

Foraminifera from the Chilka Lake on the east coast of India

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Abstract

A total of sixty-nine foraminiferal species belonging to 27 genera and 19 families have been identified from the sediment samples of the Chilka lake collected during three faunal surveys representing different seasons. *Miliammina fusca*, *Ammobaculites exiguus*, *Ammonia beccarii* (Linne) and *A. tepida* are the most abundant species in the fauna. A study of biofacies shows that the fauna is characterized by *Miliammina* in the inner lagoon fades and by *Ammonia beccarii* (Linne) in the outer lagoon/channel fades. During premonsoon season, higher concentrations of total populations of Foraminifera and number of species have been observed due to its marine influence. Further, the fauna is a mixed assemblage due to incursion of the nearshore foraminiferids into it through the inlet by tidal currents. Faunal diversity, in general, increases seaward from the northern sector to the outer channel. Distribution patterns of Foraminifera are delineated, particularly in relation to their ecology. The fauna of the Chilka lake has been compared with that of certain Indian and overseas estuaries and most of the species reported in this paper are also known from the Indo-Pacific faunal province.

Introduction

Information available on Foraminifera of the wetland, Chilka lake is very little. At group level, populations of Foraminifera have been studied earlier by Rajan (1965), Patnaik (1971) and Sarma and Rao (1980). Rao (1987) reported 7 species from this shallow lake. It is patent from these studies that work done so far on this fauna virtually is of very preliminary nature. Hence an attempt has been made to reconnoitre the lake thoroughly and make a detailed study in this paper on the composition and distribution patterns of Foraminifera in relation to spatial and temporal variations with a bearing on ecology. This study forms a part of the programme to assess environmental impact of the

Chilka lake for the proposed dredging of the outer channel, under the aegis of Chilka Lake Development Authority, Orissa.

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Study Area

Topography

Chilka, situated in the districts of Puri

and Ganjam in Orissa, is the largest estuarine lake (1165 km²) on the east coast of India and is located between 19° 25' and 19° 54' N and 85° 6' and 85° 38' E. Based on the hydrological characteristics, the lake is divided into four broad sectors, viz., northern sector, central sector, southern sector and outer channel. Topographical features of selected sectors for the investigation are as follows:

The northern sector of the lake is the shallowest of the four, the average width being about 15 km. The summer water depth here is around 0.5 to 1 m. It receives freshwater from the tributaries of the river Mahanadi, mainly Daya.

The central sector lies between northern and southern sectors. This part of the area dotted with islands, is smallest in size, but greatest in water depth of 2 to 3 m. The outer channel connects the lake to the sea in this segment. Here, the tidal effect is always seen.

The outer channel has a mean width of 1.5 km and length about 35 km. The channel is kept separated from the sea by a 183-274 m wide spit. The average water depth of the channel is 1 m in summer, but increases to 2 m during monsoon season.

Hydrography

In the world, shallow lakes wherein average depth is less than 3 m, are more abundant than deep ones and are commonly referred to as wetlands. In the present study, Chilka is Asia's largest shallow salt water lake. The hydrography of this lake has been studied earlier in some detail

(Jhingran, 1963; Ramanatham *et al*, 1964; Rajan, 1968 and Patnaik, 1971).

It is estimated that 13 million tonnes of silt is brought annually into the lake by the rivers and rivulets that open into it. In the lake, the sediments are mostly mud (silt + clay) in the northern, central and southern sectors, but with an admixture of mud and fine sand at the western shore of the southern and central sectors. The eastern shore of the central and southern sectors consists of sand. The bottom of the outer channel is sandy. The sediments of the lake become coarser with distance towards the mouth of the outer channel and also, there is a seaward decrease in mud.

Organic matter present in the sediments of the lake comes from two sources : 1) The decomposition and deposition of large amount of macrophytes. 2) The transported extraneous organic matter deposited by the rivers. The mean organic matter content in the sediments is 1.29% (northern sector), followed by 0.31% (central sector), 0.19% (southern sector) and 0.19% (outer channel), (Patnaik, 1987). It is thus seen that organic matter content is highest in the northern sector not only because of the dense growth of macrophytes there but also due to the fact that numerous rivers that open into it bring in large quantity of organic matter. Further, there is a seaward decrease in total organic matter content.

Transparency in the lake is lowest (4 cm) in the eastern shore of the northern sector during monsoon months due to the

influx of flood water and during summer (April and May) due to intense wave action caused by strong southerly winds. Higher transparency is noted in the central and southern sectors. In the outer channel, minimum values are recorded during post monsoon season (November) when flood water is passing through it and low values in winter (December-February) and summer (March) are due to higher concentration of planktonic organisms in the water (Patnaik, 1971).

The most important hydrological feature of the lake is salinity which governs the distribution of a large plethora of aquatic flora and fauna in the habitat. The salinity value of the lake varies considerably from month to month, from zone to zone depending upon rain, temperature, evaporation, tides etc. During monsoon season (June-September), salinity values plummet down markedly and the lowest values recorded are 0.26 PSU, while during postmonsoon season, salinity increases in the outer channel (1.08 - 15.51 PSU), central sector (0.46 - 7.87 PSU) and northern sector (0.22-0.29 PSU). Further, it reaches maximum in summer in the outer channel (6.47-24.06 PSU), central sector (3.34-8.98 PSU) and northern sector (0.74-2.69 PSU).

