

Effect of oxygen manipulations on benthic foraminifera: A preliminary experiment

*Rajani Panchang, R. Nigam, V. Linshy, S. S. Rana & B. Ingole

National Institute of Oceanography, Dona Paula, Goa - 403 004, India

*[E-mail- prajani@nio.org]

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Three sediment cores were collected at 50 m water depth on the west coast of India, off Ratnagiri, and were subjected to oxygen manipulations maintaining natural temperature and salinity. The objective was to understand foraminiferal response to changed oxygen conditions. After a fortnight, the experimental cores were sub-sectioned and analyzed for their live foraminiferal content. This data was compared with background field data obtained from the non-experimental core. The data indicate that any change in natural oxygen conditions causes lowering of foraminiferal numbers. It is clearly evident that *Fursenkoina* and *Nonions* are more adaptive to changed oxygen conditions in contrast to *Bolivinids* and *Rotalids*, which quickly die out. This study clearly demonstrates the change in foraminiferal distribution in response to oxygen changes. This experimental study further can help develop foraminifera as a proxy to decipher the past fluctuations in the OMZ in the past, including assessment of their anthropogenic origin.

[**Key words:** Foraminifera, oxygen manipulations, vertical migration, Arabian Sea, sediment core]

Introduction

Foraminifera are highly sensitive marine protists, which have a great potential to detect ecological stress at a very early stage. Due to their high fossilization potential, an understanding of the ecology of foraminifera allows interpretations of the past benthic environmental conditions. The oxygen content of bottom waters is one main environmental factor controlling foraminiferal distribution pattern in the sediment¹. Earlier field investigations have been made to interpret past oxygen-related environments based on subsurface foraminiferal data²⁻⁵. However it is difficult to attribute typical responses of foraminifera directly to changes in dissolved oxygen, because in nature, different factors like food content and oxygen concentration work together and the influence of each factor cannot be delineated. Additionally, various foraminiferal species respond differently to different conditions, because each has its own physiological ability to either adapt or retract. Laboratory experiments provide a good opportunity to analyze the response of different foraminiferal species to experiment stimulated variations on one single environmental factor. Quite a few attempts have been made in the past using varied experimental modes⁶⁻⁸.

The oxygen minima zone (OMZ: ~125-1500 m) from the west coast of India is well known. However it is coastal hypoxia (~50-60 m) which is a recent

finding⁹ and less understood along the central west coast of India. Thus, such laboratory experiments could give significant clues towards understanding the processes leading to OMZ and foraminiferal response to the same. But, no experiment has been carried out with foraminifera from the Indian waters. The main objective of the present study was to observe the effect of changed oxygenation on the vertical distribution of foraminifera and try to co-relate the results with field observations. In the present study we collected sediments off the western Indian coast and varied the oxygen concentrations in an experimental set up, while other environmental parameters like temperature and salinity were maintained and kept stable.

Materials and Methods

A box corer specially designed by the Netherlands Institute of Ecology (NIOO), Netherlands was used to collect 3 box cores in the shelf region off Ratnagiri (Fig.1), at the same location on the west coast of India (17°30'00"N and 72°42'08"E), at a depth of 50 m onboard *Ocean Research Vessel Sagar Kanya*, cruise SK-211 during the first week of October 2004. Care was taken to collect bottom sediments and the overlying water with their interface intact. Bottom water temperature was noted immediately as 11°C. In each of the box cores, a plastic liner with 8 inch

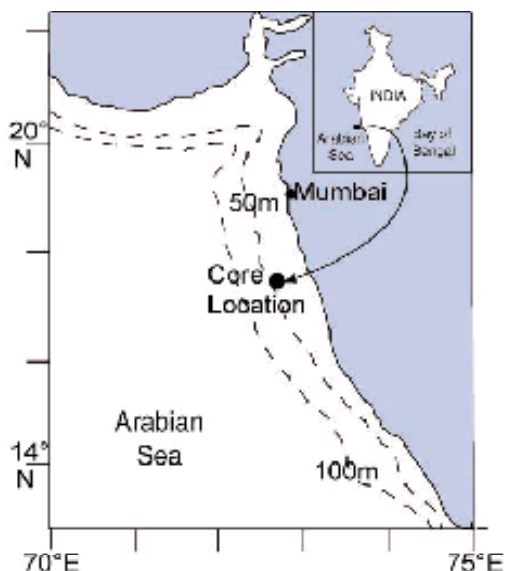


Fig. 1—Study area map showing location of cores

diameter was inserted into the sediments slowly to a depth of ~10 cm (taking care the fluffy layer is not disturbed) and immediately covered with acrylic lids. These cores contained a minimum of 10 cm of bottom sediments and 20 cm of the overlying water column. Of the three cores collected for this experiment, two cores were placed in the incubator; these served experimental cores. The remaining core was taken to the cold room, sub-sectioned immediately at intervals 0-1, 1-3, 3-5, 5-7 and 7-10 cm, stained in Rose Bengal-formalin solution to distinguish live (stained) and dead foraminifera and to generate background data to record the vertical distribution of live foraminifera in normal field conditions. The oxygen concentration in the bottom waters was found to be 68 $\mu\text{mol}/\text{l}$.

