

Living planktonic foraminifera during the late summer monsoon period in the Arabian Sea

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Abstract

During the late summer monsoon living planktonic foraminifera were collected in the southeastern Arabian Sea between 3°N and 15°N by using six vertical plankton tows. Sixteen species of planktonic foraminifera were identified. Among them, *Globigerinoides ruber* and *Globigerinoides sacculifer* are the most abundant species, while the ecologically most important species *Globigerina bulloides* is very rare. The low abundance of *G. bulloides* can be explained by the warming of the surface water in combination with deepening of the mixed layer, since this species preferentially dwells in nutrient-rich upwelling waters. The population density of planktonic foraminifera ranges between 31 and 185 specimens per 10^{-3} m^3 . The low absolute numbers of planktonic foraminifera are similar to the numbers which were reported before from the non-upwelling areas in the Arabian Sea. The low absolute numbers and the collected foraminiferal assemblages are therefore highly indicative of the Arabian Sea non-upwelling areas. Particularly significant are the low absolute and relative numbers of the non-spinose species *Globorotalia menardii* and *Neogloboquadrina dutertrei*. The absence of these species indicate the relatively low nutrient levels in this area at the tail end of the summer monsoon period.

1. Introduction

The monsoonal winds induce regional gradients in the depth of thermocline, sea surface temperature and upwelling intensity over the Arabian Sea. The hydrographic conditions influence the production rate of planktonic foraminifera and temporal variation in their assemblages. In recent years, living planktonic foraminifera from the Arabian Sea were collected by using surface plankton tows, vertical plankton hauls and sediment traps. These studies have considerably enhanced our understanding of the general distribution and ecology of Arabian Sea planktonic foraminifers (Zobel, 1971; Bé and Hutson, 1977; Duplessy et al., 1981; Zhang, 1985; Auras-Schudnagies et al., 1989; Rao et al., 1988, 1989, 1991, 1992; Guptha et al., 1990; Kroon, 1991; Curry et al., 1992).

In this paper we present data on the standing crop and distributional patterns of planktonic foraminifera collected during the tail end of the summer monsoon in the Arabian Sea.

2. Material and methods

As part of the JGOFS-INDIA programme, a cruise was organised in the Arabian Sea from September 20 to October 6, 1992, on board the ORV *Sagar Kanya*. Six vertical plankton hauls (0–200 m) were taken at four stations comprising both day and night hauls (Fig. 1). The samples were collected by using a plankton net with a mesh opening of 200 μm and square mouth opening of

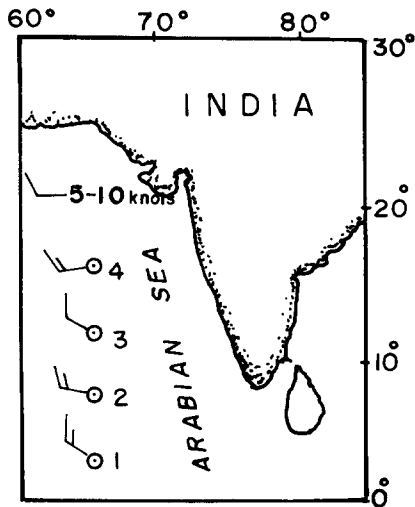


Fig. 1. Sample locations along with wind speed (knots) and direction.

50 × 50 cm. Immediately after collection, samples were preserved in 5% buffered formaline.

These samples were treated with hydrogen peroxide and sodium carbonate to eliminate the high abundances of crustaceans and kept overnight and later washed through a 63 μm mesh sieve. The filtrate thus obtained was oven dried at 30°–35°C. All the planktonic foraminiferal specimens were separated by hand picking for identification and for calculation of their absolute and relative abundances.

3. Hydrography

The Arabian Sea is largely influenced by both the southwest (SW) and northeast (NE) monsoons during May–September and November–February, respectively (Wyrtki, 1973). During the SW monsoon the Arabian Sea surface water is dominated by a strong wind driven anti-cyclonic gyre which is characterized by the westward flowing South Equatorial Current, an eastward flowing Monsoon Current, and a strong Western Boundary Current or the Somali Current. The circulation during the NE monsoon is comparatively weak and is characterized by a North Equatorial Current and an eastward flowing Equatorial Counter Current to

the south and a moderately developed anticyclonic gyre in the Bay of Bengal (Defant, 1961).

