Environmental Conditions off Karaikal, South-East Coast of India, as Deciphered from Recent Benthic Foraminiferal Distributions

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Abstract

Bottom water and sediment samples collected from off Karaikal, Arasalar River mouth and further upstream revealed that the environmental conditions control the distribution of benthic foraminiferal populations. In the offshore region, although *Ammonia beccarii* dominates the assemblage, depth of the water column seems to play a significant role in controlling the distribution of taxa constituting the assemblage. Within the depth range of sampling, a general increase in total populations of this species is observed. The nearshore stations are characterized by relatively higher total populations of such species as *Spiroloculina orbis*, *Pararotalia nipponica* and *Elphidium crispum*, all of which typically inhabit shallow waters on the east coast of India. Both living and total populations of all the species put together show a definite increase with depth of the water column; the maximum living and total populations have been counted to be 36 and 328, respectively. In proximity to the Arasalar River mouth also, *A. beccarii* predominates the assemblage which, however, is similar to those recorded from estuaries in the Indian region. The assemblage recorded from the upstream samples with relatively increased DO content but decreased salinities is still dominated by the same species, but its associated taxa are characteristic of euhaline to meso-polyhaline environmental conditions. The present study reiterates the need for examining modern benthic foraminiferal distributions and the assemblages therein from diverse environments, in order to facilitate better interpretation of fossil assemblages.

Keywords Foraminifera , Distribution ,Environment ,Karaikal , SE coast of India

1.Introduction

Foraminifera are unicellular, essentially marine micro-organisms, although some species have been recorded from brackish to hyposaline environments (Murray 1991). From the Indian region, extensive foraminiferal studies have been carried out, both from off the east and west coasts, inclusive of beaches, estuaries, channels, backwaters, creeks, rock pools and other marine marginal water bodies. Innumerable researchers have contributed immensely through their studies on Recent foraminifers, right from the late 19th 46 century till date.

2.Previous studies

The earliest work in this context was by Carter (1880) who studied them from samples that were dredged from the Gulf of Mannar. Perhaps the earliest extensive study on littoral zone foraminifera was by Gnanamuthu (1943), who illustrated and described 47 foraminiferal species from the Krusadi Island in the Gulf of Mannar. He also pointed out the similarity of this assemblage to that of the Laccadive and Maldive Islands. Ganapati and Satyavati (1958) recorded 103 species of foraminifers, belonging to 65 genera, from sediment samples collected from the littoral zone at 111 stations, extending from Calcutta (now Kolkata) in the north to Madras (now Chennai) in the south, with concentration of stations off Visakhapatnam. 57 Subsequently, in 1959, the same material was quantitatively examined by Ganapati and Sarojini, who reported 57 additional foraminiferal taxa. A check list of 64 benthonic foraminiferal species was provided by Nigam et al. (1979) from the Dabhol-Vengurla inner shore neritic environment. Setty et al. (1979) gave graphic patterns of 8 dominant foraminiferal groups in the nearshore region of the central west coast of India. Desai and Shringarpure (1982) used Recent foraminifera to study the impact of sedimentation on onshore environment. Nigam's (1986) factor analysis of 60 foraminiferal species from the shelf region off Navapur revealed 3 assemblages; he also presented a technique of comparing living and dead foraminifera for tracking sediment movement. Benthic foraminifera have also been widely used to understand the dynamics of an environment and investigate sediment transport, particularly in the nearshore region. Jayaraju (1993) studied the ecosystem and population dynamics of benthonic foraminifers from coastal and estuarine sediments of Kovalam-Kanniyakumari-Tuticorin areas, from which he identified 54 foraminiferal taxa (both living and dead) of which only 24 had living representatives. The foraminiferal ecosystem in relation to coastal and estuarine sediments of Kovalam-Kanyakumari-Tuticorin sector was discussed in detail by Jayaraju and Reddy (1995); their study was based on 180 bottom water and sediment samples, and they reported 54 foraminiferal species belonging to 3 suborders. Subsequently, they (1996) carried out factor analysis of benthonic foraminifers from the same area and presented 12 factor assemblages, the most important being the Ammonia beccarii- Asterorotalia dentata assemblage. Kathal and Bhalla (1998) examined the Recent littoral sediments along the Palk Strait and Kakinada Bay, east coast of India, and discussed the taxonomy and paleolatitudinal significance of Rotorboides granulosum (Heron- Allen and Earland). Chaturvedi et al. (2000) suggested that on the basis of total foraminiferal number, living and reworked foraminiferal specimens and other ecological variables, the Kharo 88 Creek environment in the Kutch region, Gujarat, can be divided into three biotopes, viz., upstream biotope, transition biotope and lower stream (marginal marine) biotope. Their results were based on 47 foraminiferal species, 44 of them being benthic. Kathal et al. (2000) used an approach integrating cluster analysis and comparison of taxonomical, environmental and ecological parameters of Recent foraminiferal thanatotopes to understand the foramgeographical affinities of the west and east coasts of India. They concluded that the east and west coasts have different affinities; out of 160 taxa, only 26 foraminiferal species were observed to be common to both coasts. An experiment on cultured benthic foraminifera to study their speed of movement on the glass surface of a Petri dish was performed by Khare and Nigam (2000). The first order result of this study provided initial estimates for rate of movement which varied from 0.034 to 0.139 mm/minute. They opined that such laboratory measurements after much refinement, and coupled with field studies, may be of use to model bioturbation and sediment dynamics in coastal regions. The effects of temperature variations on the reproductivity of a benthic foraminifer, Rosalina leei, in culture experiments were studied by Nigam and Caron (2000). They observed that of the paired and unpaired specimens maintained separately at three different temperatures (15, 20 and 25o 107 C), nearly one-half of the unpaired specimens reproduced at all three temperatures, while none of the paired specimens reproduced, although the type and frequency of feeding were common in all the experiments. Nigam and Chaturvedi (2000) studied foraminifers from the Kharo Creek in the Kachch region, Gujarat, and identified 47 species out of which only three were planktonic. They also observed a positive relation between angular asymmetric forms and the clay fraction in the sediment, while the high energy environment was dominated by rounded-symmetric forms. The foraminiferal content of 108 modern marine sediment samples off Vengurla-Cochin sector, west coast of India, ranging in water depth from 30 to 1,330 m, was classified into the two morpho-groups by Nigam et al. (2000). The distribution profiles of these 119 morpho-groups in the surface sediments showed that the angular-asymmetrical morpho-group was more abundant in deeper regions, while the rounded-symmetrical morpho-group tends to flourish in relatively shallower regions. Sinha et al. (2000) presented a preliminary report on the study of benthic foraminiferal content in the marine sediments of Queen Maud Land Shelf, Lazarev Sea, Antarctic, at depths ranging from 157 to 785 m. Rajeshwara Rao and Periakali (2001) discovered a new benthic foraminifer – *Cocoarota madrasensis* Rajeshwara Rao and Revets – from the bottom sediments off Karikkattukuppam; only one species had earlier been reported from the Upper Eocene sediments, and the genus had been thought to have become extinct since then. The significance of spinosity in *Ammonia dentata*, a common benthic foraminifer in the sediments of the Bay of Bengal, had earlier been emphasized by Rajeshwara Rao (1998), particularly with reference to buoyancy.

