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Frequency distribution of Foraminifera in the Chilka Lake

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Abstract

A total of sixtynine foraminiferal species have been identified from the sediment samples collected from the Chilka Lake during November 1997 and March, May 1998. These species have been quantitatively studied in regard to their relative abundance and distribution. Frequency distribution study of Foraminifera shows that *Miliammina fusca, Ammobaculites exiguus, Trochammina hadai, Jadammina macrescens, Gaudryina exilis, Ammonia beccarii* (Linné), *A. tepida* and *Asterorotalia dentata* are the dominant species of the fauna. Mean values of number of species (*S*), Shannon-Wiener index, *H (S)* and evenness index (ϵ) are highest in summer (May) for the outer channel suggesting very high species diversity of the area as compared with other parts of the lake due to strong marine influence. In contrast, Pielou's index of species dominance (*D*) decreases towards the sea. Variations in the mean diversity indices for the areas covered in the lake are related to the water characteristics prevailing there during different seasons. The sites dominated by *M. fusca* and *A. exiguus* are mostly inside the lagoon, while those dominated by *A. beccarii* (Linné) besides *T. hadai, G. exilis, Hanzawaia asterizans, H. nitidula, A. tepida, A. dentata, Elphidium crispum* and *E.galvestonense* are in the outer channel of the lake.

Application of two similarity indices - Bray-Curtis coefficient and Community coefficient - for the data shows very high faunal affinity existing between stations in the northern sector. Furthermore, the degree of faunal variation has been discussed with the data in terms of per cent number of species occurring in all the samples of sites (*Sc*) and of per cent population composed of species occurring in all the samples of sites (*Pc*) at each of the three areas of the lake.

Introduction

The importance of recent Foraminifera in oceanic research is well known (Boltovskoy and Wright, 1976). Consequently, research publications on these marine organisms of the world oceans, are cornucopian and exhaustive. A review of literature on Foraminifera of the Indian Ocean is given by Bandy *et al.*, (1971) and those of the inshore waters and estuaries by Seibold and Seibold (1981) and Rao and Balasubramanian (1996). It is obvious from these reports that no substantial work has been done on the quantitative distribution of foraminiferal species in different ecosystems in India, though such data will be useful in determining typical species of an ecosystem based on the most abundant species. Hence an attempt has been made in this paper to make a quantitative documentation of the species and study their distribution for typifying the areas in Chilka Lake with distinct biofacies.

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Study Area

Chilka Lake with an area of 1165 km^2 is the largest brackish water lagoon in Orissa State on the east coast of India and lies between 19° 25′ and 19° 54′N and 85° 6′ and 85° 38′E. It is divided into 4 sectors (Jhingran, 1963), viz. northern sector, central sector, southern sector and outer channel, based on the hydrographic features of the lake. In this study, southern sector of lake has not been covered. Therefore, salient features of topography are given earlier (Rao *et al.*, 2000) only for the other areas where samples have been collected.

Material and Methods

Fifteen sediment samples were collected from different locations as shown previously (Rao *et al.*, 2000) in the Chilka Lake during each faunal survey in November 1997 (postmonsoon season) and March, May 1998 (premonsoon season). Each sample was passed through a 105 µm sieve and the coarse fraction used for the study of Foraminifera. A total of 300 specimens were counted for calculation of percentage occurrence of foraminiferal species in total population. Abundance was expressed as the total number of specimens (live + dead) per 30 cc of wet sediment.

Diversity indices calculated for each of these samples in this study are :

1. Pielou's (Pielou, 1971) index of species dominance is given by

$$D = H(S)/H(S)_{Max}$$

where D is dominance value, $H(S)$ is Shannon-Wiener diversity index and $H(S)_{Max}$ is the maximum value of $H(S)$ in a sample.

2. Shannon-Wiener (Shannon and Weaver, 1963) function is given by the equation:

$$H(S) = \sum_{i=1}^{k} [p_i \log_2 (p_i)]$$

where $p_i = n_i/N$, n_i is the number of individuals of the i^{th} species, N is the total number of individuals of all species and S is the total number of species observed.

For equally distributed species $e^{H(S)} = S$ [because maximum value of $H(S)$ is obtained when all the species have equal frequencies in which case $H(S) = In(S)$ according to MacArthur (1965)] which in turn can be used as a measure of equitability.

3. Evenness index has been given by Heip's(Heip,1974) formula:

$$\in = e^{[H(S) -1]}/(S-1)$$

where $e^{H(S)}$ is the equivalent number of equally distributed species. Equitability is defined as the ratio of the number of species observed to the number of species that are theoretically required by MacArthur's model to achieve the same diversity with equitable (or even) distribution of individuals among the species in a population (Lloyd and Ghelardi, 1964).

