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Micropaleontological Assemblages on December-2004 Tsunamigenic Sediments Record of Climate Variation Between Cuddalore and Nagapattinam, East Coast of India

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Abstract: Ninety-nine benthic foraminiferal species belonging to 41 genera, 26 families, 17 superfamilies and 5 suborders have been identified from 84 samples which were collected from beach (23 nos), offshore (24 nos), estuaries (8 nos), inland (23 nos) and one pit sample (6 nos), between Cuddalore and Nagapattinam in the tsunami affected coastal environment. Out of 99 species, only 20 species are living ones. The following species are appreciably distributed in different stations, namely *Ammonia beccarii, Elphidiumcrispum, Rosalina globularis, Asterorotaliatrispinosa* and *Pararotalianipponica*. The total distribution of foraminifera is higher at Cuddalore and Nagapattinam whereas at Pudupettai and Samadanpettai it is noticed in the lower order. Organic matter and living species show positive relation. No relationship is observed between dead species and the organic matter, which suggests that the dead species recorded in the sediment, must have been primarily drifted/transported as empty calcareous shells. From the sand/silt/clay ratios, it is inferred that the sediments are normally sandy in nature but silty sand dominates at deeper depths. Carbonate content establishes a positive correlation with all parameters. A fluctuation of salinity values in offshore regions indicates the influx of fresh water from Colleroon river. From the overall studies of foraminiferal distribution in this region, it may be inferred that the species distribution in the offshore region is mainly derived from the inner shelf region. To observe the earlier changes in climactic condition in marine environment mainly based on information from marine sediments. The collected samples from our study area marine sediments contain a variety of foraminifera, which archive climactic information from both planktonic and benthic assemblages and in their sedimentological compositions.

Keywords: Foraminifera; Tsunami sediments; Cuddalore; Nagapattinam.

Introduction

Micropaleontology is an emerging discipline that is well suited to the study of environments and environmental changes. Recently the application of benthic foraminifera has entered a new arena, as can be used as excellent environmental monitoring of present day contaminated and polluted areas. Benthic foraminifera is also a tool for tracking transgression and regression even in lagoons connected to the open sea. Like storm events, tsunamis can also be recognised in the stratigraphical record from the identification of foraminifera. However,

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on the basis of foraminifera alone, it is difficult to distinguish between storm deposits and tsunamigenic deposits. Other criteria needed to be considered include stratigraphical context, the spatial distribution of coarse-grained sediments and sedimentological characteristics. Clague et al. (1999) analysed foraminifera in a core collected from Catalalake on the west coast of Canada. They identified a gravel layer in the core, which they suggested was deposited in 1700 AD by a large tsunami caused by a historically documented earthquake. The tsunami layer itself is barren of foraminifera. Below the layer, the fauna consists of an almost monospecific assemblage of *Miliamminafusca*. A much more diverse marsh assemblage appears in the lake after deposition of the tsunami layer, including *Miliamminafusca, Trochominarotaliformis, Trochominainflata* and *Trochominaochracea.* The authors suggest that this assemblage reflects higher salinity conditions following the deepening of the connection with the open sea by the tsunami and, possibly, by co-seismic subsidence. The tsunami layer from Meares Island, Canada contains foraminifera transported from deeper water. If the sand layer was deposited during a storm, it is difficult to explain the change in height of the former marsh surface that appears to have occurred during the formation of the sand layer. A seismic event is likely to have caused the sudden drop of the marsh surface. This makes it plausible that the sand layer is tsunamigenic in origin. Based on the results of the Q-mode cluster analysis and radiocarbon dating of cores along the Coast of Kachchh, NE Arabian Sea, Nigam and Chaturvedi (2006), hypothesised that the erosion and transportation of fine-grained sediments from relatively deep water and its deposition in shallower water are under the influence of storm/tsunami event.

Foraminifera are single celled organisms (protists), which have a long geological record because they construct a shell (test) that can be preserved as fossils. Foraminifers are predominantly marine organisms living on the sea floor, or floating in the water column. Foraminifers have been, for the past several centuries, interesting objects to study geologically. These protozoans have adapted to various niches on the seafloor, in estuaries, salt marshes and in other marine marginal water bodies. Their smaller size and vast abundance in sea floor sediments of the present day and geologic past has resulted in foraminifera becoming the most used Fossil Group for determining the age and depositional environment.

The 26th December 2004 tsunami that devastated the north Indian Ocean is a major event as the tsunami waves have travelled with tremendous velocity and have transported large quantities of waters and sediments. The study area between Cuddalore and Nagapattinam coast is well affected by Tsunami recently during December 26, 2004. In the present paper, the distribution and ecology of foraminifera and its impact on the tsunami have been carried out in detail.

Study Area

The area of the study, extending for about 115 km from the Cuddalore in the north to the Nagapattinam in the south between 10° 45′ to 11° 50′ N and 79° 30′ to 79° 52′ E is a part of the Coromandal coast, which encompasses the coast of Tamil Nadu in India (Figure 1). It has an aerial extent of 575 sq. km. It is in the

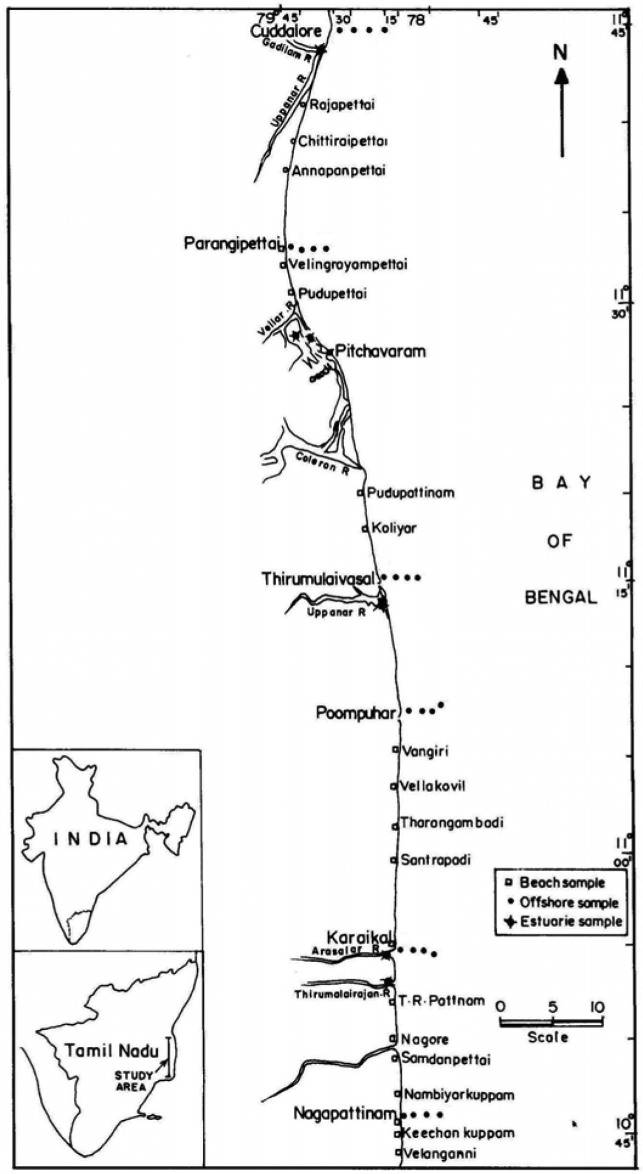

Figure 1: Location map of the sample collection.

