Near-shore benthic foraminifera from the Nizampatnam Bay, East coast of India

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ABSTRACT

Nizampatnam Bay is an embayment adjoining the Krishna Delta in its southern side, covering an area of 1,825 km$^2$. A thorough review of literature revealed that very little work has been carried out on benthic foraminifera and their assemblages in this bay. Hence, it was selected for the present study, and eleven bottom water and near-shore sediment samples were collected during February 2013 from the near-shore environment in a water depth range of 0.5 to 3.0 m. Ecological parameters such as water depth, pH, bottom water temperature, dissolved oxygen, salinity, CaCO$_3$, organic matter, sand, silt and clay contents were determined adopting standard methodology. Benthic foraminifera were separated from the samples, which yielded 48 species belonging to 23 genera, 18 families, 12 superfamilies, 4 suborders and 5 orders, which have been reported and illustrated. Out of the total population count of 1,431 specimens, 399 were observed to be rose Bengal-stained, and are considered to be living at the time of sample collection. Surprisingly, the most abundant species was observed to be *Ammonia dentata* (Parker and Jones) in the study area, rather than its more cosmopolitan counterpart, *Ammonia beccarii* (Linnaeus). The results of this study constitute an accurate and reliable benthic foraminiferal database that would be extremely useful for other researchers. Further, Nizampatnam Bay offers ample opportunities for future research as it forms a part of the prograding Krishna River delta, and benthic foraminiferal assemblages are definitely bound to be influenced by the high volume of fresh water influx into the bay.

1. Introduction

Benthic foraminifera live in variety of micro environments like marine, mangroves, coral reefs, rock pools, lagoons, estuaries, streams and even backwaters that are saline. They occur in all latitudinal zones but some are confined to specific latitudinal zones e.g. *Rotorboides granulosum* lives within 25˚N to 20˚S latitudes (Kathal and Bhalla, 1996). There are many controlling factors on foraminiferal abundance and type, including nutrition, dissolved oxygen conditions, pH, salinity, substrate and temperature (e.g. Murray, 1968; Alve and Nagy, 1986; Boltovskoy *et al*., 1991; de Rijk, 1995; Barbosa and Suguio, 1999; Debenay *et al*., 2002; Horton *et al*., 2003).

The near-shore marine environment is generally a turbulent one with wave and current action being dominant. Nizampatnam Bay is an embayment adjoining the Krishna Delta in its southern side. It has a coastline of about 125 km between Kottapattam in the south-west and False Divi Point in the north-east. The bay covers an area of 1,825 km$^2$. It is a shallow marine environment and the bottom topography of the bay is smooth and generally slopes towards
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the open sea (Reddy et al., 2012). During the south-west monsoon period, alongshore currents move in a north to north-west direction from the western margin of the Krishna Delta and towards west to north-west in the eastern part of the delta. During the north-east monsoon, the flow in the bay near delta is towards north-west, but flow in the delta is towards north-west and west. The speed of long shore currents is 15-30 cm/s (Reddy et al., 1979).

Wave directions and wave heights are variable in this region. Waves are from north-east (November-February), south and south-west (March-May), south-west and south (June-August) and south (September-October) directions. The range of wave heights is 0-2.7 m (Varadarajulu et al., 1985). According to Rao (1968), the Bay of Bengal coast can be classified into three categories based on the combined amplitude of the storm surge and wind waves. Rao’s C-type belt, which is the most dangerous zone, occurs in three locations, one of which is near Nizampatnam Bay.

Previous work on this bay includes determination of net shore drift (Kunte and Wagle, 1993); trawling operations and fishery resources (Vivekanandan and Krishnamoorthi, 1985; Vivekanandan and Meiyappan, 1999); C/N and C/P variations (Sreenivasa Rao and Dhanamjaya Rao, 2000); distribution of major and minor elements (Vasantha Rao, 2006); and heavy mineral analysis (Reddy et al., 2012). A thorough survey of literature revealed that research endeavors on such benthic foraminiferal aspects as their taxonomy, distribution and ecology are too scanty. The only available publication is that by Sreenivasa Rao et al. (1990), who studied the distribution and factor analysis of benthic foraminifera in the Nizampatnam Bay, but did not include a checklist of the benthic foraminiferal species recorded by them. This bay was, therefore, selected for the present study so as to prepare an inventory of near-shore benthic foraminiferal species in the bay, present their brief systematic paleontology, and their distribution.