For determining faunal affinity between sites, a measure of dissimilarity used by Bray and Curtis (1957) was applied in this study and it is given by

$$d_{jk} = \frac{\left|\sum_{i=1}^{s}(Y_{ij} - Y_{ik})\right|}{\left[\sum_{i=1}^{s}(Y_{ij} + Y_{ik})\right]}$$

where Y_{ij} , Y jk are the scores of the i^{th} species in the j^{th} and k^{th} samples respectively; d_{jk} ranges between 0 (highly similar) and 1 (highly dissimilar) and coefficient of similarity is :

$$S_{jk} = 1 - d_{jk}$$

$0 \leq S_{jk} \leq 1$ is for highly dissimilar case to highly similar case. S_{jk} data were plotted as a trellis diagram with percentage values.

Sampling sites were also compared by calculating Community coefficient (Pearson and Rosenberg, 1978). It is given by the formula :

$$CC_{jk} = [C_{jk}/(a_j + b_k - C_{jk}]$$

Where C_{jk} is number of species common between j^{th} and k^{th} samples, a_j is number of species in the j^{th} sample, b_k is number of species in the k^{th} sample. CC_{jk} values were also plotted as a trellis diagram with percentage values to study the qualitative association between stations based on the common occurrence of foraminiferal species in the study area.

Results and discussion

Foraminiferal abundance

In the outer channel, total concentration of Foraminifera (live + dead) per 30 cc of wet sediment is lowest ($\bar{x}$ = 303 specimens) during November, while the values for the same in March and May are 823 and 2547 specimens respectively. Highest abundance of Foramininfera ($\bar{x}$ = 990 specimens) has been observed in March and lowest ($\bar{x}$ = 204 specimens) in May in the central sector of the lake. Similar to the outer channel, in the northern sector too, lowest density of 79 specimens in November and highest of 272 specimens in May have been observed. Abundance ranges of foraminiferal density for the sites in different areas of the lake are given in Table 1.

The absolute variation (σ_{n-1}) shows a steady increase from November (306.75) to May (4611.14) in the outer channel and so also in the northern sector from November (55.07) to May (91.16), but in the central sector, it is maximum in March (1215.52) and minimum in May (152.61). The coefficient of variation (*cv%*) increases from November (101.24) to May (181.08) in the outer channel. In the central sector, it is highest in March (122.78) and lowest in May (74.81). There is a decrease of *cv%* from November (69.42) to May (33.47) in the northern sector (Table1).

Foraminiferal species

Foraminifera of the Chilka Lake have been studied in different months representing postmonsoon and premonsoon seasons. The breakdown of the 15 stations surveyed for Foraminifera during these months is as follows :

Table 1. *Mean ($\bar{x}$), standard deviation (σ_{n-1}) and coefficient of variation (cv%) of total foraminiferal abundance (no. of specimens per 30 cc of wet sediment) of all the stations in each area during different months.*

Month	Area	Abundance range	$\bar{x}$	σ_{n-1}	*cv%*
November	O.C	0-900	303.0	306.75	101.24
	C.S	9-1389	630.0	548.56	87.07
	N.S	2-126	79.3	55.07	69.42
March	O.C	12-2640	823.0	995.10	120.91
	C.S	72-3582	990.0	1215.52	122.78
	N.S	76-285	186.3	85.72	46.01
May	O.C	51-12828	2546.5	4611.14	181.08
	C.S	45-468	204.0	152.61	74.81
	N.S	148-364	272.3	91.16	33.47

Legend : O.C = Outer channel; C.S = Central sector and N.S = Northern sector

November 1997 :

A. beccarii (Linné) : 11 stations
A. tepida : 10 stations
A. exiguus : 9 stations
M.fusca, A. advena and
A. parkinsoniana : 8 stations each
T.hadai and *A. sobrina* : 6 stations each
H. canariense, J. macrescens
and *A. pauciloculata* : 4 stations each
10 species : 1 station each

March 1988 :

A. exiguus and *A.tepida* : 11 stations each
A.beccarii (Linné) : 10 stations
M.fusca and *T.hadai* : 9 stations each
A. parkinsoniana and *A. sobrina* : 8 stations each
J. macrescens, A. advena and *A. dentata* : 5 stations each
G. exilis, T. earlandi, Q. seminula,
A. pauciloculata and *E.advenum* : 3 stations each
26 species : 1 station each

May 1998 :

M.fusca and *A. exiguus* : 13 stations each
A.beccarii (Linné) : 10 stations
T.hadai and *A. tepida* : 9 stations each
A. advena : 8 stations

In all, 69 species have been identified, studied quantitatively with regard to their frequency distribution (Tables 2-4) and of them, the following species show dominance or abundance ≥ 25% at one or more sites of the study area in one season or the other, they being *M.fusca, A. exiguus, T.hadai, J. macrescens, G.exilis, A. beccarii, A. tepida* and *A. dentata.* Distribution of these species in the lake is depicted in Fig.1.

