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Seasonal distribution of benthic foraminifera at Nana Layja, Kachchh, Gujarat – India

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Benthic foraminiferal abundance from three sites at Nana Layja from the coast of Kachchh was studied over a period of one year to determine the seasonal variability. All the three sites were dominated by *Ammonia beccarii* (Brunnich, 1772), *Pararotalia calcariformata* (Le Calvez, 1949), *Elphidium advenum* (Haynes, 1973), *Eponides repandus* (Montfort, 1808) and *Quinqueloculina bosciana* (d'Orbigny, 1826). These showed considerable seasonal variability at the studied three sites. The maximum total foraminiferal abundance was found on December 2016 while the minimum was observed on June 2017. *A. beccarii*, *P. calcariformata*, and *E. repandus* exhibited a seasonal pattern similar to the total foraminiferal abundance. Whereas, *E. advenum* and *Q. bosciana* showed a different pattern of abundance with the minimum and maximum abundances found in December 2016 and June 2017, respectively. Other two rare species recorded were *Spiroloculina* sp. 1 (Alcide d'Orbigny, 1826) and *Rosalina globularis* (Alcide d'Orbigny, 1826) in all the seasons. Species diversity analysis showed that the three sites are rich in species variability with a high Shannon−Weiner Index and low Evenness Index. The physicochemical characterization of seawater collected from three sites showed distinct seasonal variations.

[**Keywords**: Benthic foraminifera, Diversity analysis, Nana Layja, Seasonal variations]

Introduction

Intertidal zones are continuously submerged and exposed to tides and hence are subjected to continuous disturbance[1]. Various studies based on benthic foraminifers have shown that they are temporally and spatially variable[2-5] due to strong and long-lasting tests usually made of $CaCO_3$. Therefore, they have been used as proxies for monitoring environmental changes[6-10].

Various biological and physicochemical parameters namely water temperature, tidal cycles, salinity, type of the sediment, depth at the collection site, nitrogen, oxygen and feed availability, saltmarsh vegetation, the amount of organic carbon as well as bacterial activities affect the population and distribution of foraminifers at the benthic level[11-15]. However, the effect of each individual factor varies seasonally and spatially[14]. Conversely, it is assumed that the plenitude & distribution of various species of benthic foraminiferans is mainly dependent on various biotic factors such as the competition & predators in the vicinity[1]. This is indicative of the fact that the reproductive rate of any one of the species will probably inhibit any contending species[16].

Gulf of Kachchh (GoK) is endowed with rich coastal biodiversity comprising mangroves, coral reefs, and seaweeds. Earlier studies have investigated the flora and fauna of GoK[17]; however, only Nigam & Chaturvedi[18] were the ones who recorded foraminiferal diversity and distribution that to only from Kharo creek through a single sampling. Further, detailed seasonal studies on spatial and temporal scales are lacking from this region. Since time-dependent investigations are quite laborious, resulting in fewer research studies on benthic foraminifers & so are from the coastal area of Kachchh. Therefore, the present study was undertaken with the objective to unravel the variations that occur due to changes in the season and its impact on the local benthic diversity and abundance. The time frame chosen was over a period of a year. Sample collection was done from the 3 sites on a quarterly basis at the Nana Layja coast. This probe to understand foraminiferal assemblage and its variations in the intertidal zone of the Nana Layja coast is the only intensive study done till date. This kind of investigations can help understand the cyclic changes & variations in the plenitude of foraminiferal shell assemblage in the intertidal zones[19-20]. Extensive recording of the species that dominates the study area and the rare specimens found occasionally at every sampling site has been recorded as well.

Materials and Methods

Study area

Kachchh district has a coastal stretch of about four hundred and five kilometres including the whole expanse of Northern coast of Gulf of Kachchh (GoK). Sandy beaches, marshlands and mangroves make up a large part of the local ecosystems expanding about twenty-five hundred & nine hundred and forty square kilometres, respectively in the Kachchh coast encompassing rich habitats that include a network of creek systems[21]. Unprecedented coastal industrialization has impacted the coastal biodiversity of GoK significantly. Nevertheless, the coast of Nana Layja located about 15 km from the coastal town of Mandvi in Kachchh has not yet witnessed any industrial development and is least affected by any anthropogenic activity. In view of this, three sites adjoining the coastline of Nana Layja were chosen for the current investigation.

Tidal waves at Nana Layja are of mixed type that mainly includes semidiurnal waves along with 6.66 m of Mean High-Water Springs (MHWS) & 5.17 m of Mean Low Water Springs (MHWN). This difference in phase is not uniform for successive tides in the Gulf and it varies as per tidal condition[22].