Methodology adopted

Eleven surface sediment and 11 bottom water samples (from the sediment-water interface) were collected from the Nizampatnam Bay during February 2013 at depth ranging from 0.5 to 3 m. All samples (both water and sediment) were collected manually with the help of local divers from the fishing hamlets. The exact locations of the sampling sites were determined by using a global positioning system (GPS). Table 1 shows the sample locations, and their geographical co-ordinates, while Figure 1 depicts the sample locations and the names of the fishing villages.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Name of the place</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kothapatnam</td>
<td>N 15°26'11.9&quot;</td>
<td>E 80°10'41.7&quot;</td>
</tr>
<tr>
<td>2</td>
<td>Chinnivaripalem</td>
<td>N 15°28'23.5&quot;</td>
<td>E 80°12'17.4&quot;</td>
</tr>
<tr>
<td>3</td>
<td>Gundammala</td>
<td>N 15°29'40.0&quot;</td>
<td>E 80°12'48.2&quot;</td>
</tr>
<tr>
<td>4</td>
<td>Peddaganjam</td>
<td>N 15°38'17.5&quot;</td>
<td>E 80°15'15.6&quot;</td>
</tr>
<tr>
<td>5</td>
<td>Chinnaganjam</td>
<td>N 15°41'11.1&quot;</td>
<td>E 80°17'01.1&quot;</td>
</tr>
<tr>
<td>6</td>
<td>Nirakshanagiri</td>
<td>N 15°42'52.1&quot;</td>
<td>E 80°18'26.4&quot;</td>
</tr>
<tr>
<td>7</td>
<td>Potti Subbayapalem</td>
<td>N 15°45'03.1&quot;</td>
<td>E 80°20'49.6&quot;</td>
</tr>
<tr>
<td>8</td>
<td>Kattarivaripalem</td>
<td>N 15°45'43.7&quot;</td>
<td>E 80°21'43.9&quot;</td>
</tr>
<tr>
<td>9</td>
<td>Wadarevu</td>
<td>N 15°47'40.0&quot;</td>
<td>E 80°24'48.3&quot;</td>
</tr>
<tr>
<td>10</td>
<td>Suryalanka</td>
<td>N 15°50'22.3&quot;</td>
<td>E 80°30'30.7&quot;</td>
</tr>
<tr>
<td>11</td>
<td>Kothapalem</td>
<td>N 15°52'03.2&quot;</td>
<td>E 80°45'21.7&quot;</td>
</tr>
</tbody>
</table>
Water samples were preserved by adding a few ml of chloroform (Newcombe et al., 1939). Sediment samples were preserved in a mixture of one part of buffered formalin in nine parts of water (4% solution) with a pinch of CaCl₂ to achieve neutrality (Walker et al., 1974). Bottom water temperature (BWT) and pH were measured on land, the former using a thermometer, and the latter using a pH meter. Salinity was estimated using the standard titration method and equation proposed by Knudsen (1901), while the dissolved oxygen (DO) content was determined UV-spectrophotometrically (Duval et al., 1974).

Calcium carbonate and organic matter (OM) in the sediment samples were determined adopting methodology after Loring and Rantala (1992), and Gaudette et al. (1974), respectively. Sand, silt and clay percentages were computed from a combination of sieving and pipette procedures, the latter in accordance with Krumbein and Pettijohn (1938). Tri-plot was prepared and Sneed and Folk’s (1958) textural nomenclature utilized for sediment descriptions. 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 recognized if rose Bengal is used (Bernhard, 1988).

The sediment samples that were preserved in a 4% solution of formalin were washed over an ASTM 230 sieve (mesh opening = 63 μm) to remove the mud content (silt + clay) and the sand fraction retained on the sieve was kept for 8 to 10 hours in a tray containing an aqueous solution of rose Bengal (1 g dissolved in 1,000 mL of distilled water) ensuring that the residue on the sieve mesh was fully covered by the solution. The material was later washed thoroughly to remove the excess stain and subsequently oven-dried at 50°C. Each dried sediment sample was reduced to 25 g after coning and quartering, and then sub-divided into 5 fractions using ASTM 35, 60, 80, 120 and +120 sieves. The relatively coarser fractions retained on ASTM 35, 60 and 80 sieves were spread on picking trays and foraminiferal tests hand-picked using a .00 Windsor-Newton soft-bristled brush under a stereo zoom binocular microscope (EUROMEX-NOVEX). The relatively finer fractions were subjected to floatation using carbon tetrachloride (CCl₄) (Cushman, 1959) and the tests were separated from the

