

Multivariate statistical study with a factor analysis of foraminiferal fauna from the Chilka Lake, India

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Abstract

Foraminiferal fauna from the surface sediments of the Chilka Lake along the east coast of India has been studied as regards distribution of its assemblages. From Q-mode factor analysis of the data, eight significant factor groups for species have been noted explaining > 89% of the variance. Among the species recorded, 16 species during post-monsoon season (November) and 34 species during pre-monsoon season (May) form the differential factor groups providing maximum information for the distribution of the fauna. Fifteen stations are also grouped by R-mode analysis with five and four significant factor groups contributing about 85% and 79% of the variance in November and May respectively. Furthermore, the first two factor groups constitute stations mostly of the inner lagoon and they form the differential factor groups for both the seasons. The faunal assemblages obtained from the cross plot of the factor loadings of the first two factors for these seasons show that the outer channel (Assemblages I and II) is quite distinct from that of the inner lagoon (Assemblage III) of the lake and thus testifying to the presence of two biofacies: facies 1 (inner lagoon facies) dominated by *Miliammina fusca*, while facies 2 (outer channel facies) by *Ammonia beccani* (Linne). It is obvious from the factor score distributions of stations against latitude (N) and species with respect to average absolute abundance that the species observed are from a continuously varying population least affected by insidious environmental changes in the study area.

Introduction

A study of Foraminifera from the Chilka Lake, east coast of India has been made earlier (Rao, *et al.*, 2000) with respect to the standing crop, species composition and biofacies. For a better understanding of distribution and ecologic patterns of these foraminifers in the world oceans, numerous authors have used multivariate statistical techniques such as a principal component analysis (Imbrie and Phleger, 1963; Malmgren and Kennett, 1973 and Be and Hutson, 1977) and a factor analysis (Howarth and Murray, 1969; Imbrie and

Kipp, 1971; Streeter, 1972; Thiede, 1975 and Jayalakshmy and Rao, 1991) in their studies. It is from this standpoint, a multivariate study with a factor analysis has been attempted in the present paper, which is an extension of the study on the fauna from Chilka Lake. This method can reduce a great number of stations and species to a few assemblages (Angel and Fasham, 1973, 1975). These assemblages can be plotted to study the distribution and the resulting patterns can be correlated with any environmental parameter or a group of parameters about which

information is available. The causal approach to factor interpretation is to impute substantive form to the underlying and unknown causes (Rummel, 1975).

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Material and methods

Method of collection of the materials, preservation, station positions and seasons have been described by Rao *et al*, (2000). For grouping of the stations and species, a multivariate statistical method termed as factor analysis has been applied (Morrison, 1978). The data on foraminiferal species presented here are in the form of actual counts and consist of 28 and 57 species in November and May sediment samples respectively. The data were subjected to row (for Q-mode) and column (for R-mode) normalization as transformation of the data (Rummel, 1975), since these data were over-dispersed (variance > mean) (Cassie, 1959 and Williamson, 1961). To get unique groups for species and stations, the criteria of varimax rotation to simple structure had been applied (Kaiser, 1958). The factor analysis model of Harman (1967) was used in this study. The number of factors "k" extracted was determined by the number of eigen values, which are greater than 1 because less than will

not be statistically significant (Guttman, 1954). The number of factors was also fixed by 'Scree' test of Cattell (1966). The eigen values were plotted against factor numbers for species and stations for November and May. The contribution of each species /station to a factor group is measured by a factor score. The distribution of factor score is used to typify the distribution patterns for species associations linked with each factor to see whether they are homogeneous and stable or varying continuously with time/ space or varying in a highly heterogeneous way, as indicated by the single mode symmetric distribution/single mode skewed distribution and multi-mode skewed distribution or separate distributions respectively. Factor scores were plotted against latitude (N) for stations and against average absolute abundance of species in November and May.

Results and discussion

Q-mode analysis of quantitative data of 28 foraminiferal species observed during postmonsoon season (November) shows 10 factor groups (Table 1A) of which 8 groups are statistically significant ($1 > 1$).