survey of India toposheets of 58/M on the scale of 1:250,000. It falls in the survey of India toposheets (58N/13, 58N/14, 58M/15 and 58M/16) prepared on a scale of 1:50,000. Sandy beaches seen in a narrow linear and discontinuous form in the entire study area is tide-dominated and a number of tidal creeks are there. Poombuhar, Tarangambadi and Nagapattinam beaches are broader and have a width of 70 to 250 mts. The study area from Nagapattinam to Cuddalore is characterised by four series of beach ridges with intervening swale systems. Dune complexes of transverse, parabolic and longitudinal types are noticed at Nagapattinam, Nagore, Karaikal, Poriyar, Thirumulaivasal and Port Novo. The coastline from Nagapattinam to Cuddalore is represented by undulating topography with a seaward slope. The Central coast of Tamil Nadu's coastal tract area is divided into upland, flood plain and deltaic plain and coastal plain (Rajamanickam et al.,1990). The coastline is more often sandy and silty in nature. The coastal plain contains various coastal morpho-units like sand complexes, mud flats and backwaters. There are no hills of any prominent height in the study area. The gradient is about 40 m over a distance of 70 km. Nearly 60% of the total area falls within 4.00 m elevation above MSL. The drainage system consists of Cauvery, Coleroon, Vellar, Uppanar and Gadillam River.

Materials and Methods

Fieldwork

The fieldwork has been carried out during the month of March 2005. A total of 84 sediment samples were collected from the beach (23 nos), offshore (24 nos), estuaries (8 nos), inland (23 nos) and one pit sample (6 nos) in the study region. The offshore samples were collected at six transects keeping the stations at Cuddalore, Parangipettai, Thirumulaivasal, Poompuhar, Karaikal and Nagapattinam. Table 1 shows the samples collected from various sites with their respective latitude and longitude. A unit volume of 100 ml of wet sediment

Table 1: Sample locations with latitude and longitude

S. No	*Latitude*	*Longitude*	*Sampling Stations*	*Beach/Offshore/ Inland/Estuaries*
1,2,	11°44′35″	79°47′21″	Cuddalore	Beach/inland
3,4,	11°40′39″	79°46′08″	Rajapettai	Beach/inland
5,6,	11°38′17″	79°45′28″	Chittiraipettai	Beach/inland
7,8,	11°37′05″	79°45′18″	Annapanpettai	Beach/inland
9,10,	11°32′47″	79°45′02″	Vellingarayanpettai	Beach/inland
11,12,	11°30′08″	79°46′08″	Pudupettai	Beach/inland
13,14,	11°17′42″	79°50′47″	Koliyar	Beach/inland
15,16,	11°15′10″	79°47′12″	Thirumulaivasal	Beach/inland
17,18,	11°07′49″	79°51′11″	Poompuhar	Beach/inland
19,20,	11°05′05″	79°50′21″	Vanagiri	Beach/inland
21,22,	11°03′18″	79°50′42″	Vellakovil	Beach/inland
23,24,	11°01′41″	79°50′41″	Tharangampadi	Beach/inland
25,26,	10°58′21″	79°49′54″	Santrapadi	Beach/inland
27,28,	10°54′17″	79°51′57″	Arasalar.R	Beach/inland
29,30,	10°54′18″	79°51′58″	Karaikal	Beach/inland
31,32,	10°53′10″	79°51′54″	Thirumulairajanar.R	Beach/inland
33,34,	10°52′48″	79°51′43″	T.R.Pattinam	Beach/inland
35,36,	10°49′31″	79°51′06″	Samdanpettai	Beach/inland
37,38,	10°48′32″	79°51′56″	Nagore	Beach/inland
39,40,	10°46′58″	79°51′58″	Nampiyarkuppam	Beach/inland
41,42,	10°45′30″	79°51′25″	Nagapattinam	Beach/inland
43,44,	10°45′02″	79°51′03″	Keechankuppam	Beach/inland
45,46,	10°51′21″	79°51′21″	Velanganni	Beach/inland

(*Contd.*)

Table 1: (*Contd.*)

S. No	*Latitude*	*Longitude*	*Sampling Stations*	*Beach/Offshore/ Inland/Estuaries*
47	11°44′35″	79°48′12″	Cuddalore	Offshore s.no.1
48	11°44′42″	79°49′21″	Cuddalore	Offshore s.no.2
49	11°43′05″	79°51′35″	Cuddalore	Offshore s.no.3
50	11°44′31″	79°52′02″	Cuddalore	Offshore s.no.4
51	11°29′59″	79°46′21″	Parangipettai	Offshore s.no.5
52	11°27′56″	79°47′41″	Parangipettai	Offshore s.no.6
53	11°28′36″	79°46′53″	Parangipettai	Offshore s.no.7
54	11°29′17″	79°46′38″	Parangipettai	Offshore s.no.8
55	11°15′36″	79°52′08″	Thirumulaivasal	Offshore s.no.9
56	11°15′47″	79°53′05″	Thirumulaivasal	Offshore s.no.10
57	11°14′58″	79°54′19″	Thirumulaivasal	Offshore s.no.11
58	11°13′45″	79°54′59″	Thirumulaivasal	Offshore s.no.12
59	11°07′42″	79°51′21″	Poompuhar	Offshore s.no.13
60	11°08′38″	79°52′42″	Poompuhar	Offshore s.no.14
61	11°08′54″	79°53′54″	Poompuhar	Offshore s.no.15
62	11°09′41″	79°52′17″	Poompuhar	Offshore s.no.16
63	10°55′35″	79°51′59″	Karaikal	Offshore s.no.17
64	10°55′59″	79°52′47″	Karaikal	Offshore s.no.18
65	10°56′56″	79°53′57″	Karaikal	Offshore s.no.19
66	10°55′43″	79°55′48″	Karaikal	Offshore s.no.20
67	10°45′35″	79°51′32″	Nagapattinam	Offshore s.no.21
68	10°46′12″	79°52′18″	Nagapattinam	Offshore s.no.22
69	10°46′59″	79°53′54″	Nagapattinam	Offshore s.no.23
70	10°45′35″	79°55′27″	Nagapattinam	Offshore s.no.24
71	11°44′35″	79°49′48″	Gadilam.R	Estuaries (Core)
72	11°29′12″	79°49′49″	Pitchavaram-1	Estuaries (Core)
73	11°28′46″	79°50′24″	Pitchavaram-2	Estuaries (Core)
74	11°29′12″	79°49′54″	Pitchavaram-3	Estuaries (Core)
75	11°22′10″	79°50′54″	Coleroon.R	Estuaries (Core)
76	11°14′49″	79°51′14″	Uppanar.R	Estuaries (Core)
77	10°55′08″	79°51′48″	Arasalar.R	Estuaries (Core)
78	10°53′43″	79°51′09″	Thirumaulairajanar.R	Estuaries (Core)
79- 84			Karaikal	Pit sample

sample taken from the top 1 cm of the substratum was preserved immediately in a 10% neutralised formaldehyde solution. A small quantity of sodium carbonate was added to maintain the alkaline medium. At each station, bottom water samples were also collected using aqua trap sampler. Global Positioning System (GPS) was used to locate the sample sites in the offshore region. Add 10 ml of chloroform and preserve the remaining water samples. Temperature, pH and Eh were measured in the field immediately after the collecting of each sample.

