level it is 1:48. During the monsoon season the ratio ranged from 1:44, 1:50 and 1:80 respectively. In the post-monsoon period in the upper level the live dead ratio ~~(ranges is from)~~ 1:92, in the middle level 1:80 and in the low tide level 1:55. This shows that more empty shells of foraminifera occur in the post-monsoon season than in the other two seasons.

The living and dead specimens in the samples differ in their relative abundance of individual species.

In the upper region in July the number of living specimens of Ammonia beccarii is 8 while the dead shells of the same species is about 2000. In April at the low tide level the numbers of living and dead specimens of this species are 28 and 650 respectively. Similarly a corresponding increase in the number of dead shells of all the species is found throughout the year.

Sand grain size and Foraminifera

Of the several environmental parameters studied, the grain size is the most important factor that shows variations in different localities. The 8 stations selected for the present study differ in the nature of substrate. There are variations in the composition of grain size in different stations as shown in Fig. 18. Some amount of correlation between the grain size and the size of foraminifera can be seen in the present study. The large sized foraminifera above 1 mm such as Elphidium advenum, E. crispum, E. craticulatum, Operculina granulosa, O. complanata and Operculinella cumingii are found in large numbers in station 1, where the substrate is with a high proportion of medium sand. Small forms with less than 0.5 mm size (Nonion boueanum, N. scapani, Discorbis rosacea, Triloculina oblonga and Cibicides lobatulus) appear in large numbers at stations 7 and 8 where higher percentage of very fine to fine sand contributes to the substrate. The medium sized forms with size range 0.5 to 1 mm (Rotalia calcar, Amphistegina lessoni and Elphidium macellum) occur more in number at stations 5 and 6 where the substrate shows a relatively high percentage of fine sand. However at station 6 all the species are present in fairly good numbers compared to other stations. Similarly Rotalia beccarii, Elphidium craticulatum, E. crispum and Quinqueloculina seminulum are found common at all the stations though they show variations in their abundance at different localities. The relationship between sand grain size and the total number of foraminifera is shown in Fig. 18.

Discussion

Ecological factors

The observations show that the abundance and distribution of foraminifera are affected by the environmental factors like temperature, salinity, dissolved oxygen, pH and the nature of the substrate.

