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BENTHIC FORAMINIFERAL COLONIZATION OF A NEW MANGROVE ECOSYSTEM – A CASE STUDY FROM PAZHAIYAKAYAL, TUTICORIN, SOUTH-EAST COAST OF INDIA

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ABSTRACT

Tuticorin, on the south-east coast of Tamil Nadu, is a major port and, in recent years, has become as active as Chennai in the state of Tamil Nadu. The area around Tuticorin is rather interesting due to its two different mangrove ecological settings: (i) the relatively new (3 year-old) artificially planted mangroves at Pazhaiyakayal and (ii) the old, already flourishing mangroves near the salt pans, south of Tuticorin. It is a well established fact that mangroves and salt marshes are dominated by arenaceous, agglutinated assemblages of benthic foraminifera, with variations therein between low mangroves/marsh and high mangroves/marsh settings. This study area was, therefore, selected for the present study to carry out detailed investigations on benthic foraminiferal taxonomy from and ecology of these two mangrove areas. An attempt has also been made to record the extent and rapidity with which these protists have been able to colonize the newly created ecosystem at Pazhaiyakayal. Accordingly, 19 benthic foraminiferal species belonging to 13 genera and 4 suborders are reported and illustrated. Among these, 5 species are arenaceous, agglutinated (suborder TEXTULARIINA), 4 are calcareous, imperforate, porcelaneous forms (suborder MILIOLINA), 4 are calcareous, hyaline forms (suborder LAGENINA), and 6 are calcareous, perforate taxa (suborder ROTALIINA). The ecology of Recent benthic foraminifera is presented with SEM illustrations with a note on the scope of future research.

Keywords: Benthic foraminifera, mangroves, colonization, ecology, taxonomy

INTRODUCTION

Mangroves, also called mangals, are found in tropical and sub-tropical tidal areas that include estuaries and marine shorelines. The inter-tidal existence to which these trees are adapted represents the major limitation to the number of species able to survive in their habitat wherein they have to survive and tolerate broad ranges in salinity, temperature, moisture and a host of other key environmental factors. It is, therefore, not surprising that only a select few species constitute the mangrove tree community. At Pazhaiyakayal, the Forest Department of Tamil Nadu initiated planting of mangrove saplings about three years ago and, when the field work was carried out in this part of the study area, the trees had grown to ~1–1.5 m in height. Benthic foraminifera constitute an important component of the mangrove ecosystem. In fact, the mangrove environment is characterized by a benthic foraminiferal assemblage that is dominated by arenaceous, agglutinated species that are generally absent in other environments such as the inner shelf or coral reefs.

Benthic foraminifera have been studied in extensive detail from a plethora of environments on and off the south-east coast of India: beach sands (e.g. Bhatia and Bhalla, 1959; Bhalla, 1968, 1970); littoral zone (e.g. Gnanamuthu, 1943; Ganapati and Satyavati, 1958; Kathal and Bhalla, 1998; Kathal, 2002a, b); continental shelf (e.g. Vedantam and Rao, 1968, 1970; Rasheed and Ragothaman, 1978; Rajasekhar, 1981; Ragothaman and Kumar, 1985; Jayaraju and Reddy, 1997; Rajeshwara Rao and Periakali, 2001; Rajeshwara Rao *et al.*, 1999; 2005; 2006); estuaries (e.g. Ramanathan, 1969; 1970; Reddy *et al.*, 1979; Reddy and Rao, 1980; Naidu, 1987); tidal creeks (e.g. Rao and Rao, 1971); streams (e.g. Rao and Rao, 1976; Kaladhar, 1981); lagoons (e.g. Naidu, 1983); bays (e.g. Rao *et al.*, 1990); backwaters (Rajeshwara Rao *et al.*, 1994); marginal lakes (Jayaraju *et al.*, 1998); and mangroves (e.g. Senthilnathan, 1985). Investigations on benthic foraminifera from mangroves are, however, scanty although India is well endowed with this invaluable floral cover.

MATERIALS AND METHODS

Bottom water and sediment (from the sediment-water interface) samples were collected from two environmental settings: (i) relatively, new (3 year-old) artificially planted mangroves at Pazhaiyakayal, and (ii) the already flourishing mangroves near the salt pans, south of Tuticorin. Accordingly, 20 representative sediment and water samples were collected each season – 15 from the Pazhaiyakayal mangroves and 5 from mangroves close to the coast near the salt pans, at depths varying from 0.8–2.9 m (Fig. 1). All the samples were collected manually, sometimes employing a professional diver, during January (post north-east monsoon; winter) and July 2008 (summer). In all, 40 bottom water and sediment samples were collected and analysed. Sediment samples were preserved in a mixture of one part of buffered formalin in nine parts of water (4% solution) with a pinch of $CaCl_2$ to achieve neutrality (Walker *et al.*, 1974). Water samples were preserved by adding a few ml of chloroform (Newcombe *et al.*, 1939).