Laboratory Technique

The preliminary physico-chemical parameters in seawater-like temperature and pH were determined onboard (motor launch) immediately after collecting the samples. From the water samples salinity has been determined using the standard titration method proposed by Knudsen (1910). Sand-silt-clay ratio was estimated by the procedure adopted by Krumbein and Pettijohn (1938). Organic carbon content is determined by using the Walkey-Black method, adopted and modified from the study conducted by Jackson (1958). Calcium carbonate was determined by using a rapid titration method (Piper, 1947). The most positive method for identifying living foraminifera is Walton's (1952) staining technique with rose Bengal by Phleger (1960) is adopted in the present study. The foraminiferal tests were then separated from the residue by floatation method using carbon tetrachloride by Cushman (1959). They were handpicked using a '00' Windsor Newton sable hairbrush. The hypotypes were mounted on brass stubs (1 cm in diameter) using a double-sided adhesive carbon tape and coated with platinum for about 3 to 4 minutes using JEOL-JFC-1600 Auto Fine Coater to render the surface of the foraminiferal tests conductive for scanning. To obtain lucid illustrations, microphotographs of different views of all the foraminiferal species recorded were taken using a Scanning Electron Microscope (JEOL JSM-6360). All the hypotypes were duly indexed with numbers and placed in the repository of the Department of Geology, University of Madras, Chennai 600 025 (Repository numbers: GEO – MSG – 001-099).

Results

The water parameters such as temperature, salinity and sediment parameters viz., $CaCo_3$, organic matter and sand-silt-clay ratio have been determined and tabulated. Table 2 shows the results of the ecological (sediment and water) parameters and the percentage of foraminiferal species for offshore samples.

Table 2: Results of the ecological parameters of the study area offshore

Station Numbers	*Depth in mts*	*pH*	*Salinity*	*Sediment type*	*O.m*	*C.c*	*Liv.Sp*	*Dead.Sp*
Cuddalore	3 m	8.18	30.18	Sand	0.123	18.23	4.86	95.13
	8m	8.19	30.24	Silty sand	1.243	19.24	3.39	96.61
	14 m	8.18	30.28	Silty sand	1.3	19.69	5.93	94.07
	19 m	8.19	30.26	Sand	1.211	20.1	6.42	93.58
Parangipettai	5 m	8.24	30.21	Sand	0.942	18.17	8.05	91.95
	10 m	8.23	30.30	Sand	1.301	20.76	19.89	80.11
	13 m	8.14	30.81	Silty sand	1.311	20.54	25.09	74.91
	15 m	8.14	30.68	Silty sand	1.232	20.46	20.83	79.17
Poompuhar	5 m	8.20	30.17	Sand	0.867	15.28	9.09	90.91
	8 m	8.21	30.28	Sand	1.013	15.31	11.6	88.4
	12 m	8.22	30.29	Silty sand	1.257	20.14	11.58	88.42
	16 m	8.22	30.23	Silty sand	1.178	20.12	12.83	87.17
Thirumulaivsal	3 m	8.20	30.16	Sand	0.648	16.54	9.43	90.57
	5 m	8.20	30.21	Silty sand	0.687	18.21	13.1	86.9
	8 m	8.22	30.24	Silt	1.423	19.12	8.69	91.31
	10 m	8.20	30.25	Silt	0.243	18.64	11.98	88.02
Karaikal	4 m	8.21	30.33	Silty sand	0.159	17.24	7.73	92.27
	7 m	8.21	30.40	Silty sand	0.985	15.18	8.16	91.84
	9 m	8.22	30.73	Sand	0.456	17.28	7.63	92.37
	12 m	8.08	31.07	Sand	0.864	15.65	7.74	92.26
Nagapattinam	3 m	8.21	30.36	Silt	1.23	21.23	7.73	92.27
	6 m	8.22	30.47	Silt	1.12	20.31	8.78	91.22
	10 m	8.23	30.70	Silty sand	1.11	21.04	10.22	89.78
	15 m	8.23	30.84	Silty sand	1.10	20.19	14.06	85.94

Temperature

The present study does not show much variation in temperature at different depths in the offshore stations (29° to 30°C). This is due to the fact that the sampling stations are located in the near shore environment within the depth of 20 m there will be not many variations in the temperature.

Salinity

The salinity of the present study varies from 30.16‰ to 31.07‰. In all the stations, the salinity values do not have much variation due to the mixing of water. Further, the river mouth area like Karaikal, Thirumulaivasal also received the same amount of salinity. The scatter plot of salinity vs. living species shows a positive correlation (Figure 2). At Poompubar and Nagapattinam, as the salinity increased towards the deeper depths (10 to 15 mts) the number of living species also increased.

Water Depth

The ecological effects of depth are difficult to assess because other ecological factors vary with depth like temperature, light intensity, pressure, oxygen and