The surface water temperature is closely related to the air temperature. It shows seasonal variation and ranges from 24.5°C in winter (January) to 30.4°C in May, the hottest month. The bottom water temperature is almost same as that of the surface temperature and is highest during May (30.1°C) and reaches lowest during

November (24.5°C). The relative humidity is high, it is generally above 70%.

Since the lake is shallow, there are no vertical and returning currents. Horizontal currents produced by winds occur throughout the lake. During monsoon and postmonsoon seasons, there is a large river discharge into it and the currents in the northern sector and in the outer channel are directed towards the sea by overcoming the tidal currents in this region. In contrast, in summer (March-May), wind stress is larger, there is no river discharge and there is a large inflow from the Bay of Bengal into the lake through the mouth during this season.

In the outer channel, the sub-surface currents are slightly stronger than the surface currents suggesting the existence of tidal currents in the area, whereas these currents are negligible or absent in the main area of the lake.

Material and methods

Bottom sediment samples were collected from different locations in the lake (Fig. 1) using a Van-Veen grab and were studied for Foraminifera during different months of the years (November 1997, March and May 1998). The first faunal survey represented postmonsoon season (November), while the second and the third ones pertained to early (March) and late (May) premonsoon seasons respectively. The samples were preserved with isopropyl alcohol, stained with rose bengal at the time of collection and washed later over a 105 µm sieve for separation of living Foraminifera in the laboratory. As

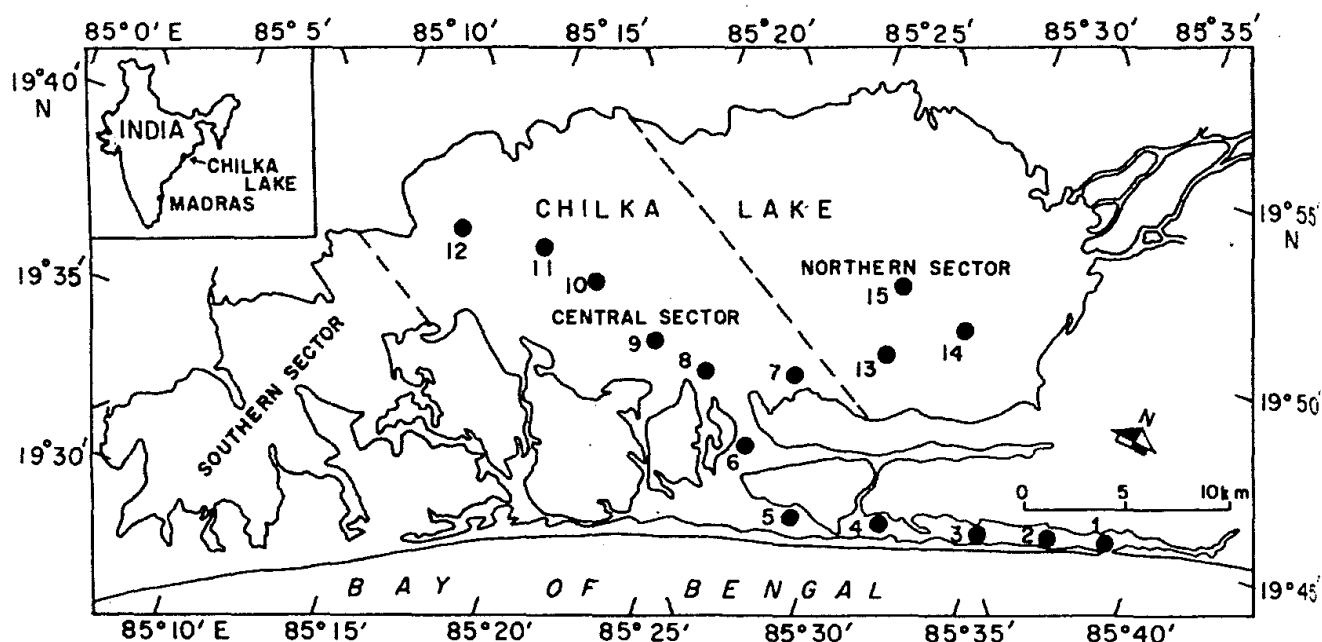


Fig. 1 - Map of the Chilka Lake (insert), study area and sampling locations.

living Foraminifera were sparse, they had not been separately dealt with in this study. Abundance was expressed as the total number of specimens (live + dead) per 30 cc of wet sediment.

Results and discussion

Foraminiferal species

A total of sixty-nine foraminiferal species belonging to 27 genera have been identified and listed below under 19 families according to Loeblich and Tappan's classification (1988):

Family : Rzehakinidae

Miliammina fusca (Brady)

Family : Haplophragmoididae

Haplophragmoides canariense (d'Orbigny)

Family : Lituolidae

Ammobaculites directus Cushman and Bronnimann

Ammobaculites exiguus Cushman and

Bronnimann

Ammotium fragile Warren

Family : Trochamminidae

Trochammina advena Cushman

Trochammina hadai Uchio

Trochammina ochracea (Williamson)

Tiphotrocha kellettae (Thalman)

Jadammina macrescens (Brady)