This grouping was supported again by the Cattell's 'Scree' test (Cattell, 1966) which resulted in a steadily decreasing curve from factor 1 to factor 8 and then became almost asymptotic to the factor together explained > 50% of the variability during this season. Sixteen species constitute the differential factor groups, with relative abundance varying from 0.3 to 35%. On the other hand, factor groups 4 to 8 explain about 33.2% of the variability. There was a decrease in the number of species included in each factor group

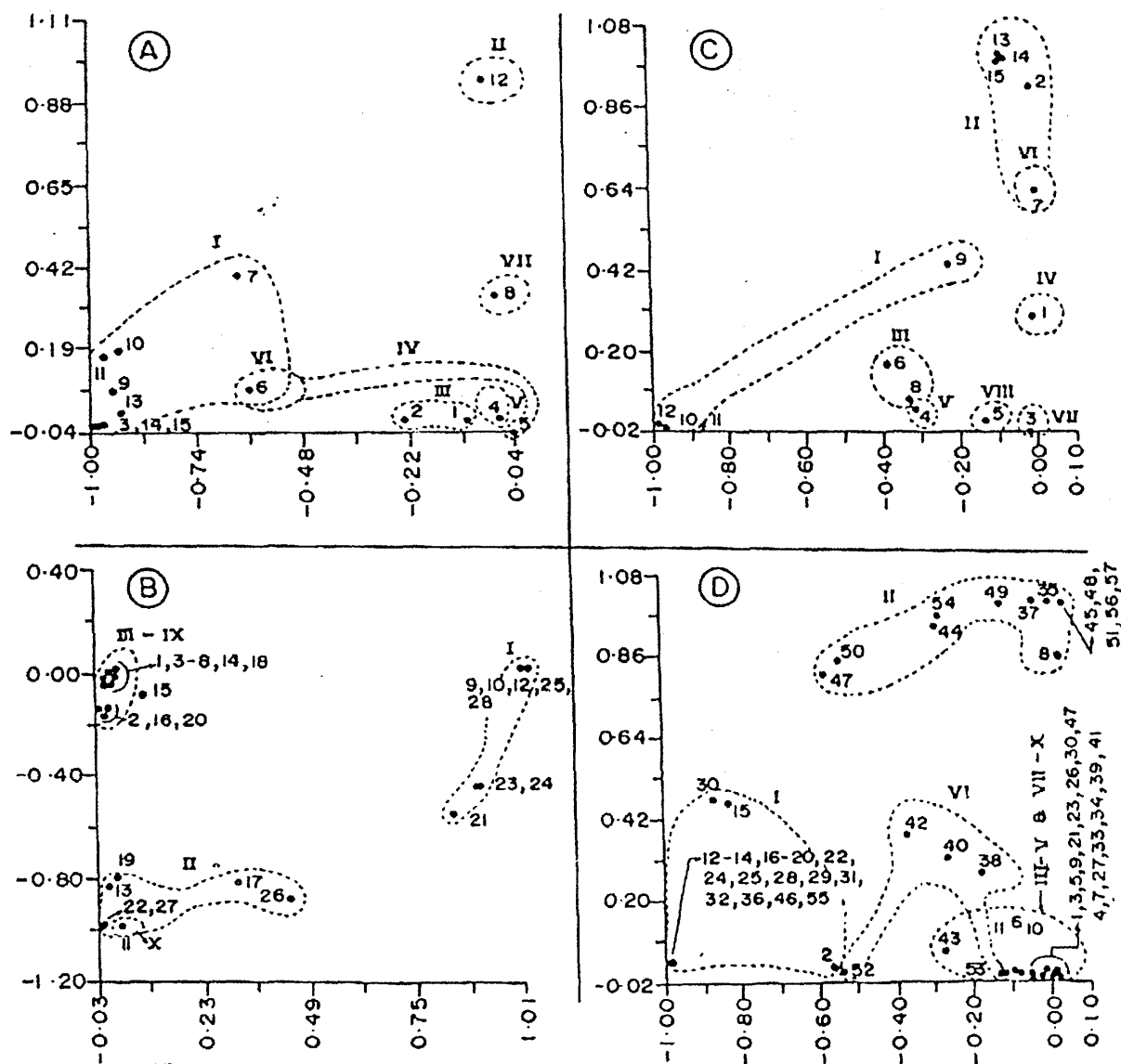


Fig. 1. Plot of the factor loading of the first two factors showing distribution of stations (A) and species (B) for November. Plot of the factor loadings of the first two factors showing distribution of stations (C) and species (D) for May. The Assemblages (I to X) are marked for stations and species