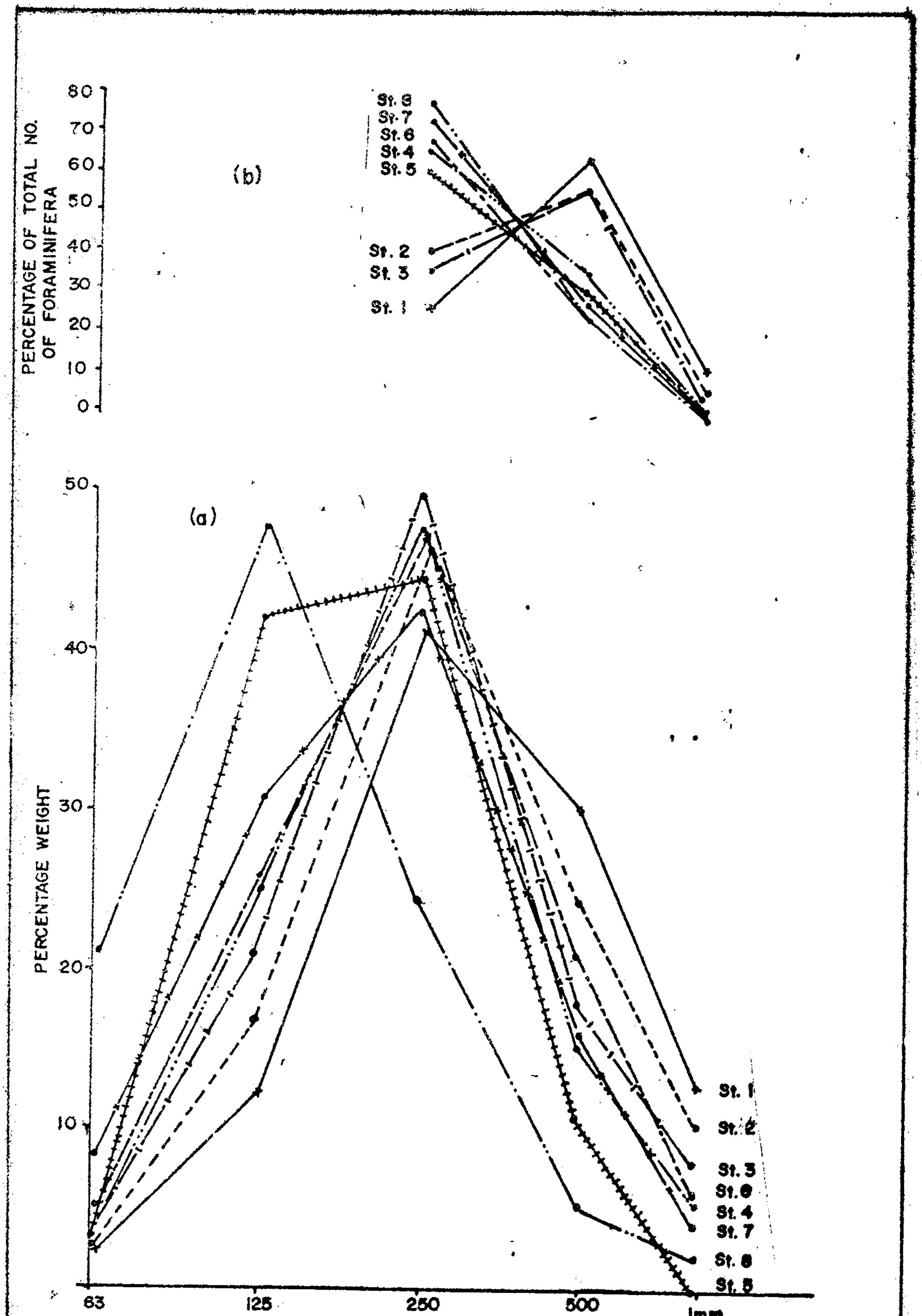
Temperature:

Some foraminifera can tolerate wide variations of temperature while others have a narrow range of

Fig. 18 Relationship between sand grain size and total number of foraminifera at 8 stations

a Percentage weight of sand grain

b Total number of foraminifera



PERCENTAGE OF TOTAL NO. OF FORAMINIFERA
80
70
60
50
40
30
20
10
0
(b)
St. 8
St. 7
St. 6
St. 4
St. 5
St. 2
St. 3
St. 1
PERCENTAGE WEIGHT
50
40
30
20
10
(a)
St. 1
St. 2
St. 3
St. 6
St. 4
St. 7
St. 8
St. 5
63
125
250
500
1mm
SAND PARTICLE SIZE IN μ

FIG. 18

tolerance. On a world-wide basis the major shallow water foraminiferal fauna is controlled by temperature. In the present study area the temperature variation is within the range of 27.0°C and 33.1°C. Since these fluctuations of the temperature are within the range of tolerance of all the species, it does not seem to be a controlling factor in the occurrence of foraminifera in the area. However it was observed that the populations were more at a temperature range of 30 to 32°C.

Salinity:

Of the several environmental factors that influence the occurrence of interstitial foraminifera, salinity is the most important. The marked fluctuations in the salinity caused by the seasonal changes especially by the monsoon rains, bring about changes in the occurrence and distribution of foraminifera in the area. Only the euryhaline species survive in the intertidal zone. It is seen that out of more than 150 species recorded from the coastal waters of the South West Coast of India only 17 are found living in the study area. This shows that the majority of the foraminiferal species are stenohaline. It is also observed that foraminiferal populations are abundant in salinities higher than 30‰ during the pre-monsoon and post-monsoon periods. Many recent workers have studied the salinity tolerane of euryhaline foraminiferal species and this aspect has been discussed in the previous chapter.