Bottom water temperature and pH were measured on board, the former using a thermometer, and the latter using a digital pH meter. Salinity was estimated using the standard titration method and equation proposed by Knudsen (1901), while dissolved oxygen was determined UV-spectrophotometrically (Duval *et al.*, 1974). Calcium carbonate and organic matter in the sediment samples were determined adopting methodology after Loring and Rantala (1992), and Gaudette *et al.* (1974), respectively. The light penetration depth was determined at the sampling stations using a white coloured metallic disc attached to a graduated cable. Sand-mud percentages were computed from a sieving procedure, using an ASTM 230 sieve

Table 1. Ecological parameters determined in the samples collected from Pazhaiyakayal (1–15) and naturally flourishing (16–20) mangroves – January 2008.

Sample No.	Depth in m	BWT in °C	pH	LPD in m	Salinity in ppt	DO in mg/l	$CaCO_3$ in %	OM in %	Sand in %	Mud in %
1	1.1	28.1	7.7	0.8	29.4	1.5	1.8	3.7	27.13	72.87
2	1.3	28.1	7.8	0.9	29.3	1.4	1.9	3.8	28.45	71.55
3	1.2	28.0	7.8	0.7	29.4	1.7	1.7	3.4	27.36	72.64
4	1.4	27.9	7.9	0.9	29.2	1.6	2.1	3.7	27.54	72.46
5	1.3	28.2	7.6	0.8	29.3	1.5	2.0	3.6	22.19	77.81
6	1.2	28.0	7.8	0.7	29.2	1.7	1.9	3.7	23.44	76.56
7	1.1	28.1	7.7	0.8	29.3	1.5	1.7	4.1	21.17	78.83
8	0.8	28.4	7.7	0.8	29.1	1.6	1.6	3.9	20.53	79.47
9	1.0	28.3	7.9	0.7	29.4	1.4	1.9	3.8	22.71	77.29
10	0.9	28.4	7.6	0.7	29.1	1.5	1.8	3.7	21.42	78.58
11	1.1	28.1	7.7	0.8	29.0	1.4	1.7	3.8	27.63	72.37
12	1.3	28.0	7.8	1.0	29.2	1.7	1.9	3.4	28.79	71.21
13	1.4	27.9	8.0	1.1	29.5	1.8	2.4	3.1	34.65	65.35
14	1.3	28.1	8.1	1.0	29.6	2.1	2.6	1.7	43.78	56.22
15	1.5	27.8	8.2	0.9	29.7	2.4	2.7	1.5	53.72	46.28
16	1.9	28.1	7.7	1.1	28.4	1.4	1.6	4.4	34.29	65.71
17	2.8	28.3	7.8	0.6	27.9	1.6	1.7	3.9	33.78	66.22
18	2.7	28.0	7.8	0.5	28.1	1.8	1.5	4.1	30.44	69.56
19	2.9	27.9	7.7	0.7	27.7	1.2	1.8	3.8	31.25	68.75
20	2.7	28.1	7.6	1.1	28.0	1.7	1.7	4.1	33.93	66.07

(sieve opening of 63 microns). The preserved sediment samples were subjected to the rose Bengal staining technique, first described by Walton (1952), in order to differentiate "living" from dead foraminifera. In spite of its limitations, the rose Bengal technique is still widely employed as it is not as cumbersome as other staining techniques (Murray, 1991); moreover, staining in tests of agglutinated species is easily recognised if rose Bengal is used (Bernhard, 1988).

The sand fraction retained on the ASTM 230 sieve was divided into relatively coarser, medium-grained and finer fractions using a nest of appropriate sieves. Benthic foraminifers from the comparatively coarser fractions were hand-picked using a soft-bristled 00 brush; the relatively finer fractions were subjected to floatation in carbon tetrachloride (CCl_4) (Cushman, 1959). The residue after floatation was checked for tests that might have escaped floatation using a NIKON stereomicroscope.

The foraminiferal tests from each sample (25 ml of wet sediment) were transferred to 24-chambered micropalaeontological slides and mounted over a thin layer of tragacanth gum according to the family, genus and species, wherever possible. The different genera and species were identified; type specimens of each species were selected and transferred to round punch micro-faunal slides with cover slips. Later, they 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 (JEOL: JFC-1100E ion sputtering device) to render the surface of the foraminiferal tests conductive for scanning. To obtain lucid illustrations, microphotographs of different views of most of the foraminiferal species present were taken using either the JEOL Scanning Electron Microscope or the EUROMEX optical light microscope using a CMOS camera. All the hypotypes were duly indexed with numbers and placed in the repository of the Department of Zoology, V.O.C. College, Tuticorin 628 001 (Registered numbers: GC–DZ–01 to GC–DZ–19).

BENTHIC FORAMINIFERAL CONTENT

The widely utilised classification proposed by Loeblich and Tappan (1987) has been followed in the present study. A species has been regarded as the sum-total of specimens sharing all test characters, with such measurable, countable, or otherwise observable, variation in size and shape of some elements or of proportions between the latter in different ontogenic stages, which fits a pattern of normal distribution and whereby these specimens are separable from other similar groupings regarded as distinct species (Hottinger *et al*., 1993). From the 40 sediment samples collected during the two seasons, 19 species belonging to 13 genera have been identified and recorded. Of these, 5 species are arenaceous, agglutinated (suborder TEXTULARIINA), 4 are calcareous, imperforate, porcelaneous forms (suborder MILIOLINA), 4 are calcareous, hyaline forms (suborder LAGENINA), and 6 are calcareous, perforate taxa (suborder ROTALIINA). A checklist of the taxa is presented as Annexure I.