except for groups 4 to 8 which all contained two species each and they contributed the same amount of information about the distribution, variability explained being almost the same. The relative abundance of species varied between 0.30 and

71% in the factor groups 4 to 9. The groups were all distinct because the species included in the different factor groups were all different and no two groups have the same species except the factor groups 4 and 9 with *A. exiguus* occurring in both

Table 1. Factor analysis (Q-mode) for the foraminiferal species of post-monsoon (A) and pre-monsoon (B) seasons

(A)						
Factor number	Species	Range of maximum factor loading	Eigen value	Closeness ratio	Variance value	Variance value (%)
1	9,10,12,21,23-25,28	0.8334 to 0.9988	8.81	31.46	7.56	27.01
2	13,17,19,22,26,27	-0.8017 to -0.9934	5.12	49.75	5.58	19.93
3	6,14	0.9731 to 0.9766	3.76	63.18	2.52	8.99
4	3,4	0.7448 to 0.9864	2.32	71.45	1.73	6.18
5	2,5	0.7909 to 0.9733	2.18	79.22	1.74	6.21
6	1,8	-0.8803 to -0.9802	1.50	84.57	1.78	6.35
7	15,20	-0.8981 to -0.9017	1.43	89.66	2.09	7.48
8	16, 18	0.7837 to 0.7882	1.05	93.41	1.97	7.05
9	4,7	-0.6497 to -0.9626	0.72	95.98	1.40	5.00
10	11	-0.9535	0.60	98.14	1.10	1.93

Legend: (1) *Miliammina fusca*, (2) *Haplophragmoides canariense*, (3) *Ammobaculites directus*, (4) *A. exiguus*, (5) *Ammotium fragile*, (6) *Trochammina advena*, (7) *T. hadai*, (8) *Jadammina macrescens*, (9) *Quinqueloculina seminula*, (10) *Q. vulgaris*, (11) *Triloculina brevidentata*, (12) *Cibicides refulgens*, (13) *Haynesina germanica*, (14) *Protelphidium tisburyense*, (15) *Ammonia beccarii* (Linne), (16) *A. advena*, (17) *A. parkinsoniana*, (18) *A. pauciloculata*, (19) *A. sobrina*, (20) *A. tepida*, (21) *Asterorotalia dentate*, (22) *A. trispinosa*, (23) *Elphidium advenum*, (24) *E. articalatum*, (25) *E. excavatum*, (26) *E. galvestonense*, (27) *E. hispidulum*, (28) *E. poeyanum*

(B)						
Factor Number	Species	Range of maximum factor loading	Eigen value	Closeness ratio	Variance value	Variance value(%)
1	2,12-20,22,24,25,28 - 32,36,46,55	-0.5643 to -0.9961	22.77	39.94	21.04	36.92
2	8,35,37,44,45,47-51, 54,56,57	0.8200 to 0.9996	11.66	60.39	12.65	22.19
3	3,8,27,33,34,43	-0.5403 to -0.9984	5.88	70.71	5.00	8.78
4	6,9,26,39,41	0.6239 to 0.9965	4.43	78.47	4.16	7.29
5	5,10,23	-0.9851 to -0.9890	3.47	84.56	3.34	5.86
6	38,40,42,52,53	0.7035 to 0.9845	2.74	89.37	3.67	6.44
7	21	-0.9930	1.77	92.48	1.61	2.82
8	1,4	0.6930,0.9231	1.71	95.47	1.51	2.64
9	11,43	-0.5176,-0.9416	0.94	97.13	1.57	2.75
10	4,7	0.6327, 0.9080	0.84	98.59	1.65	2.90