Figure 1: Study area
filter paper to be mounted on 24-chambered micropaleontological slides. The residue after floatation was checked microscopically for tests that might have escaped floatation, and the separated tests subsequently hand-picked. The specimens were then mounted on card slides divided into numbered squares (usually 24 squares) with sliding glass covers. Gum tragacanth was used to mount the specimens on the slides according to the family, genus and species, wherever possible. The different genera and species were identified and living and dead populations of all the taxa were counted. Type specimens of each species were selected and transferred to single round punch micropaleontological slides with cover slips. All the hypotypes were duly indexed with numbers and placed in the repository of the Department of Applied Geology, University of Madras, Chennai 600 0025.

**Brief Systematic Paleontology**

The 48 benthic foraminiferal species identified in the study area belong to 23 genera, 18 families, 12 superfamilies, 4 suborders and 5 orders. Among these, only one is an arenaceous, agglutinated taxon (Order LITUOLIDA), 19 are calcareous, imperforate, porcelaneous forms (Order MILIOLIDA), 3 belong to the Order LAGENIDA, 1 to the Order BULIMINIDA, and the remaining 24 are calcareous, perforate species of the suborder ROTALIIDA. Systematic paleontology for the species recorded is presented as follows:

- **Kingdom CHROMATA**
  - Subkingdom HAROSA, T. Cavalier-Smith, 2010
  - Infrakingdom RHIZARIA T. Cavalier-Smith, 2002
  - Phylum FORAMINIFERA
    - Class POLYTHALAMEA
      - Kingdom CHROMATA
        - Subkingdom HAROSA, T. Cavalier-Smith, 2010
          - Infrakingdom RHIZARIA T. Cavalier-Smith, 2002
            - Phylum FORAMINIFERA
              - Class POLYTHALAMEA
                - Order LITUOLIDA Lankester, 1885
                  - Suborder TEXTULARIINA Delage and Hérouard, 1896
                    - Superfamily LITUOLOIDEA, de Blainville, 1827
                      - Family LITUOLIDAE de Blainville, 1827
                        - Genus AMMOBACULITES Cushman, 1910
                          - *Ammobaculites exigus* Cushman and Brönnimann, 1948
                          
                            Original citation: *Ammobaculites exigus* CUSHMAN and BRÖNNIMANN, 1948, v. 24, p. 38, pl. 7, figs. 7, 8.

                - Order MILIOLIDA Delage and Hérouard, 1896
                  - Suborder MILIOLINA Delage and Hérouard, 1896
                    - Superfamily FISCHERINIDAE Millett, 1898
                      - Family FISCHERINIDAE de Blainville, 1827
                        - Genus AMMOBACULITES Cushman, 1910
                          - *Ammobaculites exigus* Cushman and Brönnimann, 1948
                          
                            Original citation: *Ammobaculites exigus* CUSHMAN and BRÖNNIMANN, 1948, v. 24, p. 38, pl. 7, figs. 7, 8.

                            Order MILIOLIDA Delage and Hérouard, 1896
                              - Suborder MILIOLINA Delage and Hérouard, 1896
                                - Superfamily NUBECULARIOIDEA
                                  - Family NUBECULARIOIDEA Millett, 1896
                                    - Subfamily NUBECULARIOIDEA Millett, 1896
                                      - Genus PLANISPIRINELLA Wiesner, 1931
                                        - *Planispirinella exigua* (Brady, 1879)
                                        

                                          Order OPHTHALMIDIIDAE Wiesner, 1920
                                            - Genus EDENTOSTOMINA Collins, 1958
                                              - *Edentostoma milletti* (Cushman, 1917)
Citation: *Edentostomina milletti* (Cushman) – LOEBLICH and TAPPAN, 1987, p. 325, pl. 334, fig. 9.

Superfamily MILIOLOIDEA Ehrenberg, 1839
Family CRIBROLINOIDIDAE Haynes, 1981
Genus ADELOSINA d’Orbigny, 1826
*Adelosina laevigata* d’Orbigny, 1826
Family SPIROLOCULINIDAE Wiesner, 1920
Genus SPIROLOCULINA d’Orbigny, 1826
*Spiroloculina communis* Cushman and Todd, 1944

Original citation: *Spiroloculina communis* CUSHMAN and TODD, 1944, pp. 63–64, pl. 9, figs. 4, 5, 7 and 8.
*Spiroloculina corrugata* Cushman and Todd, 1944

Original citation: *Spiroloculina corrugata* CUSHMAN and TODD, 1944, pp. 51, 61, pl. 8, figs. 22–25.