Methodology

Sampling procedure

In order to assess the seasonal effects, sampling was carried out for 4 seasons (*i.e.*, winter – spring – summer – autumn, respectively in the month and year as follows: December 2016, March 2017, June 2017 and October 2017), from the intertidal zone of Nana Layja (Fig. 1). Three sites of sample collection

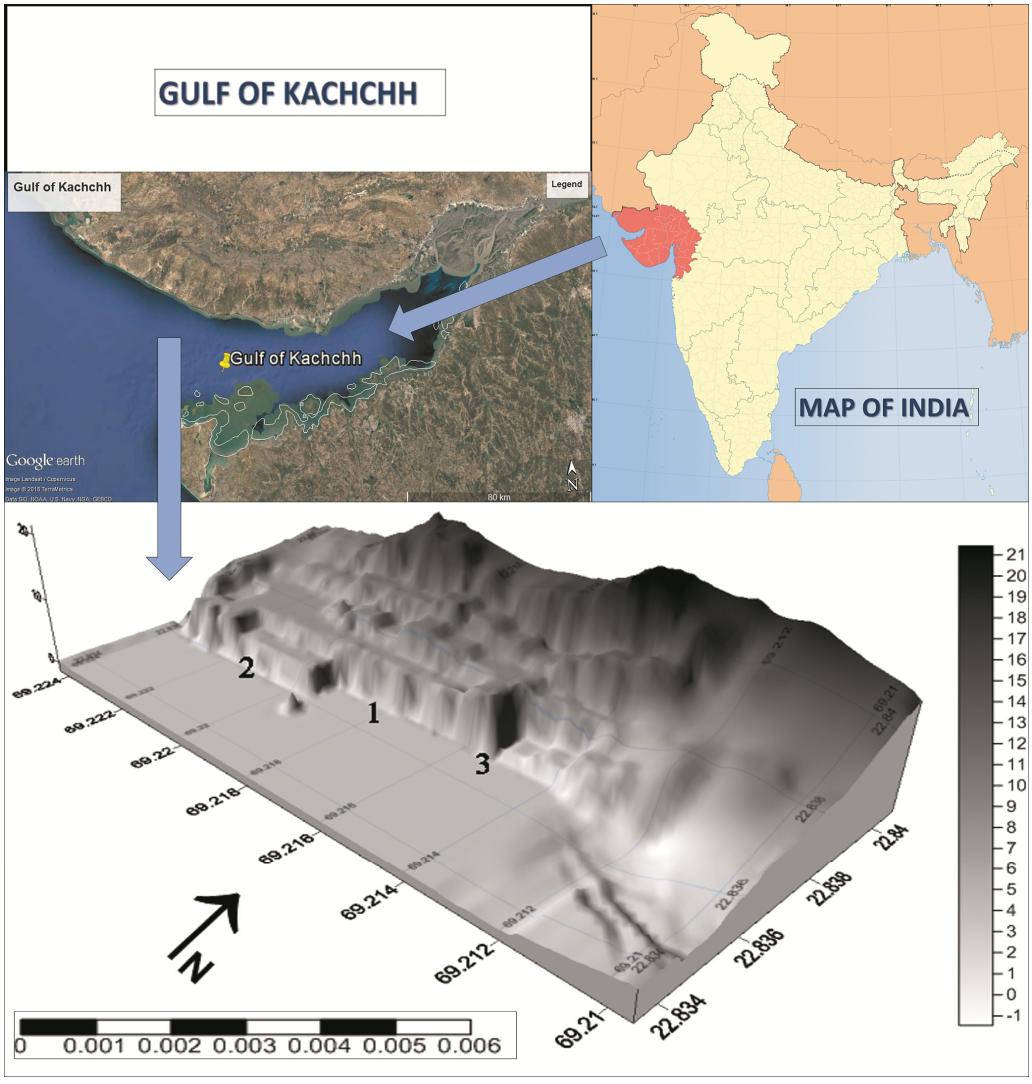

Fig. 1 — Map of the study area with sampling sites. The numbers indicate sites I, II and III, respectively

(*i.e*. Site I, Site II and Site III) were selected along the intertidal zone located at a distance of 500 metres from each other. From each sampling site, samples were collected in triplicates at 1 m interval for abundance studies. Samples for winter was collected in middle of December 2016, followed by sample collection in early March 2017 for the spring survey; followed by sampling at the end of June 2017 for summer collection, and final collection in mid-October 2017 for the autumn season. The entire study included 36 sediment samples from water depths of 50 to 100 cm from the intertidal zones between highest high tide and lowest low tide. Sampling at a depth of ~ 1 − 2 cm, sediments was gathered using a spatula carefully without disturbing the sediment floor, and stored in clean bottles made from plastic secured with a screw topped lids which were capped underwater. The samples were quickly taken to the laboratory for further studies.

Processing and picking of foraminiferans from sediment samples

In the laboratory, each sample was taken and first cleaned with water collected from the seashore through a mesh sieve of 500 microns which was again sieved using a 63 microns mesh sieve. After that, 5 cm^3 of non-sieved sediment containing all the foraminifers were taken for analysis. Finally, each replicate was microscopically analyzed and all the foraminifers were wet-picked under a Magnus Stereozoom Microscope (MSZ−TR). In total, 50,797 forams were counted during the course of the study, with an average of 1,411 foraminifers tests observed in each of the replicates. Taxonomical identification was carried out using Loeblich & Tappan[23], Sen Gupta[24] and World Foraminifera Database[25]. Dominant foraminifers were photo graphed using the CMOS camera attached to the stereo-zoom microscope (Magnus MSZ-B1 Binocular Stereo-zoom Microscope). Scanning Electron Microscope (SEM) images of selected foraminifers were taken using Zeiss EVO 18 at the Foundation titled Gujarat Ecological Education and Research (GEER), in Gandhinagar, Gujarat.