Although upwelling is intense during the SW monsoon in the Arabian Sea, it is weak and sporadic in the Laccadive Sea region (Colborn, 1975).

Temperature and salinity profiles, derived from the CTD measurements made during September–October, 1992, show that the warm mixed layer deepened northwards from about 60 m in the south to 90 m in the north (Fig. 2). Sea surface temperature ranges from 27.5° to 28.6°C and salinity from 36.02 to 36.47‰. The wind speed ranges from 5 to 18 knots (1 nautical mile/hour) with a west-northwesterly direction (Fig. 1).

4. Results and discussion

The absolute abundances of planktonic foraminifera ranges from 31 to 185 specimens per 10⁻³ m³. A total of sixteen species of planktonic foraminifera were found, of which *Globigerinoides ruber* and *G. sacculifer* are the dominant species. *G. ruber* has the highest density, which ranges from 5 to 58 per 10⁻³ m³ and shows an increasing trend from the southern to the northern Arabian Sea (Fig. 3). *G. sacculifer* is the second most dominant species and its density ranges from 2 to 14 per 10⁻³ m³, and always co-occurs with *G. ruber*. Following *G. ruber* and *G. sacculifer*, the less abundant species include *Globigerinella aequilateralis*, *Globigerina rubescens*, *Globoquadrina conglomerata* and *Globorotalia inflata*. *G. bulloides* is the only very rare species among the remaining species (Table 1).

The absolute abundances of planktonic foraminifera are very low compared with earlier reports (Zobel, 1971; Zhang, 1985; Rao et al., 1988, 1991, 1992; Gupta et al., 1990; Kroon, 1991; Table 2). Sediment trap results from the Arabian Sea suggest that in general the production of planktonic foraminifera increases significantly during summer upwelling compared to the non-upwelling season (Curry et al., 1992). The fact that the foraminiferal density is very low in the present study, may be attributed to the warming of surface water and deepening of the mixed layer in association with

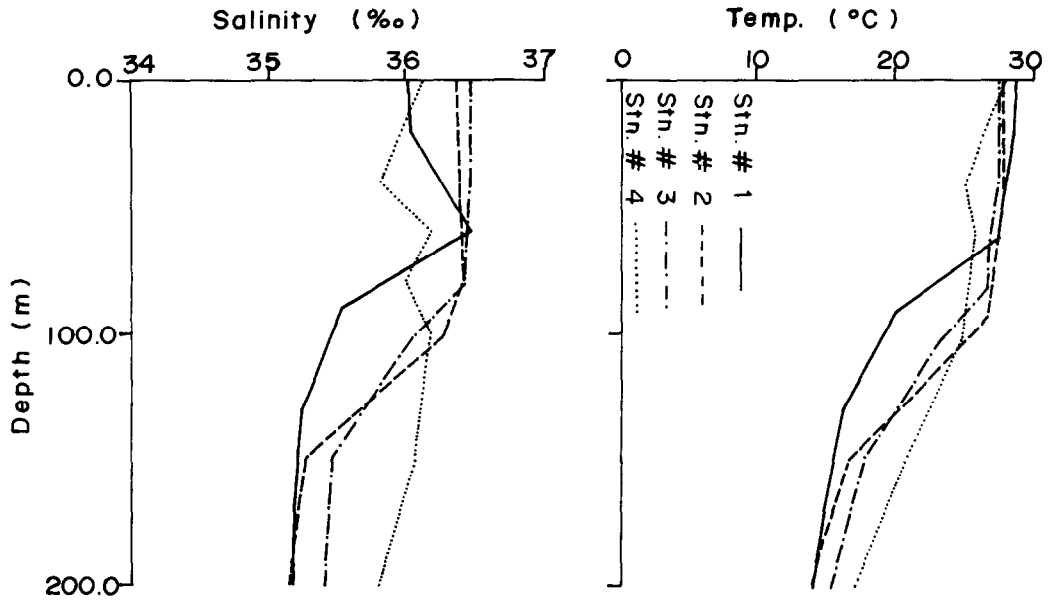


Fig. 2. Salinity and temperature profiles.