*Spiroloculina costifera* Cushman, 1917

Original citation: *Spiroloculina costifera* CUSHMAN, 1917, p. 34, pl. 6, figs. 1–3.
*Spiroloculina henbesti* Petri, 1955

Original citation: *Spiroloculina henbesti* PETRI, 1955, v. 6, no. 2, p. 82, figs. 4–6.
*Spiroloculina nitida* d’Orbigny, 1826

Original citation: *Spiroloculina nitida* D’ORBIGNY, 1826, v. 7, p. 298.
*Spiroloculina orbis* Cushman, 1921

Original citation: *Spiroloculina orbis* CUSHMAN, 1921, v. 4, p. 403, pl. 83, fig. 3.
Family HAUERINIDAE Schwager, 1876
Subfamily HAUERININAE Schwager, 1876
Genus QUINQUELOCULINA d’Orbigny, 1826
*Quinqueloculina costata* d’Orbigny, 1878

Original citation: *Quinqueloculina costata* D’ORBIGNY, 1826, v. 7, p. 301, model no. 3.
*Quinqueloculina elongata* Natland, 1938

Original citation: *Quinqueloculina elongata* NATLAND, 1938, v. 4, no. 5, p. 141, pl. 4, fig. 5.

*Quinqueloculina ferussaci* d’Orbigny, 1826

Citation: *Quinqueloculina ferussaci* d’Orbigny – PARKER, JONES and BRADY, 1865, ser. 3, v. 16, p. 24, pl. 1, fig. 12.
*Quinqueloculina kerimbatica* (Heron-Allen and Earland, 1915)

Original citation: *Miliolina kerimbatica* HERON-ALLEN and EARLAND, 1915, p. 574, pl. 43, figs. 13–23.

*Quinqueloculina lamarckiana* d’Orbigny, 1839

Original citation: *Quinqueloculina lamarckiana* D’ORBIGNY, 1839, p. 189, pl. 11, figs. 14, 15.

*Quinqueloculina seminulum* (Linnaeus, 1758)

Original citation: *Serpula seminulum* LINNAEUS, 1758, p. 786, pl. 2, figs. 1a–c.
Subfamily MILIOLINELLINAE Vella, 1957
Genus TRiloculina d’Orbigny, 1826
Triloculina rotunda d’Orbigny, 1826

*Triloculina terquemiana* (Brady, 1884)

Original citation: *Miliolina terquemiana* BRADY, 1884, p. 166, pl. 114, fig. 1.
*Triloculina tricarinata* d’Orbigny, 1826

Original citation: *Triloculina tricarinata* D’ORBIGNY, 1826, p. 299, no. 6.
*Triloculina trigonula* (Lamarck, 1804)

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Original citation: *Miliolites trigonula* LAMARCK, 1804, v. 5, p. 351, pl. 17, fig. 4.
Order LAGENIDA Delage and Hérouard, 1896
Suborder LAGENINA Delage and Hérouard, 1896
Superfamily NODOSARIOIDEA Ehrenberg, 1838
Family LAGENIDAE Reuss, 1862
Genus LAGENA Walker and Boys, 1784
*Lagena laevis* (Montagu, 1803)

Original citation: *Vermiculum laeve* MONTAGU, 1803, p. 524.
*Lagena striata* (d’Orbigny)

Original citation: *Oolina striata* D’ORBIGNY, 1839, p. 21, pl. 5, fig. 12.
Superfamily POLYMORPHINOIDEA
Family ELLIPSOLAGENIDAE A. Silvestri, 1923
Subfamily ELLIPSOLAGENINAE A. Silvestri, 1923
Genus FISSURINA Reuss, 1850
*Fissurina laevigata* Reuss, 1850

Original citation: *Fissurina laevigata* REUSS, 1850, p. 366, pl. 46, fig. 1.
Order BULIMINIDA Delage and Hérouard, 1896
Suborder ROTALIINA Delage and Hérouard, 1896
Superfamily BULIMINOIDEA Jones, 1875
Family SIPHOGENERINOIDIDAE Saidova, 1981
Subfamily SIPHOGENERINOIDINAE Saidova, 1981
Genus LOXOSTOMINA Sellier de Civrieux, 1969
*Loxostomina limbata* (Brady, 1881)