Statistical analysis

Three significant diversity indices were calculated from the sampling data for the sampling sites in order to characterize the community & understand variations in abundance and dispersal of species from the foraminiferan assemblage. The Shannon–Wiener index H(S) takes consideration of count of individuals together with the taxa number. It can be from 0 for communities that has only a 1 taxon to higher values for communities with multiple species, few individuals in each of them and is calculated by the formula H = sum ((ni/n) ln(ni/n)), where ni is the individuals encountered in the i^{th} taxa. Evenness (E_H) can be measured easily by dividing H(S) (Shannon–Wiener index) by lnS (where S is number of species in total in the community of the study area) and the formula is written as E_H = H/lnS. The calculated Evenness lies between the value between 0 and 1, where 1 represents complete evenness in the collected sample. The formula S = a*ln(1 + n/a) of Fisher's alpha diversity index is used for finding out diversity index, where 'n' stands for the number of individuals encountered and 'S' stands for number of taxa in the collected sample.

Physicochemical properties of water

Seawater was collected separately in clean plastic bottles which were pre-rinsed with seawater prior to sample collection. Triplicate samples were collected during each season. Temperature was measured on site during each sampling period using thermometer. However, electrical conductivity (EC), pH, salinity, total alkalinity and total dissolved solids which is abbreviated as TDS, were evaluated after the sample collection in laboratory using a water analyzer (Hach HQ-440d).

Results

Composition of species

Five major species of foraminifers that was present predominantly in the collected samples of 3 sites were *A. beccarii*, *P. calcariformata*, *E. advenum*, *E. repandus* and *Q. bosciana* (Figs. 2A – I & 3). *A. beccarii* and *P. calcariformata* dominated the fauna at all the three sites in Nana Layja with the relative abundance of 31.68 and 25.90 %, which accounted to a large portion of the total foraminiferal collection through the entire study (Fig. 3). They were followed in abundance by *E. advenum*, *E. repandus* and *Q. bosciana* with a relative abundance of 13.75, 8.38 and 7.82 %, respectively of the entire population (Fig. 3). Some of the rare species found were *Spiroloculina* sp. 1, *R. globularis* and some Miliolida (Figs. 2J – N).

Seasonal trend of abundance

Foraminiferal abundance showed seasonal changes from December 2016 to October 2017 as illustrated in

