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Distribution of certain ecological parameters and foraminiferal distribution in the depositional environment of Palk Strait, east coast of India

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Out of 102 species, only 36 species are living ones. The total distribution of foraminifera is higher at Devipattinam and Attankarai followed by Mandapam, Thondi and Kodiyakkarai whereas at Kottaipattinam, Manalmelkudi and Sethubavachattiram it is noticed to be in the lower order. Organic matter and living species show positive relation. The lack of relationship between dead species and the organic matter has suggested that the dead species recorded in the sediments 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 weak negative correlation with all parameters except organic matter and dead species. Fluctuation of salinity values in Attankarai indicates the influx of fresh water from Vaigai river. Based upon the ecological parameters the stations have been grouped into different environments. Among them, bar environment registers low species diversity than the other three. The following species are appreciably distributed in different stations namely *Ammonia beccarii, Elphidium crispum, Rosalina globularis, Asterorotalia trispinosa, Osangularia venusta* and *Pararotalia nipponica*. This strait is influenced by an unique environment of high order of siltation leading to the depletion of living forams. The present study highlights the abundance of living species in places of high organic matter. The ongoing process of active siltation is manifested in the bar environment and the same is reflected in the low organic matter and less species diversity.

[**Key words:** Benthic foraminifera, siltation, organic matter, carbonate, Palk Strait]

Introduction

Palk Strait is strategically an important channel, as it is shared by India and Sri Lanka without the scope of international navigation. Of late, the coastal ecosystem of the strait is endangered by the shallowing nature of the bay due to silty sedimentation[1]. It is also predicted that the entire bay will be converted into two lagoons by the year AD 2040 if the current rate of deposition of sediments is continued[2]. Loveson & Rajamanickam[3] have referred the development of spit in front of Manalmelkudi and gradual shallowing nature of the shelf region in the Palk Strait by means of the deposition of sediments through longshore currents.

Foraminifera are good indicators for paleoenvironmental studies. Based on the ecology of foraminifera number of authors[4-7] have studied environmental conditions**.** Suresh Gandhi[8] has studied the distribution of foraminifera in Palk Strait and related the living/dead ratio with rate of sedimentation. Similarly, several workers[9-14] have studied the foraminiferal ecology and its environment along the east coast of India. However, the detailed ecology of foraminifera and its relation to sedimentation has not been studied so far from this area. Hence, an attempt has been made in this paper to fulfil this lacuna.

Materials and Methods

Palk Strait is located between Rameshwaram and Kodiyakkarai (lat. 78°50′-79°55′ long. 9°15′-10°20′) (Fig.1). It is 64 km wide and 137 km long. The littoral sedimentation[15] in the entire strait is estimated as 0.6 mm/year. The coastline in the study area trends southward with an eastward trend near Devipattinam in the form of a curvature and westward trend near Kodiyakkarai enclaving Palk Strait. The drainage system consists of rivers like Ambuliar, Tedekkaiar, Vellar, Koluvnar, Vembar, Kottakarai, Gundar, Vaigai, Versuliar and their tributaries. The