Family : Verneuilinidae

Gaudryina exilis Cushman and Bronnimann

Family : Textulariidae

Textularia earlandi Parker

Family : Hauerinidae

Quinqueloculina agglutinans d'Orbigny

Quinqueloculina agglutinata Cushman

Quinqueloculina dimidiata Terquem

Quinqueloculina durandi Cushman and

Wickenden

- Quinqueloculina laevigata* d'Orbigny
Quinqueloculina lamarckiana d'Orbigny
Quinqueloculina lata Terquem
Quinqueloculina seminula (Linnaeus)
Quinqueloculina tenagos Parker
Quinqueloculina vulgaris d'Orbigny
Miliolinella subrotunda (Montagu)
Triloculina brevidentata Cushman
Triloculina subrotunda (Montagu)
Triloculina trigonula (Lamarck)
Family : Candeinidae
Globigerinita glutinata (Egger)
Family : Globigerinidae
Globigerinoides ruber (d'Orbigny)
Globigerinoides sacculifer (Brady)
Family : Bolivinidae
Bolivina pseudoplicata Heron-Allen and Earland
Bolivina striatula Cushman
Family : Stainforthiidae
Hopkinsina pacifica Cushman
Family : Rosalinidae
Rosalina globularis d'Orbigny
Rosalina leei Hedley and Wakefield
Family : Planulinidae
Planulina bassensis Collins
Family : Cibicididae
Cibicides refulgens Montfort
Family : Amphisteginidae
Amphistegina radiata (Fichtel and Moll)
Family : Nonionidae
Haynesina germanica (Ehrenberg)
Nonion depressulum (Walker and Jacob)
- Nonionellina labradorica* (Dawson)
Protelphidium schmitti (Cushman and Wickenden)
Protelphidium tisburyense (Butcher)
Family : Gavelinellidae
Hanzawaia asterizans (Fichtel and Moll)
Hanzawaia concentrica (Cushman)
Hanzawaia nitidula (Bandy)
Family : Rotaliidae
Ammonia beccarii (Linne)
Ammonia advena (Cushman)
Ammonia parkinsoniana (d'Orbigny)
Ammonia pauciloculata (Phleger and Parker)
Ammonia sobrina (Shupack)
Ammonia tepida (Cushman)
Asterorotalia dentata Parker and Jones
Asterorotalia inflata (Millet)
Asterorotalia trispinosa (Thalmann)
Family : Elphidiidae
Elphidium advenum (Cushman)
Elphidium alvaregianum (d'Orbigny)
Elphidium articulatum (d'Orbigny)
Elphidium clavatum Cushman
Elphidium craticulatum (Fichtel and Moll)
Elphidium crispum (Linnaeus)
Elphidium discoidale (d'Orbigny)
Elphidium excavatum (Terquem)
Elphidium gal estonense Kornfeld
Elphidium gunteri Cole
Elphidium hispidulum Cushman
Elphidium incertum (Williamson)
Elphidium mexicanum Kornfeld

Elphidium poeyanum (d'Orbigny)
Elphidium rugulosum (Cushman and Wickenden)

Of all the species listed above, 14 species have been recorded for the first time from Indian waters, they being *Ammobaculites directus*, *Ammotium fragile*, *Tiphotrocha kellettae*, *Quinqueloculina durandi*, *Triloculina brevidentata*, *Rosalina leei*, *Planulina bassensis*, *Protelphidium tisburyense*, *Ammonia advena*, *A. pauciloculata*, *Elphidium alvarezianum*, *E. galvestonense*, *E. mexicanum* and *E. rugulosum*. These species are illustrated on Plate 1, Figs. 1-36.

As seen from Fig. 2, during postmonsoon period, species of *Miliammina*, *Ammobaculites* and *Ammonia* cover 50% of the study area, while *Trochammina*, miliolids and *Elphidium* cover 40%, 26.7% and 20% of the stations respectively. Similar is the case during early premonsoon period (March) also, so far as *Ammonia* is concerned, but *Miliammina* and *Ammobaculites* are represented in higher percentages, whereas *Trochammina* covers only 20%, miliolids, 30% and *Elphidium*, 20% of the study area. In May, four genera - *Miliammina*, *Ammobaculites*, *Trochammina* and *Ammonia* occur in more than 60% of the stations, while the remaining two, miliolids and *Elphidium* cover less than 30% of the area.

Among the brackish species encountered in the lake sediments, eight species {*Miliammina fusca*, *Ammobaculites exiguus*, *Jadammina macrescens*, *Textularia earlandi*,

Ammonia beccarii (Linne), *Elphidium advenum*, *E. excavatum* and *E. gunteri*) are cosmopolitan in that they have a world-wide distribution. No detailed work pertaining to specific identification of the species of Foraminifera of the lake has been done before the present study, albeit previously Rao (1987) reported 7 species - *Quinqueloculina* sp., *Q. lamarckiana*, *Elphidium crispum*, *Rotalia calcar*, *Rotalia beccarii*, *Globigerina bulloides* and *Globigerinoides conglobata*. In this work, the fauna has been studied further in regard to their distribution patterns to