"Living" (rose Bengal stained) populations were observed to be rather less; therefore, total benthic foraminiferal populations have been considered for ecological studies. The relatively low "living" populations are actually attributed to the following factors: artificially rejuvenated mangroves at Pazhaiyakayal, and shallow depth of sampling at both mangrove settings.

Table 1 presents the ecological parameters determined in the sediment samples collected from the mangrove environments at Pazhaiyakayal and in proximity to the salt pans for January 2008. Table 2 presents the same parameters

EXPLANATION OF PLATE I

1. ***Ammobaculites agglutinans,*** side view, x 170.
2. ***Ammobaculites exiguus,*** side view, x 160.
3. ***Ammobaculites* sp.,** side view, x 90.
4. ***Spiroplectammina earlandii,*** side view, x 300.
5. ***Spiroplectammina earlandii,*** apertural view, x 100.
6. ***Trochammina inflata***, spiral view, x 230.
7. ***Trochammina inflata,*** umbilical view, x 250.
8. ***Quinqueloculina lamarckiana,*** side view, x 90.

Plate I

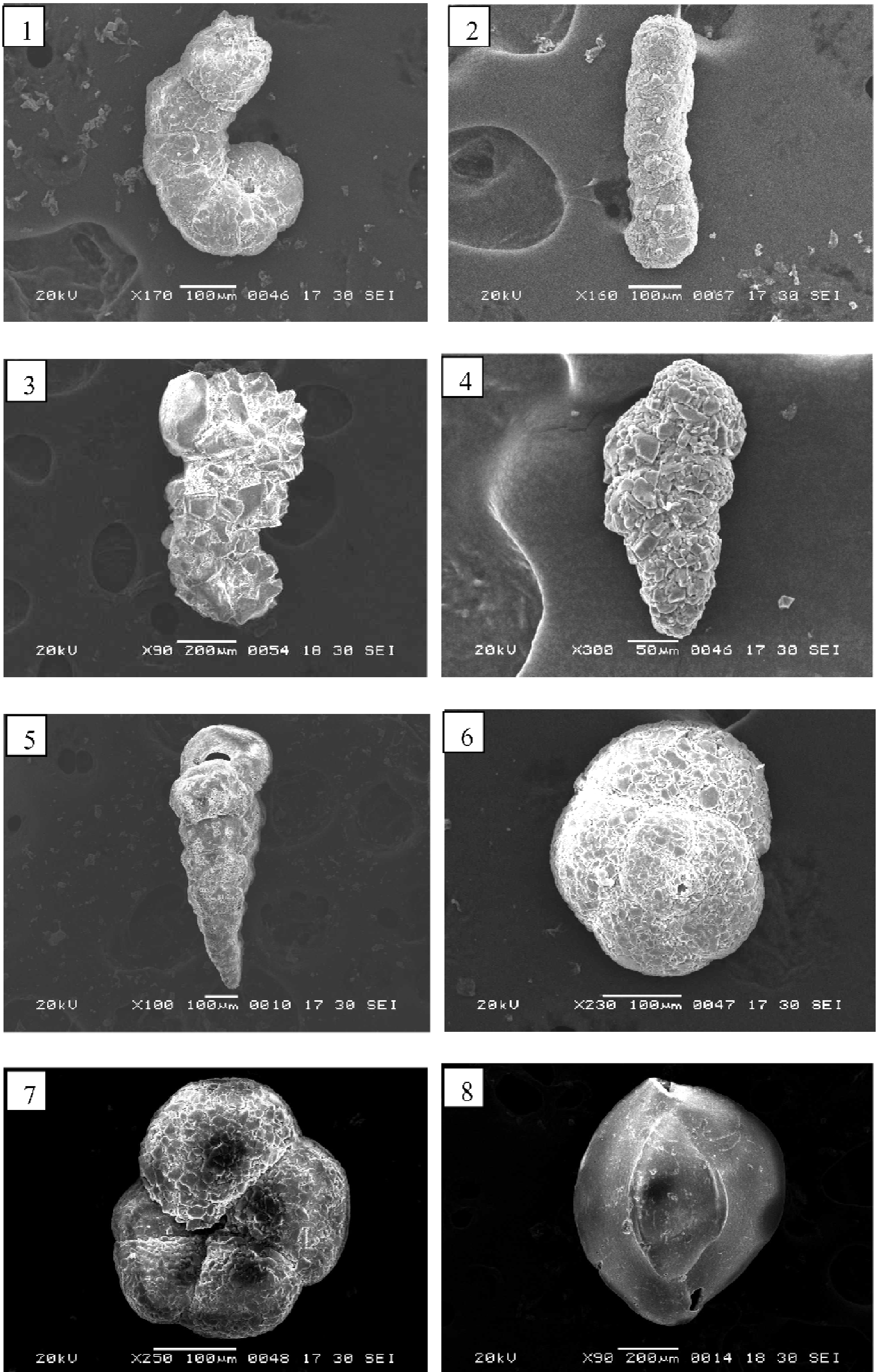
1
20kV X170 100µm 0046 17 30 SEI
2
20kV X160 100µm 0067 17 30 SEI
3
20kV X90 200µm 0054 18 30 SEI
4
20kV X300 50µm 0046 17 30 SEI
5
20kV X100 100µm 0010 17 30 SEI
6
20kV X230 100µm 0047 17 30 SEI
7
20kV X250 100µm 0048 17 30 SEI
8
20kV X90 200µm 0014 18 30 SEI

Table 2. Ecological parameters determined in the samples collected from Pazhaiyakayal (1–15) and naturally flourishing (16–20) mangroves – July 2008.