Examination of the quantitative data of foraminiferal species shows that the study area consists of two distinct faunal facies : facies 1 (inner lagoon

J.macrescens and *A. parkinsoniana*	:	7 stations each
T.advena	:	6 stations
Q.seminula and *A.dentata*	:	4 stations each
H. canariense, G. exilis, H. germanica, A. pauciloculata and *E.glavestonense*	:	3 stations each
31 species	:	1 station each

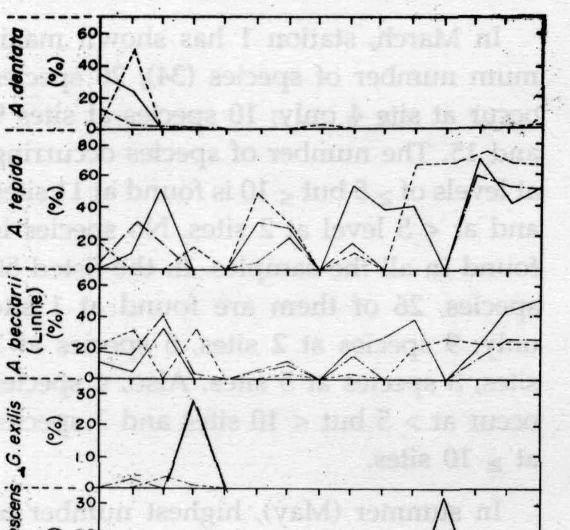

Fig. 1. *Distribution of percentage occurrence of abundant foraminiferal species in total population from the sediments.*

facies) is characterized by abundant occurrences of *M. fusca* and *A. exiguus*, while facies 2 (outer lagoon/channel facies) dominated by *Ammonia beccarii* and common forms in this area include *T.hadai, G.exilis, H. asterizans, H. nitidula, A.tepida, A.dentata, E.crispum* and *E.galvestonense.*

Thus, the sites dominated by *M.fusca* and *A.exiguus* are mostly inside the lagoon, while those dominated by *T. hadai, G. exilis, A.beccarii, A. tepida* and *A. dentata* are in the outer channel. Although *A. beccarii* and *A.tepida* are the nearshore foraminiferids, they show dominance inside the lagoon, thereby suggesting that they can tolerate brackish or lagoonal conditions in this area of the lake. Yet another reason for their dominance is that food supply is more within the lake than in a nearshore area.

Diversity indices

Number of species (*S*) is defined as the total number of species present in a sample at the sampling site. During premonsoon season (March and May), maximum number of species is observed in the outer channel and least in the central sector, while in November, the number of species decreases from the outer channel to the northern sector. Shannon-Wiener diversity index, *H*(*S*) (Shannon and Weaver, 1963) increases towards the sea in November and March. In May, minimum species diversity has been observed in the central sector with not much difference at the other two sectors. In general, equitability or evenness index (Heip, 1974) decreases from the outer channel to the northern sector irrespective of the seasons. Pielou's (Pielou, 1971) index of species dominance (*D*) increases from the outer channel to the northern sector in November, while in March and May, the trend is reverse with least value in the central sector (Fig.2).

Comparison of the foraminiferal fauna during different seasons

In November, maximum number of species (13) is found at site 2; 11 species occur at 3 sites; 10 species at site 6. The number of species > 5 but ≤ 10 is found at 6 sites. Species number < 5 is found at 4 sites. No Foraminifera have been observed at site 4. Further, none of the species is found to occur at all the sites. Out of 28 species, 10 species are found at 1 site only, 5 species at 2 sites, 3 species at 4 sites and 2 species at 3 sites. Of the total number of species recorded, 6 species occur at levels of ≥ 5 but < 10 sites. Also, 2 species occur at ≥ 10 sites.

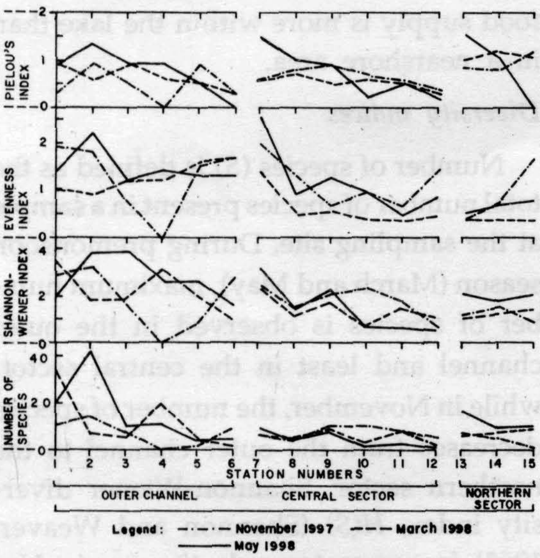

Fig. 2. *Species diversity in foraminiferal populations of the sediments.*

In March, station 1 has shown maximum number of species (34); 20 species occur at site 4 only; 10 species at sites 9 and 15. The number of species occurring at levels of ≥ 5 but ≤ 10 is found at 11 sites and at < 5 level at 2 sites. No species is found in all the samples. In the listed 50 species, 26 of them are found at 1 site only; 9 species at 2 sites, 5 species at 3 sites, 3 species at 5 sites. Also, 4 species occur at > 5 but < 10 sites and 3 species at ≥ 10 sites.