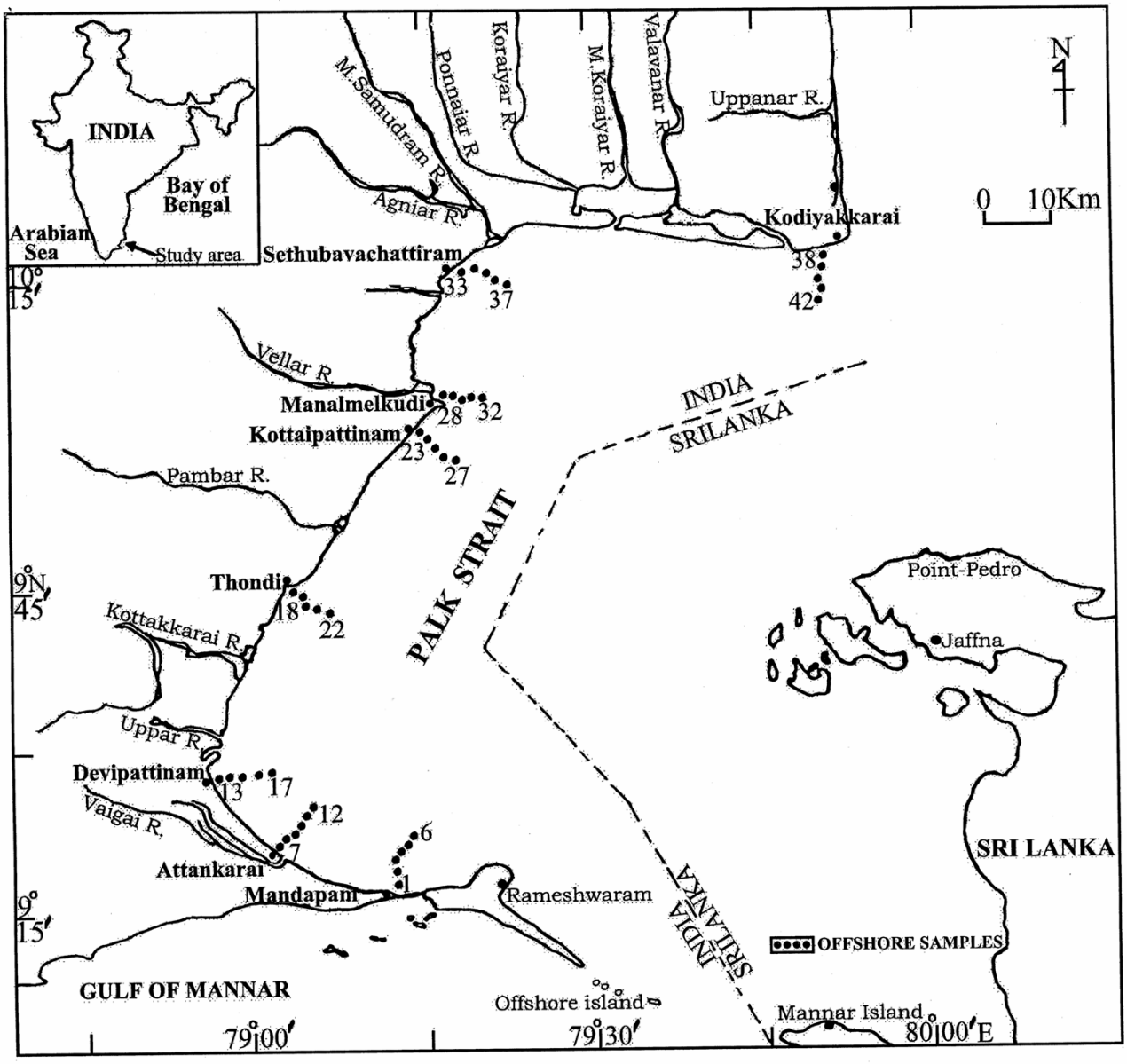

Fig.1.—Location Map

environment of sedimentation is also unique in different places in relation to depths. In Manalmelkudi, a zone of spit growth is earmarked for developing a bar environment. Mandapam, Attankarai, Thondi and Kottaipattinam stations reflect a shallow environment, while Kodiyakkarai registers sheltered environment and Devipattinam, Sethubavachattiram are characterised by channel environment where the SW monsoon is able to push the waves much into this Strait.

By using La fond Dietz snapper 42 sediment samples were collected at eight stations off viz. Mandapam, Attankarai, Devipattinam, Thondi, Kottaipattinam, Manalmelkudi, Sethubavachattiram and Kodiyakkarai to a depth range of 0-12 m. At each station five samples have been collected along a traverse maintained perpendicular to the coast. The samples were preserved in 10 % neutralized formalin. Simultaneously, rose bengal solution was applied to stain the foraminiferal tests in the field[16]. The washed samples were wet sieved using 0.063 mm sieve and then dried. The foraminifera were separated using CCl_4 method and then handpicked under stereo binocular microscope for mounting and counted to estimate the percentage of distribution. The Loeblich & Tappan's[17] systematic scheme was followed for the

classification of foraminiferal genera. On the basis of ecological parameters and the variation in the foraminiferal distribution, the study area is grouped into four depth zones with depth ranging from 0 to 2.5 m, 2.5 to 5.0 m, 5.0 to 7.0 m and deeper than 7.0 m. Calcium carbonate content was determined by volumetric method[18], while organic matter by titration method[19] and sediment granulometry by sieving method[20].