Original citation: *Bolivina limbata* BRADY, 1881, v. 21, p. 27; 1884, v. 9, p. 419, pl. 52, figs. 26–28.
Order ROTALIIDA Delage and Hérouard, 1896
Suborder ROTALIINA Delage and Hérouard, 1896
Superfamily DISCORBOIDEA Ehrenberg, 1838
Family EPONIDIDAE Hofker, 1951
Subfamily EPONIDINAE Hofker, 1951
Genus EPONIDES de Montfort, 1808
*Eponides cribrorependus* (Asano and Uchio, 1951)

Original citation: *Poroeponides cribrorependus* ASANO and UCHIO, 1951, p. 18.
*Eponides repandus* (Fichtel and Moll, 1798)

Original citation: *Nautilus repandus* FICHTEL and MOLL, 1798, p. 35, pl. 3, figs. a–d.
Genus POROEAPONIDES Cushman, 1944
*Poroeponides lateralis* (Terquem, 1878)

Original citation: *Rosalina lateralis* TERQUEM, 1878, v. 1, no. 3, p. 25, pl. 2, figs. 11a–c.
Family HELENINIDAE Loeblich and Tappan, 1987
Genus HELENINA Saunders, 1961
*Helenina anderseni* (Warren, 1957)

Original citation: *Pseudoeponides anderseni* WARREN, 1957, p. 39, pl. 4, figs. 12–15.
*Helenina perlucida* (Heron-Allen and Earland, 1913)

Original citation: *Rotalia perlucida* HERON-ALLEN and EARLAND, 1913, v. 31, p. 139, pl. 13, figs. 7–9.
Family ROSALINIDAE Reiss, 1963
Genus ROSALINA d’Orbigny, 1826
*Rosalina globularis* d’Orbigny, 1826

Original citation: *Rosalina globularis* D’ORBIGNY, 1826, v. 7, p. 271, pl. 13, figs. 1, 2.
Superfamily ASTERIGERINOIDEA d’Orbigny, 1839

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Family AMPHISTEGINIDAE Cushman, 1927
Genus AMPHISTEGINA d’Orbigny, 1826
Amphistegina radiata (Fichtel and Moll, 1798)

Original citation: Nautilus radiatus FICHTEL and MOLL, 1798, p. 58, table 8, figs. 9b–d.
Superfamily NONIONOIDEA Schultze, 1854
Family NONIONIDAE Schultze, 1854
Subfamily NONIONINAE Schultze, 1854
Genus NONIONOIDES Saidova, 1975
Nonionoides elongatum (d’Orbigny, 1826)


Superfamily CHILOSTOMELLOIDEA Brady, 1881
Family GAVELINELLIDAE Hofker, 1956
Subfamily GAVELINELLINAE Hofker, 1956
Genus HANZAWAIA Asano, 1944
Hanzawaia concentrica (Cushman, 1918)

Original citation: Truncatulina concentrica CUSHMAN, 1918, p. 64, pl. 21, fig. 3.
Genus COCOAROTA Loeblich and Tappan, 1986
Cocoarota madrasensis Rajeshwara Rao and Revets, 2001


Superfamily ROTALIOIDEA Ehrenberg, 1839
Family ROTALIIDAE Ehrenberg, 1839
Subfamily AMMONIINAE Saidova, 1981
Genus AMMONIA Brünnich, 1772
Ammonia beccarii (LINNAEUS, 1758)

Original citation: Nautilus beccarii LINNAEUS, 1758, v. 1, p. 710.
Ammonia dentata (Parker and Jones, 1865)

Original citation: Rotalia beccarii (LINNAEUS) var. dentata PARKER and JONES, 1865, pp. 387, 388, 422; pl. 19, figs. 18a–c.
Ammonia tepida (Cushman, 1926)

Original citation: Rotalia beccarii (LINNAEUS) var. tepida CUSHMAN, 1926, p. 79, pl. 1; 1931, p. 61, pl. 13, figs. 3a–c.
Genus ASTEROROTALIA Hofker, 1950
Asterorotalia inflata (Millett, 1904)

