Recent Foraminifera From the Mahanadi River Estuary, East Coast of India

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Abstract: The Mahanadi River estuary (Figure 1) is one of the major estuaries in India and the largest one in the Odisha State. It is situated within latitudes 190 47' and 200 30' N and longitudes 850 33' and 860 49' E. It originates from Amarakantak region of Madhya Pradesh and flows through Madhya Pradesh and Odisha States over a length of 890 kms having a drainage basin of about 1,41,600 sq. kms with a large catchment area. It opens into the Bay of Bengal at Pardeep in Cuttack district. It has a wide opening into the sea at its northeastern end. The tidal stretch extends up to 32 kms from the mouth. The entire area is full of mangrove vegetation together with mud flats traversed by a network of tidal creeks except some portions such as Paradeep and Astaranga mouth regions which are sandy shorelines. The studies on Recent foraminifera in relation to the prevailing ecological parameters such as salinity, temperature, dissolved oxygen, and pH, and sediment characteristics and organic matter content of the sediments have been carried out in the present investigations. These studies can be used to delineate the palaeo-environments which serve as useful tools in the exploration for petroleum. 10 sediment and 10 water samples were collected from the estuary for the study of foraminifera and sediment characters, and water analysis respectively. The foraminifera of the estuary were identified. 12 abundant species which are Ammobaculities exiguus, Ammonia beccarii, Ammonia beccarii tepida, Elphidium advenum, Elphidium hispidulum, Milliamina fusca, Nonion depressulus, Pararotalia nipponica, Pararotalia cf. globosa, Quinqueloquelina lamarckina, Quinqueloculina seminulum and Rosalina globularis and are related to the prevailing ecological parameters and the substrate characteristics including the organic matter content.

Keywords: Estuary, Ecological Parameters, Substrate, Foraminifera, Abundant Species, Organic Matter.

1. INTRODUCTION

Investigations on living Foraminifera from the waters of the Indian subcontinent have been started by some researchers only in late 1960s. The few reports that deal with the biocoenoses of lagoons and estuaries along the East and West Coasts of India are briefly presented here. Ramanathan (1969, 1970) has reported on the living assemblages of Foraminifera from the Velar River estuary located 165 km south of Madras. He related the assemblages to various ecological factors such as salinity, p^H, temperature, dissolved oxygen content, sedimentary texture, organic matter content, planktonic production and nutrients of the waters covering the surface sediments. This is the first biocoenosis report from the water of Indian subcontinent. Seasonal variations in the distribution and abundance of Foraminifera have been described form the Chipurupalle and Pudimadaka streams, the Suddagedda estuary, Dummulapeta creek and Kakinada channel by Venkata Rao, 1972, Venkata Rao and Subba Rao, 1972, 1973, 1974, 1976a, 1976b, 1976c.

The distribution and abundance of Foraminifera in relation to their ecology have also been described from Gosthanin River estuary (Nageswara Rao, 1979) and the Godavari and Krishna River estuaries (Narappa,1980). Reddy et al.

(1974) studied the distribution of Foraminifera in the Pennar estuary, Nellore District. In a subsequent publication in (1980) they gave a taxonomic account of the fauna of the Pennar estuary. Mohanti and Mitreyi (1980) have reported their observations of Foraminifera described from the Mahanadi estuary. Chandrasekhara Rao, Naidu and Subba Rao (1980) have described the agglutinated Foraminifera from the Visakhapatnam Harbour Complex. Seibold (1971, 1975) described and listed 69 benthic Foraminiferal species from the lagoon of Cochin and from two offshore profiles of the open shelf, north and south of the inlet to Cochin Harbour. Kameswara Rao (1974) described the Foraminiferal assemblages and related 'Vembanad estuary and Kayamkulam lake, Kerala coast. Setty (1976) discussed the relative sensitivity of benthic Foraminifera in the polluted marine environment of ˙Cola Bay, Goa.

Area of Present Research Investigation

The Mahanadi River estuary (Fig.1) is one of the major estuaries in India and the largest one in Odisha State. It spreads over a wide area in the Cuttack and Puri districts of about 165 kilometers of coastline along the coast of Bay of Bengal. It is situated within latitudes 19^0 47′ and 20^0 30′ N and longitudes 85^0 33′ and 86^0 49′ E. It extends from the northern end of Hukitola lake in the north in Cuttack district, to northeast of Chilika lake in the south in Puri district. The Mahanadi River originates from Amarakantak region of Madhya Pradesh and flows through Madhya Pradesh and Odisha States over a length of 890 kms having drainage basin of about 1,41,600 sq. kms with a large catchment area. It enters Odisha State through Sambalpur district followed by Balangir district and then through Boudh-Phulbani districts border areas, and finally into Cuttack district. Afterwards the Mahanadi River divides into two main rivers viz., Devi River and Mahanadi River proper. Other tributaries like Kathajodi, Kuakhaee, Daya Bargavi etc. arise from this river. The main river, the Mahanadi River, opens into the Bay of Bengal at Pardeep in Cuttack district. It has a wide opening into the sea at its northeastern end. The tidal stretch extends up to 32 kms from the mouth. The entire area is full of mangrove vegetation together with mud flats traversed by a network of tidal creeks except some areas such as Pardeep mouth region and Astaranga mouth region which are sandy shorelines.

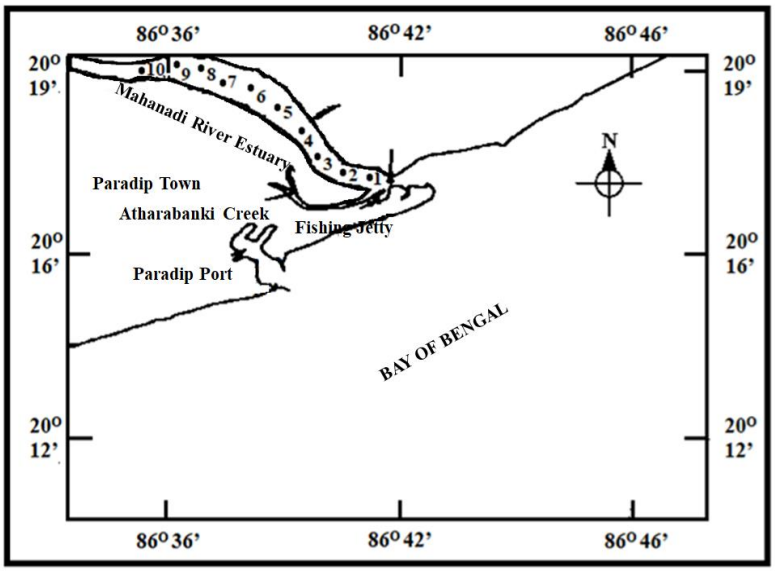

Figure 1. Sample Location Map of Mahanadi River Estuary

FIELD AND LABORATORY PROCEDURES

A total of 10 sediment and 10 water samples were collected from the Mahanadi River estuary for the study of Recent foraminifera and for the determination of the related ecological parameters in pre-monsoon (April) and post-monsoon (December) seasons in 2019. The sample location stations are named as 1, 2, 3, 4, and 5, 6, 7, 8, 9, 10. The following standard procedure has been followed in collecting the sediment and water samples:

A Phleger-type Corer (Figure 2A) consisting of 40 cm long PVC tube of about 4 cm inner diameter was manually driven into the sediment vertically. As the tube was pulled out of the sediment the lower end of the tube was closed with the palm to prevent the sediment from slipping out. The tube was brought to the bank of the stream and the core was slowly pushed up the core tube until the sediment-water interface was within 2-3 cm from the top of the core

tube. This 2-3 cm thick water column was gently siphoned off into a polythene jar of about 150 cc capacity and the upper 1 cm of the core (12.5 ml in volume, referred to as unit volume of wet sediment in this study) was removed and transferred to the same polythene jar mentioned above. Neutralized formaldehyde in a concentration of approximately 5% was added to the jar to preserve the protoplasm of the living organism from decaying and to make it adhere to the test.

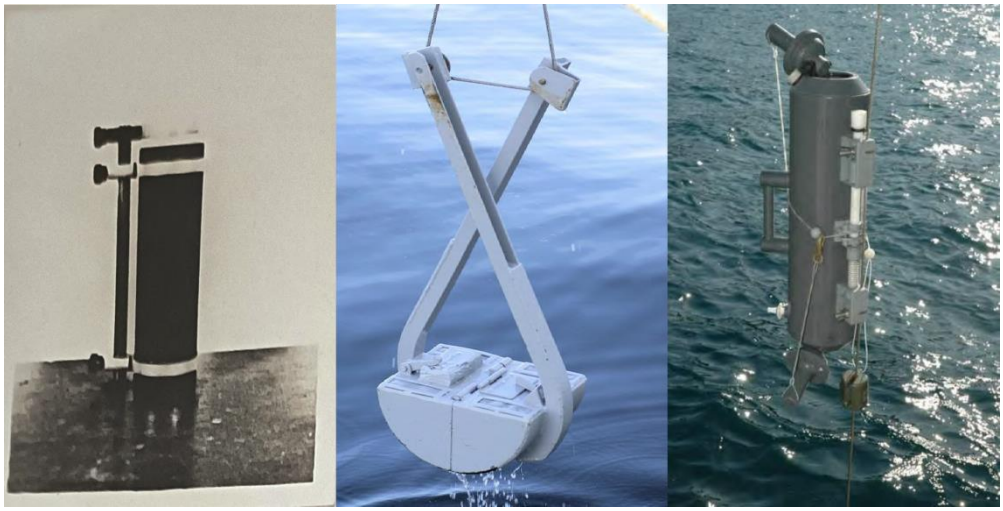

Figure 2: A. Phleger-type Corer B. Van-Veen grab C. Water sampler

A small quantity of sodium carbonate is also added to maintain the alkaline condition as the formaldehyde will become acidic with time. Finally, the jar was labelled. From the location where the sediment core was taken, 100-200 grams of material from approximately 1 cm thick sediment layer is scrapped and preserved in a labelled polythene bag for sediment texture and organic matter content determination. Van-Veen grab (Figure 2B)) was used to collect sediment samples from the deeper portion of the estuary.