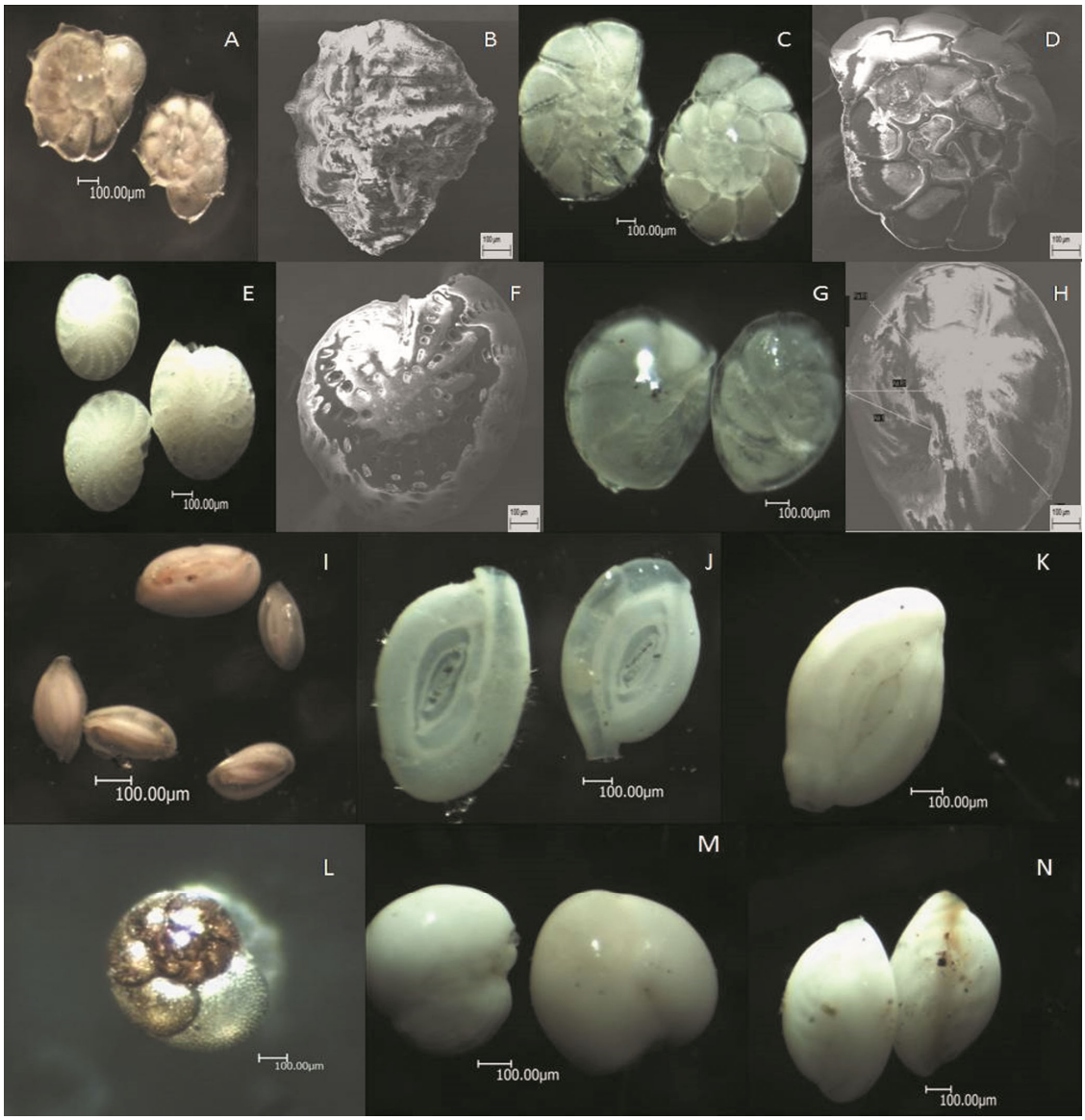

Fig. 2 — Images of 5 foraminiferal species collected along the coastal line of Nana Layja: A–B) *P. calcariformata*, C–D) *A. beccarii*, E–F) *E. advenum*, G–H) *E. repandus*, I) *Q. bosciana*, J–K) *Spiroloculina* sp. 1, L) *R. globularis*, and M–N) *Miliolida* sp.

the Figure 4 even though all the 3 sampling sites displayed consistency in the seasonal pattern of mean abundance (all the individuals/unit of area of sediment used for calculating abundance). The total abundance of foraminifera throughout the sampling term was relatively highest at the site I, followed by site III & site II (18690, 16409 and 15698 individuals, respectively). The maximum foraminiferal abundance was found in December 2016 (18883). The gradual decrease in the encountered number of forams was seen in March 2017 (13841) that reached minimum values in June 2017 (8820) (Fig. 4A). Foraminiferal abundance then increased slightly in October 2017 (9253), indicating that the foraminiferans might regained their abundance by December 2017.

Three species namely *A. beccarii*, *P. calcariformata* and *E. repandus* displayed a distribution of highest abundance of individuals in December 2016 relative to other months, which showed gradual decrease in March 2017 through June 2017 and remained almost stagnant during October 2017 (Figs. 4B – D). The largest abundance among the total assemblages in all the 3 sites was observed for *A. beccarii* (Fig. 4B). As *A. beccarii* and *P. calcariformata* contributed largely to the total fauna of foraminifers encountered, the seasonal trend of forams did not change significantly from the usual