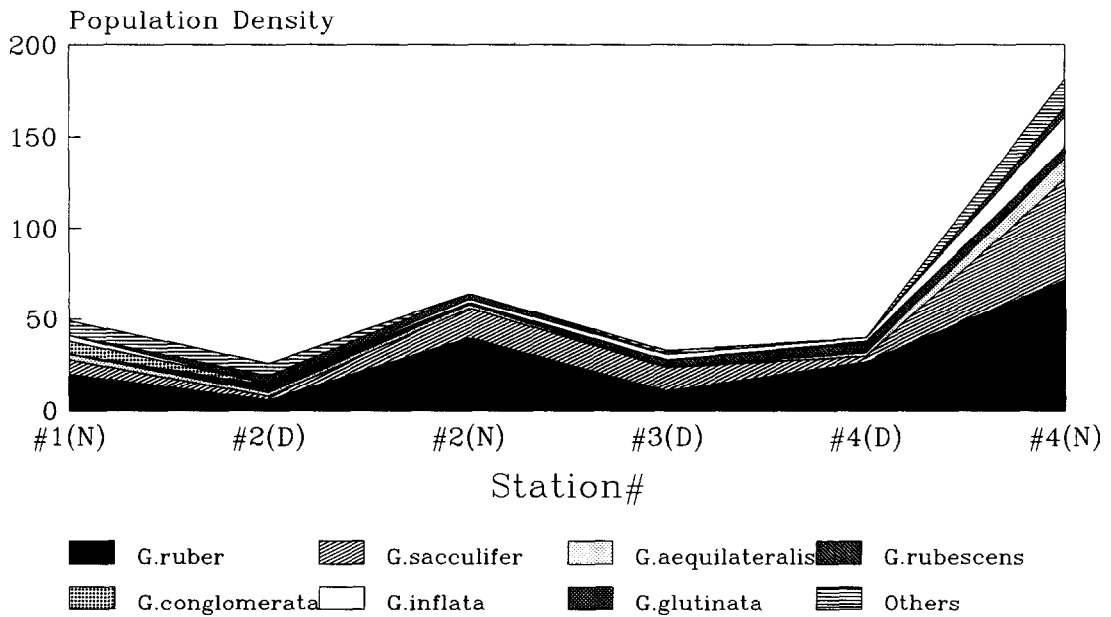


Fig. 3. Cumulative diagram of population density of planktonic foraminifera (number per 10^{-3} m^3).

the process of downwelling resulting in impoverishment of nutrients. Recently, Naidu (1993) has observed that in September the mixed layer is at a maximum ($>100 \text{ m}$) in the central Arabian Sea. Depletion of nutrients during this period was also

inferred based on the occurrence of malformed cells of *Emiliana huxleyi* (Lohmann) Hay and Mohler (Guptha et al., submitted). The lowest density of planktonic foraminifera, however, is also due to the fact that this part of the Arabian

Table 1
Population density of foraminifera

Station #:	1	2	2	3	4	4
	Night	Day	Night	Day	Day	Night
Species						
<i>G. bulloides</i>	×	×	×	×	×	2.0
<i>G. rubescens</i>	×	4.0	×	4.0	5.0	6.0
<i>G. tenellus</i>	×	×	×	1.0	×	10.0
<i>T. quinqueloba</i>	1.0	×	×	×	×	×
<i>G. conglobatus</i>	2.0	2.0	×	×	×	×
<i>G. ruber</i>	20.0	6.0	40.0	11.0	27.0	72.0
<i>G. sacculifer</i>	8.0	2.0	16.0	13.0	3.0	55.0
<i>S. dehiscentes</i>	×	1.0	×	×	×	×
<i>G. aequilateralis</i>	3.0	2.0	2.0	×	2.0	11.0
<i>G. conglomerata</i>	7.0	1.0	1.0	×	1.0	×
<i>N. dutertrei</i>	1.0	1.0	×	×	×	1.0
<i>G. inflata</i>	3.0	×	2.0	3.0	2.0	17.0
<i>G. menardii</i>	3.0	3.0	×	1.0	×	×
<i>G. hexagona</i>	1.0	×	×	×	×	×
<i>P. obliquiloculata</i>	×	2.0	×	×	×	3.0
<i>G. glutinata</i>	×	4.0	3.0	×	×	5.0

Table 2
Occurrence of planktonic foraminiferal species and the population density during different periods of the year

Time period	Occurrence	Standing crop per 10^{-3} m^3	Reference
February–March (pre-monsoon)	14		Zobel (1971)
May 1985 (just pre-summer monsoon)	28	100–3100	Guptha et al. (1990)
June (early summer monsoon)	23	13401–144961	Rao et al. (1988)
June	24		Kroon (1991)
June–July (early summer monsoon)	20	5800	Zhang (1985)
September (late summer monsoon)	16	31–185	Present paper
November (winter monsoon)	20		Zhang (1985)
November (winter monsoon)	27	2601–33664	Rao et al. (1991)
December (winter monsoon)	25	4508–21078	Rao et al. (1992)