Results

***p*H (*Hydrogen ion concentration*)**

In the study area, the *p*H values of the bottom waters show a negligible variation, at Mandapam (7-7.5), Attankarai (6.5-7), Devipattinam (7), Thondi (7), Kottaipattinam (7), Manalmelkudi (6.5-7), Sethubavachattiram (7), and Kodiyakkarai (6.57.5). The *p*H values of the stations do not exhibit considerable change but in some stations the *p*H values are changing.

Temperature

The present study does not show much variation in temperature at the different stations (29°C to 30°C). The nearshore turbulent wave action must have probably made the temperature almost uniform in all these stations.

Substrate

The relative abundance of sand, silt and clay in the sediments from eight stations indicates that most of the sediments are sandy while few are silt and silty sand in nature.

Salinity

The salinity of the present study varies from 29.9 to 38.2‰. Both the extremes of the Palk Strait, Mandapam and Attankarai (29.9 to 35.28‰) (Fig.2) in the south and Kodiyakkarai (33.67 to 35.85‰) in the north have lower salinity. This is attributable to the mixing of freshwater and lack of churning action. Devipattinam shows the highest salinity (37.2 to 38.2‰). The NE monsoon push brings the Bay of Bengal water direct to Devipattinam. Such movement may enable the presence of high salinity. The negative correlation between the salinity *vs*. depth (-0.238) can be attributed mainly to the strong mixing taking place in this Strait.

Organic matter

The organic carbon content in the study area varies from 0.05 % to 3.40 %. Almost a similar pattern is seen in shallow depths and in 5.0-7.0 m zones (av.1.1