In summer (May), highest number of species (42) is found at station 2 ; 20 species are found at site 1, 17 species at site 13, 11 species at sites 4 and 15, 10 species at sites 7 and 14. The number of species at levels ≥ 5 but < 10 is found at 3 sites. Species number < 5 is found at 4 sites. Of the 57 species recorded, 31 species are found at one site only; 9 species at 2 sites, 5 species at 3 sites. 7 species occur at > 5 but < 10 sites and 3 species at ≥ 10 sites.

A variety of measures such as of distance, information, similarity and dissimilarity have been used to summarize the overall similarity/dissimilarity between two samples taking all species into consideration. Many of these have been summarized earlier (Clifford and Stephenson, 1975). A frequent feature of faunal data

Table 2. *Percentage occurrence of foraminiferal species in total population during postmonsoon season (November)*

	Outer channel						Central sector						Northern sector		
Station number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Foraminiferal species															
Miliammina fusca	-	-	-	-	-	4.0	26.3	40.0	8.7	13.3	14.7	66.7	1.0	-	-
Haplophragmoides canariense	-	0.3	0.7	-	-	-	-	-	2.7	2.3	-	-	-	-	-
Ammobaculites directus	-	-	-	-	-	-	-	5.0	-	0.7	-	-	-	-	-
A. exiguus	-	-	1.3	-	33.3	8.0	15.7	45.0	3.7	0.7	2.0	-	1.0	-	-
Ammotium fragile	-	-	-	-	-	-	-	-	0.7	-	-	-	-	-	-
Trochammina advena	-	-	2.7	-	-	13.3	-	-	1.0	-	-	-	-	-	-
T. hadai	-	2.7	-	-	66.7	22.7	10.7	10.0	1.0	-	-	-	-	-	-
Jadammina macrescens	-	-	-	-	-	1.3	-	-	-	-	0.3	33.3	1.0	-	-
Quinqueloculina seminula	10.0	-	1.0	-	-	-	-	-	-	-	-	-	-	-	-
Q. vulgaris	5.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Triloculina brevidentata	-	-	-	-	-	-	-	-	-	-	-	-	-	3.0	-
Cibicides refulgens	5.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Haynesina germanica	-	2.7	-	-	-	-	-	-	-	-	-	-	-	-	-
Protelphidium tisburyense	-	-	-	-	-	1.3	-	-	-	2.0	-	-	-	-	-
Ammonia beccarii	10.0	5.0	32.0	-	-	5.3	10.3	-	20.3	25.7	38.0	-	20.0	46.0	50.0
A. advena	-	2.7	-	-	-	12.0	5.3	-	1.7	14.0	3.3	-	1.0	3.0	-
A. parkinsoniana	5.0	13.7	5.3	-	-	-	-	-	2.3	1.0	0.3	-	3.0	5.0	-
A. pauciloculata	-	-	-	-	-	2.7	-	-	-	2.7	1.0	-	-	1.0	-
A. sobrina	-	8.0	-	-	-	-	5.3	-	2.7	0.7	0.3	-	2.0	-	-
A. tepida	-	10.7	53.3	-	-	29.3	26.3	-	55.0	36.7	40.0	-	71.0	42.0	50.0
Asterorotalia dentata	35.0	24.0	-	-	-	-	-	-	-	-	-	-	-	-	-
A. trispinosa	-	2.7	-	-	-	-	-	-	-	-	-	-	-	-	-
Elphidium advenum	5.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E. articulatum	5.0	2.7	-	-	-	-	-	-	-	-	-	-	-	-	-
E. excavatum	5.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E. galvestonense	10.0	21.7	3.7	-	-	-	-	-	-	-	-	-	-	-	-
E. hispidulum	-	3.0	-	-	-	-	-	-	-	-	-	-	-	-	-
E. poeyanum	5.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 3. *Percentage occurrence of foraminiferal species in total population during early premonsoon season (March)*