Sea experiences only weak/sporadic upwelling during the SW monsoon. This may be explained by the sinking motion set up by the clockwise wind stress curl, which is a typical characteristic of the SW monsoon over the central Arabian Sea. This results in the inaccessibility of the nutrient-rich upwelled water either from the Somali region or from the southwest coast of India (Sastri and Ramesh Babu, 1985) to the central Arabian Sea. Fig. 4 shows indeed the very poor concentrations of chlorophyll-a suggesting the prevailing oligotrophic conditions. A second reason for the low absolute number of planktonic foraminifera is that in September intense secondary production occurs, as is shown by the presence of very high swarming of crustaceans in the plankton net. It was also noticed that the pteropods outnumbered the planktonic foraminifers in the southern two stations.

The predominance of *G. ruber* may be related to the warming of the surface waters after the upwelling period. Guptha et al. (1990) have also reported increasing abundances of *G. ruber* with increasing temperatures of surface waters. Bé and Tolderlund (1971) have reported that this species is very abundant in the equatorial region of the Indian Ocean. Fairbanks et al. (1982) observed that *G. ruber* is most common in the warm mixed layer above the thermocline. Ravelo and Fairbanks (1992) have confirmed that *G. ruber* and *G. sacculifer* proliferate in the mixed layer. Berggren and Boersma (1965) have suggested that *G. ruber* shows its peak abundance in high salinity regions. Based on laboratory experiments Hemleben et al. (1988), however, have ruled out the possibility that salinity alone is responsible for the dominance of *G. ruber*. Reiss and Hottinger (1984) have attributed the abundance of *G. ruber* to severe environmental conditions.

We point out the near total absence of *G. bulloides* (Table 1), which is the best indicator of upwelling in the Arabian Sea (Prell and Curry, 1981; Curry et al., 1992). This species generally occurs in subpolar waters, but is also abundant in cool tropical to subtropical upwelling waters. It is encountered only in one station (#4) with a standing crop of 3 specimens per 10^{-3} m^3 . The low abundance of *G. bulloides* can be explained by the warming of the surface waters in combination with

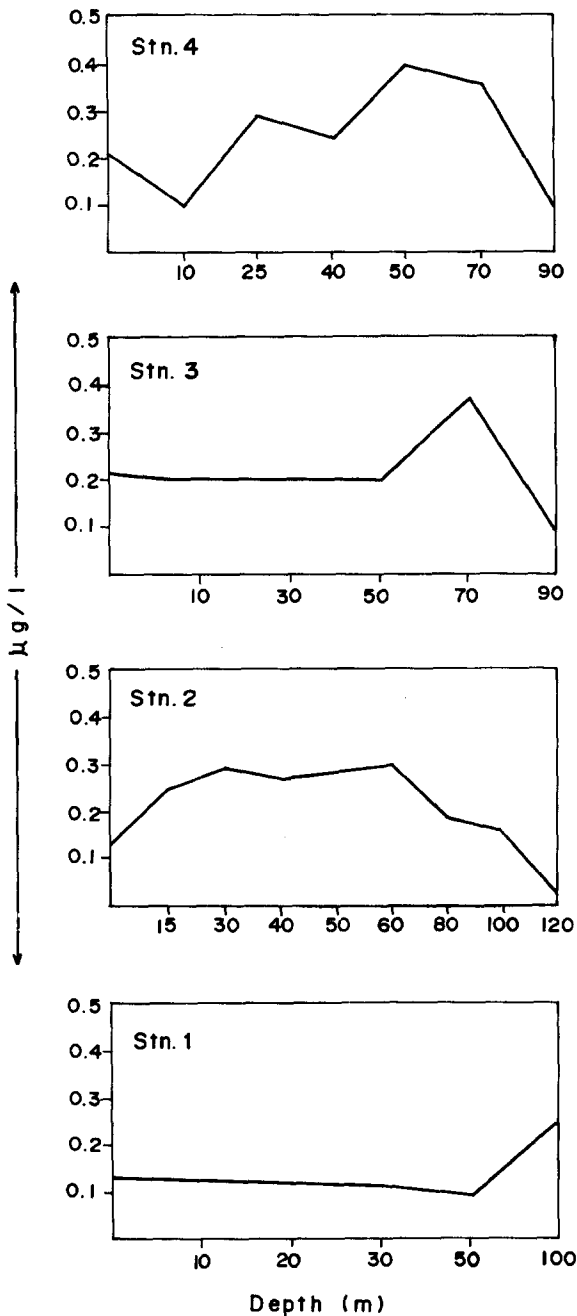


Fig. 4. Chlorophyll-a concentration ($\mu\text{g/l}$).