Sample No.	Depth in m	BWT in °C	pH	LPD in m	Salinity in ppt	DO in mg/l	$CaCO_3$ in %	OM in %	Sand in %	Mud in %
1	1.1	30.2	7.6	1.0	29.6	1.4	1.9	3.6	28.51	71.49
2	1.3	30.3	7.6	0.9	29.4	1.4	1.8	3.7	27.77	72.23
3	1.2	30.2	7.6	0.9	29.5	1.6	1.8	3.5	29.31	70.69
4	1.4	29.8	7.7	1.1	29.3	1.7	1.9	3.8	28.49	71.51
5	1.3	30.4	7.6	0.9	29.4	1.4	1.8	3.8	28.06	71.94
6	1.2	30.2	7.7	0.9	29.1	1.8	1.9	3.9	27.63	72.37
7	1.1	30.3	7.6	0.8	29.5	1.6	1.8	4.0	29.47	70.53
8	0.8	30.6	7.7	0.8	29.3	1.7	1.7	3.8	26.52	73.48
9	1.0	30.3	7.8	0.9	29.6	1.5	1.8	3.9	28.88	71.12
10	0.9	30.5	7.7	0.9	29.5	1.5	1.7	3.8	27.79	72.21
11	1.1	30.3	7.6	0.9	29.4	1.5	1.7	3.9	28.13	71.87
12	1.3	30.3	7.7	1.1	29.3	1.6	1.7	3.6	28.95	71.05
13	1.4	30.1	7.9	1.2	29.4	1.9	2.3	3.0	32.97	67.03
14	1.3	30.3	8.0	1.1	29.3	2.4	2.7	1.6	34.41	65.59
15	1.5	30.0	8.1	1.2	29.9	2.7	2.9	1.3	36.67	63.33
16	1.7	30.5	7.6	1.1	29.5	1.4	1.3	3.7	33.42	66.58
17	2.6	30.4	7.6	1.3	29.7	1.2	1.5	3.9	30.85	69.15
18	2.6	30.2	7.7	1.5	28.8	1.7	1.4	4.1	31.29	68.71
19	2.5	29.8	7.7	1.2	28.3	1.5	1.3	3.8	32.58	67.42
20	2.4	30.5	7.7	1.1	28.0	1.8	1.4	3.7	31.43	68.57

for the second collection made in July 2008. The distribution of dominant total ("living" + dead) benthic foraminiferal species in actual numbers per 25 ml of wet sediment from Pazhaiyakayal and naturally flourishing mangroves for January 2008 are presented in Table 3, while the data for July 2008 are listed in Table 4.

From Tables 1 and 2, it is evident that most of the ecological parameters are more or less consistent, with little variations, but there is an increase in the sand content towards the mouth of the inlet at Pazhaiyakayal. Otherwise, the mud content is relatively higher in 14 out of the 15 sediment samples collected in this area. This is quite consistent with mangrove settings worldwide, as the mangrove roots are instrumental in retaining the finer sediment by trapping it among them. A similar scenario is observed in the 5 sediment samples collected in the mangroves flourishing near the salt pans, south of Tuticorin.

RESULTS AND DISCUSSION

Foraminiferal ecology – Pazhaiyakayal mangroves

When an ecosystem is created, as was done by planting mangrove saplings in the Pazhaiyakayal area (courtesy Forest Department, Govt. of Tamil Nadu), monitoring it for faunal and floral colonisation assumes considerable significance. An analogous example would be the 1991 eruption of Mt. Pinatubo resulting in ashfall in June and subsequent deposition of an ash layer that drastically decimated a thriving, deep-sea benthic foraminiferal assemblage (Hess *et al*., 2001). The first wave of colonisers consisted of only a few species, considered to be infaunal detritus feeders. They still represented the living fauna in April 1994, three years after the eruption. The abundance, diversity and complexity of the community structure increased with time. Between 1994 and 1996, species with different feeding modes, such as suspension feeders, appeared on top of the ash layer. At the same time, many of the early re-colonisers disappeared and were only present in dead assemblages, but new taxa such as *Trochammina* species occurred in the sediment. The artificially planted Pazhaiyakayal mangroves, therefore, presented a unique opportunity to examine the extent and rapidity of habitat colonisation since the plantation was effected in 2005.