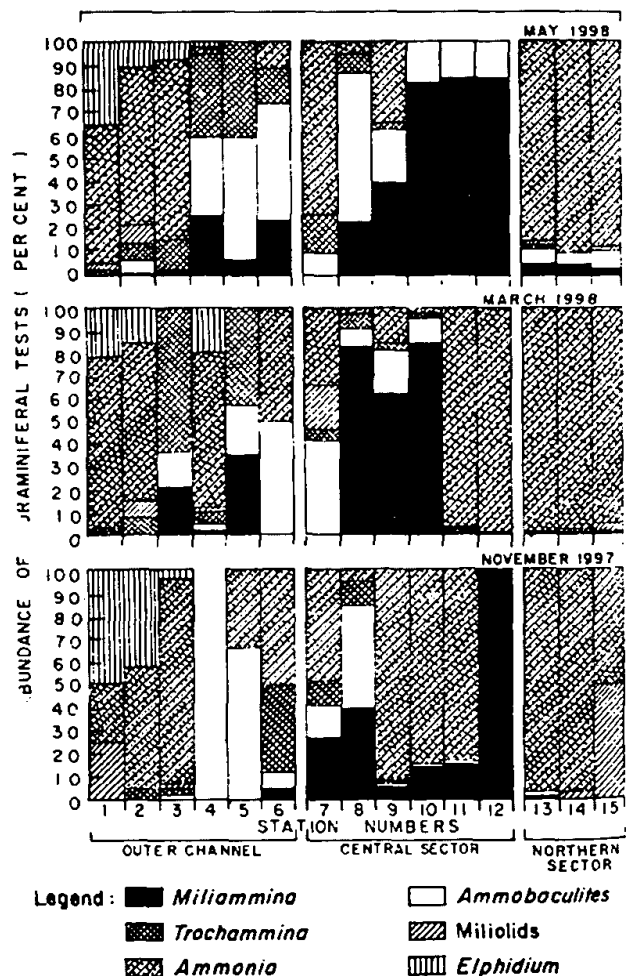


Fig. 2 - Plot of the abundance (per cent) of foraminiferal tests of principal species.