A systematic study of benthic foraminifera was made by Gandhi et al. (2002) on 42 sediment samples collected between Mandapam and Kodiyakkarai, off Palk Strait, Tamil Nadu, India. In all, they identified 102 benthic foraminiferal species belonging to 52 genera, 38 families, 23 superfamilies and 5 suborders. A comparison of total foraminiferal numbers (TFN) between 1972 and 1990 by Nigam et al. (2002) revealed a decrease in foraminiferal population in Mandovi estuarine sediments, from 10-139 specimens per gram in 1972 to 2-42 specimens per gram in 1990. Similarly, there was also a reduction in total species number (TSN), from 18 (in 1972) to 14 (in 1990). This was attributed to the influence of mining pollution caused by continuous mining activities in the region. Mazumder et al. (2003) analyzed 128 surface sediment samples (76 grab and 52 core top samples) for benthic foraminiferal contents from the region off Goa, India, in the eastern Arabian Sea up to a water depth of 3,300 m, and identified 195 species. Species belonging to Bolivina, Cassidulina, Lernella, Uvigerina and Eponides were found to be the most abundant within the depth zone of 150 to 1,500 m, a zone considered to be the oxygen minima zone (OMZ) for the Arabian Sea. Interestingly, *Bulimina marginata*, which has been reported to be present in considerable numbers within the OMZ in other regions of the world's oceans, accounted for only about 2% of the total benthic foraminifera population in the Arabian Sea. On the contrary, *Bulimina costata*, which constituted more than 15% of the total foraminifera, has not been reported to be abundant from the OMZ of any other region of the world. Saraswat et al. (2003) examined the role of 12-S mitochondrial gene on dimorphism and coiling direction in a benthic foraminiferal species, *Pararotalia nipponica*, using PCR amplification and re-amplification. They observed that all the four different groups selected for their study viz., dextral megalospheric, dextral-microspheric, sinistral-megalospheric and sinistral microspheric should be clubbed together as only one species, but could not explain the reason for the morphological differences.