In the Pazhaiyakayal mangroves, the sediment substrate is mud-dominated, and the benthic foraminiferal assemblage is characterised by arenaceous, agglutinated benthic species such as *Ammobaculites agglutinans*, *A. exiguus*, *Spiroplectammina earlandii* and, to a certain extent *Trochammina inflata*. The distribution pattern is almost the same during both seasons – January and July 2008, with slightly higher overall total populations in the latter season. Many other arenaceous, agglutinated taxa are absent, probably due to the fact that these mangroves have been artificially planted by the Forestry Department of the Government of Tamil Nadu, in order to rejuvenate the mangrove ecosystem in this region. Notable species that are yet to establish their habitat are *Miliammina fusca*, *M. obliqua*, *Haplophragmoides* spp., *Cribrostomoides* spp., *Jadammina macrescens* and *Ammoglobigerina globigeriniformis*, which have been reported from mangrove settings across the country (e.g. Ramanathan, 1970).

Interestingly, among the lagenids and rotaliids, *Fissurina cucullata*, *F. laevigata* and *Sigmavirgulina tortuosa* occur in relatively higher numbers, considering the depth of the water column, which is rather very shallow. These three species have been reported from relatively deeper and calmer waters offshore by many workers (e.g. Rajeshwara Rao, 1998), preferring muddy substrates. It is now quite clear from the present study that more than depth of the water column, it is the relatively calmer environment (turbulence-free) and nature of substrate that

EXPLANATION OF PLATE II

1. ***Quinqueloculina seminulum,*** side view, x 150
2. ***Quinqueloculina seminulum***, inclined apertural view, x 220
3. ***Quinqueloculina tropicalis***, side view, x 100
4. ***Quinqueloculina tropicalis,*** apertural view, x 270
5. ***Triloculina trigonula,*** side view, x 130
6. ***Buchnerina* sp.,** side view, x 300 (CMOS photograph)
7. ***Fissurina cucullata***, side view, x 350
8. ***Fissurina cucullata***, apertural view, x 430

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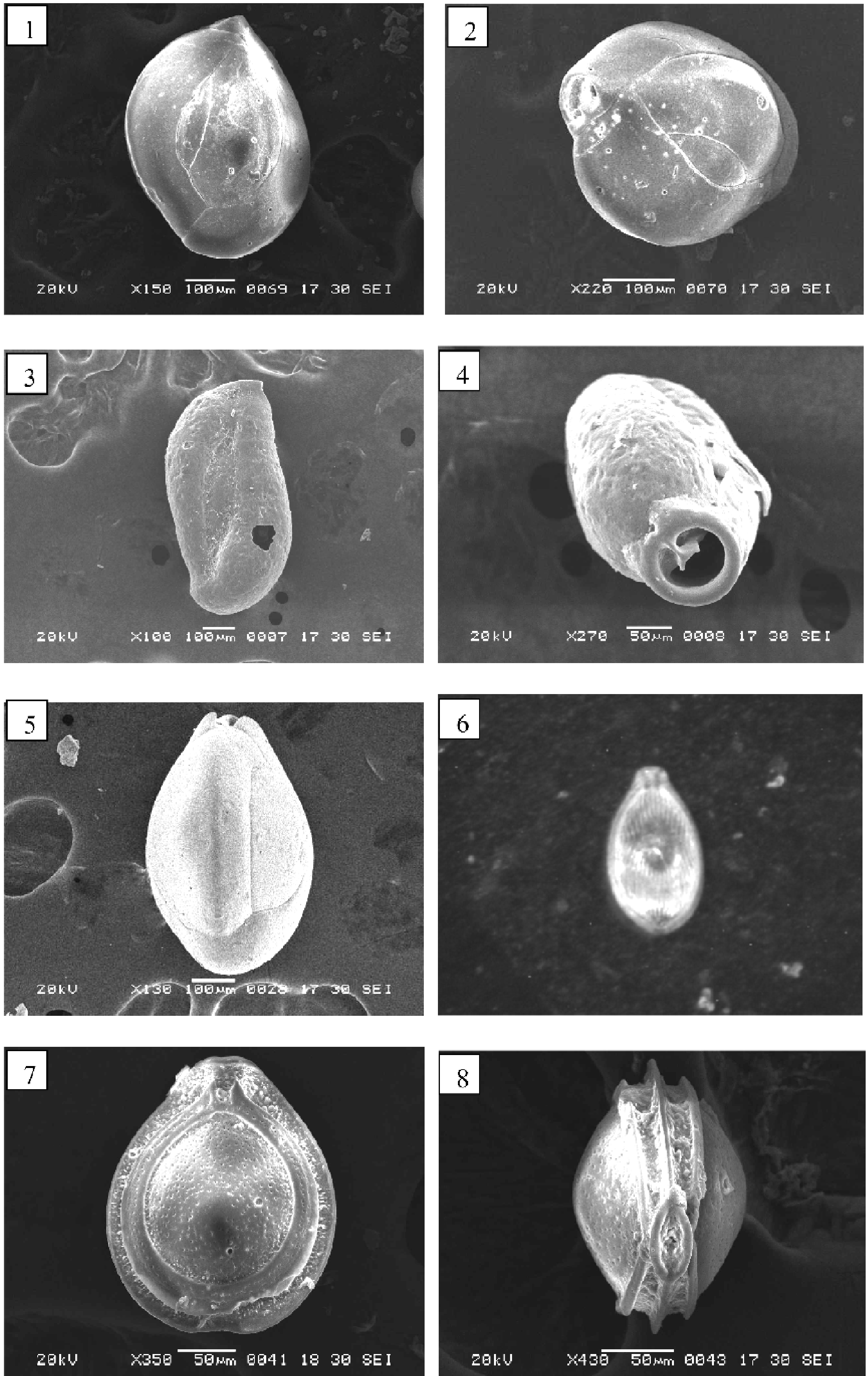
Plate II