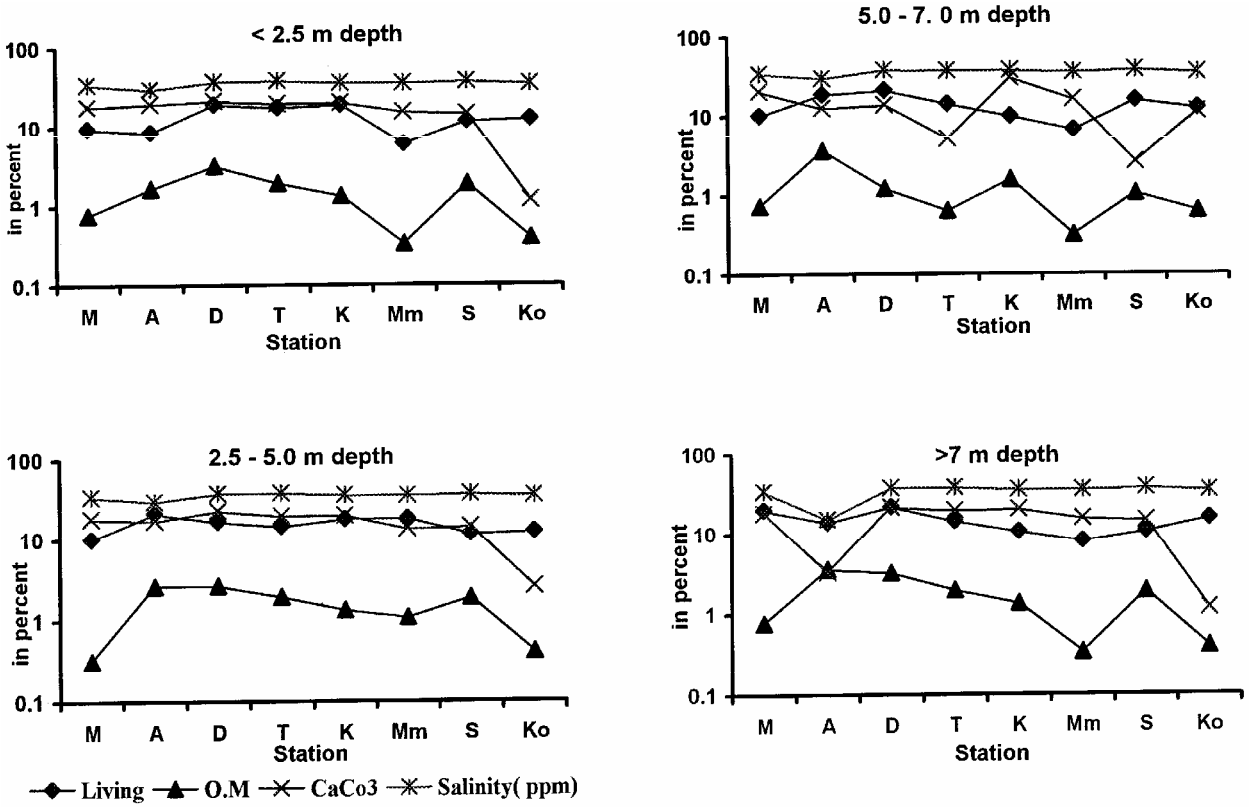

Fig.2.—Distribution of foraminiferal species and its ecological parameters

Table 1—Similarity matrix of ecological parameters

	DE	DS	LI	CC	OM	SA	ME	SD	SK
DE	1.000								
DS	-0.317	1.000							
LI	0.350	°-0.913	1.000						
CC	#0.049	0.016	-0.044	1.000					
OM	0.196	*-0.388	°0.499	@ 0.251	1.000				
SA	-0.238	0.095	-0.087	-0.025	@ -0.254	1.000			
ME	°0.643	-0.172	0.192	-0.179	-0.138	-0.121	1.000		
SD	*0.404	0.158	-0.119	-0.191	-0.157	0.155	°0.637	1.000	
SK	*0.458	@ -0.255	*0.413	-0.156	0.216	#-0.344	°0.550	* 0.416	1.000

Level of significance

° 99.9%	DE - Depth	SA - Salinity
* 99.0%	DS - Dead speceis	ME - Mean
# 98.0%	LI - Living speceis	SD - Standard deviation
@ 90.0%	CC- Carbonate content	SK - Skewness
	OM- Organic matter	

and 1.6 %) but at deeper depths it is observed to be slightly high to the level of average 1.7 % (Fig.2). Station-wise distribution shows a rise in organic matter from Attankarai to Kottaipattinam in the nearshore (0-2 m). The low organic matter in Mandapam (0.78), Manalmelkudi (0.63) and Kodiyakkarai (0.40) in the shallow depth (0-5.0 m) was reflecting a large change in the concentration of organic matter and the same may be ascribed to the prevailing high order of turbidity due to fast moving currents. Kodiyakkarai records a low organic matter content of 0.55 %, probably, the lowest in the study area.

There is a good positive correlation (0.499) between the living species and organic matter and very low negative correlation (-0.388) with the dead species (Table 1).

Carbonate content

The carbonate content ranges between 1.17 % and 30 %. Carbonate content was high at 0 to 2.5 m and > 7.0 m depths when compared to other zones (Fig.2). However, at Thondi up to 5 m an increase of carbonate content (10 to 20 %) was noticed. This can be attributed to the rise in living and dead species and the presence of appreciable broken shells mixed up in the sand in this area. A higher carbonate content (20.15 to 30 %) was noticed in Kottaipattinam. At Kodiyakkarai the calcium carbonate content reaches 19.5 % at 7 m depth.

Distribution of biotic parameters

From the 42 sediment samples, 102 benthic foraminiferal species belonging to 51 genera, 38 families, 22 super families and 5 suborders have been identified. Of which, 36 species are provided as living specimens. Among the species present, *Ammonia beccarii, Ammonia dentata, Osangularia venusta, Elphidium crispum, Asterorotalia trispinosa, Quinqueloqulina seminulam, Pararotalia nipponica* exhibit prolific abundance. Six species namely *Spiroloculina communis, Quinqueloqulina lamarckiana, Quinqueloqulina seminulam, Ammonia beccarii, Elphidium crispum, Elphidium discoidale* have shown an uniform distribution in more than six stations. The southern part of the Palk Strait which includes the stations Mandapam to Kottaipattinam show the presence of species like *Spiroloculina indica, Quinqueloqulina agglutinans, Quinque-loqulina parkari, Quinqueloqulina tropicalis, Triloculina tricarinata, Cymbaloporetta bradi, Pararotalia calcar, Elphidium advenum,* whereas the same are noticed to be directly absent in the northern part of Palk Strait which includes the stations from Sethubavachattiram and Kodiyakkarai and *Nonion elongatum, Asterorotalia inflata* are characteristically present in the stations from Sethubavachattiram and Kodiyakkarai, whereas the same is distinctly absent in the southern stations from Kottaipattinam to Mandapam.