The temperature of the incubator was set to 11°C and allowed to stabilize for over 6 hours. Of the two experimental cores in the incubator, one of the cores was subjected to high oxygen concentration by aeration using an aquarium pumping system. In the other core, low oxygen conditions were attained by continuous and steady introduction of high nitrogen (98%) air into the overlying water column. Electrically motored magnetic stirrers were inserted in both core liners to assure well circulation of the gases in the water column, taking care that the fluffy layer is not disturbed. This complete set up was transported to the onshore laboratory. A temperature controlled container lab (from NIOO, Netherlands), was being regulated for the desired temperature. Thus, the

experimental set up was then removed from the incubator to the thermo lab, which offered more working space. The two experimental cores were covered with a black sheet to simulate ocean bottom illumination conditions of the sampling location. Salinity was measured regularly and also at the end of the experiment as 36.15 ppm. To maintain continuous food supply, a pipette was used to uniformly spread bulk diatom culture over the sediment surface at regular intervals. After incubation of 15 days, the two experimental cores were also sub-sectioned comparable to the background core and each layer was stained with Rose Bengal/formalin. The stained specimens were counted in each subsection of all the three cores.

Results and Discussion

The oxygen concentration in the water column in the experimental cores just before sub-sectioning was 3.6 $\mu\text{mol}/\text{l}$ in the low oxygen core and 303.9 $\mu\text{mol}/\text{l}$ in the high oxygen core. Majority of the total foraminiferal assemblage comprised *Fursenkoina*, *Bolivina*, *Nonion*, *Rotalia* and *Reophax*, listed according to degree of abundance. A small number of *Bulimina*, *Cancris*, *Ammotium*, *Globobulimina* were also present which have been clubbed as 'others'. Many soft-shelled forms also exist, but have not been considered in the present study as they have no fossilization potential and thereby of no geological significance. This is a preliminary report and only presents the effect of oxygen manipulations on major foraminiferal genera. The similar horizons of the three differently treated cores have been compared to delineate effects of oxygen manipulations on foraminiferal distributions with sediment depth. No foraminifers were found in the sub-sections beyond 5 cm.

The response of the foraminifers to drastic alteration in oxygen conditions is shown in Fig.2. The live total foraminiferal number (live TFN) is lower than normal in both cases of lowered and increased oxygen (Fig. 2B). This indicates that oxygen is a very critical factor for foraminifera. *Fursenkoina* (Fig.2C) seems to be sensitive and die out with reduction in oxygen and congregate at the surface with increase in oxygen. *Bolivinid* (Fig.2D) numbers fall drastically with any change in oxygenation. *Nonions* (Fig.2E) also adapt along with changing oxygenation. They are seen to migrate to the surface (from oxygen depleted to more aerated zones) on lowering oxygen. This is in confirmation with the report of Alve & Bernhard⁷. In