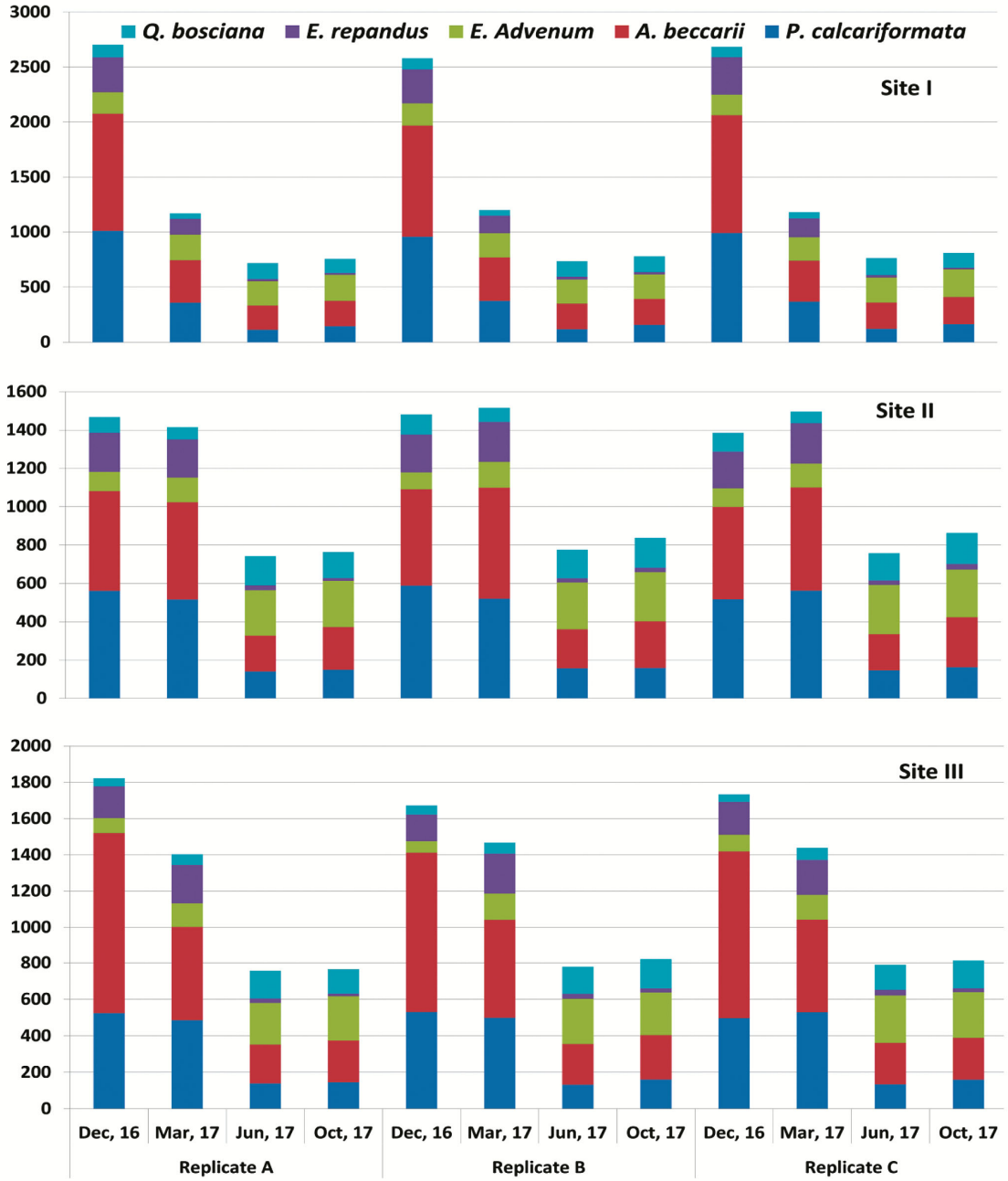

Fig. 3 — Foraminiferal abundance & composition at sampling sites I, II, III with replicates

trend of all forams throughout the course of study (Figs. 4A – C). The seasonal trend of *E. repandus* was also similar to the general trend of foraminiferal abundance (Figs. 4A & D). The other two species, *i.e. E. advenum* and *Q. bosciana* showed a different pattern of abundance (Figs. 4E & F). The lowest relative abundance for *E. advenum* was observed in December 2016 which gradually increased in March 2017 through June 2017 and reached the maximum in October 2017. In the case of *Q. bosciana*, the relative abundance decreased from December 2016 to March 2017 but then it increased as it reached a maximum in October 2017. The seasonal trend of both the species mentioned above displayed considerable variation from the general trend. The environmental data collected showed that the population of only these two species preferred, higher values of TDS, temperature, salinity and total alkalinity in summer season. Though the two species do not contribute considerably to the entire population of foraminifera