RAJESHWAR RAO, GEETHA AND SHANMHUGAVEL

Table 3. Total benthic foraminiferal populations in sediments from Pazhaikayal (1–15) and naturally flourishing (16–20) mangroves–January 2008.

Sample/Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A. agglutinans	5	3	7	4	5	6	10	8	5	6	4	3	2	0	0	3	5	2	1	4
A. exiguus	13	11	17	19	20	26	19	15	14	11	9	8	3	0	0	19	13	11	14	15
A. sp.	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
S. earlandii	9	13	11	8	14	9	11	7	10	8	13	15	19	22	19	5	7	4	5	9
T. inflata	5	3	4	7	6	4	3	2	1	3	2	1	3	5	4	11	7	9	5	14
Q. lamarckiana	0	0	0	0	0	0	0	0	0	0	0	1	1	3	5	0	0	0	0	0
Q. seminulum	0	0	0	0	0	0	0	0	0	1	2	1	3	1	3	0	0	0	0	0
Q. tropicalis	0	0	0	0	0	0	0	0	0	0	1	0	1	2	1	0	0	0	0	0
T. trigonula	0	0	0	0	0	0	0	0	0	0	0	1	0	2	1	0	0	0	0	0
Buchnerina sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
F. cucullata	38	27	31	47	39	51	32	45	19	23	17	13	7	2	0	33	29	47	42	36
F. laevigata	13	10	9	11	14	11	9	15	16	9	10	7	3	0	0	9	12	8	10	15
P. fissurinea	3	5	4	3	5	3	2	3	1	3	2	3	0	1	0	7	3	5	5	4
S. tortuosa	11	7	8	13	15	11	12	14	13	17	9	10	7	3	0	0	0	0	0	0
N. elongatum	3	1	0	2	0	1	2	0	1	0	0	0	5	17	25	7	9	6	10	5
P. nipponica	2	1	3	0	1	0	3	0	1	0	0	2	5	11	19	5	8	4	9	7
A. beccarii	27	37	31	49	52	58	49	53	51	47	61	59	112	153	207	78	69	71	59	66
A. tepida	0	0	0	0	0	0	0	0	0	1	0	2	1	1	3	1	0	2	1	3
C. simplex	2	0	1	0	1	0	0	0	0	4	3	7	5	9	11	4	8	5	3	2

seem to favour these small-sized benthic foraminiferal taxa.

Ammonia beccarii is the most dominant of all the benthic foraminiferal species from the Pazhaiyakayal mangroves. This species is cosmopolitan with records all over the world from hyposaline to hypersaline environments (Murray, 1991). *Ammonia beccarii* has been reported from very low salinity pools or lakes to higher salinity marine environments. Phleger and Parker (1951) reported *A. beccarii* living at salinities between 44 and 46‰. 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 *Trochammina inflata* and *Ammonia beccarii* are capable of coping with wide range of salinity; lowest salinity species included *Textularia* (*=Spiroplectammina*) *earlandi* and *Ammobaculites exiguus*. In terms of total populations and widespread abundance, the Pazhaiyakal benthic foraminiferal assemblage is characterized by *A. beccarii*, *Fissurina cucullata*, *Ammobaculites exiguus*, *F. laevigata*, *Spiroplectammina earlandi* and *Sigmavirgulina tortuosa* during both January and July 2008.

Foraminiferal ecology – Naturally flourishing mangroves

Five bottom sediment samples were collected from the naturally flourishing mangroves near the salt pans (Fig. 1). It was expected that the total benthic foraminiferal populations would be relatively higher in this area, but the results indicate otherwise. This is attributed to dumping of waste, solid and liquid, and other activities such as salt panning and pumping of industrial effluents. The assemblage, however, is dominated by the same taxa that were observed in the Pazhaiyakayal mangroves.

Among the arenaceous, agglutinated species, *Ammobaculites exiguus* is the dominant, along with *Trochammina inflata* and *A. agglutinans*. This area is also characterised by the absence of *Miliammina fusca*, *M. obliqua*, *Haplophragmoides* spp., *Cribrostomoides* spp., *Jadammina macrescens* and *Ammoglobigerina globigeriniformis*. The rotaliids are typified by the predominant *Ammonia beccarii*, along with *Fissurina cucullata* and, to some extent, *F. laevigata*, *Nonionoides elongatum* and *Pararotalia nipponica*. The distribution of benthic foraminifers in this area also reveals that more than the depth of the water column, the lack of turbulence and presence of muddy substrate seem to influence the populations of such species as *Fissurina cucullata* and *F. laevigata*.