Samples of water just in contact with the sediment surface were collected in two amber-coloured bottles of 250 ml and 100 ml for dissolved oxygen and salinity determination respectively. The empty bottle with the stopper in place was held with its mouth close to the bottom and then the stopper was removed. When the bottle was filled with water the stopper was replaced and the bottle was taken out of the water. To the bottle of 250 ml capacity 1 ml each of Winkler A (manganous sulphate solution) and Winkler B (alkaline potassium iodide solution) was added to fix the dissolved oxygen. The bottle was fitted tight with the stopper and thoroughly shaken until the precipitated manganous hydroxide was evenly dispersed. Care was taken so that no air bubble was present in the bottle. In the deeper portion of the estuary an improvised water sampler (Figure 2C)) was used to collect the bottom water samples. Temperature of the waters near the sediment-water interface was measured at the same time as the sediment sample was collected. The said water was collected in a polythene bottle of 1000 ml capacity and a thermometer was inserted immediately after it was brought to the surface and the temperature was read. Hydrogen ion concentration (p^H) was measured, using p^H papers.

RECOGNITION OF LIVING FORAMINIFERA

Differentiation of the living Foraminifera from the dead ones is the first step of the studies of biocoenosis. Earlier, several staining methods were used, such as the 'Methgreosin' method (Rhumbler, 1935), the Biuret test (Phleger, 1945, 1951) and Millon's reagent (Phleger, 1952). Walton (1952) developed the rose-Bengal technique which has since been in wide use with minor modifications (Schafer and Sengupta, 1969; Ellison and Nichols, 1970). Walker et al. (1974) have reported that heated acetylated or heated saturated Sudan black B solutions are more accurate and penetrative than conventional rose-Bengal for distinguishing living from non-living Foraminifera.

Following Walton, in the present study, the sediment samples preserved in neutralized formaldehyde were washed free of silt and clay over an ASTM-230 mesh sieve having openings of 0.063 mm. The sieve with the residue was kept immersed in an aqueous solution of rose-Bengal (which is prepared by dissolved 1 gram of rose-Bengal dye in one liter of distilled water) for an hour. Then the material on the sieve was gently washed to free it of the excess stain

and then it was dried. The Foraminiferal tests are separated from the residue that was mostly of terrigenous sand by floatation in carbon tetrachloride. The residue was examined and Foraminiferal tests in it were picked and added to the floated crop. The Foraminiferal crop was examined under a binocular microscope. The different Foraminiferal species were identified, and their living and dead individuals were counted separately with much care, wetting each specimen. Finally, the counts are summarized in faunal charts.

Chlorinity

Chlorinity is estimated both by chemical and physical methods. The physical methods are based mainly on the determination of density, refractive index, or conductivity. Of late, conductivity salinometers have been widely employed (Riley and Chester, 1971). In the present study, Chlorinity was estimated by the standard titration method of Knudsen (Strickland and Parsons, 1968). The precipitable halide halogen in a 10 ml volume of water sample was determined by titrating with standard silver nitrate solution using potassium chromate as indicator. Corresponding salinities for the chlorinities were read from the Knudsen's Tables.

Dissolved Oxygen

In the present study, the Winkler's chemical method (Strickland and Parsons, 1968), in which the dissolved oxygen oxidizes an equivalent amount of divalent manganese to basic hydroxides, and after acidification in the presence of iodine, the oxidized manganese again reverts to divalent state, and iodine, equivalent to the original dissolved oxygen content of water, is liberated, which can be titrated against standard sodium thiosulphate solution. In the laboratory, 1 ml of concentrated sulfuric acid was added to the bottle containing water sample already treated with Winkler's solutions. The bottle was shaken so well that all the precipitate is dissolved. Within an hour of acidification, 100 ml of the solution was pipetted out and titrated with solution of sodium thiosulphate (which has been standardized), using starch as indicator. The original volume of the treated sample is 100 ml, but the volume of sea water used is 100(250-2)/250 = 99.2 ml. For this sample, the oxygen content, expressed in units of milliliters of dissolved oxygen per liter of sea water is 56.45 N x V x ml O2/liter, where N=normality of the sodium thiosulphate solution and V= volume of the sodium thiosulphate solution run down.

ESTIMATION OF SAND, SILT, AND CLAY RATIOS

Numerous methods are available for both dispersion and size analysis of sediments (Krumbein and Pettijohn, 1938; Muller, 1967; Carver, 1971). Most of the sediment samples under study are composite types containing sand, silt, and clay in varying proportions. They were therefore initially dispersed with sodium hexametaphosphate (Calgon) solution of 0.025 N and kept overnight. The dispersed sediment was washed through a BSS-240 mesh sieve having openings of 0.066 mm until clear water passes through, but care is taken that washings do not exceed 1000 ml. The suspension mixture was analyzed for silt and clay size particles by the pipette method in accordance with the procedure outlined by Krumbein and Pettijohn (1938). The material retained on the sieve was dried and weighed which gives the weight of material coarser than 1/16 mm, i.e., sand. The respective weights of sand, silt and clay that constitute the sediment were converted into weight percentages and plotted on a trilinear diagram with its apexes representing 100% sand, silt and clay, and any point within the diagram a mixture of these three components.

Organic Matter Content of the Sediments (OM)

The term organic matter is used to designate that portion of sediment, which has arisen through organic activity, and which contains carbon in any form other than mineral carbonate (Sverdrup et al., 1942; Trask, 1939). Very often organic matter of sediments and soils is estimated by determining organic carbon by dry combustion, wet combustion, or titrimetric methods. Organic carbon values are multiplied by a factor of 1.72 to obtain organic matter values, especially when sediment organic matter content is derived from land. In the present study, Walkley-Black's method has been employed for estimating the organic matter (Jackson, 1967; Gaudette et al., 1974). An aliquot of 0.5 gm of dried and ground sediment sample was placed in 500 ml conical flask. Ten ml of 1 N potassium dichromate solution was pipetted on to the soil, and the two are mixed. Twenty ml of concentrated sulfuric acid containing 0.1 gm of silver sulphate was added and mixed by gentle rotation for one minute. The mixture was allowed to cool for 30 minutes. A standardization blank (without soil) was run in the same way. The solution was diluted to 200 ml with distilled water and 10 ml of 85% phosphoric acid, 0.2 gm of sodium fluoride and 30 drops of diphenylamine indicator were added. The solution was back titrated with 0.5 N ferrous ammonium sulphate solution. The end point was indicated by a

brilliant green. The organic matter was calculated by the equation % OM=10(1- (T/S)) X 1.34 where S = standardization blank titration, ml ferrous solution and T= sample titration, ml ferrous solution. The factor 1.34 has been derived as follows:

(1.0 N) X 12/4000 X 1.72/0.77 X 100/0.5=1.34

in which 0.5 is the sample weight, 1.72 the factor for organic matter from carbon, and 12/4000, the net weight of carbon. The 77% recovery factor found by Walkley has been used.

ECOLOGY OF FORAMINIFERA

Salinity

The salinity of the Mahanadi River estuary varies from 18.0 ‰ (1) to 25.3 ‰ (2) in December and from 19.0 ‰ (10) to 30.8 ‰ (1) in April (Table.1a). In any season salinity decreases in the upstream direction from the mouth.

Table 1a. Salinity and Temperature of the Bottom Waters of the Mahanadi Estuary

Month	Mahanadi Estuary													
	Sample No.	1	2	3	4	5	6	7	8	9	10	Difference	Min	Max
	Salinity (‰) in the year 2019													
April	Values	30.8	30.1	28.9	29.1	26	25.5	24	23	21.1	19	11.8	19 (10)	30.8 (1)
December	Values	25.1	25.3	24	23.6	22.8	23	22.1	21	19.2	18	7.1	18 (10)	25.3 (2)
Temperature (°C) in the year 2019														
April	Values	30.2	30.6	31.1	30.9	32	31.8	32.3	32.4	32.8	32.7	-2.5	30.2 (1)	32.8 (9)
December	Values	28.6	28.8	29.1	29.7	30	29	27.1	29	29.7	30.6	-2	27.1 (7)	30.6 (10)

Temperature

The water temperature is highest in April and lowest in December in the Mahanadi River estuary. Temperature of the bottom waters of the estuaries varies from 27.1°C (7) to 30.6° C (10) in December and from 30.2° C (1) to 32.8° C (9) in April. (Table.1a). It is observed that the temperature of the bottom waters of all the estuary increases in the upstream direction from the mouth.

Dissolved Oxygen

Dissolved oxygen content of the waters of the Mahanadi River estuary varies from 3 mg/l (10) to 4.3 mg/l (2) in December and from 2.5 mg/l (10) to 4.6 mg/l (4) in April (Table.1b). From the above data it is observed that the dissolved oxygen has somewhat higher values in December than in April, and it shows somewhat higher values towards the mouth of the estuary than in the upstream. This difference is perhaps due to the increased temperatures towards the upstream which causes the escape of some dissolved oxygen from the warm waters.

Hydrogen Ion Concentration (p^H)

Hydrogen ion concentration (p^H) of waters of the Mahanadi River estuary varies from 7.0 (8) to 8.1 (1) in December and from 6.9 (10) to 8.1 (1) in April (Table.1b). The above values indicate that the waters of the estuary support higher populations of the Foraminiferal populations. P^H values of less than 7.0 indicate acidic conditions which dissolve the $CaCO_3$, and hence, doesn't support abundant occurrence of Foraminiferal species.

Table 1b. Dissolved Oxygen and pH Contents of Bottom Waters of the Mahanadi Estuary

Month	Mahanadi Estuary												
	Sample No.	1	2	3	4	5	6	7	8	9	10	Difference	Min	Max
	Dissolved Oxygen (mg/l) in the year 2019													
April	Values	3.9	4.2	4.1	4.6	4.3	3.9	3.6	2.9	2.7	2.5	1.4	2.5(10)	4.6(4)
December	Values	4.1	4.3	4	3.9	3.9	3.7	3.1	3.5	3.3	3	1.1	3(10)	4.3(2)
pH (Hydrogen ion Concentration) in the year 2019														
April	Values	8.1	8.0	7.9	7.6	7.8	7.3	7.4	7.2	7	6.9	1.2	6.9(10)	8.1(1)
December	Values	8.1	8.0	7.8	7.4	7.7	7.1	7.3	7	7.1	7.3	0.8	7(8)	8.1(1)

Substrate (Sediments)

The Mahanadi River estuary is characterized by clayey silt in the lower estuary, silty sand or sandy silt in the middle estuary and silty sand or sand in the upper estuary in April and clayey silt or silty clay in the lower estuary, silty sand or sand in the middle estuary and sand in the upper estuary in December (Table 2). Sand with admixture of silt or mud is the prevailing substrate in the estuary throughout the year.