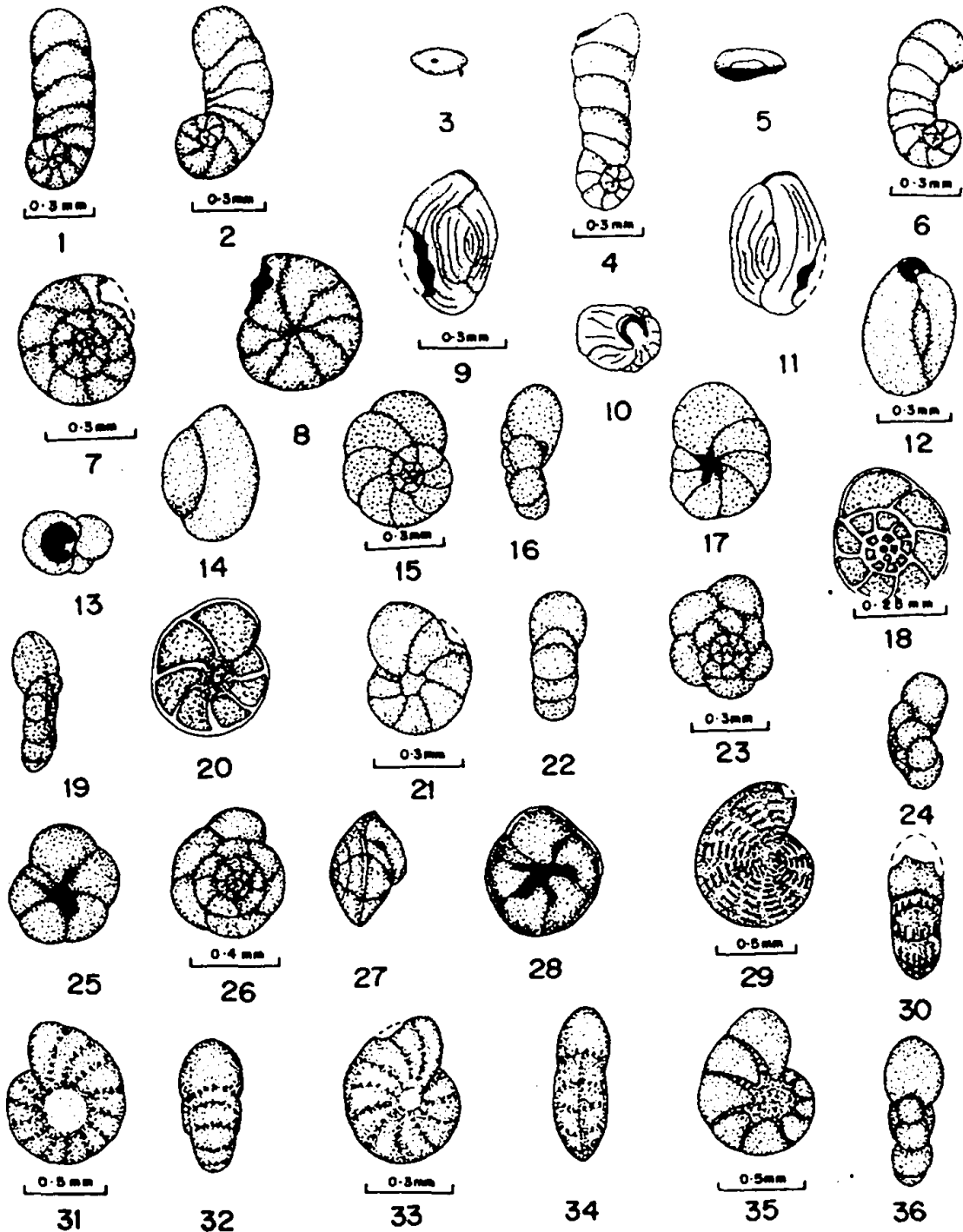


Plate 1 - Foraminiferal species [*Ammobaculites directus* Cushman and Bronnimann : 1, side view. *Ammotium fragile* Warren - 3 specimens : 2, side view; 3, apertural view; 4, side view; 5, apertural view; 6, side view. *Tiphotrocha kellestae* (Thalman) : 7, dorsal view; 8, ventral view. *Quinqueloculina durandi* Cushman and Wickenden : 9, 11, opposite sides; 10, apertural view. *Triloculina brevidentata* Cushman : 12, 14, opposite sides; 13, apertural view. *Rosalina leei* Hedley and Wakefield : 15, dorsal view; 16, peripheral view; 17, ventral view. *Planulina bassensis* Collins : 18, dorsal view; 19, peripheral view; 20, ventral view. *Protelphidium tisburyense* (Butcher) : 21, side view; 22, peripheral view. *Ammonia advena* (Cushman) : 23, dorsal view; 24, peripheral view; 25, ventral view. *Ammonia pauciloculata* (Phleger and Parker) : 26, dorsal view; 27, peripheral view; 28, ventral view. *Elphidium alvarezianum* (d'Orbigny) : 29, side view; 30, peripheral view. *Elphidium galvestonense* Kornfeld : 31, side view; 32, peripheral view. *Elphidium mexicanum* Kornfeld : 33, side view; 34, peripheral view. *Elphidium rugulosum* (Cushman and Wickenden) : 35, side view ; 36, peripheral view)

augment our knowledge on the ecology of the lake.

Abundance of Foraminifera

During postmonsoon season (November), mean abundance of total populations of Foraminifera at the stations covered in different areas of the lake is low, while it shows a population increase in March, followed by further increase in May (Fig. 3). In this seasonal study, only the months which depicted first signs of a sudden increase in populations were selected in lieu of months showing peaks of abundances. As compared with the month of November, in March there is a sudden increase at stations : 1, 4 and 5 (outer channel), 8, 11 and 12 (central sector) and 13, 14 and 15 (northern sector), whereas in May a population increase is noted at stations : 1, 2, 4 and 5 (outer channel), 8 and 12 (central sector) and 13, 14 and 15 (northern sector). Thus, the total number of Foraminifera in the lake is high in summer due to favourable environmental conditions particularly with regard to salinity. Murray (1968a, 1968b) also observed higher abundance of Foraminifera in the estuary he has investigated during summer. The ranges of abundance for the lake are 0-1389, 12-3582 and 45-12828 specimens per 30 cc of sediment during November, March and May respectively.

Further, as seen from Fig. 3, the absolute variation (σ_n) shows a steady increase from November to May in the outer channel (306.75 to 4611.14) and in the northern sector (55.07 to 91.16), but in the

central sector, it is maximum in March (1215.52) and minimum in May (152.61). The relative measure of dispersion, coefficient of variation ($c\%$) also increases at a gradual rate during these months in the outer channel (101.24% (November) to 181.08% (May)), while in the central sector, it is minimum in May (74.81%) and maximum in March (122.78%). In contrast, in the northern sector, there is a decrease in the $c\%$ value from November (69.42%) to May (33.47%), which is just opposite to the trend of absolute variation indicating that $cv\%$ has to be used for

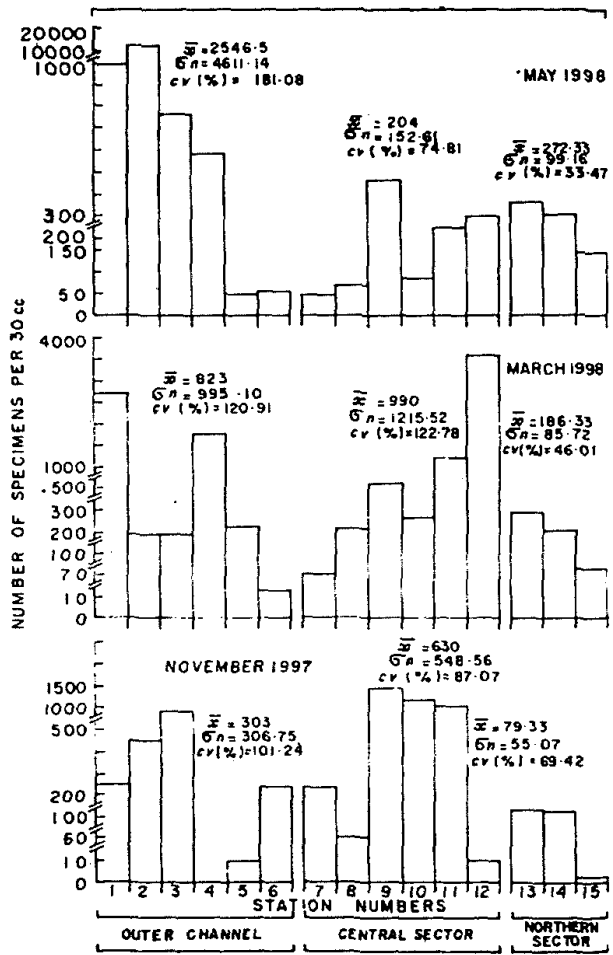


Fig. 3 - Distribution of the total Foraminifera (live + dead) per 30 cc of wet sediment sample.

comparative purposes when average values are different.