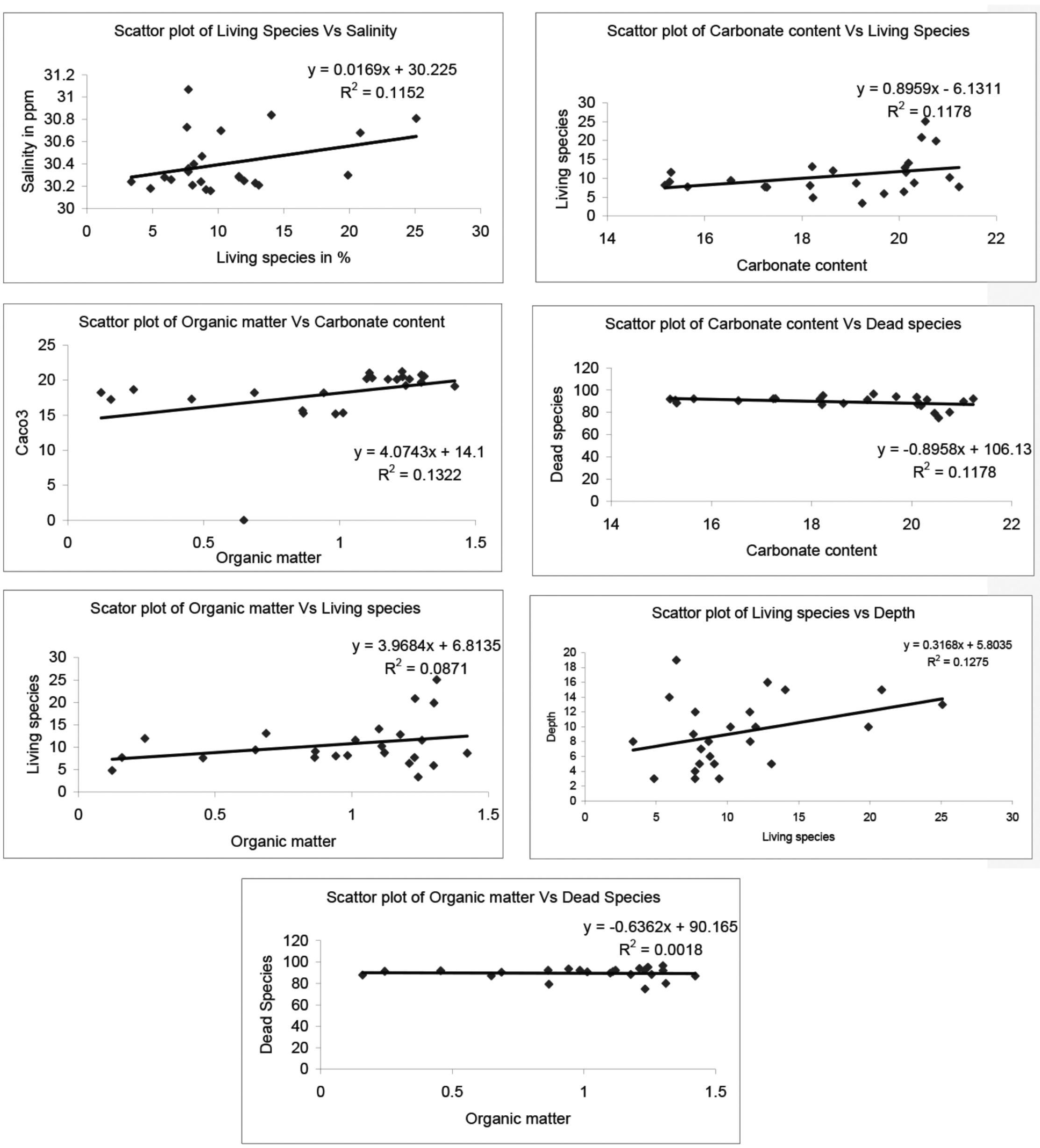

Figure 2: Scatter plots of the experimental parameters.

calcium carbonate concentration, etc. (Boltovskoy and Wright, 1976).

For the present study, samples were collected from a depth of 0 to 20 m. The correlation between depth vs living species also indicates a positive relation (Figure 2). The nature of sediment (sand, silt and clay) varied with depth. The depth controls the overall populations of benthic as well as planktonic foraminifers. Some species like *Globigerina, Bolivina, Nonion* distributed in the near shore environment indicating that they can travel from a longer distance.

Hydrogen Ion Concentration

The mean pH values for all the sampling stations do not exhibit considerable changes.

Sand-Silt-Clay Ratio

In the study region, the beach sands show coarser in nature. In the offshore region, the sand is dominant in maximum stations. Silty sand is distributed in deeper portions. Living foraminiferal populations are more abundant in the silt and silty sand substrate in the study area.

Organic Matter

In the study area, organic matter content ranging from 0.123 to 1.423% is noticed. In the near-shore region, the organic matter is less in amount. Karaikal and Thirumulaivasal recorded lower values of organic matter compared to the other stations. The scatter plot of organic matter vs living species shows a positive correlation (Figure 2) and a negative correlation with dead species (Figure 2) indicate a good relation with the biomass. Further, the trend of organic matter vs dead species picturises that due to tsunami activities the drifting of sediment brought from the inner shelf regions has played a great role in the contribution of dead species. The percentage of count living species indicates a rise in total amount of living species in the deeper portion may be due to oxygenated conditions prevailing in that region.

Calcium Carbonate

At Nagapattinam, Poombuhar and Parangipettai a higher amount of carbonate content is noticed than other stations. In Cuddalore, a gradual increase of carbonate content is noticed whereas in Karaikal it is decreased in the deeper depths. The scatter plot of carbonate content vs living species and organic matter shows the positive correlation and negative correlations with dead species (Figure 2). It means that a weak and strong relationship is being maintained between carbonate and living and dead species. But, now carbonates must have been the product originated from the other factors, probably the drifted shells from elsewhere. It indicates that the carbonate present in this region is not *in situ*. It can be drifted and deposited from the other regions due to tsunami activities.

Distribution of Foraminifera

For the sake of clarifying, brevity and convenience of discussion, the distribution of foraminifera in the study area is classified into the beach, offshore, inland and estuarine environments.

A total of 99 benthic foraminiferal species belonging to 41 genera, 26 families, 17 superfamilies and 5 suborders have been reported and illustrated. Among these, 7 are arenaceous, agglutinated taxa suborder TEXTULARIINA, 49 are calcareous, imperforate, porcelaneous forms suborder MILIOLINA, 1 belong to the suborder LAGENINA, 3 are planktonic species suborder GLOBIGERININA and 40 are calcareous, perforate species suborder ROTALIINA.

Discussion

Beach Environment

Sand is deposited all along the coast. Black sand is covered in Tharangambadi and Thirumullaivasal region. The following table shows the total number of foraminiferal species in actual number on the beach (Table 3).

In the tsunami-affected regions between Cuddalore and Nagapattinam, a total of 39 species belonging to 16 genera are identified in the beach samples. Among them, *A. beccarri* shows a higher abundance in all the stations, barring one or two, followed by *A. dentata* and *Q. seminulum*. The following species are distributed in more than ten stations namely *S. communis, S. sp. Q. lamarckiana, Q. seminulum, Q. sp. A. beccarii*, *A. dentata* and *E. incertum*. At Cuddalore, *Elphidiumadvenum* is present in equal numbers along with *Elphidium sp*. In Vellakovil, an abundant distribution of *Amphisteginaradiata* and *E. incertum* is noticed.

Cuddalore has registered the high species diversity with a total number of 107 species, in the North. At Vellakovil, the highest species diversity is marked by 200 species in the central. Velangani registered (325) the highest species diversity in the south. In Pudupettai and Samadanpettai, the lowest number of species is

Table 3: Distribution of Foraminifera between Cudallore to Nagapattinam (Beach)

List of species	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*
Amphistegina radiata	1			1							5	3	2	3		5		5			3		1
Spiroloculina antillarum																					1		
S. communis		2	4	4	2		1	2	1		14	4	2	4		2	4						2
S.costifera																							1
Spiroloculina sp1	5	1					1	1	1	1	7	4		3		2		1	1	1	4	2	2
Spiroloculina sp2							1			1	4	1				2	3	1	1		2	1	1
S.orbis						1						4	2		4	3						2	4
Massilina.sp										1					1						1		2
Quinqueloculina agglutinans																	1						
Q.lamarckiana			1	2	1			2	1				2			1					4	2	4
Q.seminulum	15	21	14	10	8	3	8	12	4		18	8	8		6	14	15	12	8	7	25	6	30
Q.oblanga	2																						
Q.semiplicata										1				4		2	2					2	2
Quinqueloculina.sp1	2		1		1				1	4	2	2	2				3		1		4	2	4
Quinqueloculina.sp2	4				1	1			1	2	4								1		1		3
Miliolinella circularis																	1				1		1
M.pyrgoformis											1					1							1
Triloculina rotunda																	2			2			
T.scheriberiana																							1
T.oblanga																							2
T.trigonula			1							2				2		4	2			1	8		2
T.tricarinata	1			1										1		2					4		
Eponides.sp																	1						
Nonionoides boueanum																					18		8
Nonion eleongatum	2	2	1		2						4				2	2					5		10
Pararotalia nipponica	1																			2			
A.beccarii	30	27	15	17	7	8	19	22	25	28	86	32	14	10	12	35	25	13	12	17	55	8	110
A.dentata	26	12	6	4	3	4	8	15	18	18	40	31	4	12	4	20	4	4	3	4	20	12	95
A.tepida	2						2	4	8		4			2		8	3			4	4		12
Asterorotalia inflata												3		4		5				2			5
A. trispinosa													1		1					1			4