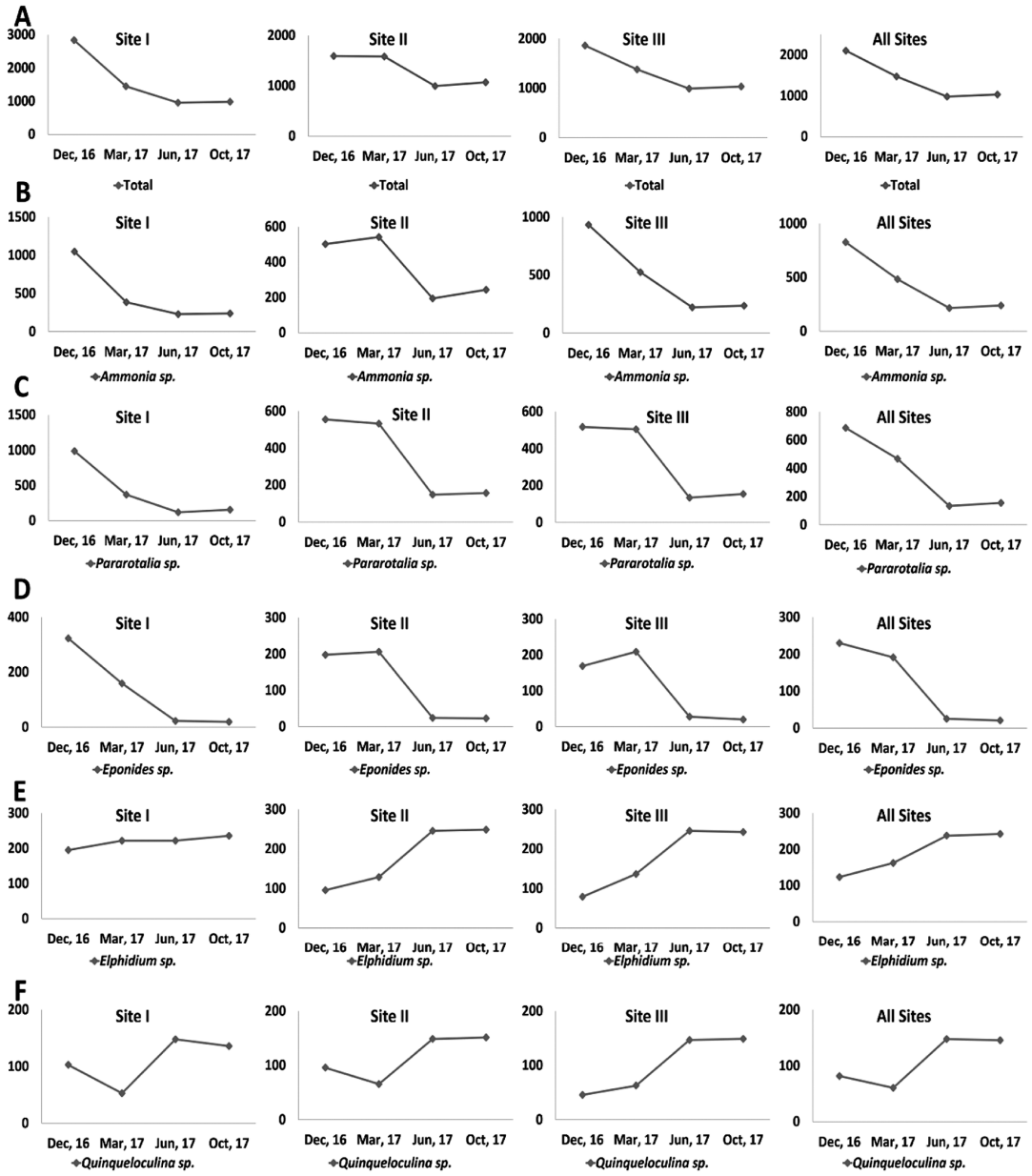

Fig. 4 — Variation with respect to seasons of all the observed foraminiferal species: A) All species, B) *A. beccarii*, C) *P. calcariformata*, D) *E. repandus*, E) *E. advenum*, and F) *Q. bosciana*. Abundance is reflective of observed specimens per 5 cm^3

seen. The general tendency of the rest of all foraminiferal fauna remained unaffected.

Species diversity

The species diversity (Shannon–Wiener index, H(S), Evenness index (E_H) & Fisher's alpha index) was calculated for the 3 sampling locations (Fig. 5). The values of H(S) at the two sites I and II are a bit higher than that at the site III, indicating towards diverse foraminiferan assemblage. It ranged from 1.543 to 2.262 (with the mean of 2.010) and 1.661 to 2.286 (mean = 1.976) and 1.373 to 2.261 (mean = 1.915) at site I, II and III, respectively (Fig. 5A). The cyclic pattern for the H(S) values at sites I, II, III was quite clear, it was increasing gradually from December 2016 to March 2017, showing a peak in June 2017 and decreasing afterward in October 2017. Although there was a considerable increase in H(S) from December 2016 to March 2017 at the sites I and III, there was a small increase at the site II during the same period (1.661 to 1.689). Values for E_H differed from those of H(S), with a decrease in March 2017 and an increase afterward till October 2017 at sites II