Nigam et al. (2004) recorded the presence of *Ammolagena clavata,* an agglutinated benthic foraminiferal species for the first time from the Indian Ocean region, in the depth range of 1,650-2,050 m, compared to the depth range of 684-2,503 m in the Pacific and 553-4,500 m in the Atlantic regions. They observed this species to be attached to the planktonic foraminiferal species, *Globorotalia menardii,* in addition to large quartz grains or on some other larger benthic foraminiferal species. In order to develop a viable foraminiferal proxy for heavy metal pollutants, juvenile specimens of *Rosalina leei* were subjected to different mercury concentrations (0 - 180 ng/l) in growth experiments conducted by Saraswat et al. (2004). They observed that total growth achieved was significantly lower in case of specimens kept at relatively higher mercury concentrations then those maintained in normal saline water. The most significant result of this experiment was the addition of abnormal chambers in the specimens kept at higher mercury concentrations.

Citing several case studies from the Arabian Sea, Nigam (2005) demonstrated how environmental issues can be addressed using foraminifers, particularly climatic variations in the past. He emphasized the need for supplementing the traditional hard part foraminiferal studies with a detailed foraminiferal-culture program with a molecular biological approach. A study by Nigam et al. (2005) revealed drastic fall in total foraminiferal number in the lower reaches of the Mandovi River estuary, from 138/g in dry sediment sample in 1994 to 41/g in 2001. The decline was also noted in diversity from 22 in 1994 to only 5 species in 2001. The ever-increasing suspended load in Mandovi Estuary, probably due to mining activities in the catchment area of the river, was suggested as the plausible reason for the decline of fauna. Panchang et al. (2005) noted a substantial increase in the maximum total foraminiferal number (TFN) in the Zuari River estuary, from 1,143 specimens in 1972 to 3,057 specimens per gram sand in 2003; there was also a corresponding increase in the total species number (TSN) from 24 in 1972 to 50 in 2003, in compliance with considerable decrease in total suspended matter TSM over the years. Their study demonstrated the potentiality of foraminifera in detecting mining pollution. The ecology and distribution of a rare miliolid foraminifer, Quinqueloculina cristata Millett, was dealt with in detail by Rajeshwara Rao et al. (2005); their study was based on 56 bottom sediment samples collected from the inner self of the Bay of Bengal.

Temporal variations in abundance and mean proloculus diameter of the benthic foraminiferal species, *Epistominella exigua,* was reconstructed over the last ~50,000 yr B.P. by Saraswat et al. (2005a), from a core collected from the distal Bay of Bengal fan; downcore variations showed significant changes in the abundance of E. exigua during this period. In view of the present-day abundance of this species from areas with strong seasonal organic matter supply, they postulated that postulated that mean proloculus diameter can also be used to infer increased seasonality in organic matter production, and thus variations in the strength or duration of monsoon. Saraswat et al. (2005b) reconstructed the sea surface temperature (SST) for the central equatorial Indian Ocean, over the 211 last ~137 Ky, from Mg/Ca of the planktonic foraminiferal species, *Globigerinoides ruber*. They opined that the equatorial Indian Ocean SST was approximately 2.1^{o} C colder during the last glacial maximum as compared to present times.

Nigam (2006) examined the foraminifers present in the shelly sediment layers in Goa and Lothal Dockyard (Cambay) and related them to the possibility of higher sea level around 6,000 years B.P., and thereby their probable utility in archeological studies. according to Khare and Nigam (2006), foraminiferal studies on a shallow water sediment core off Karwar, central west coast of India have revealed significant changes in the monsoonal precipitation during the last around 720 years. The results hinted towards some possibility of linkage of monsoonal precipitation with solar variability during this period. Nigam et al. (2006) carried out culture experiments to observe the response of Pararotalia nipponica (Asano) to different salinities and estimate its salinity tolerance limits. They observed that specimens of P. nipponica kept in 33‰ saline water achieved optimum growth, while rest of the specimens maintained at either higher or lower salinities showed comparatively less growth. *Pararotalia nipponica* specimens kept at 10 and 15‰ salinity started becoming opaque and later dissolved within a span of 25 days. They concluded that comparatively lower salinities are much more detrimental to foraminiferal tests than higher salinities. In order to document foraminiferal response to various pollutants, and to develop effective foraminiferal proxies for pollution monitoring through time, Nigam et al. (2006) opined that culture studies need to be supplemented with advanced crystallographic and molecular studies in order to find the actual mechanism(s) through which foraminifers respond to the pollutants. In order to understand foraminiferal response to changed oxygen conditions, Panchang et al. (2006) collected three sediment cores at 50 m water depth on the west coast of India, off Ratnagiri, and subjected them to oxygen manipulations maintaining natural temperature and salinity. The results data indicated that changes in 241 natural oxygen conditions caused lowering of foraminiferal numbers, although some species were more adaptive. Saraswat et al. (2007) analyzed the Mg/Ca ratios of planktic foraminifera, and reconstructed the SST in the Indian Ocean over the past 137,000 years, providing a new reconstruction of the changing extent of the warm pool, the east-west gradients and their influence on ENSO through time. A comparison of their results with those from the Pacific Ocean have shown that throughout the larger part of the last ~137 ka B.P., the equatorial Indian Ocean (EIO) was the warmest part of the tropics. Rajeshwara Rao et al. (2010) studied benthic foraminifera from three diverse ecological settings from around Tuticorin on the south-east coast of India – offshore region, mangroves and a coral island. They identified 85 species belonging to 42 genera, 23 families, 15 superfamilies and 4 suborders.