Elphidium advenum	6		1						2							4							4
E. crispum													2			2		2			3		5
E.discoidale	1		1						1												4		2
E. incertum	2	4	1		2	2			3		8	7	3			10					4		1
Elphidium.sp	6										1				1				1		2		2
Parrellina hispidula											2									1	3	2	1
Cibicides lobotulus	1					1	9	11	1								3			1	2		2
Globigerina bulloides															2								1
TOTAL	107	69	46	39	23	20	49	69	67	58	200	99	42	45	33	124	69	36	28	43	178	39	325
Individual species	17	7	11	7	9	7	8	8	13	9	15	11	11	10	9	19	14	7	8	12	23	10	31

1. Cuddalore 2. Rajapettai 3. Chitirapettai 4. Annapanpettai 5. Velingarayanpettai 6. Pudupettai 7. Koliyar 8. Thirumulaivasal 9. Poompuhar 10. Vanagiri 11. Vellakovil 12. Tharangampadi 13. Santrapadi 14. Arasalar.R 15. Karaikal 16. Thirumilairajan.R 17. T.R. Pattinam 18. Nagore 19. Samdanpetai 20. Nampiyarkuppam 21. Nagapattinam 22. Keechankuppam 23. Velangani

recorded (20 and 28 species, respectively). At Karaikal, Velangani, planktonic species *Globigerina bulloides* are recorded. *Q.oblanga* is present only in Cuddalore station and *Cibicideslo botulus* is recorded in higher amounts in Kulaiyar and Thirumullaivasal.

In the station of low diversity, at Pudupettai, only 9 species of foraminifera are present. At Samdanpettai, again less diversity of species is identified. The species are represented by *SpiroloculinaSp 1, Spiroloculina Sp2, Q.lamarckiana, A.beccari, A.dentata, Elphidium Sp.* The genera *Ammonia*, *Quinqueloculina* and *Spiroloculina* are distributed at all the stations. At Karaikal and Velangani, the genus *Globigerina* is distributed but with a lesser amount.

The total number of foraminiferal species shows that the lowest species count is noticed in Stn.6 (Pudupettai) and highest in Stn. 11 (Vellakovil), Stn 21(Nagapattinam) and Stn. 23 (Velangani). There is a decreasing trend from Stn. 1 to Stn. 6 (Cuddalore to Pudupettai) in a southerly direction and again there is an upward trend from Stn. 7 to 11 (Kooliyar to Vellakovil).

The total number of species and individual species shows a more or less similar trend (Figure 3). The number of individuals is lower in Annapanpettai, Pudupettai, Koliyar, Thirumullaivasal, Vanagiri, Karaikal, Samdanpettai and Nagore. The total number of living foraminifera in the study area shows that the highest diversity is noticed in Stn.1 (Cuddalore) and then a sudden decrease in the trend upto Stn. 6 (Pudupettai). Peak is at Stn. 10 (Vanagiri) and lower species in Stn., 17, 18, 19 (T.R. Pattinam to Nagore).

In the study area, the width of the beaches varies from place to place and has been reported by Revathi (2002). However, in the study area the width of the beach changes largely from 20 to more than 200 m in Nagapattinam, Karaikal, Tharangambadi, Poombuhar, mouth of Coleroon river and Velar rivers. Due to the configuration of the beaches, the distribution of foraminifera also varies in different places. Further,

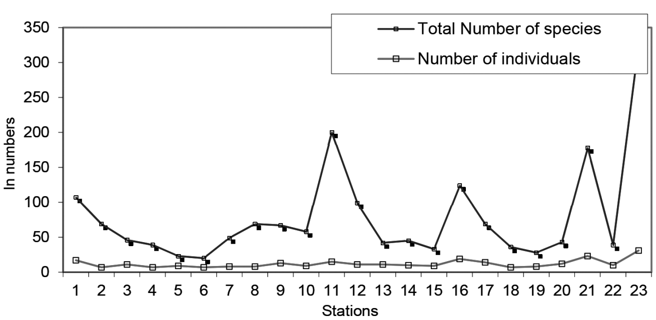

Figure 3: Number of individuals and total species of foraminifera beach.

tsunamigenic sediments brought towards the land region also affects the distribution of foraminifera.

Inland Region

The distribution of foraminifera is comparatively very low in the inland region compared to the beach. The maximum diversity is noticed in Cuddalore and Annapanpettai in the north and Thirumulairajan. R, Nagore, Nagapattinam, Keechankuppam and Velangani in the south. Figure 4 shows the total distribution of foraminiferal species in the inland region. The lowest species is noticed in Koliyar and Pudupettai in the north. *A.beccarii* is widely distributed in all the samples. Inland pit sample at Karaikal. *Golobigerina* distributed in this region indicates that it is transported from the offshore region. Along the study area, saltpans are noticed at a few places namely Nayakankuppam, near Tharangambadi, near Karakalacheri and near Vepancheri. No microfauna are observed in this region. It indicates that the saltpans are not much affected by tsunamigenic sediments in this region.

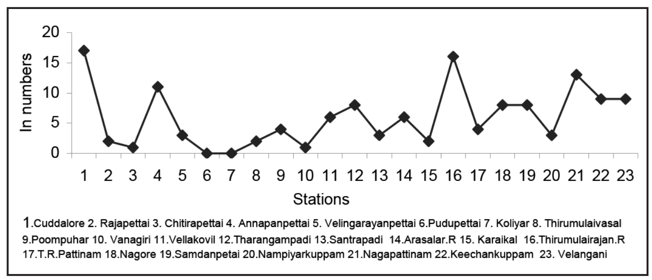

Figure 4: Total number of foraminiferal species in inland areas.

The species distributed in the inland region is mostly of beach and offshore environments. The study area receives inputs from number of small channels and rivers like Gadilam, Uppanar, Arasalar, Coleroon, Tirumulairajanar and Vettar. The land areas through which these rivers and channels flow are well known for agricultural activities. Tsunamigenic sediments entered into the land areas through the rivers and recede back to the shore. During the tsunami, the sediments were brought from the offshore to inland and again washed back to the shore. Further, in the inland region, beach ridges and sand dunes are destroyed by wave actions and produced like sand sheets. Hence, the total populations of foraminiferal species are very low in the Inland region compared to the beach.