	Outer channel						Central sector						Northern sector		
Station number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Foraminiferal species															
Miliammina fusca	-	-	16.7	2.3	33.3	-	-	77.6	61.0	84.0	3.7	0.3	0.3	-	-
Haplophragmoides															
canariense	1.7	-	-	-	-	-	1.0	-	-	-	-	-	-	-	-
Ammobaculites exiguus	-	-	13.3	2.3	22.3	50.0	41.0	8.3	19.3	11.3	-	-	0.3	0.7	1.3
Ammotium fragile	-	-	-	-	-	-	-	-	1.0	-	-	-	-	-	-
Trochammina advena	-	-	-	0.3	11.0	-	-	-	-	-	-	-	-	-	-
T. hadai	0.3	3.3	50.0	5.3	30.7	-	4.3	6.0	1.0	2.3	-	-	-	-	-
T. ochracea	-	-	-	-	-	-	-	-	1.0	-	-	-	-	-	-
Jadammina macrescens	0.3	-	-	-	-	-	-	-	-	-	2.4	1.7	0.3	-	1.3
Gaudryina exilis	0.3	-	3.3	1.0	-	-	-	-	-	-	-	-	-	-	-
Textularia earlandi	-	-	16.7	0.7	2.7	-	-	-	-	-	-	-	-	-	-
Quinqueloculina agglutinans	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Q. agglutinata	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Q. dimidiata	-	-	-	0.7	-	-	-	-	-	-	-	-	-	-	-
Q. durandi	-	-	-	0.3	-	-	-	-	-	-	-	-	-	-	-
Q. lamarckiana	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Q. lata	-	-	-	-	-	-	12.7	-	-	-	-	-	-	0.7	-
Q. seminula	-	3.3	-	0.3	-	-	-	-	-	-	-	-	-	-	1.3
Q. vulgaris	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Triloculina brevidentata	-	-	-	-	-	-	-	-	-	-	-	-	-	0.7	1.3
T. subrotunda	-	-	-	-	-	-	8.3	-	-	-	-	-	-	-	-
Globigerinita glutinata	-	-	-	-	-	-	-	2.7	-	-	-	-	-	-	-
Globigerinoides ruber	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
G. sacculifer	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Bolivina striatula	-	-	-	0.3	-	-	-	-	-	-	-	-	-	-	-
Amphistegina radiata	0.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Haynesina germanica	3.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hanzawaia asterizans	0.3	3.3	-	-	-	-	-	-	-	-	-	-	-	-	-
H. concentrica	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H. nitidula	0.7	-	-	0.3	-	-	-	-	-	-	-	-	-	-	-
Ammonia baccarii	22.6	30.0	-	31.7	-	-	3.3	-	3.0	-	20.7	24.7	20.2	22.0	21.0
A. advena	-	-	-	2.0	-	-	-	-	-	-	0.7	-	1.0	1.7	1.3
A. parkinsoniana	16.0	-	-	15.7	-	-	-	-	1.0	-	1.7	3.0	4.0	2.7	2.7
A. pauciloculata	0.3	-	-	-	-	-	-	-	1.0	-	1.0	-	-	-	-
A. sobrina	9.0	-	-	3.7	-	-	-	2.7	1.0	-	0.7	1.7	-	2.0	1.3
A. tepida	15.0	-	-	14.0	-	50.0	29.3	-	10.7	2.3	68.0	68.0	72.8	69.0	67.0
Asterorotalia dentata	6.7	53.3	-	0.3	-	-	-	2.7	-	-	-	-	-	-	1.3
A. inflata	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A. trispinosa	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Elphidium advenum	0.7	3.3	-	-	-	-	-	-	-	-	1.0	-	-	-	-
E. alvarezianum	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E. articulatum	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E. clavatum	-	3.3	-	-	-	-	-	-	-	-	-	-	-	-	-
E. craticulatum	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E. crispum	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E. discoidale	0.3	-	-	1.0	-	-	-	-	-	-	-	-	-	-	-
E. excavatum	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E. galvestonense	11.7	-	-	9.3	-	-	-	-	-	-	-	-	-	-	-
E. gunteri	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E. hispidulum	3.7	-	-	8.3	-	-	-	-	-	-	-	-	-	-	-
E. poeyanum	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4. *Percentage occurrence of foraminiferal species in total population during late premonsoon season (May)*

	Outer channel						Central sector						Northern sector		
Station number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Foraminiferal species															
Miliammina fusca	-	0.3	1.7	16.3	11.7	22.3	-	21.7	38.3	82.0	83.7	84.0	4.0	4.0	2.7
Haplophragmoides canariense	-	1.7	-	-	-	-	-	2.3	-	-	-	-	1.0	-	-
Ammobaculites directus	-	-	-	-	-	-	-	-	-	-	-	-	0.3	-	-
A. exiguus	-	3.7	-	21.7	29.3	50.0	6.7	63.0	23.0	18.0	15.0	16.0	8.0	5.0	8.0
Ammotium fragile	-	-	-	3.0	-	-	-	-	-	-	-	-	-	-	-
Trochammina advena	-	1.3	3.0	5.0	6.0	-	6.7	-	-	-	-	-	0.3	-	-
T. hadai	1.0	3.7	9.3	20.7	53.0	16.7	6.7	8.7	2.7	-	-	-	-	-	-
Tiphotrocha kellettae	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jadammina macrescens	-	0.3	-	-	-	-	13.3	-	1.3	-	1.3	-	0.3	0.3	0.7
Gaudryina exilis	-	2.3	-	28.0	-	-	-	-	-	-	-	-	-	0.3	-
Textularia earlandi	-	0.3	-	1.0	-	-	-	-	-	-	-	-	-	-	-
Quinqueloculina dimidiata	-	0.7	-	-	-	-	-	-	-	-	-	-	-	-	-
Q. laevigata	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-
Q. lamarckiana	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-
Q. seminula	1.3	2.7	-	-	-	-	-	-	-	-	-	-	0.7	-	0.7
Q. tenagos	-	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-
Q. vulgaris	-	0.7	-	-	-	-	-	-	-	-	-	-	-	-	-
Miliolinella subrotunda	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-
Triloculina brevidentata	-	2.0	-	-	-	-	-	-	-	-	-	-	0.3	-	-
T. trigonula	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-
Globigerinita glutinata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.7
Globigerinoides sacculifer	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-
Bolivina pseudoplicata	-	-	-	1.0	-	-	-	-	-	-	-	-	-	-	-
B. striatula	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-
Hopkinsina pacifica	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-
Rosalina globularis	-	-	-	-	-	-	6.7	-	-	-	-	-	-	-	-