Faunal diversity

In March, higher average number of species is observed in the outer channel (12.1) and least in the central sector (7.2), while in May, corresponding values are 18.5 and 5.0 for the respective areas following the same trend, but with higher spatial dispersion. In November, the number of species decreases from the outer channel (8.8) to the northern sector (5.3). Species diversity measured by Shannon - Wiener index (Shannon and Weaver, 1963) increases towards the sea in November (1.28 - 2.30) and March (1.36 - 2.23). In May, minimum mean diversity index has been found in the central sector (1.51) with not much difference in its value in the outer channel (2.73) and the northern sector (2.09).

Foraminiferal test types

Based on the nature of the test, Foraminifera are sub-divided into 3 groups - arenaceous, porcelaneous and hyaline. The arenaceous forms are mainly represented by families, Rzehakinidae, Haplophragmoididae, Lituolidae, Trochamminidae, Verneuilinidae and Textulariidae, while Foraminifera with porcelaneous tests by the family Hauerinidae. All other benthic and planktonic forms fall into the hyaline group. Distribution patterns of these test types in this study (Fig. 4) show that they are almost equally distributed in November, March and May in the outer channel, whereas in the central sector, the porcelaneous forms

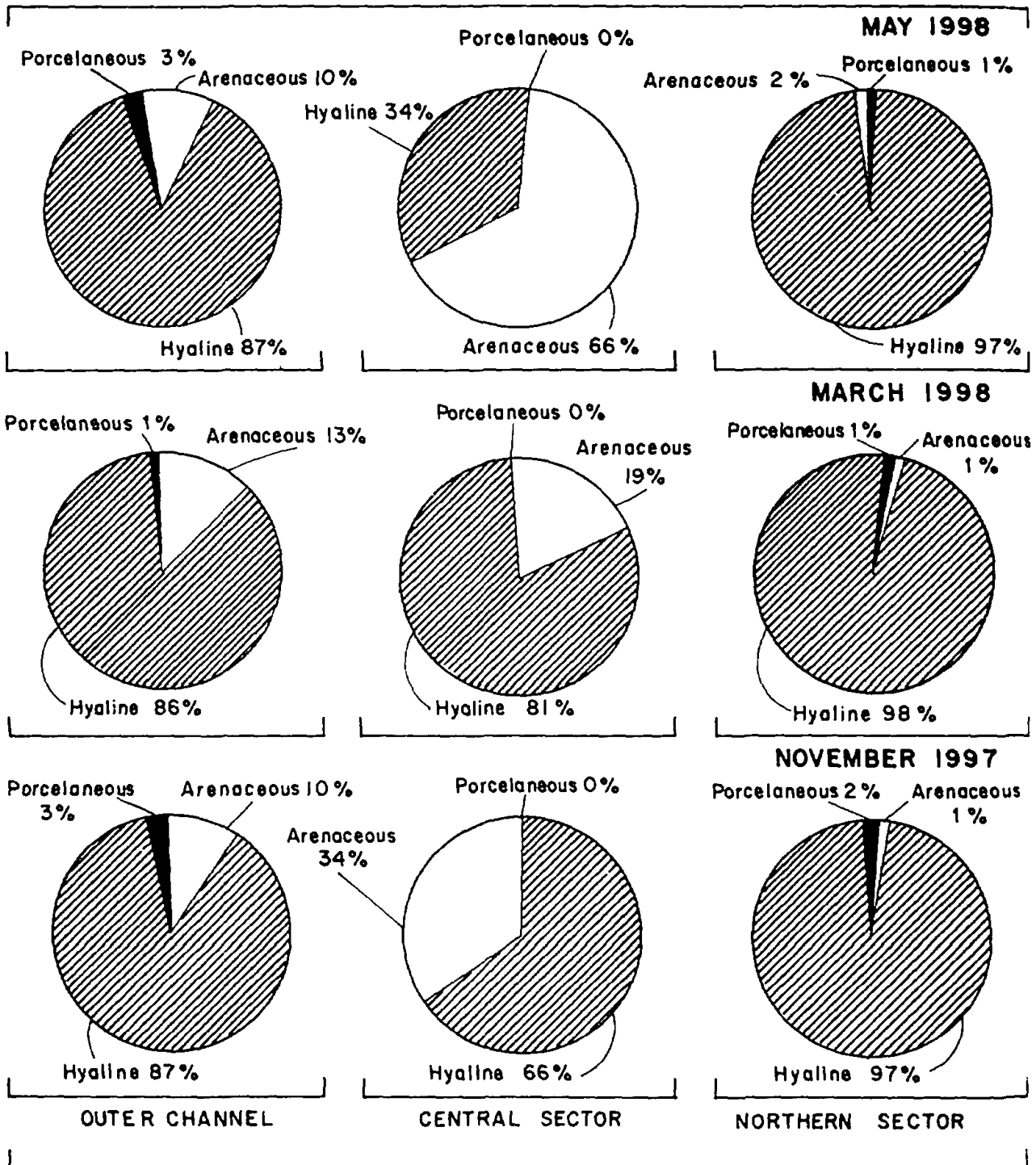
are totally absent and the predominant test type is hyaline in November and March. But in May the area is dominated by arenaceous tests (66%), followed by hyaline type (34%). In the northern sector, hyaline is the most dominant type forming 97% of the fauna, while others occur in the range of 1-2% in different months (Fig. 4). It is also obvious from the distribution of test types that areas of calcareous foraminiferal assemblages have high foraminiferal numbers, whereas those of arenaceous assemblages have low foraminiferal numbers.