Based on the above ecological factors and their variation, the study area can be grouped by means of different ecological parameters with shallow, channel, bar and protected environments (Table 2). From the above studies, a characteristic difference in ecological parameters like low organic matter and salinity in Kodiyakkarai, high carbonate content in

Table 2— Results of four different environments in Palk Strait

Ecological factors	*Bar environment*	*Shallow environment*	*Shadow environment*	*Channel environment*
Depth zone	0 - 2.5 m	2.5 -5.0 m	5.0 -7.0 m	>7.0m
Stations	Manalmelkudi	Mandapam	Kodiyakkarai	Devipattinam
		Attankarai		*Sethubavachatiram*
		Thondi		
		Kottaipattinam		
Organic matter(%)	0.05-0.63	0.32-1.95	0.64	1.02-1.18
Carbonate content (%)	13.35-17.48	9.97-24.47	19.47	13.62-20.20
Standard deviation (phi)	1.27	0.48 –1.44	1.97-2.45	1.51-2.19
Mean (phi)	1.74 – 1.83	1.04-1.70	3.60-3.81	4.19-5.12
Skewness (phi)	-0.25- -0.30	-0.19- -0.85	0.21-0.25	0.01- -0.09
*p*H	6.5	6.5-7	7.5	7.0
Living species (in %)	2.69-9.49	3.09-21.20	11.55-13.32	10.64-21.71
Salinity(ppm)	34.84-34.89	29.96-37.78	33.67	37.32-38.00
Substrate	*Sand*	*Sand*	*Sity sand*	*Silty sand & Silt*
Algae	*Low*	*Intermediate*	*Low*	*Low- High*
Abundant & common genera	Ammonia	Rosalina	Ammonia	Ammonia
	Elphidium	Ammonia	Elphidium	Pararotalia
	Pararotalia	Osangularia	Asterorotalia	Quinqueloculina
	Spiroloculina	Pararotalia	Nonionoides	Spiroloculina
	Quinqueloculina		Bolivina	Triloculina

Kottaipattinam and silty sand in Kodiyakkarai was noticed.

Bar environment (0-2.5 m) Manalmelkudi is found to have the lowest diversity in the shallow depth zone. It is inferred that the maximum disturbance taking place in this depth may be attributed to the observed anticlockwise movement of currents getting initiated at the depth. It is expected that such momentum to make up a regular reversal currents. The distribution of living species was the least at Manalmelkudi. Only few species namely *Ammonia beccarii, Rosalina globularis* and *Quinqueloculina lamarckiana* were seen alive. The species namely *Ammonia beccarii, Spiroloculina costifera, Triloculina trigonula, Pararotalia nipponica* and *Rosalina globularis* are present in this environment. Among them *Ammonia beccarii* is considered to be highly tolerant to different ecosystems [21]. The present observation supports the survival of species having high order of tolerance in turbulent conditions. Under such turbulent environment having sandy substratum with salinity ranging between 34.84-34.89 ‰, organic matter to ranges from 0.05-0.63 %.

In the shallow environment (2.5–5 m) at Mandapam, Attankarai, Thondi and Kottaipattinam the species such as *Ammonia beccarii, Pararotalia nipponica, Spiroloculina communis, Miliolinella circularis, Quinqueloculina polygona, Q. seminulum, Triloculina trigonula, Elphidium crispum, Asterorotalia dentata, Rosalina globularis* and *Osangularia venusta* were widely distributed. Among the different stations Mandapam shows a high order of diversity in the shallow depths. Kottaipattinam and Thondi registered the least distribution. In view of the instability noticed in the channel bed, the number of living species must have been reduced compared to

the other samples collected in deeper zones. Attankarai station did not show higher number of living species like Kottipattinam and Thondi where the terrigenous supply is expected to maintain turbidity and instability in the substratum. The river Vaigai is considered to be a major river when compared to Kottaipattinam creek but most of the detrital sediments brought by the creek must have been retained in the downstream itself rather than reaching the nearshore. Organic matter ranged between 0.32-1.95 % due to the nature of sandy substratum in this environment.

In the protected environment (5–7 m) at Kodiyakkarai the diversity remains to be more or less same, suggesting lack of changes in the living conditions of the seabed. The species *Rosalina globularis* was absent in this station instead *Ammonia beccarii, Elphidium incertum, Ammobaculities exigus, Quinqueloculina elongata, Massilina secans tropicalis, Nonionoides boveanum* and *Osangularia venusta* are present in this station, whereas *Asterorotalia trispinosa* and *Bolivna nobilus* are seen in dead condition. In this station the sea bed is dominated by silt and low salinity (33.67 ‰), organic matter (0.64 %). The presence of unique positive skewness (0.21-0.25) in this station leads to infer the possibility of existence of non-beach sediments.