a deepening of the mixed layer because this species prefers to dwell in nutrient-rich upwelling waters. Rao et al. (1991) have reported the moderate occurrence of *G. bulloides* in the vertical tows

north of 12°N , while it is almost absent at 11°N in the eastern Arabian Sea. Curry et al. (1992) have reported from sediment traps that *G. bulloides* is most predominant during the SW monsoon in the western Arabian Sea, while it is reported that it was only moderately present during the October–November months in the central Arabian Sea in the vicinity of the study area. This confirms that the rare occurrence of *G. bulloides* in this part of the Arabian Sea can be attributed to non-upwelling conditions.

Kroon (1991) reported on the distribution of surface planktonic foraminifera during the summer upwelling months (June and July) from this part of the southern Arabian Sea. His faunal assemblage VI from this region is similar to the present assemblage, which is remarkable because we used deep tows rather than surface tows. His observations and ours suggest indeed that this is a non-upwelling region with prevailing oligotrophic conditions. The only difference with his data is that he reported *G. trilobus* (= *G. sacculifer*) as the dominant species, whereas it is *G. ruber* in the present study.

Significantly low absolute abundances of non-spinose species such as *N. dutertrei*, and *G. menardii* are attributed to the oligotrophic conditions. These species are generally found in high abundances in areas of intense upwelling where the thermocline is shallowest (Thunell and Reynolds, 1984; Kroon, 1991; Gupta et al., submitted).

The planktonic foraminiferal assemblages largely comprise spinose forms, their relative abundance ranges between 52 and 97.1%, while the relative abundance of non-spinose species ranges from 2.9 to 48%. This may be explained by the fact that when secondary production is intense during the tail end of the summer monsoon, spinose forms increase substantially their number as these species are omnivorous with a preference to a carnivorous diet of copepods (Bé et al., 1977; Anderson et al., 1979). Conversely, due to impoverishment of phytoplankton as a result of depletion of nutrients, the herbivorous non-spinose species, which feed mainly on diatoms and dinoflagellates could not flourish. Low non-spinose/spinose ratios may indicate weak/non-upwelling areas. Similarly, Kroon (1991) has also reported that high non-

spinose/spinose ratios characterize the upwelling areas in the northern Indian Ocean.

It was also observed that the density of planktonic foraminifera shows a tendency to increase during night collection contrary to the observations of Rhumbler (1911), Bradshaw (1959), Bé and Hamlin (1967), Parker (1960) and recently Rao et al. (1991). Rao et al. (1991) reported higher densities during the day except in the northern Arabian Sea where they encountered a high standing crop during the night. The vertical migration of zooplankton from deeper depth in the photic zone towards the surface at night is very well known. Based on day–night tows Holmes (1982) reported vertical migration of planktonic foraminifera, with higher densities of foraminifera during the night. Although Berger (1969) stated that the variation in abundance of foraminifera may be due to patchiness rather than diel migration. In the present study, as day and night collection of zooplankton were made at the same stations, the possibility of patchiness can be excluded. Recently, Hemleben et al. (1988) concluded that it is becoming increasingly clear that the variation in nature and availability of prey in response to the variation in physical parameters is playing a vital role in the planktonic foraminiferal absolute and relative abundances.

5. Conclusions

It is inferred that during the end of the summer monsoon in the southeastern Arabian Sea, the low diversity and low absolute abundance of planktonic foraminifera may be due to:

(1) Weak/non-upwelling conditions associated with depletion of nutrients.

(2) Intense grazing by secondary producers.

The oligotrophic conditions are characterized by a relatively high standing crop of *G. ruber* and *G. sacculifer* and the almost near total absence of *G. bulloides*. The oligotrophic conditions are a result of the warming of the surface waters, followed by deepening of the mixed layer in association with the process of down-welling during this period (September–October).

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