Planktonic Foraminifera

Three species of planktonic Foraminifera - *Globigerinita glutinata*, *Globigerinoides ruber* and *G. sacculifer* have been encountered in the sediment samples of the lake in summer. Their presence in the lagoon suggests that their transport into it through inflow of sea water from the Bay of Bengal by tidal currents during premonsoon season.

Faunal biofacies

Generally, the fauna is characterized by two facies : facies 1 (inner lagoon facies) encompasses most abundant species, *Miliammina fusca*, while common associated species in this area being *Ammobaculites exiguus*, *Jadammina macrescens*, *Ammonia advena* and *A. sobrina*. Facies 2 (outer lagoon/channel facies) is dominated by *Ammonia beccarii* (Linne), and common species include species of *Elphidium* such as *Elphidium crispum*, *E. gal estonense* and *E. poeyanum* besides *Ammonia parkinsoniana*, *A. tepida*,



Asterorotalia dentata, *Trochammina hadai*,
T. advena, *Gaudryina exilis*, *Textularia*
earlandi, *Hanzawaia asterizans* and H.

nitidula. These biofacies have been con-
 firmed with adequate evidence by exam-
 ining the data and also by making use of

a multivariate statistical study with a factor analysis for unique grouping of stations and species. In this context, it is pertinent to point out that upper reaches of the estuarine environments around the world are mostly dominated by the cosmopolitan *Miliammina fusca* (Murray, 1968_a, 1968_b, and Boltovskoy and Wright, 1976) and also there exists geographic differences in the species composition of the estuarine faunas.

Ecological implications of foraminiferal distribution

Miliammina fusca, *Ammobaculites exiguus*, *Ammonia beccarii* (Linne) and *Ammonia tepida* are the most abundant and most widely distributed species in the lake. They also confirm one hypothesis that species which are wide in distribution, have got tolerance for a wide range of environmental conditions.

Species which are very rare and which occur only at one site and are present in all the faunal surveys are *Ammotium fragile*, *Quinqueloculina vulgaris*, *Elphidium excavatum*, *E. poeyanum* and *Asterorotalia trispinosa*. Of these species, *A. fragile* and *E. excavatum* are brackish and the remaining three are truly marine forms.

A. fragile is restricted to the inner lagoon (stn. 9). Also, *Ammonia parkinsoniana* and *A. sobrina* are virtually confined to the lagoon where they show relatively higher concentrations as compared with the outer channel. *P. tisburyense*, which occurs at sites 6, 9 and 13 where salinity of the waters ranges between 0.93 and

3.73 PSU, is another lagoonal form which seems to prefer brackish conditions in the lake. Butcher (1948) first described this species from the brackish environs of Cape Cod, Massachusetts. Boltovskoy (1958) also observed this species in freshwater environs of the Rio de la Plata in the vicinity of Buenos Aires, where salinity of the waters varied between 0.1 and 0.15 PSU. Further, occurrence of this species in living condition in the fluvial deposits of Rio de la Plata has been confirmed by Boltovskoy and Lena (1971).

Low saline waters within the lagoon (0.22 to 8.98 PSU) typically contain *Miliammina*, *Haplophragmoides*, *Ammobaculites*, and *Trochammina*, while waters of higher salinities particularly in the outer channel (ca. 24.06 PSU), are dominated by miliolids and *Elphidium* fauna. Despite *Cibicides*, *Hanzazwaia*, *Gaudryina*, *Textularia*, *Asterorotalia* and *Elphidium*-miliolid fauna are mostly limited to the outer channel, some species such as *Textularia earlandi* (Seibold and Seibold, 1981), *Quinqueloculina lata* and *Q. seminula* besides *A. tepida* in this study seem to have tolerance for lagoonal conditions.

Comparisons with other estuarine studies in India

Among 20 species of Foraminifera listed (Ramanathan, 1970) from Vellar estuary, 7 species are common to the Chilka lake, they being *Miliammina fusca*, *Ammobaculites exiguus*, *Triloculina brevidentata*, *Ammonia beccarii* (Linne), *A. sobrina*, *A. tepida* and *Elphidium discoidale*

and there is no discussion by him on the faunal zonation.

Out of 40 foraminiferal species recorded from Suddagedda River estuary (Rao and Rao, 1974), 14 species are known from Chilka lake. The fauna differs from the present study in having *Ammonia beccarii* (Linne) biofacies throughout the estuary.

Reddy and Reddy (1982) reported 44 species from the Araniar River estuary. This study shows that 17 species are found in Chilka lake. Unlike in the present study, the upper reaches of Araniar are dominated by *Ammobaculites* sp. and *Trochammina* sp., the middle estuary by *Cibicides* sp., but lower reaches of the river show some similarity in showing dominance mainly by *Ammonia beccarii* (Linne).

Narappa, Rao and Rao (1982) recorded 90 and 73 foraminiferal species from Godavari and Krishna estuaries respectively. From the former estuary, 29 and from the latter, 25 species are common to the Chilka lake. In all, 23 species are common and *Miliammina fusca*, *Ammonia beccarii* (Linne) and *A. tepida* are the most abundant forms in these three estuaries. No faunal zonation studies have been made in Godavari and Krishna estuaries.

From the classified list of 45 species of Foraminifera reported earlier (Reddy and Rao, 1980) from Pennar estuary, only 16 species are found in Chilka lake.