3.Study area

Karaikal is a major port city on the south-east coast of India in the Union Territory of Pondicherry (Fig. 1). The climate is tropical with the maximum temperature of around 39° C during the period between April and May. The annual average temperature varies from 25.9 to 30.6° C with an averagehumidity of ~65%. The area is frequently subjected to cyclonic storms. The average wind velocity ranges from 5-10 kmph, but can increase dramatically during the depressions that form in the Bay of Bengal and subsequently intensify into cyclones or, rarely, supercyclones. According to Rao (1981), the tropical cyclones during the post-monsoon transition period are associated with very heavy rains and stormy winds, especially in the coastal areas.

4.Materials and methods

Eleven sediment and water samples were collected during December 2012 from the study area off Karaikal (Fig. 1) from the littoral zone, and farther offshore; a core was also retrieved (C1), although the results from it have not been included as part of the present study. Figure 2 to 5 shows the field observations in the study region. The five offshore samples (K2 through K6) were collected at water depths ranging from 4.0 m to nearly 15 m. One sample (K1) was collected from the mouth of Arasalar River, and five more samples (R5 through R1) were collected progressively upstream, at depths ranging between 1.5 and 2.3 m. All the samples were collected manually using a mechanized country boat, and the sample locations were fixed using a hand-held global positioning system (GPS). Sediment samples were collected from the sediment-water interface in clean, polythene bags, preserved immediately in a 10% neutralized formaldehyde solution, and neatly labeled for further sample processing, analysis and foraminiferal separation. Water samples were collected in pre-cleaned (washed with dilute nitric acid) polyethylene bottles after rinsing them with the water samples to be collected. Bottom water temperature (BWT) and pH were measured onboard using a thermometer and a portable pH meter, respectively. Salinity was estimated using the standard titration method and equation proposed by Knudsen (1901). Dissolved oxygen (DO) was determined using the standard titration method (Winkler's procedure). The sand-mud contents in the sediment samples were estimated using standard sieving procedures. Calcium carbonate was determined spectrophotometrically after Loring and Rantala (1992), while organic matter was estimated using the standard procedure after Gaudette et al. (1974).

The sediment samples were wet-sieved through ASTM 230 mesh (opening = 63 μm) and kept immersed in a solution of rose Bengal for at least 6 hours (Walton, 1952). Although the rose Bengal staining technique overestimates living populations (Bernhard, 1988), it is still the most widely used technique due to its simplicity (Murray, 1991); moreover, staining in tests of agglutinated species is easily recognized if rose Bengal is used (Bernhard, 1988). The samples were then thoroughly washed to remove excess stain and oven-dried at 50° C. After coning and quartering the samples, 25 g of each oven-dried sediment sample was divided into five fractions using a convenient set of sieves: ASTM nos. 30, 60, 100 and 140. The relatively coarser fractions (+30 and +60) were subjected to manual separation of foraminiferal tests using a 0.00 Windsor sable-haired brush (brush with soft bristles), while the comparatively 302 finer fractions (+100, +140 and -140) were slowly sprinkled over carbon tetra chloride in a beaker. Foraminiferal tests that floated in the CCl_4 solution were separated by filtering the solution; the sunken fraction was cross-checked for any tests that might have escaped floatation.