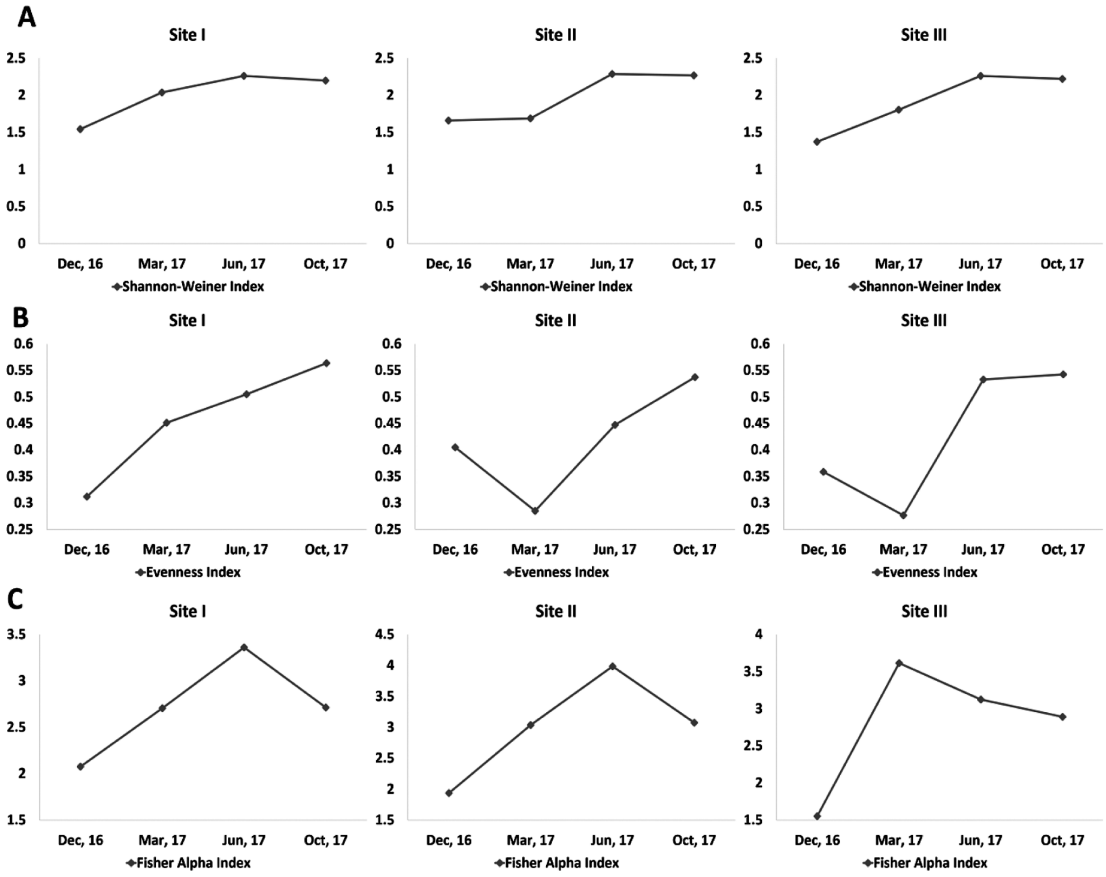

Fig. 5 — Diversity indices: A) The Shannon–Weiner Index, H(S), B) The Evenness Index, E_H, and C) The Fisher's Alpha Index

and III. At site I, the cycle was more analogous to H(S) where there was an increase in value throughout the four seasons with the peak observed in October 2017. All the three sites have similar E_H values ranging from 0.312 to 0.564 (with the mean = 0.458), 0.285 to 0.537 (mean = 0.419) and 0.277 to 0.542 (mean = 0.428) for sites I, II and III, respectively as shown in figure (Fig. 5B). For Fisher's alpha index, the pattern was similar at all the three sample locations. The values increased at first and then decreased with the peak observed in June 2017 at site I and site II; while the peak was observed in March 2017 at site III. The Fisher's alpha showed a range between 2.077 & 3.360 (with the mean = 2.714), 1.937 to 3.984 (mean = 3.008), and 1.551 to 3.615 (mean = 2.795) at sites I, II, III, respectively (Fig. 5C).

Physicochemical characterization of seawater

The seasonal variability of physicochemical parameters of seawater was analysed in all the four seasons which showed minor seasonal variations. Temperature, TDS, salinity and total alkalinity showed a similar trend throughout the year with lowest values in December 2016, then increased in March 2017 and showed maximum values in June 2017 and then marginally lower values in October 2017 (Figs. 6A, D − F). On the other hand, pH and EC were highest in March 2017 and then declined in June 2017 through October 2017 (Figs. 6B − C).

Discussion

The foraminiferal assemblage at the three studied sites comprised of *A. beccarii*, *P. calcariformata*, *E. repandus*, *E. advenum* and *Q. bosciana* alongside a few individuals of *Spiroloculina* sp. 1 and *R. globularis* were also found. This association of forams has been found extensively around the coastline of India, with examples such as in Kharo creek[18], Pennar river estuary[26], Krishnapatnam port[27], Mandapam and Tuticorin[28], Tamil Nadu coastline[29], Gosthani river estuary[30], Palk Strait and Adyar river[31] and Palar estuary[32], even though the complete faunal composition may vary. Notwithstanding the non-occurrence of patchiness in the foraminiferan collection of the studied samples in replicate samples