Organic Matter Content of the Sediment (OM)

Organic matter content of the Mahanadi River estuary varies from 0.3 % (10) to 0.99 % (1) in April and from 0.2 % (7) to 0.8 % (1) in December (Table V 2). From the above data it is observed that clayey silt, silt, or sandy silt type sediments contain more organic matter than the other coarser grained sediments.

LIVING POPULATIONS OF FORAMINIFERA

The following remarks may be made concerning the living population distribution (Tables 3-4) in the Mahanadi River estuary:

i. The living population size is variable between 1 and 458 in April, and between 1 and 868 in December 2019.

ii. Seasonal average living population size for different stations shows that populations are large sized in the lower and middle parts of the estuary.

iii. Population size per unit volume of sediment shows that it is largest in December and lowest sized in April.

iv. Living population size is supported by the fine-grained sediments and higher organic matter content.

TOTAL (LIVING + DEAD) POPULATIONS OF THE FORAMINIFERA

The following remarks may be made concerning the total (living + dead) population distribution (Tables 3-4) in the Mahanadi River estuary. Remarks (i) to (iv) made in respect of the living populations are equally applicable to the total population distribution in the estuary. Total (living + dead) population size is variable between 1 and 1,058 specimens per unit volume of sediment in April, and total (living + dead) population size is variable between 1 and 1804 specimens per unit volume of sediment in December 2019.

Table 3. Ranking of Some Important Foraminiferal Species of the Mahanadi River Estuary in Order of Frequency

April 2019

Species	Occurrence in percent of stations	
	Living	**Living + Dead**
Ammobaculites exiguus	30	30
Ammonia beccarii	100	100
A. beccarii tepida	100	100
Elhidium advenum	40	60
E. hispidulum	50	70
Miliammina fusca	20	60
Nonion depressulus	40	70
Pararotalina nipponica	30	60
P. cf. globose	10	50
Quinqueloculina lamarckina	20	40
Q. seminulum	100	100
Rosalina globularis	40	60
December, 2016		
Ammobaculites exiguus	40	50
Ammonia beccarii	100	100
A. beccarii tepida	100	100
Elhidium advenum	50	80
E. hispidulum	70	70
Miliammina fusca	30	70
Nonion depressulus	40	70
Pararotalina nipponica	40	70
P. cf. globose	30	50
Quinqueloculina lamarckina	30	60
Q. seminulum	100	100
Rosalina globularis	40	60

Table 4. Occurrence of Living and Total (Living + Dead) Foraminiferal Populations in the Mahanadi River Estuary in April 2019.

SPECIES	**Mahanadi River Estuary**																			
	1		**2**		**3**		**4**		**5**		**6**		**7**		**8**		**9**		**10**	
	L	**T**	**L**	**T**	**L**	**T**	**L**	**T**	**L**	**T**	**L**	**T**	**L**	**T**	**L**	**T**	**L**	**T**	**L**	**T**
Agglutinated Foraminifera																				
Ammobaculites agglutinans	–	–	–	–	2	2	–	–	–	–	3	4	2	5	–	–	–	–	–	–
A. Exiguous	2	11	–	13	2	14	–	5	–	3	–	1	–	–	–	–	–	–	–	–
Miliammina fusca	831	1,017	1	11	–	14	–	4	–	6	–	2	–	5	–	–	–	–	–	–
M. fusca var.	–	2	–	4	–	3	–	2	–	1	–	–	–	–	–	–	–	–	–	–

Trochammina advena	_	_	_	3	_	1	_	_	_	2	_	_	_	_	_	_	_	_	_	_
Calcareous Foraminifera																				
Ammonia beccarii	34	63	21	40	203	318	18	62	53	120	457	1,059	50	180	30	37	13	37	17	37
A. beccarii tepida	2	7	9	28	17	52	1	115	30	96	91	391	34	115	2	4	6	17	4	11
A. dentata	_	2	_	6	_	2	_	1	_	3	_	_	_	_	_	_	_	_	_	_
Asterorotalia inflanta	_	3	_	4	_	2	_	1	_	_	_	_	_	_	_	_	_	_	_	_
A. multispinosa	_	1	_	_	_	3	_	_	_	4	_	_	_	_	_	_	_	_	_	_
A. trispinosa	3	16	_	4	_	1	_	3	_	1	_	_	_	_	_	_	_	_	_	_
Bolivina spatulate	_	3	_	2	_	3	_	_	_	_	_	_	_	_	_	_	_	_	_	_

SPECIES	**Mahanadi River Estuary**																			
	1		**2**		**3**		**4**		**5**		6		7		8		9		10	
	L	**T**	**L**	**T**	**L**	**T**	**L**	**T**	**L**	**T**	**L**	**T**	**L**	**T**	**L**	**T**	**L**	**T**	**L**	**T**
Elphidium advenum	2	15	3	17	5	28	1	12	_	12	_	4	_	_	_	_	_	_	_	_
E. crispum	1	4	_	6	_	_	1	6	_	_	_	_	_	_	_	_	_	_	_	_
E. discoidale	_	3	_	1	_	2	_	2	_	_	_	_	_	_	_	_	_	_	_	_
E. hispidulum	5	18	2	8	15	67	6	13	7	37	_	2	_	1	_	_	_	_	_	_
E. incertum	_	7	_	2	_	3	_	_	_2	2	_	_	_	_	_	_	_	_	_	_
E. simplex	_	_	_	3	_	1	_	1	_	_	_	2	_	_	_	_	_	_	_	_
Florilus labradoricus	_	_	_	1	_	2	_	_	_	3	_	_	_	_	_	_	_	_	_	_
Globigerina bulloides	_	3	_	_	_	5	_	_	_	1	_	_	_	_	_	_	_	_	_	_
Globigerinoides ruber	_	1	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_
Haplophragmoides hancocki	_	4	_	3	1	6	_	1	_	3	_	3	_	2	_	_	_	_	_	_
Lagena striata	_	3	_	_	_	_	_	2	_	1	_	_	_	_	_	_	_	_	_	_
Nonion depressulus	2	13	4	15	2	16	_	9	_	10	1	8	_	3	_	_	_	_	_	_
N. grateloupi	_	2	_	_	_	1	_	1	_	_	_	_	_	_	_	_	_	_	_	_

SPECIES	**Mahanadi River Estuary**									
	1	**2**	3	4	5	6	7	8	9	10

	L	T	L	T	L	T	L	T	L	T	L	T	L	T	L	T	L	T	L	T
Quinqueloculina costata	_	1	_	_	_	2	_	_	_	1	_	_	_	_	_	_	_	_	_	_
Q. elongate	_	_	_	3	_	_	_	1	_	_	_	_	_	_	_	_	_	_	_	_
Q. lamarckina	2	4	1	3	_	1	_	_	_	4	_	_	_	_	_	_	_	_	_	_
Q. seminulum	8	19	2	16	58	77	5	157	17	66	1	2	11	41	2	3	1	3	2	2
Q. subrotunda	_	3	_	_	_	1	_	_	_	2	_	_	_	_	_	_	_	_	_	_
Rosalina globularis	2	14	6	20	2	15	_	6	_	8	_	_	_	5	_	_	_	_	_	_
Triloculina oblonga	_	1	_	2	_	1	_	_	_	_	_	_	_	_	_	_	_	_	_	_
Total	64	237	50	212	308	641	33	405	108	392	553	1475	98	355	34	44	21	57	22	50

Table 5. Occurrence of Living and Total (Living + Dead) Foraminiferal Populations in the Mahanadi Estuary in December 2019.

SPECIES	Mahanadi River Estuary																			
	1		2		3		4		5		6		7		8		9		10	
	L	T	L	T	L	T	L	T	L	T	L	T	L	T	L	T	L	T	L	T
	Agglutinated Foraminifera																			
Ammobaculites agglutinans	2	6	_	_	3	10	_	4	1	5	_	_	6	7	_	_	_	_	_	_
exiguous	4	14	_	16	2	18	_	6	1	8	_	3	_	1	_	_	_	_	_	_
Miliammina fusca	2	16	3	16	1	12	_	10	_	13	_	5	_	2	_	_	_	_	_	_
M. fusca var.	_	5	_	3	_	1	_	2	_	_	_	_	_	4	_	_	_	_	_	_
Trochammina advena	_	3	_	1	_	4	_	_	2	3	_	_	_	_	_	_	_	_	_	_
	Calcareous Foraminifera																			
Ammonia beccarii	206	841	105	671	45	92	62	95	53	97	33	52	562	1035	867	1805	63	178	65	168
beccarii tepida	192	775	72	128	39	80	30	70	16	28	18	43	285	496	534	1405	52	159	20	86
dentata	1	6	_	_	_	_	_	_	5	10	3	3	_	_	_	_	_	_	_	_
Asterorotalia inflanta	_	3	_	5	_	_	_	2	_	4	_	_	_	_	_	_	_	_	_	_
multispinosa	2	6	_	_	3	4	_	_	_	2	_	_	_	_	_	_	_	_	_	_
trispinosa	2	6	_	_	_	4	_	_	3	_	_	_	_	_	_	_	_	_	_	_
Bolivina spatulate	1	3	2	6	_	4	_	2	_	1	_	_	_	_	_	_	_	_	_	_
SPECIES	**Mahanadi River Estuary**																			
	1		**2**		**3**		**4**		**5**		**6**		**7**		**8**		**9**		**10**	