A solitary specimen of a species of *Buchnerina* was obtained from this area (Sample no. 20) at a depth of 2.7 m during the January 2008 collection. This species has a peculiar ornamentation on both sides of the test in the form of number of fine, longitudinal striae in the peripheral areas, and evenly spaced pores in the central areas. *Buchnerina* sp. differs from *B. wrightiana* (Brady) in the type of ornamentation, the latter possessing a number of radial, fine grooves (striae) in the peripheral areas, and number of longitudinal striae only visible under the optical microscope, particularly under wet condition. According to Hatta and Ujiie (1992), the longitudinal striae are not visible on SEM photographs. Keeping this in mind, this species was not photographed using a SEM; instead, a CMOS camera was used to capture images of this species using an optical light microscope. It is rather interesting to note that *B. wrightiana* was actually recorded from the coral seas off Japan (Hatta and Ujiie, 1992). The ecology of *Buchnerina* sp., however, seems to be similar to that of the fissurinids obtained in this region.

CONCLUSIONS

Benthic foraminiferal investigations on the Pazhaiyakayal (artificially planted) and naturally flourishing mangroves (near the salt pans) have yielded interesting results. Nineteen taxa belonging to 13 genera have been identified, recorded and illustrated with SEM and light microscopy photographs. Of these, a rare species of genus *Buchnerina* has been reported

EXPLANATION OF PLATE III

1. ***Fissurina laevigata,*** side view, x 350
2. ***Pseudoolina fissurinea,*** apertural view, x 500
3. ***Sigmavirgulina tortuosa,*** side view, x 250
4. ***Nonionoides elongatum,*** side view, x 160
5. ***Pararotalia nipponica,*** umbilical view, x 160
6. ***Ammonia beccarii,*** spiral view, x 120
7. ***Ammonia tepida,*** umbilical view, x 370
8. ***Cribrononion simplex***, side view, x 160

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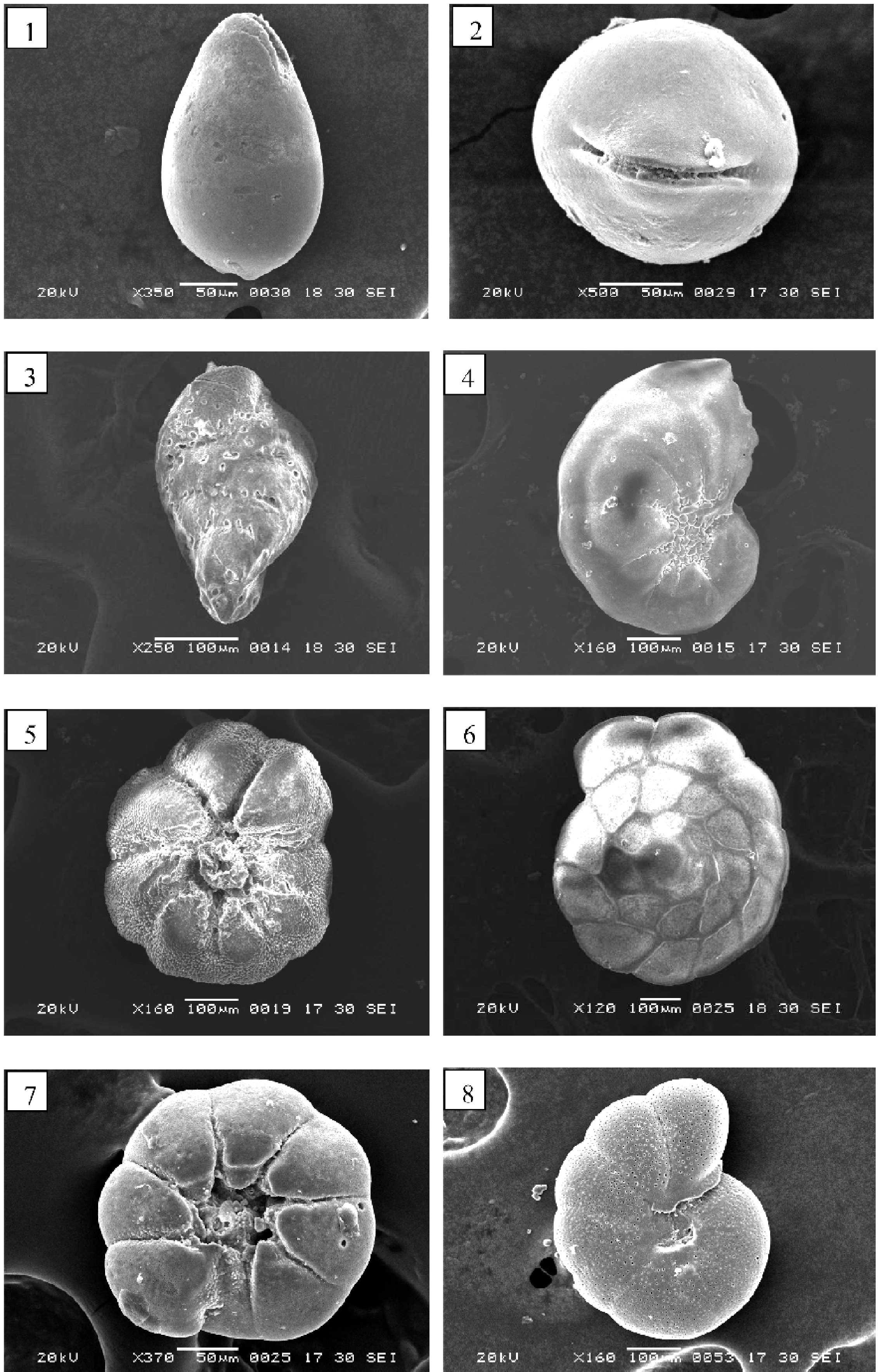
Plate III