In channel environment (>7 m) at Devipattinam and Sethubavachattiram the species *Ammonia beccarii, Rosalina globularis, Asterorotalia dentate, Elphidium crispum, Triloculina tricarinata, Spiroloculina costifera, Cymbaloporetta bradi, Lagena striata, Milliolinella circularis, Textularia agglutinans, Pararotalia nipponica* and *Osangularia venusta* were observed. At Devipattinam living species are more when compared to Sethubavachattiram. High salinity (37.32 - 38.00 ‰), organic matter and seaweeds accumulation favour for more population [22]. At Sethubavachattiram, nine living species recorded. It is already indicated that this region is being often disturbed by the monsoonal currents. Moreover, the retreating currents starting from Manalmelkudi, where only nine species reported, pass through this channel bed in anticlockwise movement. Because of the prevalence of high order of disturbance there, only *Elphidium crispum* and *Asterorotalia inflata* were seen in plenty.

Discussion

In the south, Mandapam to Thondi, a shallow environment, higher order of organic matter is noticed in the depth zone of 2.5-5.0 m. It is probably expected to have been the contribution of large amount of observed debris of seaweeds. The rich growth of seaweed in the depths of 2.5 m to 5.0 m supports the above inference[23]. The lower percentage of organic matter in bar environment is attributed to the high-energy conditions prevailing there. The presence of an average of 6.0% of living benthic foraminiferal species in Manalmelkudi supplements the poor conditions for the living benthos. The organic matter was found to be in the lowest order of concentration (1.16%) at 5 to 7 m, where the drifting currents move in anticlockwise direction and further, the monsoonal currents enter from the channel with full strength. It is found to be a zone of unstable substratum having number of minor channels criss-crossing this zone. In view of the presence of active bottom currents, settling of organic matter is expected to be much less.

The low organic matter in Kodiyakkarai may be attributable to the slow settling of fine sediments, which have been brought to the sheltered condition. Such settling of suspended load in this calm environment, which maintains turbid nature, is expected to lead to low productivity. The presence of active siltation is also supported by Jena[15].

The lack of relationship between dead species and the organic matter has suggested the dominant influence of *in situ* living species such as *Quinqueloculina seminulum, Triloculina trigonula, Rosalina globularis, Ammonia beccarii, Pararotalia nipponica, Elphidium crispum* and *Osangularia venusta* in addition to the presence of abundant seaweeds.

Carbonate content shows the weak correlation with all the parameters except dead species, depth and organic matter (Table 1). It shows that carbonates must have been from the drifted shells from Gulf of Mannar and Bay of Bengal, by strong currents into the strait and also from the large amount of broken shells through creeks and rivers in the form of a limited terrigenous supply[24].

The higher carbonate content at Thondi and Kottaipattinam is probably due to the accumulation of high order broken shell debris dumped through the creek. Large amounts of broken shells are observed even in the sands downstream of the respective creek. As far as broken carbonate shells and dead shells are concerned, it is noticed that they are being inducted into the Strait by the fast moving currents, whereas the rivers and creek supply the broken empty shells as terrigenous contribution.

At Kodiyakkarai carbonate content reaches 19.5% at 7m depth. When the sediments are macroscopically checked, a higher order of broken shells is noticed. It is presumable that this is the depth in which the bottom currents could ebb before leaving the channel. At such juncture, there is a possibility of getting the neutralisation of opposing currents and a sudden change in momentum brings a condition favourable for the deposition of light fractions including broken shells drifted seawards.

The presence of sandy beds both at the south and north of Manalmelkudi clearly establishes the active current movements around the spit. The silty nature of samples at Kodiyakkarai indicates the prevalence of calm environment, which enables the drifted suspended load to get settled.

The distribution of living forams betrays a weak positive relationship with substratum (0.1855). But, the depthwise average distribution of living forams shows more percentage of species in the substrate of silty sand and that too, in deeper depth zone. This is in agreement with Setty & Nigam[25] who reported that the foraminiferal population and diversity are the highest in very fine grained sediments.

A positive correlation was noticed in skewness with the mean and standard deviation. It suggests that the sediments are being actually exposed to the removal of tails in the nearshore due to the winnowing action and deposition of the same in a deeper depths or addition of new tails probably in the form of dead shells, fine silt, etc.