	L	T	L	T	L	T	L	T	L	T	L	T	L	T	L	T	L	T	L	T
striatula	3	6	_	7	_	4	_	_	2	5	_	_	_	_	_	_	_	_	_	_
Cibicides lobatulus	_	2	_	_	_	4	_	1	_	4	_	_	_	_	_	_	_	_	_	_
Elphidium advenum	10	1037	6	15	7	21	4	8	3		_	8	_	2	_	_	_	_	_	_
E. crispum	2	5	1	6	_	3	_	2	_	1	_	_	_	_	_	_	_	_	_	_
E. discoidale	_	3	_	2	_	4	_	_	_	3	_	_	_	_	_	_	_	_	_	_
E. hispidulum	12	41	10	40	7	24	6	14	4	18	2	14	7	30	_	_	_	_	_	_
E. incertum	3	8	1	2	_	4	_	_	_	1	_	_	_	2	_	_	_	_	_	_
E. simplex	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	——	_	_	_
Florilus labradoricus	_	3	_	1	_	2	_	1	_	_	_	_	_	_	_	_	_	_	_	_
Globigerina bulloides	_	3	_	1	_	4	_	1	_	_	_	_	_	_	_	_	_	_	_	_
Globigerinoides ruber	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Haplophragmoides hancocki	_	1	_	1	_	6	2	7	_	_	_	_	1	6	_	_	_	_	_	_
Lagena laveis	_	2	1	4	2	10	_	3	_	_	_	_	_	_	_	_	_	_	_	_
L. striata	_	6	2	7	_	6	_	1	_	2	_	_	_	_	_	_	_	_	_	_
SPECIES	**Mahanadi River Estuary**																			
	1		**2**		**3**		**4**		**5**		**6**		**7**		**8**		**9**		**10**	
	L	**T**	**L**	**T**	**L**	**T**	**L**	**T**	**L**	**T**	**L**	**T**	**L**	**T**	**L**	**T**	**T**	**L**	**T**	**L**
Nonion depressulus	3	14	2	18	1	6	3	15	_	6	_	3	_	1	_	_	_	_	_	_
N. grateloupi	_	3	_	1	_	2	_	1	_	_	_	_	_	_	_	_	_	_	_	_
Pararotalina nipponica	3	15	2	18	4	20	2	14	_	6	_	3	_	5	_	_	_	_	_	_
P. cf.globosa	2	9	12	14	2	12	_	15	_	2	_	_	_	_	_	_	_	_	_	_
Quinqueloculina costata	_	6	_	3	_	5	_	1	_	1	_	2	_	_	_	_	_	_	_	_
Q. elongate7																				
Q. lamarckina	3	17	1	12	4	17	_	12	_	9	_	_	_	2	_	_	_	_	_	_
Q. seminulum	138	423	93	261	21	140	16	120	17	122	15	178	521	646	31	87	9	50	6	19
Q. subrotunda	_	3	_	1	_	_	_	4	_	1	_	_	_	_	_	_	_	_	_	_
Rosalina globularis	3	16	2	19	1	9	2	17	_	10	_	12	_	_	_	_	_	_	_	_
Triloculina oblonga	1	2	_	2	_	_	_	3	_	!	_	!	_	_	_	_	_	_	_	_
Total	594	2305	315	1277	142	532	127	428	107	370	71	326	1381	2240	1433	3297	124	387	91	273

SPECIES OF COMMON TO SCARCE OCCURRENCE

Such of the species whose living tests never account for more than 5% of the standing crop at any station in any season are considered as species of common to scare occurrence. They number 25. These species are endemic to the estuary. These species are not considered as important ones in the determination of the depositional environments, pollution in monitoring or as indicators of paleoecology. Hence, they are not described in detail. The species of common to scare occurrence in the above estuary are listed below.

Ammobaculities agglutinans, Miliammina fusca var., Trochammina advena, Ammonia dentata, Asterorotlia inflata, Asterorotalia multispinosa, Asterorotalia trispinosa, Bolivina spatulate, Bolivina striatula, Cibicides lobatulus, Elphidium crispum, Elphidium discoidale, Elphidium inertum, Elphidium simplex, Florilus labradoucus, Globigerina bulloides, Globigerina ruber, Haplophragmoides hancocki, Lagena laevis, Lagena sriata, Nonion grateloupi, Quinqueloculina costata, Quinquelina elongata, Quinquelina subrotunda and Triloculina oblonga. The distribution of the above species is presented in Tables 3-4.

FORAMINIFERA OF ABUNDANT OCCURRENCE

Such forms as constitute more than 5% of living populations at least at one station during the year of observation are included in this group 12 species have been considered as abundant in occurrence. They are ranked in order of frequency of stations where they were present in living condition during the investigation period (Table 5). The distribution patterns of the abundant species in the estuary are represented in Figures 2A, 2B, 3A, 3B.

The 12 abundant species may be sorted into two groups based on the occurrence of their populations in different segments of the estuary.

Forms ubiquitous to the estuary: *Ammonia beccarii*, *Ammonia beccarii tepida*, and *Quinqueloculina seminulum*.

Lower and middle estuarine forms: *Elphidium hispidulum*, *Elphidium advenum*, *Rosalina globularis* and *Milimina fusca*. There are no forms which are exclusive in occurrence to the upper parts of the estuary. Ecology and spatial and temporal distributional patterns of the 12 abundant species are discussed in the succeeding sections (Tables 6-17).

Table 6. Summary of the Occurrence of *Ammobaculites exiguus*

Estuary	Occurrence	Specimens/unit volume	
		Minimum Populations	Maximum Populations
Living			
Mahanadi River estuary	Occurs at 3 stations in both April And December 2019.	4 at station 1 in April and 1 at station 5 in December 2019	1 at station 1 in April and 6 at station 7 in December 2019
Total: Living+Dead			
Mahanadi River estuary	Occurs at 7 stations in April and at 6 stations in December 2019.	1 at station 6 in April and 3 at s station 4 in December 2019.	15 at station 3 in April and 10 at station 3 in December 2019.

Ecology:

Observation of the living and total population distribution in the estuary is that the ecological conditions are more favourable in December than in April for blooming of *Ammobaculites exiguous*. This species reproduces actively under the following conditions of temperature ranging from 30o to 32o C in April and from 26o to 30o.7′ C in December, salinity from 15.1 to 30.6 ‰ in April and from 12.00 to 27.7 ‰ in December, dissolved oxygen from 2,5 to 4.6 in April and from 0.85 to 5.41 in December, sediment consisting of sand, sandy clay, silt, and clay in both the seasons,

and organic matter content ranging from 0.17 to 1.30 in April and 0.00 to 0.96 in December. *Ammobaculities exiguus* is endemic to the estuary but colonizes only its lower and middle parts. The distribution patterns of the living and total (living + dead) species of *Ammobaculites exiguus* in the estuary in April and December are represented in Figures 2-3.

Table 7. Summary of the Occurrence of *Ammonia beccarii*

Estuary	Occurrence	Specimens/unit volume	
		Minimum populations	Maximum populations
Living			
Mahanadi River estuary	At all stations in April and December, 2019	12 at station 9 in April and 13 at station 6 in December 2019.	452 at station 6 in April and 861 at station 8 in December 2019.
Total: Living+Dead			
Mahanadi River estuary	At all stations in April and December, 2019	38 at station 8 in April and 50 at station 6 in December 2019.	1,052 at station 6 in April and 1,794 at station 8 in December 2019.

Ecology:

The living and total populations of *Ammonia beccarii* are distributed from the lower to the upper parts. Hence, it is considered ubiquitous along with *Ammonia beccarii tepida* and *Quinqueloculina seminulum*. This species reproduces actively under the following conditions of temperature ranging from 31o to 33.6o C in April and from 25o to 30.7o.7′ C in December, salinity from 15.1 to 30.9 ‰ in April and from 13.00 to 27.7 ‰ in December, dissolved oxygen from 2,6 to 4.8 in April and from 0.86 to 5.42 in December, sediment consisting of sandy silt, sandy clay, silt, and clay in both the seasons, and organic matter content ranging from 0.17 to 1.30 in April and 0.00 to 0.96 in December. It reproduces more actively in December than in April. Ecological conditions under which are found large standing crops of *Ammonia beccarii* are listed below. The distribution patterns of the living and total (living + dead) species of *Ammonia beccarii* in the estuary in April and December are represented in Figures 2-3.

Table 8. Summary of the occurrence of Ammonia Beccarii tepida

Estuary	Occurrence	Specimen /unit volume	
		Minimum populations	Maximum populations
Living			
Mahanadi River estuary	At all stations in April and December 2019.	3 at station 1 in April and 18 at station 5 in December 2019.	92 at station 6 in April and 536 at station 8 in December 2019.
Total: Living+Dead			
Mahanadi River estuary	At all stations in April and December 2019.	5 at station 8 in April and 28 at station 5 in December 2019.	392 at station 6 in April and 408 at station 8 in December 2019.

Ecology:

Ammonia beccarii tepida is a ubiquitous species in the estuary in both April and December but occurs in larger populations in December than in April. The following ecological conditions are highly favourable for its blooms. This

species reproduces actively under the following conditions of temperature ranging from 31o to 33.8o C in April and from 27o to 30.7′ C in December, salinity from 15.1 to 30.7 ‰ in April and from 14.00 to 27.7 ‰ in December, dissolved oxygen from 2,6 to 4.8 in April and from 0.80 to 5.42 in December, sediment consisting of sandy silty, clayey silt, silt, and clay in both the seasons, and organic matter content ranging from 0.17 to 1.30 in April and 0.10 to 0.99 in December. It reproduces more actively in December than in April. The distribution patterns of the living and total (living + dead) species of *Ammonia beccarii tepida* in the estuary in April and December are represented in Figures 2-3.

Table 9. Summary of the Occurrence of *Elphidium advenum*

Estuary	Occurrence	Specimens/unit volume	
		Minimum populations	Maximum populations
Living			
Mahanadi River estuary	Occurs at 5 stations in April and at 6 stations in December 2019.	1 at station 4 in April and 3 at station 5 in December 2019.	4 at station 3 in April and 10 at station 1 in December 2019.
Total: Living +Dead			
Mahanadi River estuary	Occurs at 7 stations in April and at 7 stations in December 2019.	5 at station 11 in April and 2 at station 12 in December 2019.	27 at station 8 in April and 38 at station 6 in December 2019.

Ecology:

Elphidium advenum occurs in living conditions in both April and December in the estuary. It mostly occurs in the lower and middle portions of the estuaries. The following are the ecological conditions which are favorable for the blooming of *Elphidium advenum*. This species reproduces actively under the following conditions of temperature ranging from 30o to 33.5o C in April and from 25o to 30.8′ C in December, salinity from 15.1 to 30.9 ‰ in April and from 13.00 to 27.8 ‰ in December, dissolved oxygen from 2,6 to 4.8 in April and from 0.87 to 5.40 in December, sediment consisting of sandy silt, clayey silt, and silt in both the seasons, and organic matter content ranging from 0.17 to 1.30 in April and 0.10 to 0.96 in December. It reproduces more actively in December than in April. The distribution patterns of the living and total (living + dead) species of *Ammonia beccarii tepida* in the estuary in April and December are represented in Figures 2-3.