RAJESHWAR RAO, GEETHA AND SHANMHUGAVEL

and illustrated. The present study clearly shows that colonization of the Pazhaiyakayal mangroves by benthic foraminifera is in progress with the assemblage typified by *Ammonia beccarii*, *Fissurina cucullata*, *Ammobaculites exiguus*, *F. laevigata*, *Spiroplectammina earlandi* and *Sigmavirgulina tortuosa*. Many other such species as *Miliammina fusca*, *M. obliqua*, *Haplophragmoides* spp., *Cribrostomoides* spp., *Jadammina macrescens* and *Ammoglobigerina globigeriniformis* are yet to establish their habitats. Surprisingly, no significant changes have been observed between the artificially planted, relatively new mangroves at Pazhaiyakayal and the already naturally flourishing mangroves. This study emphasizes the need for continuous monitoring of newly created mangrove settings to comprehend the extent and rapidity of their colonization by benthic foraminifera, as these protists could be effectively used as proxies for monitoring the progress and health of such ecosystems.

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ANNEXURE I

Checklist of benthic foraminiferal species

Ammobaculites agglutinans (d'Orbigny) (Pl. I; fig. 1)
Spirolina agglutinans D'ORBIGNY, 1846, p. 137, pl. 7, figs. 10–12.
Ammobaculites exiguus Cushman and Bronnimann (Pl. I; fig. 2)
Ammobaculites exiguus CUSHMAN and BRONNIMANN, 1948, v. 24, p. 38, pl. 7, figs. 7, 8.
Ammobaculites sp. (Pl. I; fig. 3)
Spiroplectammina earlandi (Parker) (Pl. I; figs. 4–5)
Textularia earlandi PARKER, 1952, p. 458, pl. 2, figs. 4, 5.
Trochammina inflata (Montagu) (Pl. I; figs. 6–7)
Nautilus inflatus MONTAGU, 1803, p. 8, pl. 18, fig. 3.
Quinqueloculina lamarckiana d'Orbigny (Pl. I; fig. 8)
Quinqueloculina lamarckiana D' ORBIGNY, 1839, p. 189, pl. 11, figs. 14, 15.
Quinqueloculina seminulum (Linnaeus) (Pl. II; figs. 1–2)
Serpula seminulum LINNAEUS, 1758, p. 786, pl. 2, figs. 1a–c.
Quinqueloculina tropicalis Cushman (Pl. II; figs. 3–4)
Quinqueloculina tropicalis CUSHMAN, 1924, p. 63, pl. 23, figs. 9, 10; pl. 9, fig. 6.
Triloculina trigonula (Lamarck) (Pl. II; fig. 5)
Miliolites trigonula LAMARCK, 1804, v. 5, p. 351, pl. 17, fig. 4.
Buchnerina sp. (Pl. II; fig. 6)
Fissurina cucullata Silvestri (Pl. II; figs. 7–8)
Fissurina cucullata SILVESTRI, 1902, p. 146, figs. 23–25.
Fissurina laevigata Reuss (Pl. III; fig. 1)
Fissurina laevigata REUSS, 1850, p. 366, pl. 46, fig. 1.
Pseudoolina fissurinea Jones (Pl. III; fig. 2)
Pseudoolina fissurinea JONES, 1984, p. 119, pl. 4, figs. 19, 20.
Sigmavirgulina tortuosa (Brady) (Pl. III; fig. 3)
Bolivina tortuosa BRADY, 1881, p. 57; 1884, v. 9, p. 420, pl. 52, figs. 31, 32.
Nonionoides elongatum (d'Orbigny) (Pl. III; fig. 4)
Nonionina elongata D'ORBIGNY, 1826, v. 7, p. 294, no. 20.
Pararotalia nipponica (Asano) (Pl. III; fig. 5)
Rotalia nipponica ASANO, 1936, v. 43, no. 515, p. 614, pl. 31, figs. 2a–c.
Ammonia beccarii (Linnaeus) (Pl. III; fig. 6)
Nautilus beccarii LINNAEUS, 1758, v. 1, p. 710.
Ammonia tepida (Cushman) (Pl. III; fig. 7)
Rotalia beccarii (Linne) var. *tepida* CUSHMAN, 1926, p. 79, pl. 1; 1931, p. 61, pl. 13, figs. 3a–c.
Cribrononion simplex (Cushman) (Pl. III; fig. 8)
Elphidium simplex CUSHMAN, 1933, pt. 2, p. 52, pl. 12, figs. 8, 9.