Original citation: Rotalia schroeteriana PARKER and JONES var. inflata MILLETT, 1904, p. 504, pl. 10, figs. 5a–c.
Asterorotalia multispinosa (Nakamura)

Citation: Asterorotalia multispinosa (Nakamura) - RAO and RAO, 1974, table 7, pl. 2, figs. 12a, b.
Asterorotalia trispinosa (Thalmann, 1933)

Original citation: Rotalia trispinosa THALMANN, 1933, v. 26, no. 2, pp. 249, 250, pl. 12.
Genus PSEUDOROTALIA Reiss and Merling, 1958
Pseudorotalia schroeteriana (Carpenter, Parker and Jones)

Original citation: Rotalia schroeteriana CARPENTER, PARKER and JONES, 1862, p. 213, pl. 13, figs. 7–9.

Family ELPHIDIIDAE Galloway, 1933
Subfamily ELPHIDIINAE Galloway, 1933
Genus ÊLPHIDIUM de Montfort, 1808
Elphidium advenum (Cushman, 1922)

Original citation: Polystomella advena CUSHMAN, 1922, p. 56, pl. 9, figs. 11, 12.
Elphidium crispum (Linnaeus, 1758)
Original citation: Nautilus crispus LINNAEUS, 1758, p. 709.

Elphidium discoidale (d'Orbigny, 1839)
Original citation: Polystomella discoidalis D'ORBIGNY, 1839, p. 56, pl. 6, figs. 23, 24.

Elphidium hispidulum Cushman, 1936
Original citation: Elphidium hispidulum CUSHMAN, 1936, v. 12, pt. 4, p. 83, pl. 14, figs. 13a, b.

Elphidium incertum (Williamson, 1858)
Original citation: Polystomella umbilicatula WALKER var. incerta WILLIAMSON, 1858, p. 44, pl. 3, figs. 82, 82a.

Elphidium nörvangi Buzas, Smith and Beem, 1977
Original citation: Elphidium nörvangi BUZAS, SMITH and BEEM, 1977, p. 96, pl. 7, figs. 1–4.

Superfamily NUMMULITOIDEA de Blainville, 1827
Family NUMMULITIDAE de Blainville, 1827
Genus ASSILINA d'Orbigny, 1839
Assilina ammonoides (Gronovius, 1781)
Original citation: Nautilus ammonoides GRONOVIUS, 1781, p. 282, pl. 19, figures. 5, 6.

Results and Discussion

The following ecological parameters were determined in the 11 near-shore water and sediment samples: water depth, bottom water temperature, pH, dissolved oxygen (DO) and salinity with regard to water samples, and calcium carbonate (CaCO$_3$), organic matter, sand, silt and clay contents in the sediment samples. Table 2 presents the details regarding the above mentioned physic-chemical parameters. From the table, it is evident that there are no significant variations, as all the samples were collected within a narrow water depth range of 0.5 to 3.0 m. Moreover, as the water samples were collected during the beginning of February, the bottom water temperatures are comparatively on the lower side. There are, however, changes in some parameters such as pH, dissolved oxygen, salinity and sediment texture, in some of the samples collected in the bay.

The pH of seawater is higher than that of river water, and the pH values of the former can vary depending upon the aquatic volume of input into a water body such as the Nizampatnam Bay. There are also many canals and tributaries of the Krishna River, opening at several points along the coast near Nizampatnam, facilitating terrestrial runoff into the bay and, thereby decreasing the pH values (Vivekanandan and Meiyappan, 1999). According to Kunte and Wagle (1993), the Krishna River delta is prograding and, as a consequence, there is development of sandbars and spits and consequent filling up of the lagoonal areas occurring. This is clear evidence of sufficient input of fresh water from the Krishna River to reduce the pH of the Nizampatnam Bay water to values relatively less than those of normal seawater. This could also be the reason for the diminished salinity values in the vicinity of the bay. Table 2 shows that DO values are relatively lower in the stations in the vicinity of Nizampatnam, suggesting that increased influence of terrestrial influx is causing enhanced organic matter input. Heavy rainfall and high runoff supply more humic matter during the monsoon and increase the organic matter. The Nizampatnam Bay receives its rainfall from the north-east monsoon as well as cyclonic storms, so it is quite possible that the influx of organic matter is high, more so in view of the fact the Krishna River is perennial. Organic matter is bacterially decomposed, but the process requires the presence of oxygen. So, the
decreased values of DO at these two stations are clearly a pointer to either of these processes. The increased organic matter values at these stations conform to this inference.