(1) *Miliammina fusca*, (2) *Haplophragmoides canariense*, (3) *Ammobaculites directus*, (4) *A. exiguus*, (5) *Ammotium fragile*, (6) *Trochammina advena*, (7) *T. hadai*, (8) *Tiphrotrochn keilettae*, (9) *Jadammina macrescens*, (10) *Gaudryina exilis*, (11) *Textularia earlandi*, (12) *Quinqueloculina dimidiata*, (13) *Q. laevigata*, (14) *Q. lamarekiana*, (15) *Q. seminula*, (16) *Q. tenagos*, (17) *Q. vulgaris*, (18) *Miliolinella subrotunda*, (19) *Triloculina brevidentata*, (20) *T. trigonula*, (21) *Globigerinita glutinata*, (22) *Globigerinoides sacculifer*, (23) *Bolivina pseudoplicata*, (24) *B. siriata*, (25) *Hopkinsina pacifica*, (26) *Rosalina globularis*, (27) *R. leei*, (28) *Planulina bassensis*, (29) *Amphistegina radiata*, (30) *Haynesina germanica*, (31) *Nonion depressulum*, (32) *Nonionellina labradorica*, (33) *Protelphidium schmitti*, (34) *P. tisburyense*, (35) *Hanzawaia asterizans*, (36) *H. concentrica*, (37) *H. nitidula*, (38) *Ammonia beccarii*, (Linne), (39) *A. advena*, (40) *A. parkinsoniana*, (41) *A. pauciloculata*, (42) *A. sobrina*, (43) *A. tepida*, (44) *Asterorotalia dentate*, (45) *A. inflata*, (46) *A. trispinosa*, (47) *Elphidium advenum*, (48) *E. alvarezianum*, (49) *E. crispum*, (50) *E. discoideale*, (51) *E. excavatum*, (52) *E. galvestonense*, (53) *E. hispidulum*, (54) *E. incertum*, (55) *E. mexicanum*, (56) *E. poeyanum*, (57) *E. rugulosum*

the groups indicating that it has the characteristics of the ecology of both the groups.

Similarly, R-mode analysis used to group the 15 stations during postmonsoon period yielded 7 factor groups (Table 2A) of which the first four of them were sufficient to indicate ($1 > 1$) about the foraminiferal distribution being designated as the differential factor groups which provide with atleast 50% of the information. Also in this season, the number of factors obtained by 'Scree' test was four, after which the curve plotted became parallel to the factor axis asymptotically (Fig. 1A).

The groups 1 and 2, which included mostly the stations in the central and northern sectors, have formed the differential factor groups. At all the stations in group 1, *A. tepida* was the most abundant species ($> 25\%$). *M. fusca* and *A. tepida* showed the same abundance (26.3%) at station 7. Further, the former species showed the highest abundance of 66.7%. Groups 3 to 6 included stations of the outer channel. At stations 1 and 2 of group 3, *A. dentata* was the most dominant species. Common species at station 1 were *Q. seminula*, *A. beccarii* (Linne) and *E. galvestonense*. At station 2, *E. galvestonense* showed relative frequency of 21.7% and common forms being *A. parkinsoniana* and *A. tepida*. Group 4 comprised stations 5 and 6. At the former station, two arenaceous species occurred, they being *T. hadai* and *A. exiguus* with relative frequencies of 66.7% and 33.3% respectively, while station 6 showed the dominance of *A. tepida* and the common forms included *T. advena*, *T. hadai* and *A. advena*. Group 5 containing station 4 has been taken only for the uniformity with the other season. Group 6 consisted of a lone station 6

which showed the species composition as described earlier for this station in group 4. Group 7 included station 8 which showed *M. fusca* (40%) and *A. exiguus* (45%) as the dominant species. *T. hadai* is common, while *A. directus* was a rare species at this site. In summer (May), Q-mode factor analysis applied to 57 foraminiferal species abundance, has revealed 10 factor groups (Table 1B) of which the first eight groups were statistically significant ($1 > 1$), thereby justifying the 'Scree' test. Twenty-one species of group 1 and 13 species of group 2 were observed to be highly informative explaining about 59.1 % of the spatial variation. The eigen value-factor plot done for species grouping has resulted in 8 factors for which 1 values were greater than 1. In this case after factor 8, the curve became tangential to the factor axis indicating that the 8 factors were only statistically significant (Fig. 1D).