R. leei	-	-	-	-	-	-	-	-	-	-	-	-	0.3	-	-
Planulina bassensis	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-
Amphistegina radiata	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-
Haynesina germanica	1.3	2.7	-	-	-	-	-	-	-	-	-	-	0.3	-	-
Nonion depressulum	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-
Nonionellina labradorica	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-
Protelphidium schmitti	-	-	-	-	-	-	-	-	-	-	-	-	1.0	-	-
P. tisburyense	-	-	-	-	-	-	-	-	-	-	-	-	0.3	-	-
Hanzawaia asterizans	11.0	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-
H. concentrica	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-
H. nitidula	9.7	0.7	-	-	-	-	-	-	-	-	-	-	-	-	-
Ammonia beccarii	17.0	15.6	40.0	1.0	-	5.3	6.7	-	14.0	-	-	-	12.0	26.0	23.0
A. advena	-	0.3	-	-	-	-	13.0	4.3	2.7	-	-	-	9.0	9.7	10.0
A. parkinsoniana	7.3	7.7	15.7	-	-	-	13.3	-	-	-	-	-	2.0	1.0	2.0
A. pauciloculata	-	-	-	-	-	-	6.7	-	-	-	-	-	-	0.7	1.3
A. sobrina	3.7	4.3	7.7	-	-	-	-	-	1.3	-	-	-	1.0	0.7	1.3
A. tepida	6.0	29.7	12.7	-	-	5.7	20.0	-	16.7	-	-	-	59.0	52.3	49.0
Asterorotalia dentata	12.0	4.3	1.7	1.0	-	-	-	-	-	-	-	-	-	-	-
A. inflata	8.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A. trispinosa	-	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-
Elphidium advenum	1.3	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-
E. alvarerzianum	2.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E. crispum	6.0	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-
E. discoidale	1.0	0.7	-	-	-	-	-	-	-	-	-	-	-	-	-
E. excavatum	1.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E. galvestonense	-	5.0	6.3	1.3	-	-	-	-	-	-	-	-	-	-	-
E. hispidulum	-	0.3	1.7	-	-	-	-	-	-	-	-	-	-	-	-
E. incertum	1.0	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-
E. mexicanum	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-
E. poeyanum	6.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E. rugulosum	1.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-

is that many of species are absent from a majority of samples, which leads to zero values in more than half of the data matrix. Transformation of data does not alter this. Thus, measures which take into account of joint absences are not robust enough to be generally applicable (Field *et al.,* 1982). Therefore, the measure used by Bray and Curtis (1957) has been applied here, since it is not affected by joint absences (Field and McFarlane, 1968) and hence sufficiently robust for faunal data. Yet it gives more weight to abundant species than to rare ones.

In this study, in November, similarity by this measure in the outer channel is < 40%. St 3 is observed to have > 70% similarity with stations of the northern sector. Similarity between the stations of central sector and northern sector is found to be better (60-90%) mostly. Within the northern sector, 60-90% similarity for the common species has been observed.

In March, stn 8, 9 and 10 are found to have 70-80% similarity, while stn 11-15 have shown > 90% similarity in the occurrence/ non-occurrence of common foraminiferal species. The outer channel stations have shown only < 40% similarity with stations of the central and northern sectors. Similarly stations of the central sector have shown only < 50% affinity with stations of the northern sector except sts 10-12.

During May, stn 10, 11 and 12 are found to be highly similar and so also stn 13-15 in the northern sector with respect to abundance of common species. Stations which are highly dissimilar are the clusters : stn 1-3 with stn 10-12; stn 4-6 with stn 13-15 and stn 10-12 with stn 13-15. All other pairs of stations have similarity between 30 and 60%. In the outer channel, less similarity (< 60%) is observed between stations as compared with other parts of the lake in this month (Fig. 3A,B,C).