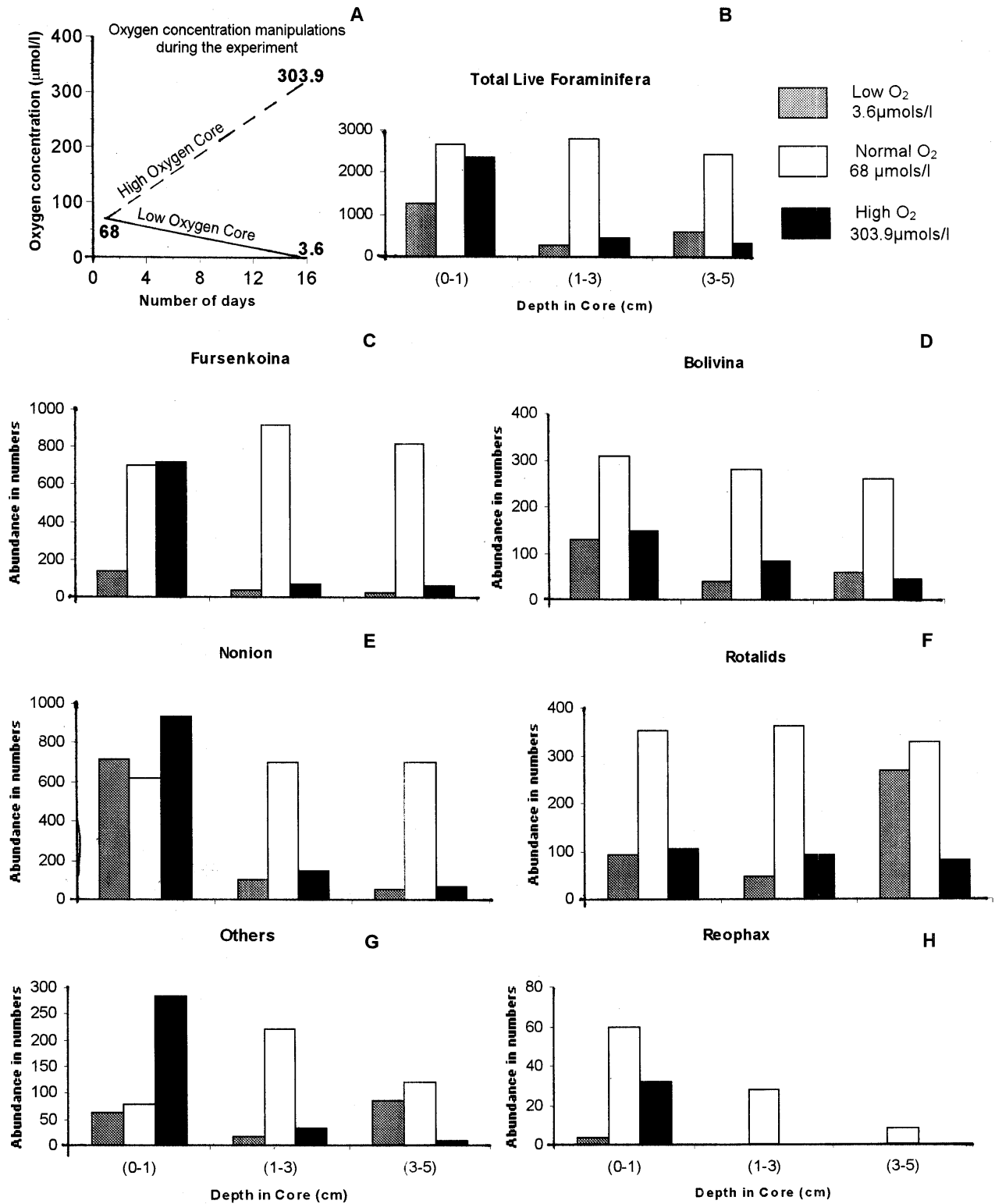


Fig. 2—Responses of varied foraminiferal groups to oxygen manipulations. The graphs show variation in abundances of (A) dissolved oxygen (B) total live foraminifera (C) *Fursenkoina*, (D) *Bolivina*, (E) *Nonion*, (F) *Rotalids* (G) others and (H) *Reophax*, at different levels in the experimental cores in comparison to the background core

contrast *Rotalids* (Fig.2F) die out with changing conditions; both increased or decreased oxygen. *Reophax* (Fig.2H) are agglutinated elongated forms, which do not have surface pores. Thus, their resistance to low oxygen is evident by their tendency to move towards the surface on oxygenation. This explanation is supported by the widely accepted idea that foraminiferal pores are conduits for oxygen supply to the intracellular milieu^{10,11} and that larger, more numerous pores could presumably provide more oxygen.

Genera like elongated *Fursenkoina* and rounded *Nonion*, seem to be more adaptive to change in oxygenation. They both are sensitive and move towards zones with better aeration. A contrast observation can be made about the elongated *Boliviniids* and rounded *Rotalids*. They both show low adaptive abilities, i.e. they tend to die out with any change in oxygenation. Though it is not possible to spell out the behaviour of these foraminifera based on their morphology, we can say that with reduction in oxygen, *Fursenkoina* and *Nonion* species would not only adapt, but would also move to more oxygenated zones i.e. migrate towards the surface. This observation is in agreement with Alve & Bernhard⁷ who have opined that foraminifera select an optimal oxygen regime, regardless of its position with respect to sediment-water interface. However, the *Boliviniid-Rotalid* numbers would drastically fall. This signature if found in subsurface horizons, could be used as an indication of depletion of oxygen in the environments in the past and *vice versa*.

Present observations are in agreement with the TROX model proposed by Jorissen *et al.*¹ that suggests that in fully eutrophic environments, it is the critical oxygen level that determines the penetration depth of infauna and in extreme situations where all the oxygen is depleted at the sediment surface deeper sediment layers will be anoxic and all benthic foraminifera will be found exclusively at the sediment-water interface.

Limitations of the experiment

This being the first field based experimental study in the country, certain limitations could not be avoided, but can surely be incorporated in the next attempts. *In situ* sediment oxygen profiling could not be incorporated due to unavailability of highly sophisticated oxygen sensitive electrodes. If sediment oxygen profiles were available we would be able to explain anomalies like that seen in concentration of

Nonions at the surface on both lowered and increased oxygenation. This however is not very significant, as our objective was to understand the effect of changing bottom water oxygen concentration and any changes in the deeper sedimentary horizons would be relative. Identification of the specimens was restricted to the generic level as the specimens were extremely small, and on prolonged exposure to warmer temperatures would loose stain and decay.

Significance of the study

The eastern Arabian Sea is since long known for the existence of its oxygen minima zone (OMZ)¹²⁻¹⁴. However, the major concern is about its shrinking or expanding spatial extent due to natural climatic changes as in the past or possibility in the future due to anthropogenic contributions. These can be answered by using proxies developed through such an experimental approach of studying the diverse responses/adaptations of foraminifera to changed oxygen concentrations. Experimental studies like present attempt only can provide information required to create more accurate databases to be used in other applications of palaeoecology, palaeoceanography, petroleum exploration and pollution studies.

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