<u>Dissolved oxygen</u>:

The availability of dissolved oxygen is an important environmental factor that controls the occurrence of foraminiferal population. The lower limit of oxygen tolerated by most microorganisms is 1 to 2 ml/l (Emery and Stevenson, 1957). The oxygen values in the present study are higher than those of the adjacent sea water, especially during the monsoon period (4.4 to 7.2 ml/l). So the oxygen content of the interstitial water in the area under investigation is not a limiting factor as regards the occurrence of foraminifera.

<u>pH</u>:

From the ecological stand point hydrogen ion concentration is another important factor that influences the occurrence of foraminifera, since the acidity of the medium causes postmortem dissolution of the calcareous test (Lee, 1974). Generally the pH of the interstitial water is lower than that of the coastal water. In the present observation the values of pH ~~dissolved oxygen~~ show seasonal fluctuations with the lowest value (7.7) in

July and the highest value (8.4) in April, indicating that the pH condition in the pre-monsoon period is more favourable for foraminiferal growth. However, these variations in the pH are within the limits of tolerance of the foraminiferal species inhabiting the intertidal area and hence this ecological parameter is not a limiting factor in this region.

Relationship between sand grain size and foraminifera

Leoblich and Tappan (1953), Graham et al (1959), Lee et al (1969), Ramanathan (1970) and Murray (1973) studied the relationship between foraminifera and grain size and found that an inverse relationship exists between the medium diameter of sand and the number of foraminifera. When the diameter of the sand increases there is a decrease in the number of foraminifera and vice-versa. The diversity in the occurrence of foraminifera in the present area also shows this interesting distributional trend. The population is found in larger numbers at stations 6 to 8 where the sediment is with more finer particles. A relatively lesser population is seen at station 1 where the substrate is with more coarser particles. As regards the ocurrence of foraminifera and the nature of the substratum it seems that the difference in the size of the grain particles at various localities is an effective factor in the occurrence of the micro-organisms in the area (Fig. 18). However, the living foraminifera recorded from the intertidal area can be considered as eurytopic to sand habitat.

The foraminiferal fauna

Ecological grouping:

The range of tolerance applies to all limiting environmental factors. A species will survive only if none of the environmental factors exceeds the range of tolerance for survival. Even if a single factor exceeds the limit of survival, the species will die off. In the shelf water, the changes of ecological parameters take place slowly so that the organisms get time to be in equilibrium with the environment. But in the intertidal environment the ecological changes are great and fast. So the great majority of the foraminiferal species that are brought to this area, will die due to the adverse environmental conditions and deposit their calcareous shells. As a result, the sands of many tropical beaches are made up of a large amount of foraminiferal shells.

Out of more than 150 species of foraminifera collected from the sands of the intertidal area, 17 species have adapted themselves to inhabit the interstitial area. Since these species have their natural habitat in the coastal marine environment, the capacity of tolerance of various species differ in the intertidal area. Based on the tolerance limits and abundance, these 17 species are divided into 3 groups - group 1, includes the most dominant species; group 2, the second dominant species and group 3, the rare species.

Group 1: Species whose concentrations are more than 50% of the total population are included in this group. They constitute the highly tolerant euryhaline and eurythermal species. These forms thrive in conditions which would be regarded as adverse for normal stenohaline foraminifera (Murray 1968). The species included in this group in the order of abundane are *Ammonia beccarii*, *Elphidium crauticulatum*, *E. crispum* and *Quinqueloculina seminulum*. These four species can be regarded as the true interstitial foraminifera. Of these four species, *Ammonia beccarii*, the major inhabitant of the interstitial area is the most abundant and widespread species which sometimes constitute more than 50% of the total foraminiferal assemblage.