Also, sampling sites have been compared by the Community coefficient (Pearson and Rosenberg, 1978) for measuring the degree of affinity of the foraminiferal fauna between stations of the lake. The similarity between stations of the three areas of the lake is based only on the presence/ absence of species (Sneath and Sokal, 1973).

In November, between stn 6,7,9,11 and 13, similarity is > 50%, while in all other pairs of stations, similarity is < 40%. In March, the presence/ absence of species has shown 50-65% similarity between the pairs of stations (3,5), (5,10), (11,13), (12,13) and (13-15), while in May, there is only < 40% common occurrence of species between all pairs of stations except stn 6 and 9 (62%), stn 6 and 10 (40%), stn 7 and 9 (50%) and between the stn 10, 11 and 12 (> 66%) (Fig. 3D,E,F).

Data in terms of per cent number of species occurring in all the samples of sites (*Sc*) and of per cent population composed of species occurring in all the samples of sites (*Pc*) at each area were used to analyse faunal variation by the formulae given by Lynts (1966). *Sc* is given by

$Sc = (C/S) *100$

where C is number of common species and S is total number of species in each area.

Pc is defined as

$Pc = (n/N) *100$

Where *n* is number of specimens of common species and *N* is total number of specimens in each area.

Sc values range from 0 - 20% in November, 0 - 8.3% (March) and from 2 - 35% in May. These data suggest that species composition shows least variation in March and maximum in May. On the other hand, *Pc* values', ranges of different months (November : 0 - 99.6%; March : 0 - 99.6% and May : 17.8 - 95.9%) indicate that populations of Foraminifera vary highly between stations of each area regardless of the seasons.

Environmental stress on the lake due to shrinkage in area, siltation, inflow of freshwater from the rivers and different types of pollution

Chilka Lake is choking with weeds and

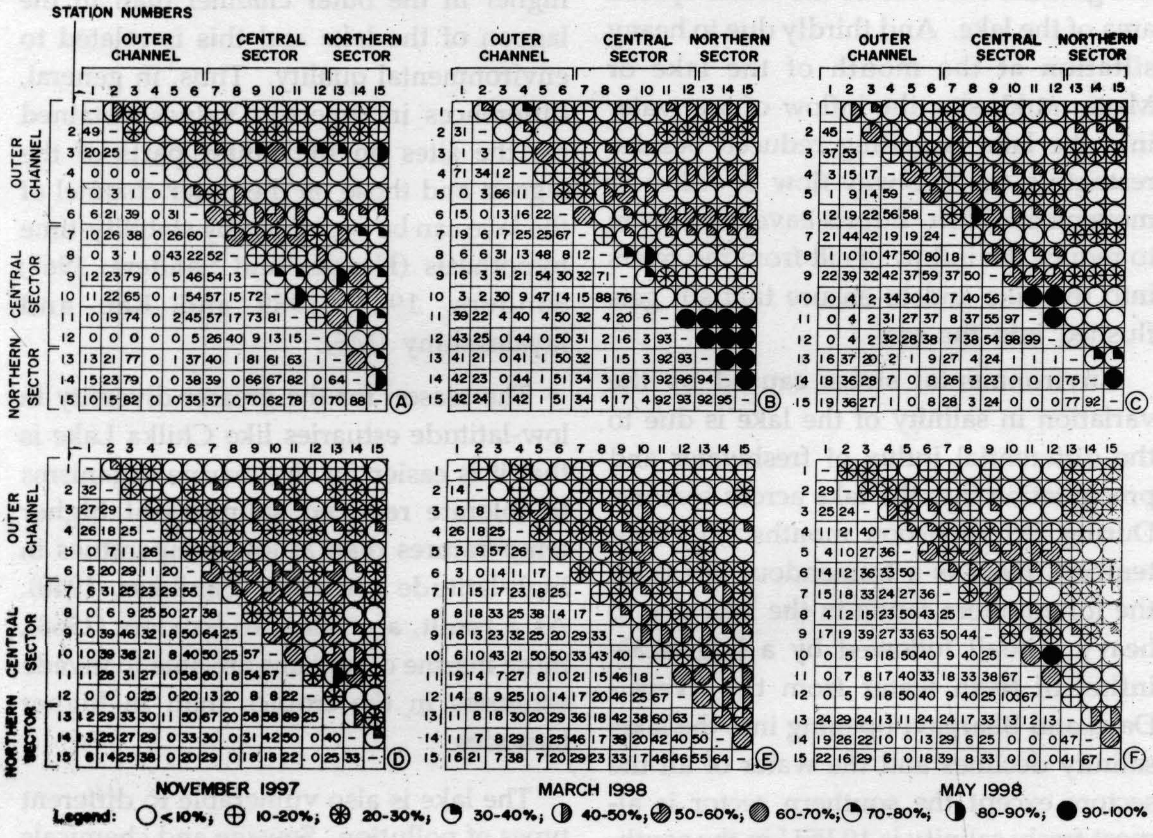

Fig. 3. *Trellis diagrams based on Bray-Curtis coefficient (abundance of species), (A,B and C) and Community coefficient (presence or absence of species), (D,E and F) showing percentage affinity index between stations for areas of the lake in different months.*

being encroached upon from different sides. As a result, the water spread area of the lake has shrunk.