Foraminiferal tests separated by hand-picking and floatation were mounted over a thin layer of tragacanth gum on 24- or 48-chambered micropaleontological slides, according to their family, genus and species, wherever possible. Each slide was duly labeled with the sample numbers and, after viewing all the slides, hypotypes of the identified species were mounted on micropaleontological single punch (round) slides. These hypotpes were studied in detail for their morphological features and distinctive characters under a stereo zoom binocular microscope (Radical; Model– wf 10x/20). The tests exhibiting all the characters of a typical adult specimen of a species were mounted on brass stubs (1 cm in diameter) using a double-sided adhesive carbon tape, and utilized for scanning electron microscope (SEM) photography (JEOL-6360; JFC-1100; Department of Geology, University of Madras); this table top model uses a sputtering device which coats an ultra thin film of platinum on the specimens to make them conductive to electron scanning as, otherwise, they are poor conductors. All the hypotypes were duly indexed with numbers, labeled, and placed in the repository of the Department of Geology, University of Madras, Chennai 600 025 (Repository numbers: MSG–01 through MSG–33). Based on the widely utilized generic classification of Loeblich and Tappan (1987), 33 benthic foraminiferal species belonging to 18 genera, 13 families, 8 superfamilies and 3 suborders were identified; they have not been been illustrated as they are all established taxa.

5. Results and discussion

Living benthic foraminiferal populations There have been differing opinions on the reliability and utility of total foraminiferal populations as paleoenvironmental indicators. Scott and Medioli (1980) observed highly variable living populations and assemblages that were influenced by climatic and micro-environmental changes over a 3-year period in a Nova Scotia salt marsh. On the other hand, there were no significant changes in total foraminiferal assemblages over the same time period, as the total population integrates the small and seasonal variations into a definable assemblage that reliably reflects prevailing marine conditions. They concluded that consideration of total associations more accurately depicts modern environments and is, therefore, more useful for most paleoenvironmental studies. In the study area, it was observed that living (rose Bengal-stained) benthic foraminiferal populations were insignificant and, therefore, total populations have been considered for comprehending the modern environmental conditions therein (Table 1).

5.1. Offshore environment

In the samples collected off Karaikal (K2 through K6), Ammonia beccarii is easily the dominant species accounting for at least 35% of the total benthic foraminiferal populations (Table 1). Within the depth range of sampling, a general increase in total populations of this species is observed. The nearshore stations are characterized by relatively higher total populations of such species as *Spiroloculina orbis, Pararotalia nipponica* and *Elphidium crispum*, all of which typically inhabit shallow waters on the east coast of India (Ragothaman and Kumar, 1985; Murray, 1991). Pararotalia nipponica has been widely recorded from the Indian region: Bhalla (1972; taxonomic observations); Reddy (1973; Pennar Estuary); Venkatachalapathy and Shareef (1978; Mangalore coast); Kumar (1988; Palk Strait); and Manivannan et al. (1996; Gulf of Mannar). Rajeshwara Rao (1998) observed the occurrence of *Elphidium craticulatum* associated with *E. crispum* at the nearshore stations off Karikkattukuppam, near Chennai. In the study area, however, the occurrence of E. craticulatum has not been observed. The following taxa exhibit an overall decrease in total populations with increase in depth: *Spiroloculina orbis*, *Cibicides lobatulus*, *Pararotalia nipponica, Elphidium crispum* and *Assilina ammonoides*. On the contrary, *Ammonia dentata*, Ammonia tepida 364 and *Asterorotalia trispinosa* show marginal increase in their populations with depth (Table 2). This indicates the control exerted by water depth on total populations in the offshore region of the study area. Some species such as *Spiroloculina depressa, Quinqueloculina agglutinans, Q. costata* and *Q. lamarckiana* do not show significant variations in populations in relation to depth, indicating that they are, perhaps, influenced more by other ecological factors such as the nature of substrate. None of the specimens *of A. dentata* possessed long, slender spines, and their short, blunt spines are characteristic of shallow waters (Ragothaman, 1974; Rajeshwara Rao, 1998). All the other species are rarely distributed. Both living and total populations of all the species put together show a definite increase with depth of the water column; the maximum living and total populations have been counted to be 36 and 328, respectively, at K6 which is the deepest among the offshore stations.

According to Myers (1943), the greatest number of *Elphidium crispum* were found on compact sandy bottoms or in a mixture of sand and gravel in the sublittoral zone. Murray (1963) observed that cultured specimens of *E. crispum* preferred a clean, hard substrate to a soft clayey one. In the study area, the sediment samples from off Karaikal are typically sandy in nature; gravel was, however, not observed in any of the samples, and could be one of the reasons for relatively smaller total populations of this species. On the other hand, Levy et al. (1993) opined that *Elphidium crispum* and *Quinqueloculina seminulum* are both sand-dwelling species in his studies on Recent foraminifera from the continental margin off Portugal; he also noted that *Q. seminulum* was more abundant when sand was more than 90%. Although the offshore samples have sand content in the range of 85.7–92.1%, this species is not as common as in the upstream samples, indicating that the nature of substrate is not a controlling factor.