Group 1 showed negative factor loading (-0.9961) for species 12-55 (Table 1B). All species in this group were typical of a nearshore region and were very rare. In Group (2), positive factor loading for *H. asterizans* was 0.9996. Species showing relatively higher ranges in concentration were *A. dentata* (1-12%), *H. nitidula* (0.7-12%), *A. inflata* (0-8.3%) and *E. crispum* (1-6%). *A. tepida* in Group (3) showed relative frequency of 5.7-59%. All other species in this group constituted $\leq 1\%$. Common species such as *J. macrescens* and *A. advena* showed relative frequency of 0.3 -13.3% in Group (4). *Gaudryina exilis* was the most abundant species showing relative frequency of 0.3 to 28% in Group (5) with maximum abundance in the outer channel. In Group (6), *A. beccarii* (Linne) was the most abundant, while *A.*

parkinsoniana was common species with relative frequencies of 1 to 40% and 1 to 15.7% respectively. Group (7) included a lone and rare species - *G. glutinata*. *M. fusca* and *A. exiguus* were abundant species showing relative frequencies of 0.3 to 84% and 3.7 to 63% respectively in Group (8) and were confined to the inner lagoon, i.e., central sector. Group (9) consisted of *A. tepida*, the most dominant species showing relative frequency of 5.7 to 59% with the highest abundance in the northern sector as it has got tolerance for lagoonal conditions. Group (10) included two abundant species - *A. exiguus* and *T. hadai* showing relative frequencies of 3.7 to 63% and 1 to 53% respectively. The former species showed maximum abundance inside the lagoon, while the latter in the outer channel.

R-mode factor analysis to group the stations during this period into ecologically meaningful sites, has classified the 15 stations into 8 factor groups (Table 2B) of which the first four were statistically significant with groups 1 and 2 constituting the differential factor groups which provided maximum information about the species distributions in the area. The differential factor groups included mostly the stations inside the lagoon. The 'Scree' test used to determine the optimum number of eigen values or factor groups showed that from factor 5 onwards, the eigen value-factor curve became asymptotic to the factor axis which was same as the number of factors with $1. > 1$ (Fig. 1C).

Group 1 included stations 9-12 of the central sector in the lake. *M. fusca* was the most dominant species (38.3 to 84%) followed by *A. exiguus* (16 to 23%), *A. tepida* (16.7%) and *A. beccarii* (Linne) (14%).

Group 2, with the exception of sites 2 and 7, included stations 13-15 of the northern sector. *M. fusca* and *A. exiguus* higher concentrations in the central sector (site 7) and northern sectors (sites 13-15). *A. tepida* (29.7%) and *A. beccarii* (Linne) were common at the site 2. *J. macrescens*, *A. advena* and *A. parkinsoniana* showed (13 to 13.3%) relative abundance at site 7. *A. tepida* was the most dominant species at stations 13-15, common species being *A. beccarii* (Linne) (12%) at sites 13 and 15 and *A. advena* (10%) at site 15. Group 3 consisted of stations 6 and 8. At both stations, *A. exiguus* was the most dominant species (> 50%) and common species - was *M. fusca* (22%). Station 1 situated in the outer channel was included in group 4 and consisted of two common species like *H. asterizans* (11%) and *A. dentata* (12%), five rare species and nine very rare species. All were nearshore foraminiferids. Group 5 included station 4 of the outer channel. *G. exilis* was the most dominant species (28%). Group 6 included station 7 of the central sector. Common forms (13-20%) were *J. macrescens*, *A. advena*, *A. parkinsoniana* and *A. tepida*. Group 7 comprised station 3 of the outer channel. The species observed were *A. beccarii* (Linne) (40%), *A. parkinsoniana* (15.7%) and *A. tepida* (12.7%). station 5 of group 8 in the outer channel *T. hadai* was the most abundant species (53%).