Table 10. Summary of the Occurrence of *Elphidium hispidulum*

Estuary	Occurrence	Specimen s/unit volume	
		Minimum populations	Maximum populations
Living			
Mahanadi River estuary	Occurs at 6 stations in April and at 7 stations in December 2019.	3 at station 2 in April and 3 at station 6 in December 2019.	16 at station 3 in April and 11 at station 1 in December 2019.
Total: Living +Dead			
Mahanadi River estuary	Occurs at 8 stations in both April and December 2019.	1 at station 7 in April and	65 at station 3 in April and

		12 at station 4 in December 2019.	42 at station 2 in December 2019.

Ecology:

Elphidium hispidulum occurs in living condition in all the four estuaries in both April and December but reproduces more actively in December. It mostly occurs in the lower and middle parts of the estuary. This species reproduces actively under the following conditions. This species reproduces actively under the following conditions of temperature ranging from 30o to 33.5o C in April and from 25o to 30.9′ C in December, salinity from 16.1 to 30.8 ‰ in April and from 13.00 to 27.9 ‰ in December, dissolved oxygen from 2.5 to 4.6 in April and from 0.85 to 5.41 in December, sediment consisting of silty sand, silty clay, clay and silt in both the seasons, and organic matter content ranging from 0.18 to 1.311 in April and 0.10 to 0.98 in December. It reproduces more actively in December than in April. The distribution patterns of the living and total (living + dead) species of *Elphidium hispidulum* in the estuary in April and December are represented in Figures 2-3.

Table 11. Summary of the Occurrence of *Miliammina fusca*

Estuary	**Occurrence**	**Specimens per unit volume**	
		Minimum populations	**Maximum populations**
Living			
Mahanadi River estuary	Occurs at 2 stations in April and at 3 stations in December 2019.	1 at station 6 in April And 1 at station 3 in December 2019.	2 at station 1 in April and 4 at station 1 in December 2019.
Total: Living +Dead			
Estuary	**Occurrence**	**Specimens/ unit volume**	
		Minimum populations	**Maximum populations**
Mahanadi River estuary	Occurs at 7 stations in both April and December 2019.	2 at station 6 in April and 1 at station 7 in December 2019.	16 at station 1 in April and 17 at station 3 in December 2019.

Ecology:

The distribution of living and total population shows that *Miliammina fusca* blooms in December and is a dominant species in the lower and middle parts of the estuary. The species reproduces actively under the following conditions. This species reproduces actively under the following conditions of temperature ranging from 30o to 32.5o C in April and from 26o to 30.8′ C in December, salinity from 15.1 to 30.8 ‰ in April and from 13.00 to 27.9 ‰ in December, dissolved oxygen from 2.5 to 4.6 in April and from 0.84 to 5.41 in December, sediment consisting of sand clayey sand, silty sand, and silt in both the seasons, and organic matter content ranging from 0.17 to 1.31 in April and 0.10 to 0.88 in December. It reproduces more actively in December than in April. The distribution patterns of the living and total (living + dead) species of *Milliammina fusca* in the estuary in April and December are represented in Figures 2-3.

Table 12. Summary of the Occurrence of *Nonion depressulus*

Estuary	**Occurrence**	**Specimens / unit volume**

		Minimum populations	Maximum populations
Living			
Mahanadi River estuary	Occurs at 4 stations in both April And December 2019.	3 at station 6 in April and 2 at station 3 in December 2019.	3 at station 2 in April and 3 at station 6 in December 2019.
Total: Living +Dead			
Mahanadi River estuary	Occurs at 7 stations in both April and December 2019.	4 at station 7 in April and 1 at station 7 in December 2019.	16 at station 3 in April and 16 at station 4 in December 2019.

Ecology:

Nonion depressulus is endemic to the estuary. Its living as well as dead species occur in both seasons, but more populations are found in December in the lower and middle parts of the estuary. *Nonion depressulus* appears to actively reproduce under the following ecological conditions. This species reproduces actively under the following conditions of temperature ranging from 30o to 32.5o C in April and from 26o to 30.8′ C in December, salinity from 16.2 to 30.8 ‰ in April and from 13.00 to 27.8 ‰ in December, dissolved oxygen from 2.6 to 4.8 in April and from 0.84 to 5.40 in December, sediment consisting of sandy silt, clayey silt and silt in both the seasons, and organic matter content ranging from 0.18 to 1.32 in April and 0.10 to 0.96 in December. It reproduces more actively in December than in April. The distribution patterns of the living and total (living + dead) species of *Nonion depressulus* in the estuary in April and December are represented in Figures 2-3.

Table 13. Summary of the Occurrence of *Pararotalia nipponica*

Estuary	Occurrence	Specimens / unit volume	
		Minimum populations	Maximum populations
Living			
Mahanadi River estuary	Occurs at 3 stations in April And at 4 stations in December 2019.	2 at station 5 in April and 3 at station 2 in December 2019.	2 at station 1 in April and 4 at station 3 in December 2019.
Total: Living +Dead			
Mahanadi River estuary	Occurs at 6 stations in April and at 7 stations in December 2019	3 at station 6 in April and 2 at station 6 in December 2019.	16 at station 1 in April and 21 at station 3 in December 2019.

Ecology:

Pararotalia nipponica is also an endemic to the estuary and most of the living and total population are confined to the lower and middle parts of the estuary. The percentage of stations about the occurrence of living and total population are presented in Table 5. This species appears to actively reproduce under the following ecological conditions. This species reproduces actively under the following conditions of temperature ranging from 30o to 33.3o C in April and from 26o to 30.7′ C in December, salinity from 16.0 to 30.8 ‰ in April and from 13.00 to 27.7 ‰ in December, dissolved oxygen from 2.5 to 4.8 in April and from 0.85 to 5.42 in December, sediment consisting of sandy silt, clayey silt and silty sand in both the seasons, and organic matter content ranging from 0.18 to 1.33 in April and 0.10 to 0.96

in December. It reproduces more actively in December than in April. The distribution patterns of the living and total (living+dead) species of *Pararotalia nipponica* in the estuary in April and December are represented in Figures 2-3.

Table 14. Summary of the Occurrence of *Pararotalia cf. globosa*

Estuary	Occurrence	Specimen s/unit volume	
		Minimum populations	Maximum populations
Living			
Mahanadi River estuary	Occurs at 1 station in April and at 3 stations in December 2019.	3 at station 1 in April and 2 at station 2 in December 2019.	2 at station 1 in April and 12 at station 5 in December 2019.
Total: Living +Dead			
Mahanadi River estuary	Occurs at 5 stations in both. April and December 2019.	2 at station 7 in April and 3 at station 5 in December 2019.	11 at station 2 in April and 16 at station 4 in December 2019.

Ecology:

Living and total populations distribution *Pararotalia cf. globosa* indicate that the species actively reproduces in December than in April. This species is endemic to the estuary and blooms under the following ecological conditions. This species appears to actively reproduce under the following ecological conditions. This species reproduces actively under the following conditions of temperature ranging from 30o to 33.6o C in April and from 26o to 30.8′ C in December, salinity from 16.30 to 30.8 ‰ in April and from 13.00 to 26.9 ‰ in December, dissolved oxygen from 2.7 to 4.8 in April and from 0.84 to 5.42 in December, sediment consisting of sand, silt, silty clay silty sand in both the seasons, and organic matter content ranging from 0.18 to 1.33 in April and 0.10 to 0.96 in December. It reproduces more actively in December than in April. The distribution patterns of the living and total (living + dead) species of *Pararotalia nipponica* in the estuary in April and December are represented in Figures 2-3. The distribution patterns of the living and total (living + dead) species of *Pararotalia. cf. globosa* in the estuary in April and December are represented in Figures 2-3.

Table 15. Summary of the Occurrence of *Quinqueloculina lamarckina*

Estuary	Occurrence	Specimens/unit volume	
		Minimum populations specimens /unit volume	Maximum populations
Living			
Mahanadi River estuary	Occurs at 2 stations in April and at 3 stations in December 2019.	2 at station 2 in April and 1 at station 3 in December 2019.	2 at station 1 in April and 2 at station 1 in December 2019.
Total: Living +Dead			
Mahanadi River estuary	Occurs at 4 stations in April and at 6 stations in December 2019.	1 at station 4 in April and 2 at station 7 in December 2019.	5 at station 5 in April and 17 at station 1 in December 2019.

Ecology:

Quinqueloculina lamarckina is also endemic to the estuary and its living and dead species are mostly confined to the lower and middle parts of the estuary. As per the observations about its distribution patterns, the post-monsoon

season supports more populations than the pre-monsoon season. This species reproduces actively under the following ecological conditions. This species reproduces actively under the following conditions of temperature ranging from 30o to 33.3o C in April and from 26o to 30.7′ C in December, salinity from 15.10 to 30.70 %o in April and from 13.00 to 27.7 %o in December, dissolved oxygen from 2.7 to 4.6 in April and from 0.85 to 5.41 in December, sediment consisting of sand, silt, silty sand, and clayey silt in both the seasons, and organic matter content ranging from 0.18 to 1.33 in April and 0.10 to 0.96 in December. It reproduces more actively in December than in April. The distribution patterns of the living and total (living + dead) species of *Quinqueloculina lamarckina* in the estuary in April and December are represented in Figures 2-3.

Table 16. Summary of the Occurrence of *Quinqueloculina seminulum*

Estuary	Occurrence	Specimens/unit volume	
		Minimum populations	Maximum populations
Living			
Mahanadi River estuary	At all stations in April and December 2019.	1 at station 6 in April and 6 at station 10 in December 2019.	58 at station 3 in April and 522 at station 7 in December 2019.
Total: Living +Dead			
Mahanadi River estuary	At all stations in April and December 2019.	3 at station 10 in April and 18 at station 10 in December 2019.	159 at station 4 in April and 644 at station 7 in December 2019.

Ecology:

Quinqueloculina seminulum is ubiquitous to all the estuary, i.e., it occurs at all the stations in both living and dead conditions. The living populations of *Quinquelina seminulum* in relation to ecological factors indicates that the species reproduces in December or even earlier as evidenced by larger number of dead tests found accumulated by December. The favorable ecological conditions for the reproduction *Quinquelina seminulum* are as follows. This species reproduces actively under the following conditions of temperature ranging from 30o to 33.3o C in April and from 26o to 30.7′ C in December, salinity from 16.20 to 30.70 %o in April and from 13.00 to 27.7 %o in December, dissolved oxygen from 2.5 to 4.6 in April and from 0.85 to 5.41 in December, sediment consisting of sandy silt, silty clay, and clay in both the seasons, and organic matter content ranging from 0.18 to 1.33 in April and 0.10 to 0.96 in December. It reproduces more actively in December than in April. The distribution patterns of the living and total (living + dead) species of *Quinqueloculina lamarckina* in the estuary in April and December are represented in Figures 2-3.