5.2.Arasalar River mouth

The river mouth sample (K1) is also dominated by *Ammonia beccarii*, which significant, are typical of modern-day estuaries along the Indian coast, and are present in the following order of abundance: *Ammonia tepida*, *Quinqueloculina seminulum, Paratotalia nipponica, Elphidium advenum* and *P. calcar*. The presence of all these taxa have been recorded by several workers: Ramanathan (1969; Vellar Estuary); Reddy (1973; Pennar Estuary);

Venkata Rao and Subba Rao (1974; Suddagedda Estuary); Antony and Kurian (1975; Vembanad Estuary); Kaladhar (1981; Tandava Estuary); Reddy (1981; Araniyar Estuary); and Yeruku Naidu (1983; Vamsadhara Estuary). An interesting comparison between specimens *of A. beccarii* collected from the Mediterranean Sea (salinity 37–39‰) and from the Black Sea (salinity 18– 22‰) was mentioned by Furssenko (1978) in which he observed the tests of the latter to be smooth, with fewer chambers, lacking ornamentation and umbilical plugs, indicative of morphological adaptations to reduced salinity. In the study area, both offshore as well as upstream, tests of this species displayed umbilical plugs and possessed relatively more number of chambers, more similar to those from the Mediterranean.

In their studies of foraminifera of the Maldivian Archipelago, Levy et al. (1996) recognized three groups based on bathymetry, and observed that such taxa as Quinqueloculina seminula were dominant at depths <10 m, but also continued into the next group (10 to 50 m). The minor presence of *Textularia agglutinans* and *Ammobaculites exiguus* could also be considered to be indicative brackish environment, which is so characteristic of mangroves and salt marshes. Based on observations of foraminiferal associations from the Waitemata Harbour, New Zealand, where salinity variations ranged from brackish to normal marine, Hayward et al. (1997) concluded that *Ammonia beccarii* is one of the species capable of coping with wide range of salinity; lowest salinity species included *Ammobaculites exiguus*.

5.3. Upstream samples

The upstream samples (R5 through R1) are characterized by relatively higher dissolved oxygen (DO) content (Table 3) when compared to the offshore samples. Most of the organisms that inhabit natural waters constantly consume the dissolved oxygen; for life to be sustained, therefore, the DO has to be replenished, a process that is generally accomplished by a process called re-aeration. Stream flow is the main source of re-aeration and mixing in freshwater systems (Butler and Burrows, 2007), and the higher upstream DO values corroborate this fact. Comparatively reduced salinities in these samples result in typical euhaline to meso-polyhaline conditions (Wagner, 1957) that favor those taxa that are able to adapt better (Murray, 1991). These samples exhibit much reduced species diversity and are primarily dominated by *Ammonia beccarii* (58.8–76.5% of the total populations), *Pararotalia nipponica* and *Quinqueloculina seminulum* and *Ammonia tepida*. The predominance of *A. beccarii*, a cosmopolitan species, is not surprising as this species was observed to reproduce at varying temperature conditions in laboratory cultures, suggesting thermal acclimation during the early growth stages of the individual (Schnitker, 1974). Bradshaw (1957, 1961) observed that *Rotalia beccarii tepida (= Ammonia tepida)* could reproduce between salinities of 15 to 40‰, although the time required for a new generation varied with salinity; the growth rate of the specimens was, however, greatest at 34‰. He concluded that the salinity and temperature limits of survival are not that important for this species as the survival limits are often not reached in nature. Proliferating living populations of *A. tepida* were recorded in an inland pool near the Dead Sea, Israel, by Almogi-Labin et al. (1992). This species is hardy and opportunistic, but flourishes mainly in shallow, saline to brackish environments, and its fossil distribution in the Dead Sea Rift shows that it tends to disappear in mature lakes, either due to competition from non marine foraminiferids, or due to excessive freshening of the aqueous environment (Almogi-Labin et al. 1995). It is, therefore, obvious that *A. tepida* is one of the better adapted species in the study area.

6.Conclusions

From the benthic foraminiferal distributions off Karaikal, near the Arasalar River mouth, and its upstream area, it is evident that several ecological parameters exert their influence, either individually or in combination with one another. In the offshore region, although Ammonia beccarii dominates the assemblage, depth of the water column does seem to play an important role in controlling the distribution of the taxa constituting the assemblage. At the Arasalar River mouth also, *A. beccarii* predominates the assemblage which, however, is similar to those recorded from estuaries in the Indian region. The assemblage recorded from the upstream samples with relatively increased DO content but decreased salinities is still dominated by the same species, but its associated taxa are characteristic of euhaline to meso-polyhaline environmental conditions. This study reiterates the need for studying modern benthic foraminiferal assemblages from diverse environments, as this would imply better interpretation of fossil assemblages.