Estuarine Environment

Six-core samples upto a length of 1 m in the estuaries have been collected and analysed (Figure 5). In

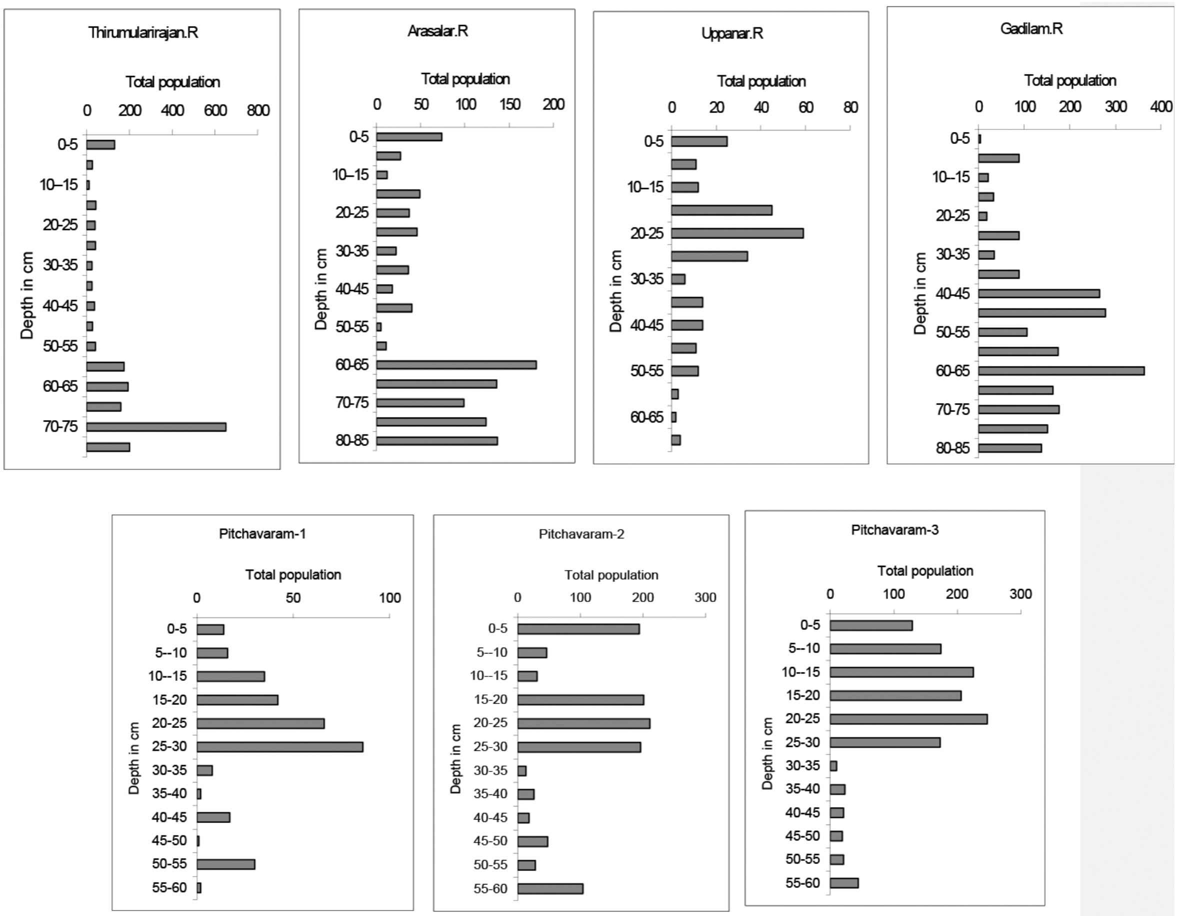

Figure 5: Down core distribution of foraminiferal species (estuaries samples).

Thirumulairajan, R, Arasalar, R and Gadilum, R, an increasing trend of foraminiferal diversity is noticed at the depth of 60 cms to 85 cms whereas in Uppanar, R near Thirumulaivasal shows a decreasing trend at the depth of 30 cms. Again at Pitchvaram1, 2, 3 cores show a more or less similar pattern with an increasing trend from 0 to 30 cms. At Pitchavaramand Parangipettai, the mangroves are located closer and hence the tsunamigenic sediments have not been entered into the adjoining settlements.

The total number of individual species is higher at Thirumulairajan core (22 species) and lower at Uppanar. R (13 species). Figure 5 shows the distribution of foraminiferal species in various core samples. The highest species distribution is noticed in the Coleroon. R. The following species are distributed in the Coleroon estuary namely *T. agglutinans, T. conica, Trochomina inflata, S. costifera, Vertebralina striata, Quinqueloculina agglutinans, Q. lamarkiana, Q. seminulam, T. trigonula, Bolivnanobilus, Reusella simplex, A. beccarri, A. dentata, A. tepida, Asterorotalia trispinosa, Pararotalia nipponcia* and *Elphidium crispum.* The Coleroon River estuary lies near Pudupattinam. In Thirumularirajanar, Arasalar and Gadilam river, the upper surfaces received a lesser amount of microfossils, which may be due to the washout of the tsunamigenic sediment whereas in Coleroon, foraminifera are higher in amount, it may be due to the broader width of the river mouth than the other areas is inferred.

Offshore Locations

Out of the 92 taxa identified, only 39 species were living at the time of sample collection. Among them, most of the species are sparingly distributed. The actual number and distribution of total and living foraminiferal species in the offshore region is shown in the Figure 6. The significant variation in the distribution of total and living species assemblages may be due to sedimentation as well as due to the wave actions and tidal currents, Murray (1973). Since the samples are collected after tsunami, due to the wave actions, the living dead populations also varied in this region.

The general trend in modern shallow water foraminiferal assemblages is the increasing species