On the west coast of India, Rao (1974) recorded 32 species of Foraminifera from Mandovi and Zuari estuaries in Goa. Out

of them, 17 species are not known to be present in the Chilka lake. Faunal zonation studies show that the lower reaches of Mandovi and Zuari estuaries are characterized by *Ammonia beccarii* sp. as in the present study, but in the upper reaches of these estuaries by *Trochammina* instead of by *Miliammina* facies as observed in the Chilka lake. Further, studies on Foraminifera from the Cochin backwaters by Rao and Balasubramanian (1996) reveal that 29 species are common to both Cochin and Chilka lake estuaries.

It is obvious from the above faunal studies that one species - *Asterorotalia pulchella* - *trispinosa* - is recorded only on the east coast of India. So far, this species is recorded neither from the Arabian Sea nor from the estuaries on the west Indian coast and it is possible that this species is endemic to the Bay of Bengal.

Certain overseas comparisons

The upper reaches of the estuaries, in general, are dominated by arenaceous Foraminifera and dominant species of the arenaceous assemblages vary from area to area. From the faunal studies made elsewhere, it is known that Miramichi River (Bartlett, 1966) and Mobile Bay (Walton, 1964) are characterized by *Miliammina* fauna, while the Mississippi Sound (Phleger, 1954) by *Palmerinella*. *Ammobaculites* is common to Texas bays (Parker *et al*, 1953), Sabine lake (Kane, 1967) and Chesapeake estuaries (Ellison, 1972). Of the environs, Miramichi River and Mobile Bay are close to Chilka lake

in showing faunal affinity in that the arenaceous ensemble is dominated by *Miliammina*. Out of 39 species recorded from Tampa Bay, 12 species are common to the Chilka lake and the bay. Further, *Miliammina* is not recorded in this bay, but it occurs in higher abundance in Mobile Bay (Walton, 1964).

Among 41 species reported from Sabine lake (Kane, 1967), 13 are common to Chilka, Sabine lakes and neretic region of the Gulf of Mexico. Of these common species, 3 forms - *Gaudryina exilis*, *Ammonia pauciloculata* and *Asterorotalia inflata* are found only in the Gulf of Mexico. Another 2 species, *Jadammina macrescens* and *Elphidium mexicanum* are present only in the Sabine lake. The remaining 8 species - *Miliammina fusca*, *Bolivina striatula*, *Elphidium discoideale*, *E. gunteri*, *E. poeyanum*, *Quinqueloculina lamarkiana*, *Q. seminula* and *Ammonia beccarii* (Linne) occur in both these environs. Of the four foraminiferal biofacies described for these areas, *Ammobaculites* is the most dominant facies of the fauna within the Sabine lake which along with Texas bays of the southwestern U. S. and the Rappahannock River of northwestern Virginia, thus differ from Chilka lake in the dominance of arenaceous species in the arenaceous assemblages.

Murray (1968_b) studied foraminiferal fauna from the Christchurch Harbour, England, a shallow estuary where mean water depth is 2 m. He reported *Miliammina fusca*, *Elphidium oceanense*, *E. sp.*, and *Protelphidium anglicum* from low salinity waters of the upper estuary, while

the lower estuary is dominated by *Ammonia beccarii* (Linne) and *Reophax moniliformis*. Diversity index is low in the upper estuary as comparable to the present study.

As evident from the above comparative study on Foraminifera from the estuaries in India and elsewhere, it is seen that besides brackish species, the fauna is constituted by the large number of shallow-water Foraminifera which are transported into the lake by tidal currents depending on a suitable season. It is favourable for the nearshore foraminiferids to colonise the estuary inasmuch as food supply is more abundant in waters of the estuarine area than those of the nearshore (Rao and Balasubramanian, 1996).

Conclusions

1. Species and genera are more numerous in the outer channel of the lake than within the lagoon.
2. Sixty-nine foraminiferal species have been identified from 15 sediment samples. *Miliammina fusca*, *Ammobaculites exiguus*, *Ammonia beccarii* (Linne) and *Ammonia tepida* are the most abundant species of the lake. *Ammonia*, *Miliammina*, *Ammobaculites*, *Trochammina* and *Elphidium* are the dominant genera of the fauna.
3. The percentage of arenaceous forms is low in the outer channel, but increases within the lagoon, especially in the central sector. These forms are very low in the northern sector. In

general, porcelaneous tests are relatively high in the outer channel as compared with the lagoon. Hyaline types dominate the fauna in the areas of study with an exception in May in the central sector.

The summer fauna characterized by the dominance of *Trochammina advena*, *T. hadai*, *Gaudryina exilis*, *Textularia earlandi*, miliolids, species of *Hanzawaia*, *Ammonia beccarii* (Linne), *Ammonia tepida*, *Asterorotalia dentata* and species of *Elphidium*, in the outer channel suggests that it is an incursive fauna brought into it through the inlet by strong tidal currents from the marginal marine environment. These species are virtually limited to the outer channel.

It is patently provable that the lake is more productive during May (late premonsoon) as evidenced by higher concentrations of Foraminifera.

Areas of calcareous assemblages depict high foraminiferal abundance, while areas of arenaceous assemblages have low foraminiferal abundance.

Zonation of the lake into two facies, viz., inner lagoon facies dominated by *Miliammina fusca* and outer lagoon/channel facies typified by *Ammonia beccarii* (Linne), finds corroboration from the examination of relative abundance data of foraminiferal species as well as from a multivariate statistical study using a factor analysis for grouping of stations and species.

This study reveals that environmental conditions are better in summer, especially with regard to salinity for Foraminifera to thrive than during other seasons.

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