From the plot of the factor loadings of the first two factors for stations of post-monsoon season (November), it was seen that the assemblages marked (Fig. 2A) were same as the significant factor groups in Table 2A and they were such that the assemblage I contained stations 7-15 except sites 8 and 12. The assemblages III to VI together contained stations of the

Table 2. Factor analysis (R-mode) for the stations of post-monsoon (A) and pre-monsoon (B) seasons

(A)						
Factor number	Stations	Range of maximum factor loading	Eigen value	Closeness Ratio	Variance value	Variance value (%)
1	3,6,7,9-11, 13-15	-0.6121 to 0.9831	7.83	52.17	7.29	48.57
2	12	0.9532	2.27	67.28	1.26	8.40
3	1,2	0.8840 , 0.9578	1.63	78.16	1.74	11.63
4	5,6	-0.5892, -0.9707	1.22	86.30	1.49	9.91
5	4	-0.9990	1.00	92.94	1.01	6.71
6	6	-0.5072	0.42	95.76	0.38	2.56
7	8	-0.8927	0.28	97.66	1.27	8.46
(B)						
Factor number	Stations	Range of maximum factor loading	Eigen value	Closeness Ratio	Variance value	Variance value (%)
1	9-12	-0.7753 to -0.9829	6.47	43.14	3.86	25.75
2	2,7,13-15	0.6253 to 0.9867	4.28	71.65	4.57	30.45
3	6,8	-0.8508 to -0.9234	1.65	82.64	2.29	15.26
4	1	0.9362	1.05	89.65	1.14	7.58
5	4	-0.7990	0.52	93.10	0.80	5.36
6	7	-0.7411	0.40	95.14	0.60	4.02
7	3	-0.7804	0.32	97.88	0.78	5.21
8	5	-0.8154	0.24	99.50	0.88	5.86

outer channel, with station 6 showing similarity with the assemblage I in the foraminiferal distribution. During premonsoon season (May) also, it was observed that the assemblages of stations (Fig. 2C) obtained were similar to those of factor groups given in Table 2B. During this period, the assemblage I contained stations 9-12 and the assemblage II contained stations 13-15 along with station 2. The assemblages III to VIII, except VI had low factor loadings on factors 1 and 2 and thus making the outer channel distinct

from that of the inner lagoon of the lake which included both the central and northern sectors.

Plot of the factor loadings of the first two factors for species of November gave rise to four distinct species assemblages (Fig. 2B) of which the assemblages I, II, III to IX and X were widely separated from each other, whereas assemblages III to IX showed high similarity in their distribution. In May, four distinct sets of assemblages of species (Fig. 2D) has been ob-