The foraminiferal assemblages are dominated by calcareous forms with rare agglutinated taxa. *Ammonia beccarii, Elphidium crispum, Rosalina globularis, Asterorotalia trispinosa, Osangularia venusta* and *Pararotalia nipponica* are dominant in samples collected from the study area. Other calcareous hyaline forms include *Bolivina, Elphidium* and *Rosalina*. Miliolids include *Articulina, Miliolinella, Peneroplis, Quinqueloculina* and *Triloculina* are commonly distributed in this Strait. Agglutinated taxa in Palk Strait include *Ammobaculites, Quinqueloculina, Reophax* and *Textularia.*

High order of living foraminiferal species, ranging from 15 to 19 % in the stations of Attankarai, Devipattinam and Thondi supplements the good living conditions in the substratum. The presence of an average of 6.0 % benthic foraminiferal species in Manalmelkudi supplements the poor conditions for the living benthics. A lack of relationship between the dead species and the organic matter enables one to infer that the empty tests are mostly filled in by the non tissue materials, probably of sediments only, must have been transported from elsewhere.

Two types of agglutinated species namely *Textularia agglutinans, Textularia porrecta, Reophax*.sp *Quinqueloculina agglutinans*, are widely distributed in the Attankarai and Mandapam regions where the substrate is predominantly sandy. The continuous accumulation of sediments debouched through Vaigai river might have imparted the arenaceous nature to these species. Nigam[26] has reported that *Nonionella* is prominent in medium to coarse (siltysand/sand) substrate. However, in the present study, its distribution was noticed in sand (Mandapam, Attankarai) and siltysand (Kodiyakkarai) substrates. Similar conditions are also seen in final depth at Mandapam and Kodiyakkarai. Setty *et al*.[27] have reported that *Bolivina* prefers muddy substratum and are restricted to bathyal and marginal conditions. The studies on morphotype and habitat preference of benthic foraminifers indicate that *Bolivinids* prefer organic-rich sediments[28]. Its distribution in the nearshore samples of Mandapam and Kodiyakkarai indicates a longer distance of transportation by the currents towards the shore from a muddy substratum in the shelf region.

The distribution of the living species has shown a limitation in the environmental conditions prevailing between the north and south Manalmelkudi of the study area. South of Manalmelkudi records *Spiroloculina indica, Quinqueloculina agglutinans, Q. parkari, Q. tropicalis, Triloculina tricarinata, Cymbaloporetta bradi, Pararotalia calcar, Elphidium advenum* which are found distinctly absent in the north. Most of the species found in the southern region alone are considered to be the varieties very well associated with seaweeds and algae. It has already been supplemented in the earlier discussion accounting the number of species reported from this region. In the north zone of Manalmelkudi, two species *Nonion elongatum* and *Asterorotalia inflata* are uniquely found whereas they are distinctly absent in the south. From the distribution of these two, one thing is certain that the southern portion of the study area reflects a better biodiversity by higher species distribution than in the northern portion of Manalmelkudi spit. In the south, the impact of both

the monsoons is reported to accommodate the redistribution of the sediments and the currents are sufficiently more. So, the turbidity is likely to be comparatively lesser than the north. The high order of disturbance remains in the north because the distance within which the advancing currents have to come back through the anticlockwise movement is highly limited and the configuration of the coast also helps to divert the currents faster. Moreover, the southern portion receives a larger quantity of terrigenous supply particularly the river Vaigai which is a major river of this region. This is supported by Prabakar Rao[29], who has noticed that over a period of one year, a net volume of 24,000 m^3 sediments as a wave induced longshore transport move from Gulf of Mannar to Palk Bay.

Conclusion

From the present study four different environments like bar (0–2.5 m), shallow (2.5–5.0 m), protected (5.0–7.0 m) and channel (>7.0 m) are identified in this strategically important study area. Compared to the surrounding regions lack of foraminiferal species diversity is marked and the existence of active siltation is inferred. The seabed in the Strait is dominantly influenced by the representation of a variety of dead species that too, with infillings of sediments in the place of organic matter. The difference in the overall distribution of the different species suggests the probability of the entry of sediments from different sources one in the north and the other from the south, laden with dead species keeping the Manalmelkudi spit as the dividing line among them.

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