Group 2: The next abundant species included in this group are also widely distributed throughout the year and are not much subjected to normal seasonal environmental changes. But their numerical strength is not as much as that in the first group. Also during certain months their occurrence is restricted to the low and middle levels. These forms constitute less than 50% of the total population and are Rotalia calcar, Elphidium advenum, E. macellum, Nonion boueanum, Cibicides lobatulus, Operculina granulosa, Operculinella cumingii and Quinqueloculina bicornis.

Group 3: The third group is confined to species with rare occurrence and the forms coming in this group constitute about 20% of the total population. During the monsoon season these forms are found rarely in the middle and lower levels. The species included in this group are able to tolerate only small variations in the environmental conditions. This group includes the species Triloculina oblonga, Nonion sloani, Discorbis rosacea, Operculina complanata and Amphistegina lessonii.

In addition to the above 17 species, live specimens of a few other speices have also been recorded in small numbers from the low tide mark. However, the dead shells of these species are found in plenty in the other zones. They are *Ammobaculites dilatatus* (Cushman and Bronnimann), *Miliammina fusca* (Brady), *Trochammina inflata* (Montague), *Textularia agglutinans* (d'Orbigny), *Spiroloculina depressa* (d'Orbigny), *Triloculina tricarinata* (d'Orbigny), *Quinqueloculina delicatulum* (d'Orbigny), *Rotalia calcar* (d'Orbigny), *Discorbis globularis* (d'Orbigny), *Elphidium excavatum* Terquem, *E. Translucens* Natland, *Bolivina nobilis* (Hantken) and *B. striatula* Cushman.

Numerical density :

Reiter (1959) has observed 71 individuals of living foraminifera in 40 cc sample taken from the coast of Jade Bay, North Sea. From the coast of Santa Monica Bay he has recorded 129 species and out of those only 17 were found in the living condition. From the beach of California, Reiter (1959) collected 27 species of living foraminifera and 2280 shells in 10 cm^2 sample. Out of the 120 species collected from San Diego, Cooper (1961) found 64 species as living representatives. Boltovskoy (1964) recorded 98 living species from Puerto Deseado beach and Hedley *et al* (1967) recorded 63 species from the tidal belt in New Zealand.

In the shores of Mexico, Segura (1963) recorded a total number of living and dead assemblage ranging from 4 to 6480 in 10 cm^2 of sand. Out of more than 150 species collected during the present investigation, only 17 are found living. The other species are represented only by dead shells. When compared with the findings of the above mentioned workers, the number of living specimens is poor in the present study area where the maximum number of living and dead assemblage ranges from 48 to 2700 in 25 ml sample. From the data of 8 stations studied it is clear that the live-dead ratios of foraminiferal specimens does not vary significantly from station to station. The number of living specimens is poor in the study area though the number of dead shells is more. The reason for the difference in the relative abundance of live-dead individuals is due to the addition of dead shells of other species washed on to the shore.

Zonal variations:

A comparative study of the foraminifera in the three levels of the tidal area at the 8 stations has shown that the low water level supports the maximum number of species. Except for the species *Nonion sloani*, Operculina complanata, Quinqueloculina bicornis and Discorbis rosacea which do not occur alive in the monsoon season all the other species are found in the low water level throughout the year. The most dominant species Ammonia beccarii constitutes more than 50% of the total population at this level. The upper level supports the minimum number of foraminifera in all the seasons and during the monsoon period only A. beccarii and Quinqueloculina seminulum occurs at this level. In the middle level only 7 species are present during the monsoon period while all the species occur in the other two seasons.

As it is shown in Fig. 16 in the low tide level the maximum number of living specimens is 48 in April and the minimum 20 in July. In the upper level the number is 28 in April and 8 in July, while in the intermediate level the number was 38 and 12 respectively.

During the monsoon months the change in the ecological conditions in the upper level is more pronounced than at the other two levels. The film of water present around the sand particles of the upper level is less than that in the other two levels. Also the evaporation of water is more at this level. This may be the reason that foraminifera are generally less in number at the upper level than in the other two levels.

The high rate of dead shells in the upper mark can be explained by the fact that the empty shells being lighter than the living specimens, the waves carry them up and deposit there.