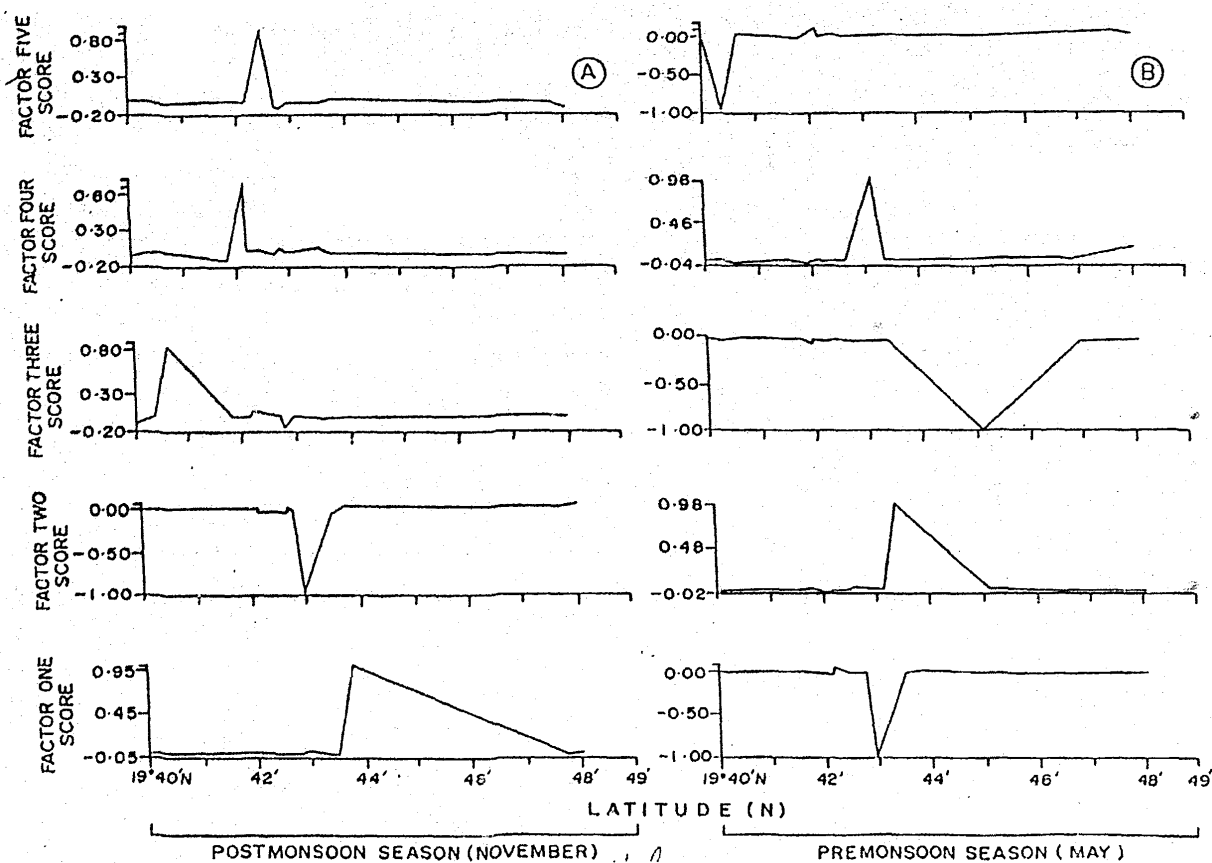


Fig. 2. Plot of the factor scores against latitude (N) for November (A) and May (B) for stations

tained of which the assemblages I and II were distinct and separate, while species assemblages III to X except the assemblage VI, were highly similar with the least number of species.

Factor score distributions of species/stations of November and of May had revealed positively/ negatively skewed distributions. Plot of the factor scores versus latitude (N) for November (Fig. 3A) showed that high positive values for the factor scores are obtained for factors 1 and 3 to 5 in the ranges of 0.45 -0.95 and 0.30 -0.80 respectively; these values in turn correspond to the areas 19° 43' to 19° 45'N and 19° 40' to 19° 43'N. High nega-

tive factor scores were obtained for areas located in between 19° 42' and 19° 44' N (Fig. 3A). In May, high negative factor scores were noted for factors 1, 3 and 5, which are for the stations located between 19° 40' and 19° 41' N and also for the stations between 19° 44' and 19° 45' 30' N while high positive factor scores for factors 2 and 4 observed for the stations located between 19° 42' and 19° 44' N (Fig. 3B).

Further, plot of the factor scores against species average absolute abundance per station for November (Fig. 4A) showed high negative values (-0.80 to -0.60) for the species with average abundance in

the range of 50- 80 specimens per station for factor 1, while high positive factor scores (0.54 to 0.79) for factor 2 for the species with average abundance between 35 and 45 specimens per station. For factor 3, high positive factor scores (0.64 to 0.84) were for rare species with average abundance between 12 and 15 specimens per station. Similarly, factor scores of factor 4 were highly negative for very rare species with average abundance < 5 specimens per station.

In May, factor scores of factors 1 and 2 were similar to those observed in November, while factor scores of factor 3

were highly negative (-0.70 to -1.00) for abundant species with average abundance between 45 and 55 specimens per station. Furthermore, factor scores of factor 4 were moderately high (0.20 to 0.45) with average abundance between 30 and 45 specimens per station (Fig. 4 B).