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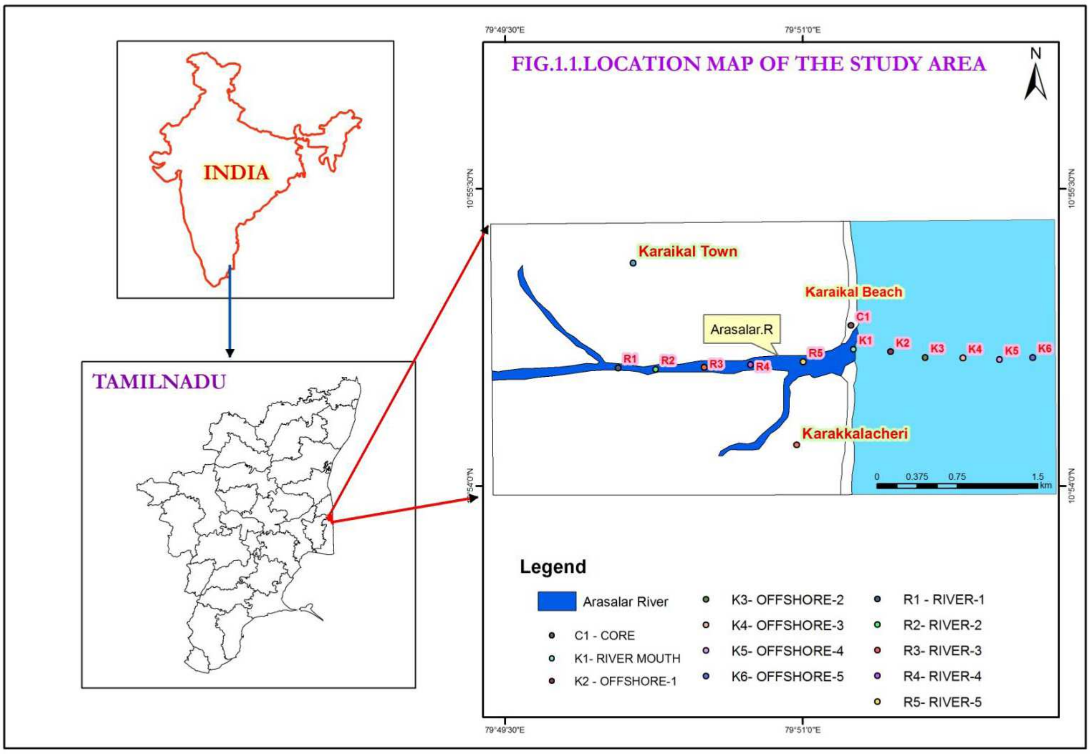

Fig.2.Sample preserved with formaldehyde Fig.3. Shell fragments at the beach

Fig.4. A view of Arasalar rivermouth Fig.5. Sandy beach of Karaikal

Table.1. Results of Environmental parameters of the study region

Stn. no.	BWT in °C	pH	Depth (m)	DO ($ml.L^{-1}$)	Sal. (‰)	Sand (%)	Silt (%)	Clay (%)	$CaCO_3$ (%)	OM (%)
R1	29.0	7.3	1.5	4.94	27.6	82.2	10.3	7.5	2.1	1.41
R2	29.1	7.4	2.0	4.98	29.2	92.7	5.4	1.9	1.6	2.12
R3	29.0	7.3	2.3	3.24	29.1	50.7	47.3	2.0	1.6	2.51
R4	29.1	7.7	2.0	3.24	29.5	73.9	25.1	1.0	1.2	2.14
R5	29.4	7.6	2.2	3.36	30.8	81.2	17.5	1.3	3.4	0.93
K1	29.3	7.7	3.1	2.98	31.3	77.4	21.2	1.4	1.4	1.41
K2	29.7	8.1	4.0	1.24	35.1	92.1	7.4	0.5	4.5	2.32
K3	29.8	8.2	6.5	1.73	35.3	88.0	10.0	2.0	7.3	2.14
K4	30.0	8.2	8.3	1.72	35.2	87.5	11.5	1.0	7.4	2.14
K5	30.1	8.1	12.5	1.72	35.5	89.0	10.0	1.0	6.7	2.00
K6	29.9	8.3	14.8	2.44	35.4	85.7	13.2	1.1	5.5	1.87

Table 1 Percentages of living (rose Bengal-stained) and total populations in the study area