The zonal variations in the occurrence of foraminifera in the tidal area has been discussed by Richter (1964) while studying the foraminifera in the coast of Jade Bay. He found significant variations in the occurrence of species at different tide levels. He pointed out that the low water mark was dominated by Elphidium excavatum while the high water mark was dominated by E. craticulatum. According to him the maximum standing crop was in the high water level and the minimum in the mid water level, the low water level showing an intermediate standing crop. This does not agree with the present findings. The present observation shows the minimum number of specimens in the upper level and the number gradually increase towards the low tide mark. The difference in the occurrence of foraminifera at the three levels of the tidal area has been discussed by Segura (1963) based on the collections from the coast of Mexico. The pattern of distribution observed by him agrees with the present findings.

Regional variations:

Based on the occurrence and distribution of foraminiferal species the area under investigation can be separated into three provisional regions. The southern region (stations 1 to 4) is dominated by Elphidium crispum, E. craticulatum, E. advenum, Operculina granulosa, O. complanata and Operculinella cumingii. The northern region (stations 7 and 8) is dominated by E. macellum, Nonion boueanum, Discorbis rosacea and Cibicides lobatulus. The middle area (stations 5 and 6) is dominated by Ammonia beccarii, Rotalia calcar, Amphistegina lessoni and Quinqueloculina bicornis. Besides these, certain cosmopolitan species are found throughout the area. A. beccarii, Quinqueloculina seminulum, Elphidium craticulatum, Amphistegina lessoni and Cibicides lobatulus.

Hedley et al (1967) while analysing the foraminiferal fauna from the beaches of New Zealand over 1000 miles latitudinal range, found no significant regional variations in the fauna. Cooper (1961) in his studies on the foraminifera from the California beach, separated the beach specimens into three provisional fauna based on the variations in their occurrence and abundance in the latitudinal range. In the present study the pattern of distribution and abundance of foraminiferal species at the 8 sites are found to be quite different from one another. As stated in the earlier part the southern stations (1 to 4) are dominated by larger forms. The northern stations (7 and 8) are dominated by smaller forms and the middle stations (5 and 6) are with medium sized forms. Thus a grouping of foraminiferal fauna, based on the regional occurrence and abundance into three types as proposed by Cooper (1961) can be seen in the present study, though the latitudinal range is not considerable.

Seasonal variations:

When a correlation is sought between the foraminiferal distribution and the ecological parameters, it appears that those factors with seasonal cycles are responsible for the population trends. Since variations in temperature, salinity, pH and dissolved oxygen are season dependent, it is believed that they are important in controlling the foraminiferal occurrenec and abundance.

Regarding the seasonal occurrence of foraminifera the maximum number is found in the post-monsoon season and the minimum in the monsoon season in all the stations. This shows that the occurrense of these microorganisms in the tidal area fluctuates seasonally. It is also evident that the ecological conditions are favourable for these protozoans during pre-monsoon and post-monsoon periods. Because of the unfavourable ecological conditions in the monsoon period living specimens are few.

The decline in the number of living individuals in the monsoon period may be due to the low rate of production in the standing crop during this period. In June with the onset of the monsoon a sudden change in the ecological condition occurs and as a result majority of these microorganisms perish. This is the reason for the decline in the number of living individuals in the monsoon period. From November onwards the ecological conditions become favourable and the standing crop increases and reaches its maximum in April.

The data reveal that the seasonal fluctuations in the density of foraminifera is mainly due to the changes in salinity from season to season. The fauna shows its maximum density in the pre-monsoon period when the salinity reaches its maximum value. The foraminiferal standing crop decreases in number with the decrease in salinity. The number of foraminifera increases with the increase in salinity and the peak density, of about three times as that of the monsoon season is observed in the pre-monsoon season.