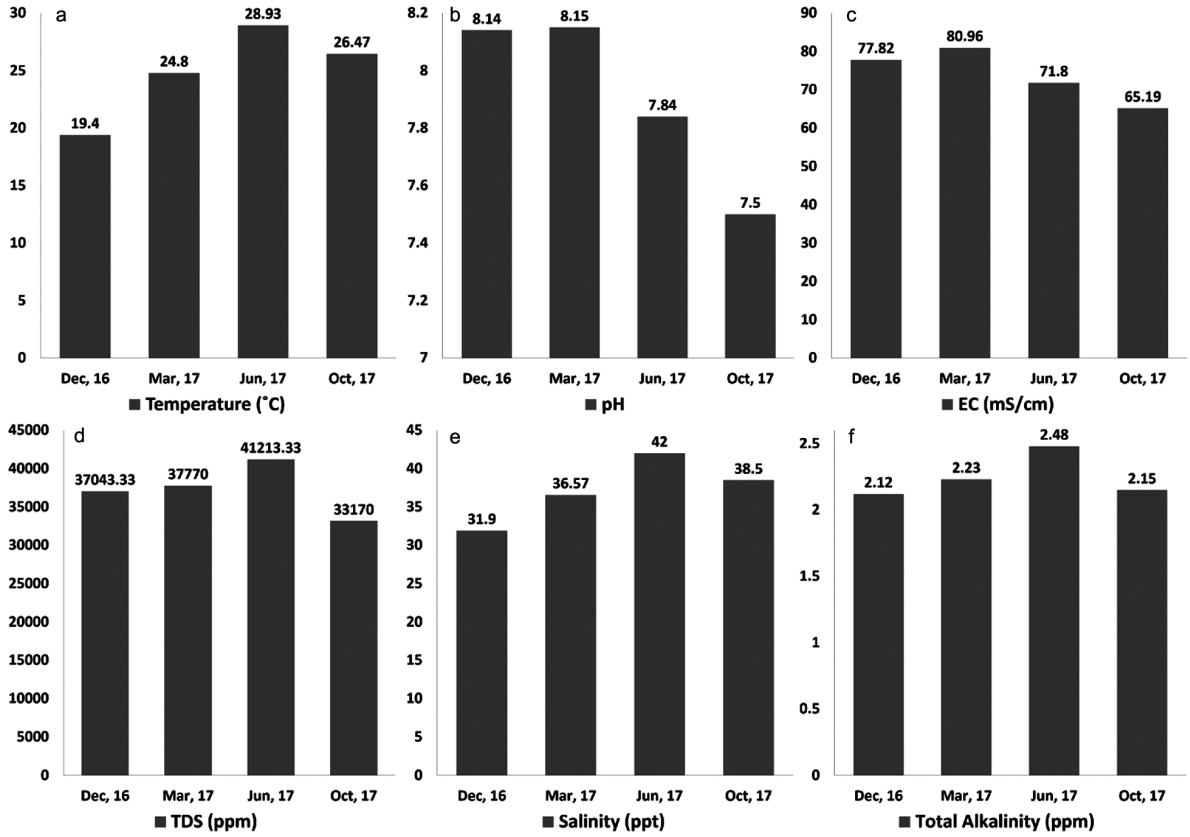

Fig. 6 — Seasonal variation in physicochemical parameters: A) Temperature (˚C), B) pH, C) EC (mS/cm), D) TDS (ppm), E) Salinity (ppt), and F) Total Alkalinity (ppm)

in the study area, a significant difference in the foraminiferan assemblage among the sites I, II, III was identified. For *A. beccarii*, *P. calcariformata* & *E. advenum*, there were important variations in the observed occurrence amongst the sites. The site II showed lesser abundance of *A. beccarii* compared to both site I and III. Inversely, the relative abundance of *P. calcariformata* & *E. advenum* was higher in the site I with respect to other two sites studies. For both *E. repandus* and *Q. bosciana*, the overall abundance amongst all the three sites was relatively equal. The relative abundance of *E. repandus* was slightly higher at site I while that of *Q. bosciana* was higher at the site II.

Seasonal analysis of foraminiferal abundance elucidates the effect of seasons on foraminiferal distribution throughout the year[33-34]. The results show that the seasonal variability has a significant influence on foraminiferal distribution in the intertidal zones at Nana Layja; however, no earlier reports are available on their seasonal distribution pattern from Kachchh[35]. Highest foraminiferal abundance was observed in December 2016 at all the three sites pointing towards that fact that the conditions for reproduction are related to the surrounding general environment where the foraminifers live, instead of site-specific conditions. The lowest abundance was observed in late summer, during June 2017. Alike present study, high abundance in winter in the intertidal zone is also reported by Arslan *et al*.[36] in Arabian Gulf with a decline in total assemblage in June – July (summer), respectively as our study revealed that the foraminifers, might reproduce rapidly after monsoon.

A. beccarii and *P. calcariformata* dominated the three sites, constituting about 31.67 and 25.9 % of the total faunal assemblage. Nigam & Chaturvedi[18], Reddy *et al*.[26] and Jayaraju *et al*.[27] also reported their dominance in the Kharo creek from the Western coastal area of India & in the Pennar river estuary & Krishnapatnam port on Eastern coastal region of India. During the course of this study, number of *A. beccarii* & *P. calcariformata* peaked during December 2016, which reduced through March to June 2017 and marginally increased in October 2017. Although *E. repandus* represented only about 8.38 % of the total assemblage, its seasonal trend pattern was

similar to that of *A. beccarii* and *P. calcariformata*. *E. repandus* was reported to be one of the dominant species by Nigam & Chaturvedi[18] in Kachchh and other part of Indian coast[35,37].

E. advenum and *Q. bosciana* constituted 13.75 and 7.82 % of the total abundance. They followed a different seasonal trend than the general trend. Their abundance was least in December 2016 which kept on increasing and peaked during June 2017. Thereafter, there was a minor drop in abundance in October 2017. Likewise, Abbas & Achyuthan[29] and Naresh Kumar *et al*.[30], found that *E. advenum* and *Q. bosciana* dominated the intertidal stations at the eastern coast of the country; whereas at Kharo creek, Kachchh, *E. advenum* and *Q. bosciana* were one of the dominant species. Other rare species, *Spiroloculina* sp. 1 and *R. globularis* didn't display any sign of any seasonal pattern throughout the study at the study area. It can be due to the fewer number of observed specimens at the study region.

Conclusions

The study (December 2016 to October 2017) at intertidal zone on the coast of Nana Layja, Kachchh was carried out to understand and find temporal variability of total foraminiferal assemblages. It recorded important constituents of foraminiferal community including species composition, abundance and diversity along the intertidal zone at three different sites of Nana Layja (GoK). Significant seasonal variations were observed in the foraminiferal populations of the selected sites. The largest abundance was observed during the month of winter, and a minimum was found during the summer season. Although most of the foraminifers followed a general trend of abundance, *E. advenum* and *Q. bosciana* were observed to follow a different trend. Their highest abundance was in summer while their lowest was in winter. Thus, this study will serve as baseline data for future research on foraminiferal diversity and distribution based on seasonality at the Gulf of Kachchh.

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Conflicts of Interest

The authors have no conflicts of interest to declare.

Author Contributions

MHT, KAB, and SPP helped in designing the study. KAB, and SPP collected and analysed the data; and MHT, KAB, and SPP helped in analyzing data and drafting the paper.

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