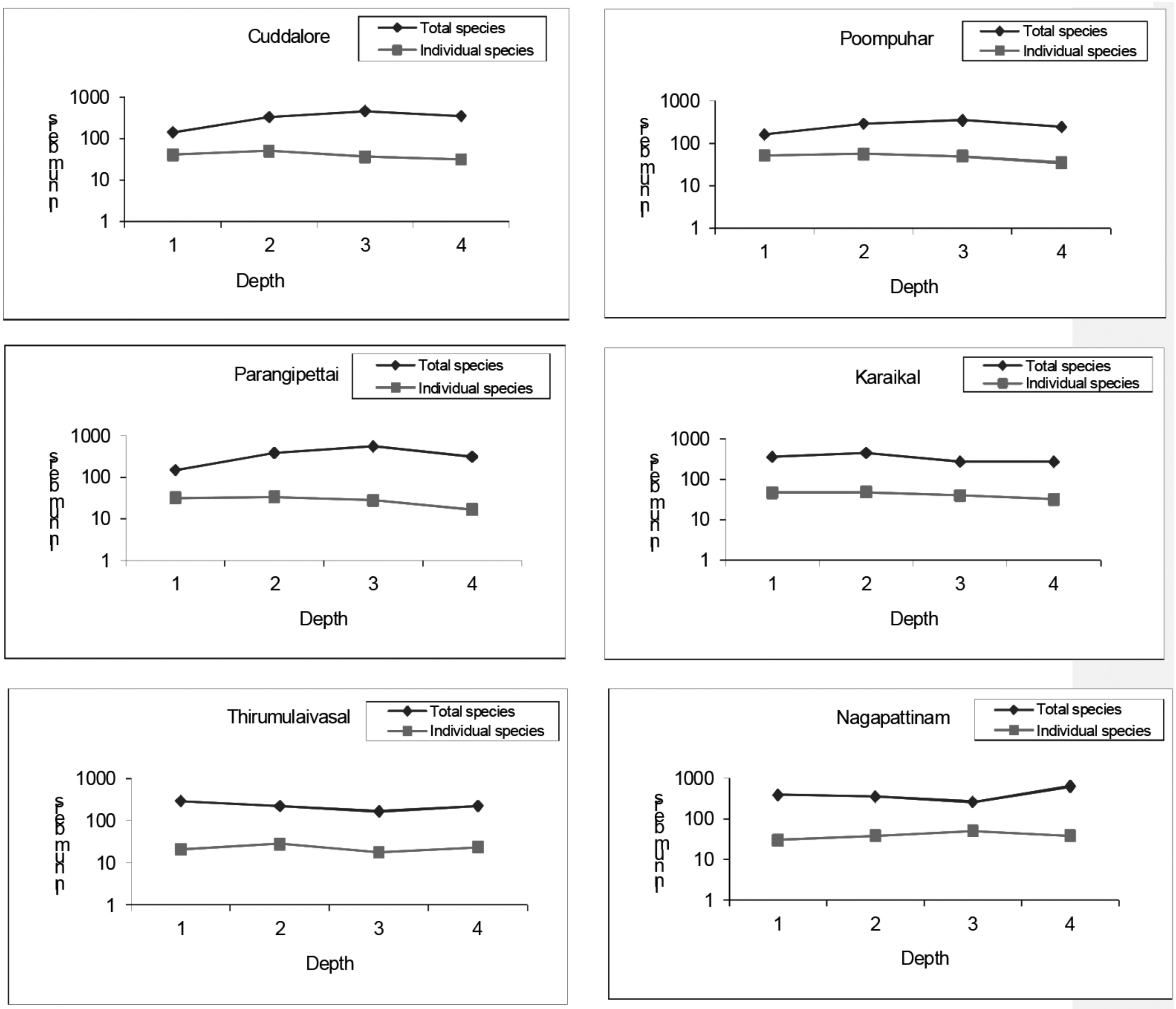

Figure 6: Stationwise distribution of the total and individual foraminfieral species-offshore.

diversity in line with increasing salinity gradients and environmental stability. The genera *Ammonia, Elphidium, Amphistegina, Quinqueloculina, Triloculina* and *Spiroloculina* are dominating the total assemblage followed by *Nonionoides*, *Globigerina* in the study region. The following species are distributed in more than four stations, *Spiroloculina communis, Quinqueloculina elongatum, Q. lamarckiana, Q. seminulum, Triloculina trigonula, Cibicides lobatululs, A. beccarii, A. dentata, A. tepida, E. crispum* and *Assilina ammonoides*. The following species are found only in a few stations, namely, *Elphidium norvangi, Rectobolivinaraphanaus, Cribrononion simplex, Cymbaloporettabradi, Hanzawiaconcentrica, Eponoidesrapandus, Cancrisauriculus, Bolivinahadai, Cycloferniasemiplicata, Quinqueloculina cf. mosharrafi, Spiroloculinanitida* and *S. henbesti.*

Station-wise Distribution of Total and Individual Foraminiferal Species

Figure 7 shows the station-wise distribution of total and individual foraminiferal species in the offshore region. The distribution of total foraminiferal species according to the different stations brings out an appreciable rise and fall among the stations. The stations, Cuddalore, Parangipettai, and Poompuhar, show a similar trend. Here, an increasing trend is noticed from shallow to deeper depths. Whereas in Thriumulaivasal and Nagapattinam decreasing trends are noticed upto 10 mts depth and an increasing trend is noticed in the deeper depths. In Karaikal, an alternate rise and fall trend is noticed. The individual species distribution shows that an increasing trend is noticed towards the shallow regions than the deeper parts. Even though, the individual species are more in the shallow regions the

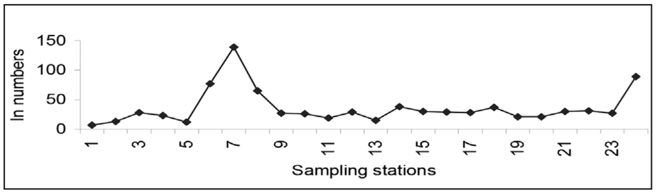

Figure 7: Total number of living foraminifera species in the offshore.

total number of foraminiferal species is more abundant in the deeper depths ranging from 8 to 12 mts.

Station-wise Total Diversity of Living Species

The total number of living foraminiferal species in the offshore region shows that an increase in the number of living foraminifera is observed in the Parangipettai region than in the other region. The lowest order of diversity is noticed in Cuddalore more or less a close similarity in the trend is noticed in the remaining stations. Because of high order of disturbance in the seabed and the strength of erosion, the least number of living diversity is noticed in this region. A close similarity is also noticed with living and total foraminiferal species. Wherever the total species is high, the living species is also considerably increasing.

Ecological Implications of Foraminifera

The distribution and abundance of living foraminifera are controlled by a number of natural factors which include temperature, salinity, water depth, nutrients, sediment substrate, dissolved oxygen content, calcium carbonate, organic matter, etc. These various environmental factors are, obviously, not independent of each other as, for example, light and temperature are related to water depth, and calcium carbonate solubility is related to temperature and salinity. The results of ecological parameters and living/dead species are shown in Table 2.

In the present study, only morphological abnormalities are observed in the *Spirolociluina* with two apertures. The broken species in beach, offshore and inland region is also noticed. It may be due to the tidal actions and strong current activities.

The comparison of pre-tsunami data available from earlier workers like Ragothaman (1974) Portnova samples; Rasheed and Ragothaman (1978) Portnova samples; Rao et al. (2005) Pitchavaram samples; Kathal (2002) Littoral sediments of East coast of India; Kumar and Srinivasan (2004) Coleroon River estuary; Stephen (2005) Nagapattinam to Nagore, with present post-tsunami work has been carried out. The study reveals that in the offshore region at the shallow depths the fossil enrichment is more in post-tsunami sediments than the pre-tsunami samples. Due to the tsunami activities, a large amount of sediment is transported from the deeper depths and deposited near the shore regions, hence a higher amount of species diversity is noticed in the near shore region.

From the field study along the coast, it is observed that the topography has been smoothened as tsunami overtopped the dune, ridges and transported the material into the low lying areas in a few regions. It is difficult to estimate where the material is transported unless the dune material is different from the type of soil in the land. Sand deposits over mudflats, alluvial flats clearly reveal that a considerable amount of beach deposits have been transported in the inland. While the eroded features provide insight into the transport of the sediments, how much material has been brought from the deep sea and continental shelf is not clear. Rip clasts of clay lumps and rare coral debris definitely indicate that the tsunami has brought sediments from the sea.

The fact that a considerable amount of sediments are transported into the sea during backwash is clear as the tsunami has carved channels as much as 5 m wide and 30 m long and the material of the trench formed is removed during back wash. So, it is evident that both transportations from seabed to land, transport of beach material to inland and transport back to the sea has taken place. The erosion appears to be more in the northern part of the area investigated; on the other hand, deposition dominates over erosion in the southern part of the area, which is characterized by flat topography (Sanjay Gandhi, 2005).