The overall pattern of the seasonal distribution of foraminifera in the area conforms with that in the interstitial area of sandy beaches such as those studied by Boltovskoy (1964) in the coast of South America, Smith (1968) in the coast of Fiji, Hedley et al (1967) and Murray (1971) in the coast of New Zealand. In all these areas the foraminiferal fauna show marked seasonal fluctuations in the standing crop according to salinity changes - an increase in number with an increase in salinity and a decrease in number with a decrease in salinity.

Size variations:

Rich and diversified foraminiferal fauna occur in the near shore shallow area and generally the foraminifera is within the size range of 0.2 to 1.5 mm. The intertidal area is populated by organisms transported from the nearby shallow region. Of more than 150 species of foraminifera collected from the continental shelf of Kerala, 30 species are large sized forms with the size range between 1 and 1.5 mm, 22 species are smaller with less than 0.25 mm size. The remaining species are within the size range from 0.25 to 1 mm. Foraminifera of less than 0.25 mm size are not found living in the intertidal zone. The medium sized forms are found rarely in the area. The large sized foraminifera above 1 mm, belonging to the families Miliolidae, Nonionidae and Rotaliidae are the common forms occurring in the intertidal zone. Phleger (1956) has reported Quinqueloculina, Ammonia and Elphidium as the typical and characteristic genera of the sandy beaches of Texas. The present investigation area also seems to be mainly populated by larger species belonging to the above genera and thus agreeing with the findings of the above authors.

Standing crop and production:

Hedley et al (1967) remarked that most beaches seem to be populated by species from the nearby sub-litteral areas and that these faunas vary according to the geographical position. Murray (1967) has shown that the regions of small standing crop must have low production and regions of very large standing crop must have high production. According to him the fauna in a beach area represents the fertility of the sea floor of the near shore region. In the present study the Cochin coast (station 6) is an area of high production. The abundance of phytoplankton provides a good supply of food for foraminifera. The foraminiferal standing crop at station 6 is relatively high and this may be due to the high production in the near shore waters of this area.

Comparison with other areas

From the study of the distribution of foraminifera given above, it is seen that the number of species is less here compared to other beaches of the world. Since this is the first attempt to study the living foraminifera from the intertidal area in India, a comparison of the special distribution of these organisms with other parts in India is not possible. But, as already mentioned the foraminifera in the intertidal area has been a subject of study in several regions of the world. Of the 17 live species recorded, 10 are known interstitial forms in sandy beaches of the world and the remaining 7 species are not seen in any of the previous records of intertidal collections. The known foraminiferal species are (in order of their abundance in the present collection) Ammonia beccarii, Elphidium craticulatum, E. crispum, E. advenum, E. macellum, Quinqueloculina seminulum, Nonion boueanum, Cibicides lobatulus, Discorbis rosacea and Quinqueloculina bicornis. The following species observed in the present collection seem to be the first record from the intertidal area: Rotalia calcar, Amphistegina lessonii, Nonion sloani, Operculina granulosa, O. complanata, Triloculina oblonga and Operculinella cumingii.

Foraminifera from the beach environment of Martha's Sineyard Island in England had been studied by Todd and Low (1961) who recorded the species Quinqueloculina seminulum, Ammonia beccarii and Elphidium craticulatum from the area. These three species have also been reported by Sequra (1963) from the beach samples of Mexico. In Puerto Deseado coast of South America, Boltovskoy (1970) recorded Elphidium macellum as the most dominant species. Smith (1968)has observed Q. seminulum as the dominant species in the tidal flat of Chile. A beccarii, Q. seminulum, Nonion boucanum, E. craticulatum and E. macellum have been reported from Jade Bay at North Sea coast by Haake (1962). In the New Zealand beaches Hedley et al (1967) has recorded Q. seminulum, E. craticulatum, A. beccarii and Cibicides lobatulus as the typical beach forms.

SUMMARY

The present investigations confine to a study of the distribution of foraminifera in the estuarine environment and the interstitial area of the sandy beaches of the South West Coast of India with a view to correlate the distribution and intensity of occurrence of the various species with hydrographic conditions and the substrate characteristics of the area.