Table 17. Summary of the Occurrence of *Rosalina globularis*

Estuary	Occurrence	Specimens /unit volume	
		Minimum populations	Maximum populations
Living			
Mahanadi River estuary	Occurs at 4 stations in both April and December 2019.	2 at station 5 in April And 1 at station 3 in December 2019.	7 at station 2 in April And 3 at station E-6 in December 2019.
Total: Living +Dead			

Mahanadi River estuary	Occurs at 6 stations in both April and December 2019.	4 at station 7 in April And 8 at station 3 in December 2019.	21 at station 2 in April and 18 at station 2 in December 201.

Ecology:

Rosalina globularis is a lower-middle estuarine species. Its living and total populations are more in December than in April. The ecological conditions which favour its reproduction are as follows. This species reproduces actively under the following conditions of temperature ranging from 30o to 33.6o C in April and from 26o to 30.9′ C in December, salinity from 16.30 to 30.60 ‰ in April and from 13.00 to 27.7 ‰ in December, dissolved oxygen from 2.5 to 4.6 in April and from 0.85 to 5.41 in December, sediment consisting of sand, silty sand, silt, and clay in both the seasons, and organic matter content ranging from 0.18 to 1.33 in April and 0.10 to 0.96 in December. It reproduces more actively in December than in April. The distribution patterns of the living and total (living + dead) species of *Rosalina globularis* in the estuary in April and December are represented in Figures 2-3. The distribution patterns of the living and total (living + dead) species of Rosalina globularis in the estuary in April and December are represented in Figures 2-3.

2. CONCLUSIONS

Micropaleontology is very useful in determining the age and correlation of rock formations, to identify the type of rocks and sediments, to locate the positions of marker beds, and to determine the conditions of tectonics of sedimentary basins. Among all the microfossils, foraminifera are most useful because of their minute size, wide variation, wide distribution, and their occurrence in marine environment. According to James Hutton, the present is the key to the past. Therefore, the Recent foraminifera of the Mahanadi estuary have been studied in relation to various ecological variables to delineate the *palaeoenvironment, palaeoclimate, palaeobathymetry*, etc. The Mahanadi estuary is one of the major estuaries in India. It originates from *Amarakantak* region of Madhya Pradesh and flows through Madhya Pradesh and Odisha States over a length of 890 kms having drainage basin of about 1,41,600 sq. kms with a large catchment area. It opens into the Bay of Bengal at Paradeep in Cuttack district. 10 sediment and 10 water samples were collected from the estuary for the study of foraminifera and sediment characters, and water analysis respectively. The ecological parameters such as salinity, temperature, pH, dissolved oxygen, and organic matter content of the substrate estimated. The foraminifera of the estuary were identified. 12 abundant species which are *Ammobaculities exiguus*, *Ammonia beccarii, Ammonia beccarii tepida, Elphidium advenum, Elphidium hispidulum, Milliamina fusca, Nonion depressulus, Pararotalia nipponica, Pararotalia cf. globosa, Quinqueloquelina lamarckina, Quinqueloculina seminulum and Rosalina globularis* and are related to the prevailing ecological parameters and the substrate characteristics including the organic matter content. Foraminifera can serve as important tools in the exploration for hydrocarbons, especially in deltas. This has led us to investigate the foraminifera of the Mahanadi estuary from which vast sediments consisting of much organic matter are supplied to the delta. Organic matter is an important source matter for the generation of hydrocarbons.

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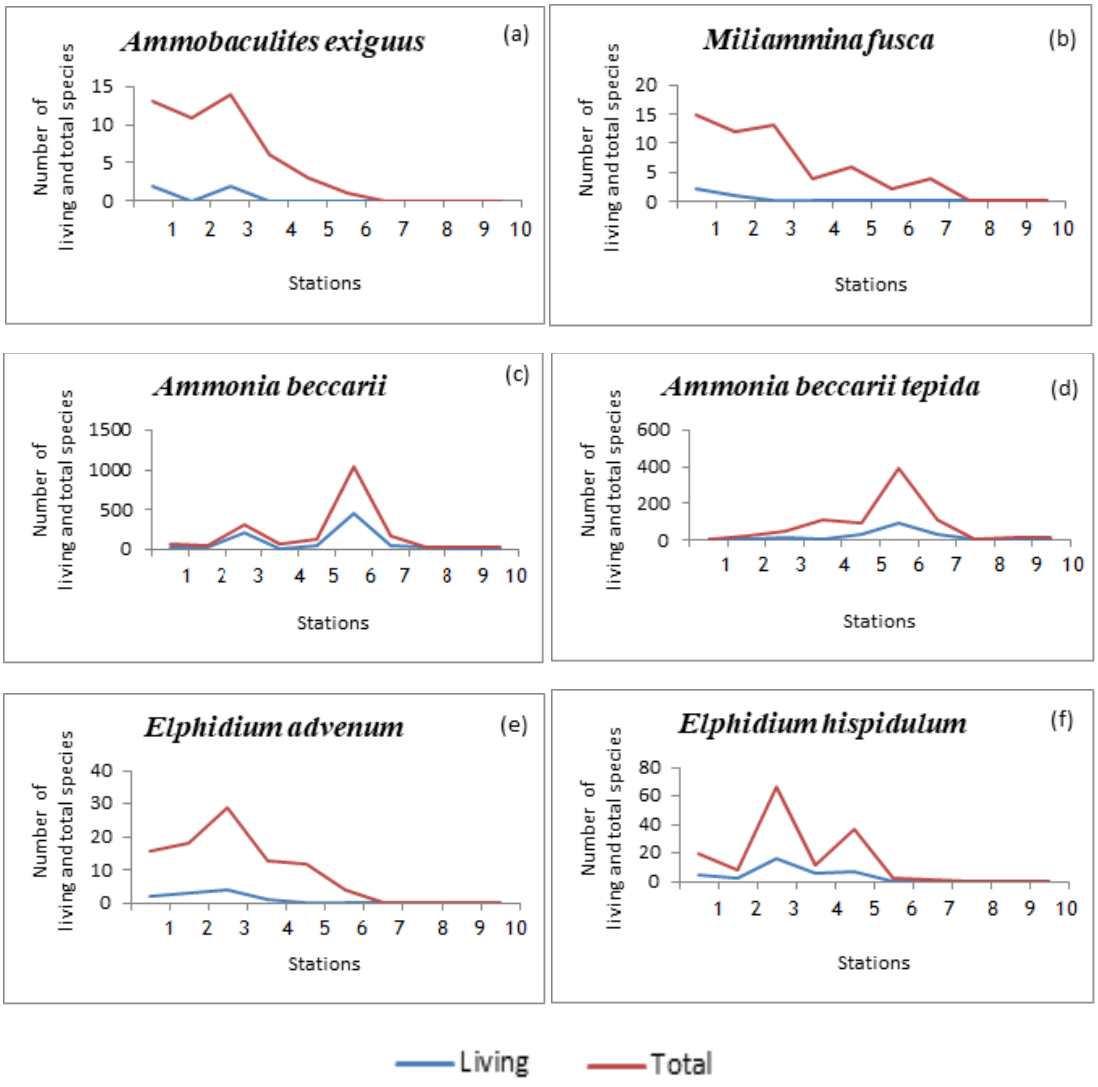
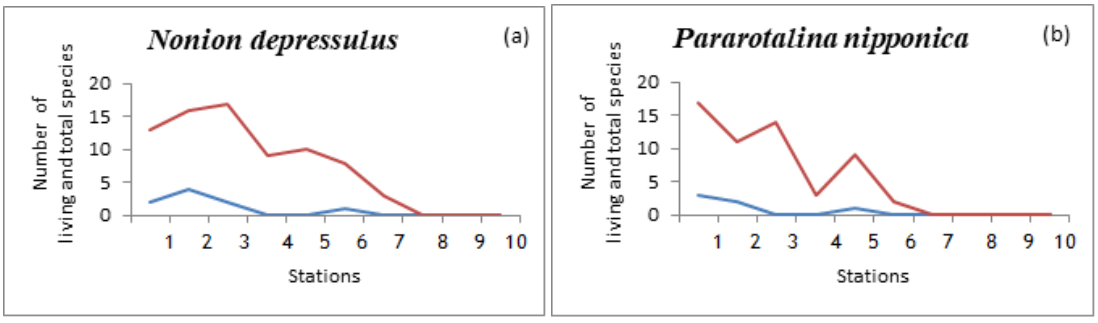


Figure 2A. Distribution Pattern of Living (L) and Total (Living+Dead) Species in the Mahanadi Estuary (April 2019).