Silting has had its toll on the lake : the depth of water is now only 3 ft in some places; earlier it was around 30 ft. It is estimated that 13 million tonnes of silt is brought annually into the lake by rivers that open into it. The negative impacts of this massive inflow of silt are manifesting themselves in 3 ways : Firstly, the slit is getting deposited into the lake rendering it less shallow. Secondly, it is resulting in the gradual decrease of the water spread area of the lake. And thirdly due to heavy siltation at the mouth of the lake or Magarmukh site, the inflow of sea water into the lake is getting reduced besides restricting the two-way flow of water or movement of fish. Efforts have to be made to reduce the inflow of silt from the rivers into the lake and to ensure that silt gets flushed into the sea.

Environmental stress caused by the variation in salinity of the lake is due to the differential influx of freshwater and precipitation into the lake across seasons. During SW monsoon months (July-September), there is a tremendous stress on the foraminifera fauna in the lake due to heavy rainfall followed by a large-scale influx of fresh water from the rivers - Daya and Bhargavi-opening into the lake; salinity declines and the water of all the sectors except the southern sector is almost fresh; salinity is 10 PSU in the southern sector because of the relatively stagnant water mass and poor mixing. With the advent of postmonsoon season (October-December), there is a slight increase in the salinity of the lake in all the sectors, but it shows a declining trend in the southern sector due to slow mixing. During premonsoon season (February-May), the water of all the sectors is as saline as the sea water except in the southern sector. This period is most productive for the lake as there is a large inflow from Bay of Bengal, no precipitation and less freshwater influx. As a corollary, stable hydrographic conditions exist in the lake.

Foraminiferal species diversity ($H(S)$) is higher in the outer channel than in the lagoon of the lake and this is related to environmental quality. Thus, in general, differences in diversity values obtained for the sites on the innter parts of the lagoon and those on the outer channel of the lake can be explained by stability-time hypothesis (Hessler and Sanders, 1967; Sanders, 1968, 1969 and Rao and Jayalakshmy (MS).

The reason for the greater diversity in low-latitude estuaries like Chilka Lake is that it is easier for the marine organisms to tolerate reduced salinities at higher temperatures than at low temperatues in high-latitude estuaries (Panikkar, 1940). As a result, according to Sanders (1968), more marine organisms are able to invade estuaries in the tropics than in higher latitudes.

The lake is also vulnerable to different types of pollution. Sewage and chemicals brought into the lake from the towns in the catchment and the washing of hazardous pesticides and insecticides sprayed on crops is damaging the water quality. Industrial pollutant load in the immediate vicinity of the lake is less and whatever that is present in the lake is from the catchment through the rivers draining into the lake.

Conclusions

1. A total of sixtynine foraminiferal species have been recorded from the sediment samples collected during different faunal surveys; the breakdown of the total number of species in the study area is: November (28 species), March (50 species) and May (57 species). Thus, the fauna is poor in the number of species during months of heavy rainfall (November) when waters in the lake are almost fresh, but fairly rich during dry season (March and May) because of the prevalence of marine conditions in the area.

2. Certain species - *M. fusca, A. exiguus, T. hadai, J. macrescens, G. exilis, A. beccarii, A. tepida* and *A dentata* are the dominant species of the fauna based on the percentage occurrence of species in total population.

3. Species of *Elphidium* and miliolids are rare in November, but these forms are common in the lake, especially at the outer channel in March and May (summer).

4. In general, number of species, Shannon-Wiener diversity index and evenness index have shown higher mean diversity values for the outer channel as compared with other areas of the lake, thereby suggesting that it is an area of high diversity, which can be related to the higher environmental quality.

5. By contrast, the degree of dominance increases away from the sea and is highest in different seasons for the northern sector. Further, the community dominants in this part of the lake are *A. beccarii* and *A. tepida* during November and May, whereas it is only a lone species, viz. *A. tepida* in March.

6. One reason for the greater diversity in low-latitude estuaries like Chilka Lake during favourable period like dry season is due to the fact that it is not difficult for the marine organisms to tolerate reduced salinities at higher temperatures. Yet another reason for these organisms to invade the lake is that food supply is more inside an estuary than in a nearshore area.

7. The degree of faunal affinity using Bray-Curtis coefficient and Community coefficient of similarity indices for the sites in different parts of the lake has shown more affinity between stations for the northern sector.

8. *Sc* and *Pc* values evaluated based on the common occurrence of species and number of specimens of common species respectively, indicate that populations of Foraminifera vary highly between stations of each area of the lake irrespective of the seasons.

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