Name of species	R1		R2		R3		R4		R5		K1		K2		K3		K4		K5		K6	
	L	T	L	T	L	T	L	T	L	T	L	T	L	T	L	T	L	T	L	T	L	T
A. eriguus	0	0	0	0	0	0	0	0	0	1.2	0	1.6	0	1.0	0	0.9	0	1.4	0	1.0	0	0
T. agglutinans	0	0	0	0	0	0	0	0	0	0	0	2.4	0	1.6	0	0.9	0	0.7	0	1.7	2.8	2.1
T. bocki	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0.4	0	0.7	0	1.0	0	0.9
S. communis	0	0	0	0	0	0	0	0	0	0	0	0.8	0	3.1	0	1.8	0	1.4	0	1.0	0	1.5
S. corrugata	0	0	0	0	0	0	0	0	0	0	0	0	0	1.0	0	0.4	0	0	0	0.7	0	0.3
S. depressa	0	0	0	0	0	0	0	0	0	0	0	0	6.3	3.6	3.7	3.5	0	2.2	0	2.1	2.8	2.7
S. orbis	0	0	0	0	0	0	0	0	0	0	0	0.8	0	6.3	0	3.1	0	1.8	0	1.0	0	0
Q. agglutinans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.7	5.3	0	5.1	0	3.5	2.8	4.0
Q. costata	0	0	0	0	0	0	0	0	0	0	0	0	0	2.1	3.7	3.1	0	2.9	0	2.8	5.6	3.4
Q. lamarckiana	0	0	0	0	0	0	0	0	0	1.2	0	0.8	0	2.6	3.7	3.9	0	2.9	4.0	4.2	2.8	3.0
Q. polygona	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0.7	0	1.2
Q. seminulum	0	5.9	0	13.0	0	17.1	0	10.2	0	8.8	0	7.3	0	1.0	0	1.3	0	0.7	0	0.7	0	1.5
M. circularis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.00	0	0.6
T. tricarinata	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0.4	0	0	0	1.0	0	2.1
T. trigonula	0	0	0	0	0	0	0	0	0	0	0	0	0	2.6	0	1.3	0	1.4	0	1.7	0	0.6
E. repandus	0	0	0	0	0	0	0	0	0	0	0	0	0	2.1	0	0.9	0	1.8	0	0.3	0	0.3
R. globularis	0	0	0	0	0	0	0	0	0	1.2	0	0.8	0	0	0	1.3	0	1.1	0	1.0	0	0.6
C. lobatulus	0	0	0	0	0	0	0	0	0	0	0	0	0	1.6	3.7	5.3	13.6	5.8	0	1.4	0	0
A. radiata	0	0	0	0	0	0	0	0	0	0	0	0.8	0	1.0	0	1.3	0	0.7	4.0	2.4	5.6	4.0
N. stella	0	0	0	0	0	0	0	0	0	0	0	2.4	0	0	0	0	0	0	0	0	0	0.6
N. Labradorica	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0.9	0	0.4	0	0.7	0	0.9
N. boueanum	0	0	0	0	0	0	0	0	0	0	0	0	0	1.0	0	1.3	0	0.7	0	1.0	0	0.6
P. calcar	0	0	0	0	0	0	0	0	0	1.2	0	3.2	0	0	0	2.2	0	1.1	0	1.4	0	0.6
P. nipponica	0	5.9	0	8.7	0	11.4	0	18.4	12.5	13.8	0	5.6	6.3	6.3	3.7	3.9	9.1	2.5	0	2.8	0	0.9
A. beccarii	100	76.5	100	73.9	100	62.9	100	59.2	75.0	58.8	77.8	53.2	81.3	40.6	63.0	35.1	63.6	43.3	64.0	37.7	47.2	37.2
A. dentata	0	0	0	0	0	0	0	0	0	1.2	0	2.4	0	3.6	3.7	5.7	4.5	2.5	4.0	4.2	5.6	7.0
A. tepida	0	11.8	0	4.3	0	8.6	0	10.2	12.5	8.8	22.2	8.9	0	1.6	0	1.8	4.5	2.5	12.0	8.0	11.1	5.8
A. trispinosa	0	0	0	0	0	0	0	0	0	0	0	0	0	1.6	0	0.9	4.5	7.6	12.0	7.6	13.9	11.3
E. advenum	0	0	0	0	0	0	0	0	0	0	0	4.0	0	2.6	0	1.8	0	2.5	0	1.7	0	0.9
E. crispum	0	0	0	0	0	0	0	0	0	0	0	0	6.3	6.3	3.7	3.9	0	1.1	0	0.7	0	0.3
E. discoidale	0	0	0	0	0	0	0	2.0	0	3.8	0	2.4	0	1.6	0	3.9	0	3.2	0	2.1	0	2.1
E. incertum	0	0	0	0	0	0	0	0	0	0	0	2.4	0	0	0	0	0	0	0	1.7	0	1.2
A. ammonoides	0	0	0	0	0	0	0	0	0	0	0	0	0	3.6	7.4	3.5	0	1.4	0	1.0	0	1.5