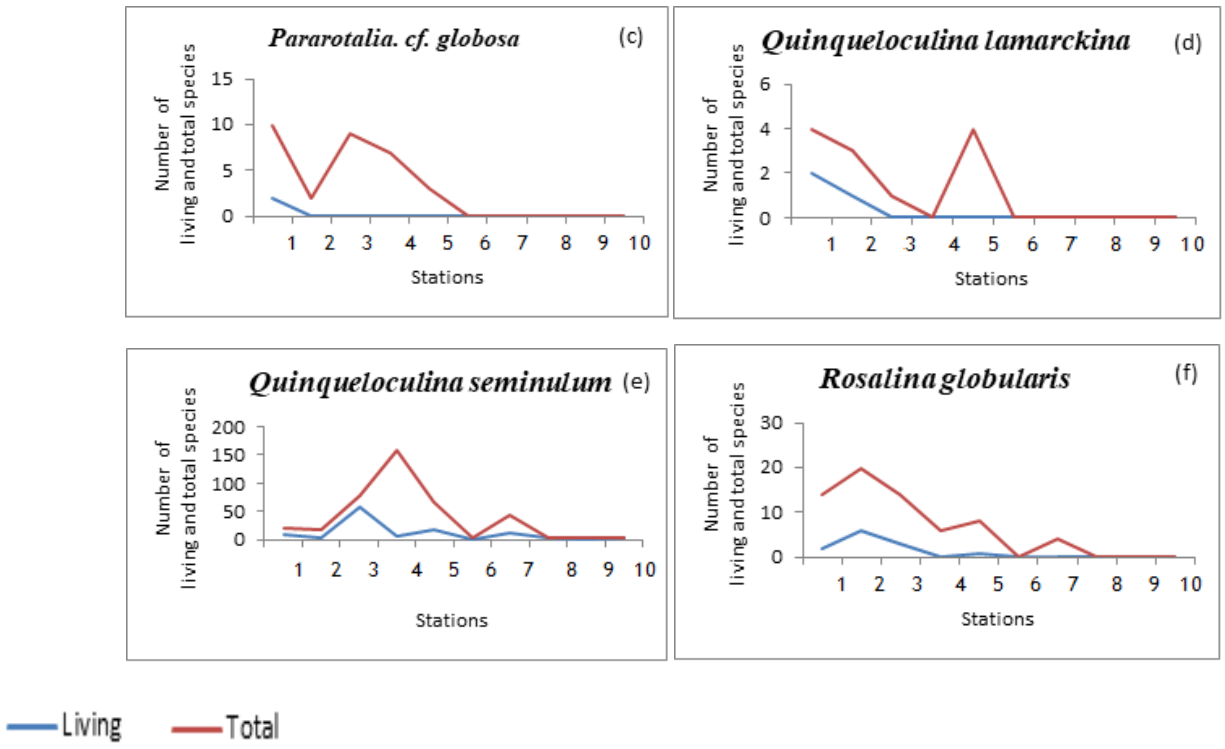
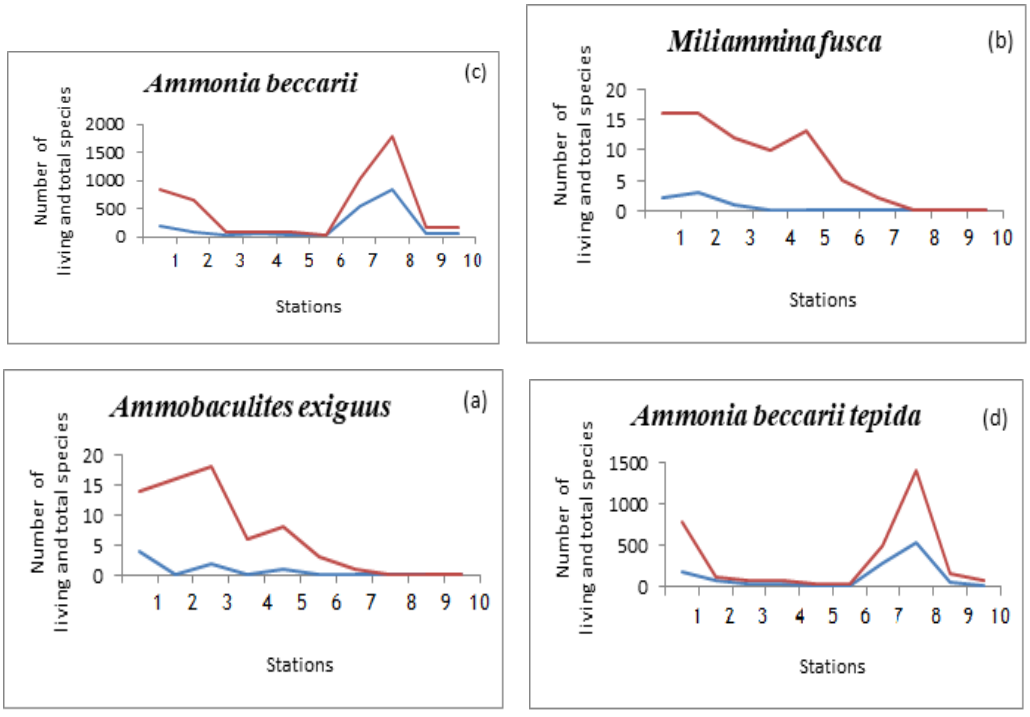


Figure 2B. Distribution Pattern of Living and Total (Living+Dead) Species in the Mahanadi Estuary (April 2019).



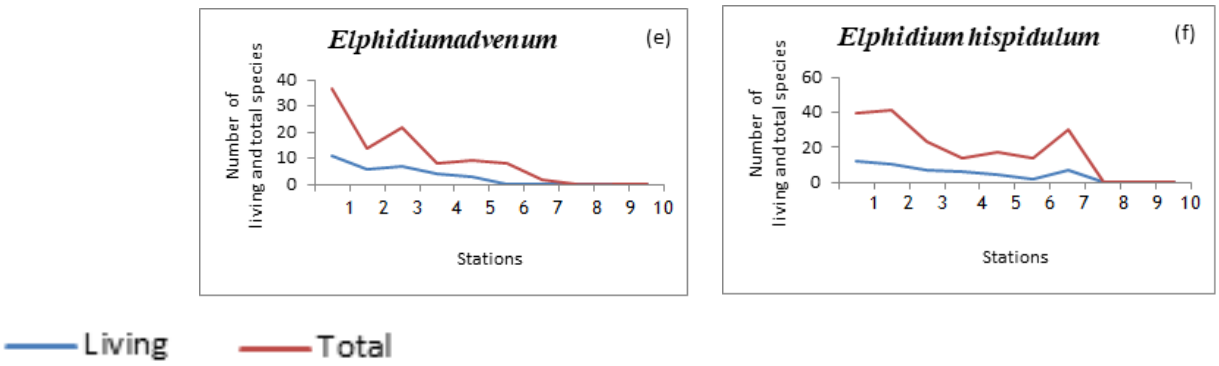


Figure 3A. Distribution Pattern of Living (L) and Total (Living+Dead) Abundant Species in the Mahanadi Estuary (December 2019).

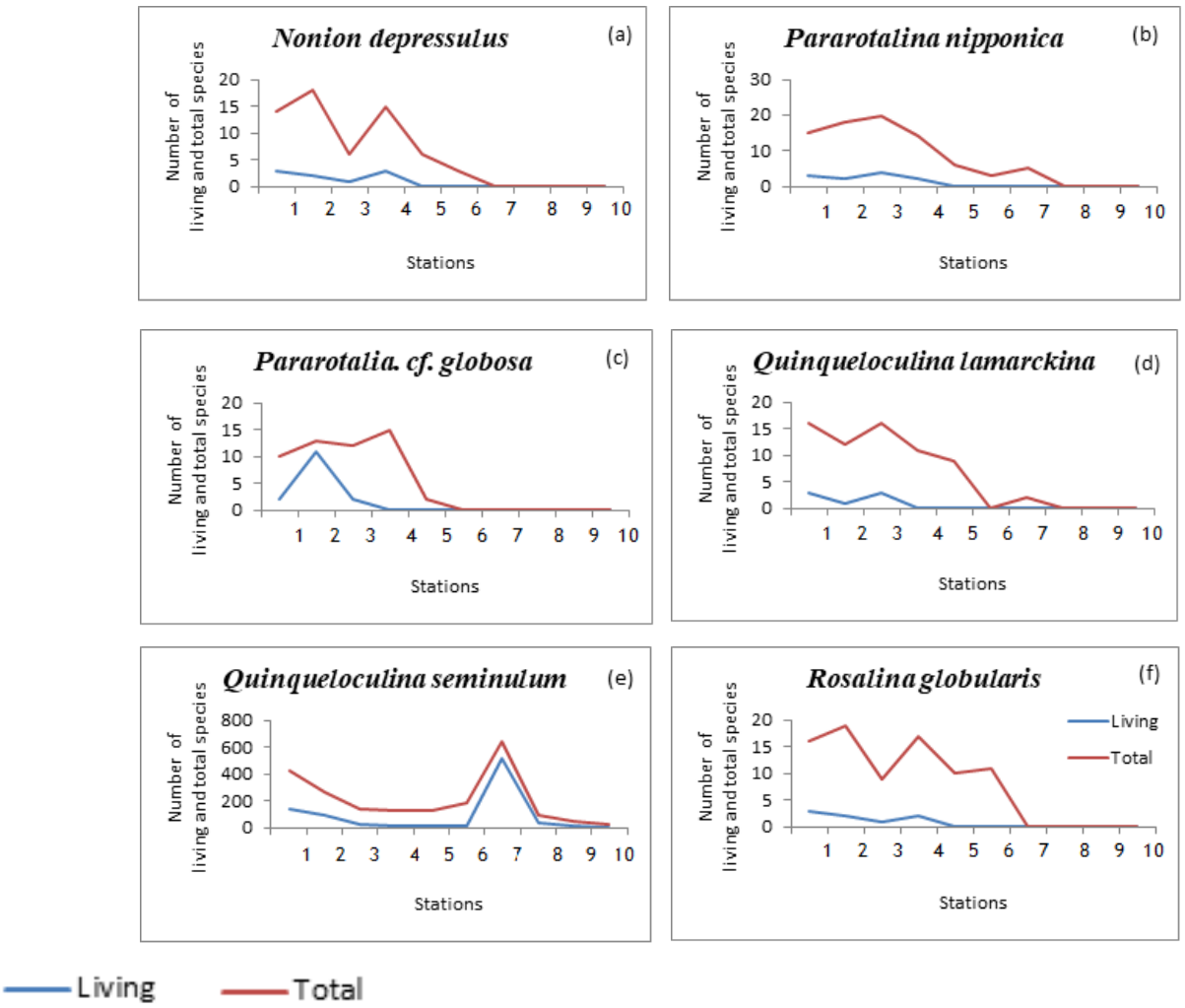


Figure 3B. Distribution Pattern of Living (L) and Total (Living+Dead) Abundant Species in the Mahanadi Estuary (December 2019).