The total distribution of foraminifera is higher at Cuddalore in the North, Vellakovil near Tharangambadi, in the central and Velangani and Nagapattinam in the south in the beach samples. Offshore regions, Cuddalore, Parangipettai and Nagapattinam receive abundant species. The configuration of the beach controls the distribution of foraminifera from offshore to the beach. Hence the distribution of foraminifera is varied since the width of the beaches is also varied at different places taken in the study area. In the narrow-beaches, the tsunamigenic sediments reside back quickly whereas in the wider-beaches the tsunamigenic sediments travelled towards the inland region.

Cuddalore, Tharangambadi, Karaikal and Nagore are behaving as the nodal drift points, with equal volume of sediment transport in either directions annually. Highly beach levels are varied in Poompuhar, Tharangambadi and Nagapattinam, the width of the beach is 70 m, 250 m and 120 m. These are the sandy beaches and the width varies upto 30 m in Poompuhar, 0 to 225 m in Tharangambadi and Nagapattinam 0 to 56 m/ Year (Jena, 1997). The distribution of foraminifera is dominant in this region may be due to the configuration of the width of beaches being higher in that region as compared to the other places.

The study area receives inputs from number of small channels and rivers like Gadilam, Uppanar, Arasalar, Coleroon, Tirumulairajanar and Vettar. The land areas through which these rivers and channels flow are well known for agricultural activities. Tsunamigenic sediments entered into the land areas through the rivers and reside back to the shore. The total populations of foraminiferal species are very low in the Inland region compared to the beach. Living populations are found to be low to moderate in number in the study area.

In the study area the mangrove swamps occur in the marshy areas along the coast of Pitchavaram region. The distribution of foraminifera is not much affected due to tsunami in this region. The mangrove vegetations grow irregularly around Pitchavaram lagoon, consisting of *Rhizophora*, *Avicennia marina*, *Bruguiera cylindric*, *Aegiceras corniculata ceriops decandra*, etc. (Meher-Homji, 1973). About 8 sq. km are now under mangrove vegetations, reported by Anbarasu (1994).

Several authors, Yassini and Jones (1995); Murray (1991); Nigam et al., (1979); Haig (1988) have studied and reported the distribution of foraminifera in various regions and concluded that the distribution of species occurred in different environments. The species *Amobaculites exiguus* are distributed on the continental shelf and slope of West Africa. *Trochammina inflata* is common in hyposalinal tidal marshes throughout the world. This is a typical foraminifera of intertidal marshes and is adapted to lowered salinity and exposure. This species is distributed on the continental shelf and slope. *Textularia agglutinans* is a cosmopolitan species, continental shelf and slope off West Africa. Some agglutinated foraminifera, e.g. *Textularia* are also abundant in the study region. *T. agglutinans* which is characteristic of more open marine conditions. The distribution of species of *Pararotalia,* which is a very good indicator of strong marine influence environments, is noteworthy.

Textularia candeiana is found on the shelf and slope off West Africa, the middle shelf of the south east coast of Australia. *Textularia conica* is mostly distributed in the Coral Sea. *Textularia porrecta* is from the middle and outer shelf off the south east coast of Australia. *Vertebralina striata* is found in inner neritic sand and mud facies of the Papuan Lagoon, Mediterranean and Indo Pacific warm and shallow waters. *Spiroloculina affixa* occurs in open estuaries.

Globorotaliatumida is found at the north of Latitude 22º S. *Globigerina bulloides* occurrence from the middle and outer shelf, continental slope, and occasionally in shallow areas. *Bolivinahadai* from deeper water samples off Cochin. *Brizalinastriatula* lagoons, open estuaries, sheltered oceanic embayments, inner and middle shelf, off the southeast Australian coast. *Loxostominadurrandii* is from the shelf sediments off both east and west coasts of India. *Loxostominalimbata* is from the inner neritic sand and mud facies of the Papuan Lagoon, New Guinea. *Siphogenerinavirgula* at inner neritic sand and mud facies of the Papuan Lagoon, New Guinea. *Cancrisauriculus* is observed to be a shelf species. *Eponides* continental shelf and slope off West Africa. *Eponidesrepandus* is an inner shelf species. *Rosalina globularis* is also found on the continental shelf and slope off West Africa. *Discorbinellabertheloti* were observed from the intertidal zone of the inner shelf, middle shelf, and rarely in the inlet channels of coastal lagoons of the southeast coast of Australia.

Amphisteginaradiata are reported from the coral seas. *Nonionellastella* is from inner shelf sediments off the east coast. *Nonionellinalabradorica* is found in West African shelf and slope. *Rosalina globularis* is a tolerant species, which exists in turbid waters. The prolific abundance of *Quinqueloculina* and *Spiroloculina* directs the prevalence of cosmopolitan species. The innershelf species like *Bolivina*, *Orbulina, Globigerina* and *Textularia*etc are widely distributed in all the beach and the samples could be attributed to the deposition by drifting onshore currents. *Bolivina* prefers muddy substratum and is restricted to bathyal and marginal conditions.

Kamalakanan et al. (2005) have studied the tsunamigenic sediment from the Nagapattinam coast and inferred that the majority of foraminiferal species have habitat in coastal water environment and hence the sediment would have been removed from the coastal water zone by tsunami waves and spread over along the coastal line.

Rao et al. (2005) have studied the tsunami laid sediments along the North Chennai coast and suggested that the fossils distributed in these areas have been transported from the inner shelf region, probably at depths less than 30 m.

Climate Indicators

Marine formanifera species are useful for the evaluation of ecological responses to both long-term and sudden climate change. The accuracy of paleoclimate changes mainly expressed in the diversity of species, external morphological characters, and geochemistry of their skeletal remains from ocean sediments. The careful present studies have delivered a wealth of information on changes of oceanic climate. In addition, climatic factors such as temperature, salinity, water depth, oxygen content of the seafloor and changes in sea level have an impact on benthic foraminifera *(Ammonia beccarii*, *Elphidiumcrispum*, *Rosalina globularis*, *Asterorotaliatrispinosa* and *Pararotalianipponica*) and their habitats. The total distribution of foraminifera is higher at Cuddalore and Nagapattinam whereas at Pudupettai and Samadanpettai it is noticed in the lower order because of the climactic conditions related to input of the heavy rainfalls and related temperature variations.

Conclusions

The study highlights the presence of composite cosmopolitan fauna of 99 species belonging to 41 genera, 26 families, 17 superfamilies and 5 suborders from the samples collected from the beach, inland, estuaries and offshore. From the overall studies of foraminiferal distribution in this region, it may be inferred that the species distribution in the offshore region is mainly derived from the inner shelf region. Due to tsunami activities, the offshore species are deposited in the beach and transport beach material inland and transport back to the sea. Based on the study, we have found remarkable changes in the species composition, abundance, distribution and associated sedimentary characteristics of foraminifera species. Moreover, this study provides the basis for reconstructing past climates and abrupt climatic changes, especially temperature, salinity and precipitation. Foraminifera are the most valuable indicators of future climate changes in the study area.

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