Thus, factor analysis method helps in providing average distribution patterns for various species associations, which are highly useful for modeling and simulation studies. Besides, this method does not impose a hierarchical structure as in cluster analysis on the foraminiferal data, thereby making the interpretation easier.

Conclusions

Twenty-eight and fifty seven species of Foraminifera have been observed during post-monsoon and pre-monsoon seasons respectively and *M. fusca*, *A. exiguus*, *A. beccarii* (Linne) and *A. tepida* were the most abundant. Q-mode factor analysis applied for grouping of the species showed 8 significant factor groups by 'Scree' test during both the seasons of which the first three factor groups constituting 16 species in November, while in May the first two factors consisting of 34 species formed the differential factor groups. The first eight significant factor groups for both the seasons had explained >89% of the spatial variability in the foraminiferal distribution. R-mode analysis used for grouping of stations indicated 5 and 4 significant factor groups explaining about 85% and 79% in November and May respectively. Plot of the factor loadings of factors 1 and 2 for species had resulted in 3 distinct assemblages in which the first, second and third (factor groups 3 to 9) assemblages were widely separated from each other, with high similarity for factor

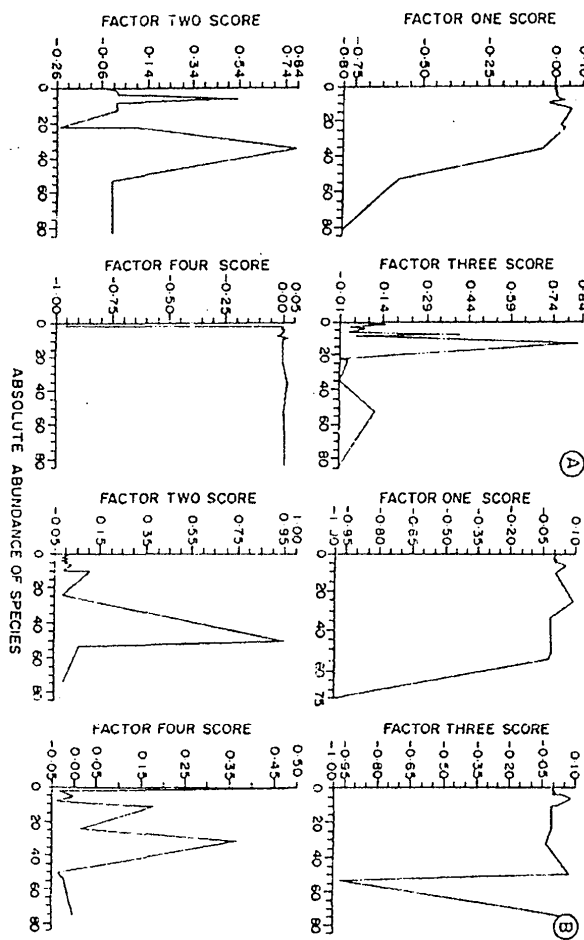


Fig. 3. Plot of the factor scores versus average absolute abundance of species for November (A) and May (B).

groups included in the third assemblage in November. In May, four distinct assemblages had been observed of which the first and the second assemblages (factor groups 1 and 2) were distinct and separate from the third assemblage, with high similarity between factor groups 3 to 10 included in the third assemblage. This grouping showed that the outer channel (assemblages I and II) was quite distinct from that of the inner lagoon (assemblage III) of the lake based on foraminiferal species distributions and thereby confirming the presence of two biofacies: facies 1 (inner lagoon facies), (Assemblage III (factors 3 to 10)) ' containing the most dominant species, *M. fusca*, while common forms in this area being *A. exiguus*, *J. macrescens*, *A. advena* and *A. sobrina*; facies 2 (outer lagoon/channel facies), (assemblages I and II (factors 1 and 2)) was dominated by *A. beccarii* (Linne). Factor score distributions of stations against latitude (N) and of species versus species average absolute abundance were unimodal and skewed distributions for both the seasons implying that the species observed were from a continuously varying population without any indication of being affected by significant environmental changes in the study area.

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