Calcium carbonate, on the other hand, is an indicator of provenance and dispersal of terrigenous material (Loring and Nota, 1973). Calcium carbonate content in a sediment sample is generally inversely related to organic matter content in that sample, because relatively higher calcium carbonate content is associated with coarse-textured sediment; on the other hand, organic matter is often related to fine-textured sediment, as it is adsorbed on to the surfaces of individual particles that constitute the sediment sample. In the Nizampatnam Bay, the CaCO₃ values are inversely related to organic matter content, confirming earlier observations made by several workers.

From Table 2, it is evident that among the 11 sediment samples collected and analyzed, almost 70% of them fall in the category of sand as per the textural classification proposed by Sneed and Folk (1958). Generally, sediment texture becomes finer as the depth of the water column increases; near-shore sediments are, invariably coarse-grained, mainly a consequence of winnowing, a process active on accreting beaches. The Krishna River delta being a prograding one, wave action contributes to depositing relatively coarser clasts on the beach and in the near-shore region due to reduced wave velocity as it recedes and carries back the relatively finer clasts. However, the presence of other sediment textures is probably an indication of variable hydrodynamics in the near-shore region of Nizampatnam Bay. According to Nageswara Rao et al. (2005), the Nizampatnam coastal sands are fine to very fine, very well sorted to moderately sorted, very coarsely skewed to fine skewed and leptokurtic in nature. When the samples were processed by washing them through an ASTM 230 sieve, to remove the mud (silt + clay) content, it was noticed that the texture was fine, conforming to the observations made by Nageswara Rao et al. (op cit.).

Based on the generic classification by Loeblich and Tappan (1987; 1992) and other modified classifications, 48 benthic foraminiferal species were identified, composed of five Orders, although the orders LITUOLIDA and LAGENIDA are poorly represented. This is typical of a near-shore benthic foraminiferal assemblage, as the hydrodynamics of such an environment favors only those species that can withstand the energy impact. What is surprising, however, is the dominance of *Ammonia dentata* over *Ammonia beccarii* in the study area. *Ammonia beccarii* is a cosmopolitan species that is environment-tolerant to a significantly high level, but its lack of abundance in the near-shore region of Nizampatnam Bay is baffling.

Rose Bengal staining technique was used to differentiate between “living” and dead populations. All the 11 stations put together, the total population was counted as 1,431, out of which 399 tests were stained, implying that they were living at the time of collection. Living population, therefore, constitutes 27.9% of the total benthic foraminiferal population in the near-shore region of Nizampatnam Bay. The sample collected off Wadarevu yielded the highest total population of 327 specimens, out of which 92 were found to be stained. However, both living and total populations are variable and not really correlatable with any of the ecological parameters determined. Species diversity was also found to be the highest at this station (Table 2).

Almost all the tests of *Ammonia dentata* exhibited short, blunt spines, rather than long, slender ones. It should be noted that Ragothaman (1974) observed tests of this species possessing both kinds of spines. According to Rajeshwara Rao (1998), tests of *A. dentata* with long, slender spines were more abundant in deeper waters off Karikkattukuppam, near
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Chennai, Bay of Bengal, while the near-shore specimens had short and blunt spines. This implies that observations on the tests of the near-shore region of Nizampatnam Bay are in concurrence with Rajeshwara Rao’s (op cit.) observations. This also means that an analysis of well-preserved fossils of A. dentata could be used as a proxy for estimating paleo water depths in such an environment.

Conclusions

Benthic foraminiferal studies in the nearshore region of Nizampatnam Bay yielded 48 species belonging to 23 genera, 18 families, 12 superfamilies, 4 suborders and 5 orders, which have been reported and illustrated. Out of the total population count of 1,431 specimens, 399 were observed to be rose Bengal-stained, and are considered to be living at the time of sample collection. Surprisingly, the most abundant species was observed to be Ammonia dentata (Parker and Jones) in the study area, rather than its more cosmopolitan counterpart, Ammonia beccarii (Linnaeus). The results of this study constitute an accurate and reliable benthic foraminiferal database that would be extremely useful for other researchers. Further, detailed studies on benthic foraminiferal assemblages in the Nizampatnam Bay will be interesting as the bay is highly influenced by fresh water influx from the Krishna River and its tributaries.

References