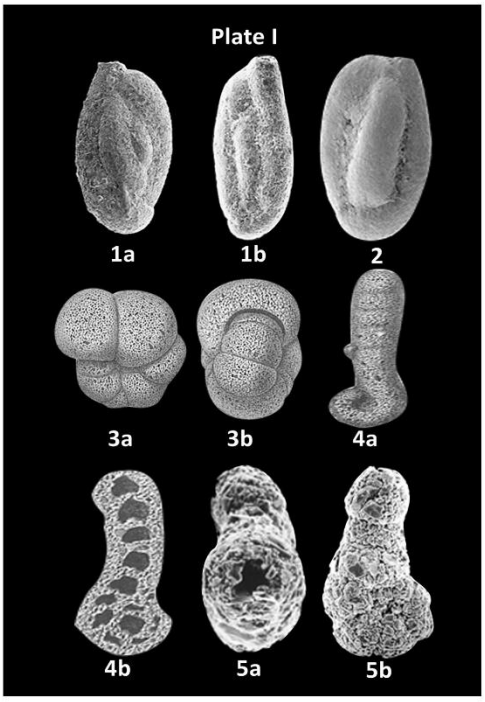


Plate I
1a
1b
2
3a
3b
4a
4b
5a
5b

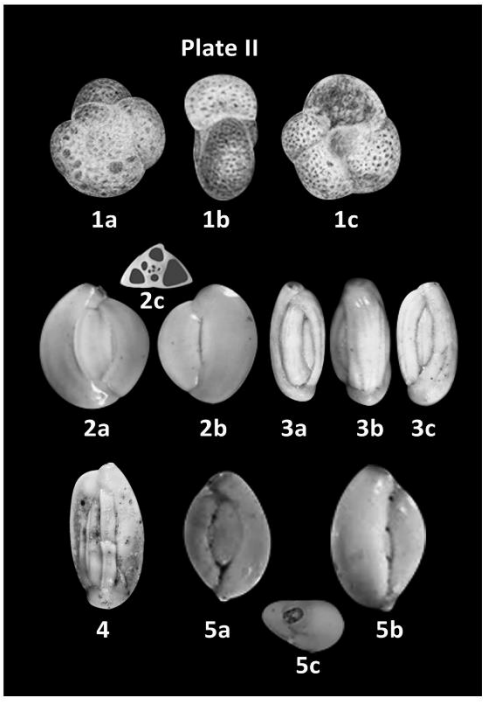


Plate II
1a
1b
1c
2c
2a
2b
3a
3b
3c
4
5a
5b
5c

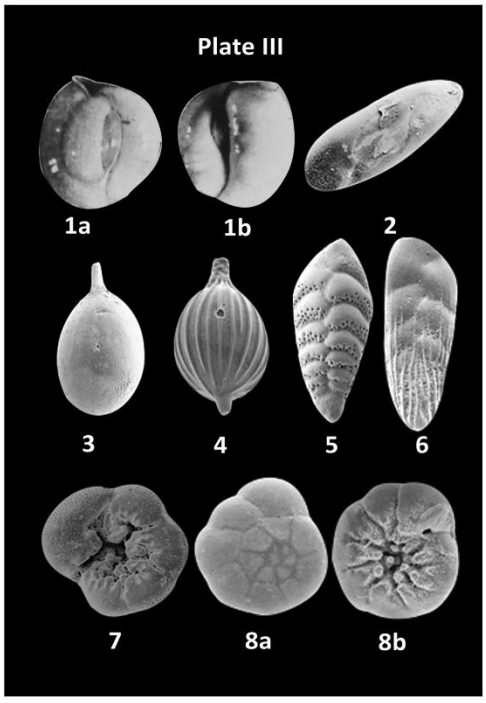


Plate III
1a
1b
2
3
4
5
6
7
8a
8b

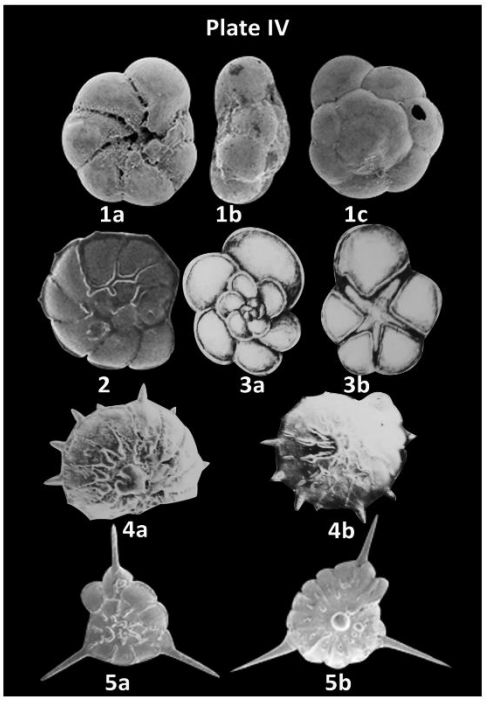
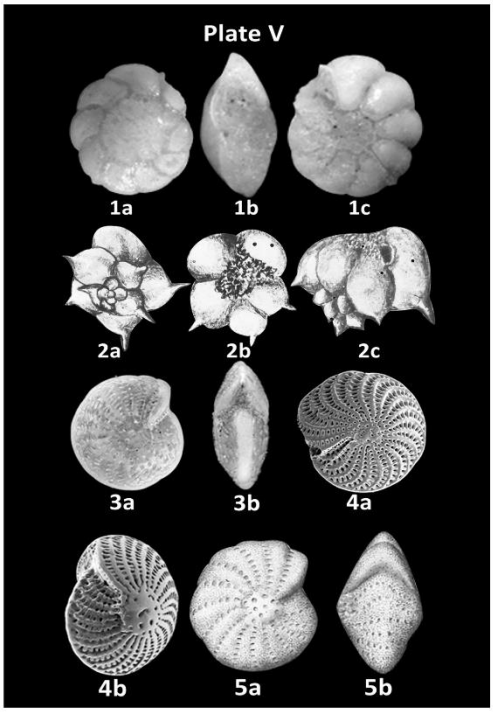
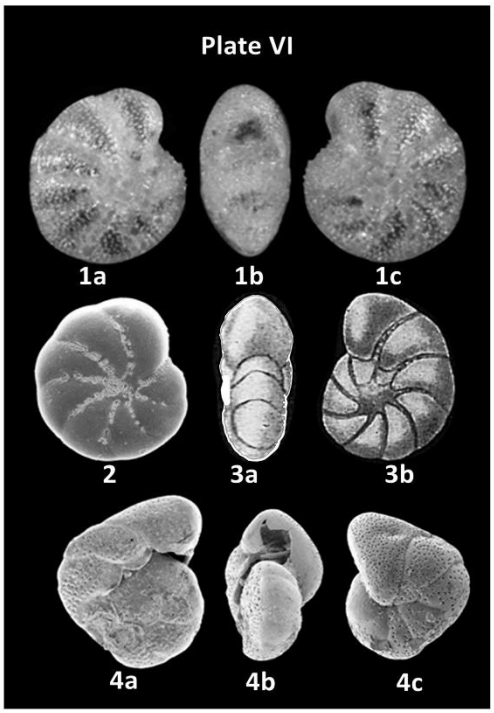
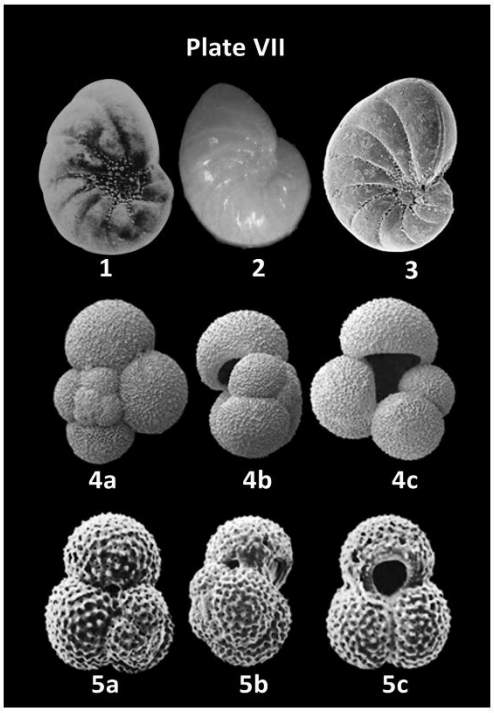


Plate IV
1a
1b
1c
2
3a
3b
4a
4b
5a
5b







Names of the Species

Plate I: 1. ***Miliammina fusca***: (a). Four chamber side (b). Three chamber side **2.** ***Miliamminafusca var***. General view **3.** ***Haplophragmoides hancocki***: (a). Spiral view, (b). Apertural view. **4.** ***Ammobaculites agglutinans***, (a). General view, (b). Cutaway view. **5.** ***Ammobaculites exiguous***: (a). Apertural view, (b). General view. **Plate VII. 2: 1.** ***Trochammina advena***: (a). Spiral view, (b). Side, (c). Apertural vie **2.** ***Quinqueloculina lamarckina***: (a). Four

Chamber view, (b). Three Chamber view, (c). Apertural view. **3. *Quinqueloculina costata***: (a). Four chamber view, (b). Three chamber view, (c). Apertural view, **4. *Quinqueloculin elongata***: General view, **5. *Quinqueloculina seminulum***: (a). Four chamber view, (b). Three chamber view, (c). Apertural view. **Plate VII. 3: 1. *Quinqueloculina subrotunda***: (a). Four chamber view, (b). Three chamber view, **2. *Triloculina oblonga***: Two chamber view. **3. *Lagena laevies***: General view. **4. *Lagena straita***: General view. **5. *Bolivina spatulate***: General view. **6. *Bolivina striatula***: General view. **7. *Rosalina globularis***: General view. **8*. Ammonia beccarii***,: a). Spiral view, (b). Umbilical view. **Plate VII. 4: 1. *Ammonia beccarii tepida***: (a). Umbilical side, (b). Apertural view, (c). Oblique side, **2. *Ammonia dentata***: General view, **3. *Asterorotalia inflanta***: (a). General view, (b). Apertural view. **4. *Asterorotalia multispinosa***: (a). Ventral side view, (b). Dorsal side view. **5. *Asterorotalia trispinosa***: (a). General view, (b). Apertural view. **Plate VII. 5: 1*. Pararotalina nipponica***: (a). Dorsal view, (b). Side view, (c). **2. *Pararotalina. cf. globose***: (a). Spiral side, (b). Umblical side, (c). Apertural side. **3. *Elphidium advenum***: (a). Ventral view, (b). Side view. **4. *Elphidium crispum***: (a). Dorsal view, (b). Side view. **5. *Elphidium discoidale***: (a). Dorsal view, (b). Side view. **Plate VII. 6: 1*. Elphidium hispidulum***: (a). Dorsal view, (b). Apertural view, (c). Ventral view. **2. *Elphidium incertem***: General view. **3*. Elphidium simplex***: (a). Apertural view, (b). General view. **4. *Cibicides lobatulus***: (a). General view (b). Apertural view, (c). Dorasal side. **Plate VII. 7: 1. *Florilus labradoricus***: General view. **2. *Nonion deressulus***: General view **3. *Nonion grateloupi***: General view. **4. *Globigerina bulloides***: (a). Apertural view, (b). Side view, (c). Spiral view. **5. Globigerinoides ruber**: (a). Spiral view, (b). Side view, (c). Umbilical view.

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