Studies on the foraminifera of the estuarine environment were carried out in the Vembanad Lake, a major estuary in the South West Coast of India extending for about 60 km from Cochin barmouth in the north to Alleppey in the south. Fortnightly collections of hydrographical data and grab samples of bottom deposit were made for a period of 2 years (July 1973 to June 1975) from fifteen stations chosen along the length of the lake.

Live foraminifera in a unit area of $(10\ cm)^2$ surface sediment sample have been estimated. Thirty two living species of foraminifera - twenty one calcareous and eleven chitinous and siliceous forms were observed in

the estuary. The species of foraminifera in the studied area appear to vary according to estuarine conditions. The general distribution of the species show that the lower reaches of the estuary is characterised by calcareous species which are absent in the upper reaches of the estuary. The species Ammonia beccarii is the most dominant calcareous form and constitutes about 50% of the total foraminiferal population in the lower half of the Vembanad estuary. Chitinous and siliceous foraminifera are dominant in the fresh water zone of the upper reahes of the area and they occur rarely in the marine zone. Miliammina fusca and Saccammina sphaerica occur abundantly in the middle region. The various species are classified into different groups based on the ecological conditions. The investigation shows that there is great diversity of genera and species in the different regions of the estuary.

The hydrographical conditions of the Vembanad lake show marked seasonal variations. Salinity is found to be the most important factor that controls the occurrene and distribution of foraminifera in the

Vembanad estuary. Attempt has been made to ascertain the lower limits of salinity into which each species penetrates. Distribution of foraminifera in different seasons shows maximum population during the pre-monsoon period and the minimum during the monsoon period throughout the estuary, reflecting the dependence on salinity. Low species concentration is noticed in the upstream end of the lake. The distribution of foraminifera in different types of bottom deposits has been studied. The nature of the substratum has great influence on the distribution of benthic foraminiferal population. The foraminiferal standing crop is more in the localities where the substrate is with fine to medium sand mixed with low percentage of mud.

Studies on the vertical distribution of foraminifera show that more than 90% of them occur in the upper 1 cm of the sediment and very rarely observed below.

Investigation of the interstitial foraminifera from the intertidal area of the sandy beaches has been conducted based on the samples collected during 1974-76 from the intertidal area from 8 localities along the

South West Coast of India extending from Cannanore in the north to Cape Comorin in the south. The distribution of foraminifera at three tide levels in relation to the ecological parameters have been studied. Seventeen species of live foraminifera are noticed in the area. The live specimens in 25 ml samples analysed vary from 5 to 48. Of the 17 species, *Ammonia beccarii* constitutes the bulk of the fauna in all the areas. *Quinqueloculina seminulum*, *Nonion sloani*, *Elphidium crispum*, *E. craticulatum*, *E. advenum* and *Cibicides lobatulus* are the other common and widespread species that occur in the intertidal region.

The foraminiferal population shows variations at the three tide levels. Of the three zones studied, the low water level supports the maximum number of foraminifera in all the seasons. The study also shows that the population is high during the pre-monsoon season and the total number is poor during the monsoon period. Of the several environmental factors salinity has the greatest influence on the distribution and abundance of foraminifera in the interstitial sand of the tidal area also.

The correlation between sand grain size and the foraminiferal population of the intertidal area is also discussed. The large sized foraminifera above 1 mm are found more at localities where the substrate is with high proportion of medium sand and the smaller forms below 0.5 mm size are abundant at stations where higher percentage of fine to very fine sand constitute the substrate. Medium sized forms in the size range of 0.5 mm to 1 mm occur more in number at areas where the substrate shows a relatively high percentage of fine sand.

A seasonal variation in the live and dead shell ratios has been noticed in the area under study. In general the number of dead shells shows a decline from the upper level to the lower level. Of the 17 species of live foraminifera collected in the present study, 10 are known interstitial forms in sandy beaches of the other parts of the world while the remaining ones have been previously recorded only from the inshore waters.

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