Foreword to thesis

Foraminifera are considered to be one of the best indicators for ecologic studies of past and present day marine environments. They are highly sensitive to the changes in the physico-chemical parameters in their ambient environment (natural as well as anthropogenic). The response to such changes may vary from variations in abundance, diversity, growth, morphology and chemistry of the hard parts. Foraminifera incorporate signatures of these changes and preserve them in their hard part called test. They are present in all marine environments and have a great diversity and abundance. The fossilization potential of the tests render foraminifera a positive edge over other micro-organisms and make them the ideal bio-indicators for short- long term changes of the marine environments, from global to local scales.

Foraminiferal research is often debated to be lying in the boundary between geology and biology. It is very much known that in order to interpret the microfossils correctly, we need to understand the biology and ecology of their living counterparts. And it is very much apt to point that this is the principle, on which the geological applications of foraminifera based on and it is commonly noted by the geologists as present is the key to the past (Principle of Uniformitarianism). In recent years, the number of studies on foraminiferal ecology has increased and lots of advanced techniques are attempted.

Experimental studies on foraminifera are a fast evolving and an important branch of foraminiferal research, which provides experimental proof to the field based results and thereby increasing their credibility. In most of the field studies, the foraminiferal characteristics are attributed to the site specific (the type and extent of stresses vary at different sites) field evidences; but such studies are yet to give a complete account of the specific responses of foraminifera to specific stresses, be it natural or anthropogenic. In the laboratory, physico-chemical parameters are altered in such a way that the response of foraminifera to specific parameters can be studied in isolation as well as in desired combinations also. This flexibility of the experimental studies, along with the high precision results (qualitative as well as the quantitative), makes it an indispensable part of modern foraminiferal research and help revolutionizing/updating our understanding of foraminiferal ecology for the application of the same in various paleoclimatic and pollution studies.
This thesis deals with the fundamental aspects and establishment of laboratory culture studies on few selected species of benthic foraminifera, learning their growth, reproduction and lifespan in the laboratory, their response to various stress conditions including heavy metals, oxygen etc. Additionally production of stress proteins in benthic foraminifera, and response of some foraminiferal species to $^{13}$C labeled algal feed is also studied as a part of collaborative work with a German laboratory.

Comprising of ten chapters, the thesis has Chapter 1 establishing the need of laboratory studies on benthic foraminifera in view of the rudimentary stage of the same in this part of the world. Realizing the fact that Indian scientific world is still to attempt and urging the need of experimental studies to evaluate the field based results, a laboratory with advanced facilities was set-up in National Institute of Oceanography, Goa and a dedicative workgroup is continuously attempting to study various aspects of foraminiferal response (emphasizing hard part alterations) to known parameters. The results discussed in this thesis are a part of the research conducted in the Foraminiferal culture laboratory, National Institute of Oceanography, Goa, acclaimed to be one of its kinds in India.

Chapter 2 is a detailed review of the studies done worldwide on the laboratory studies on benthic foraminifera. As much as 164 papers have been reviewed and the facts emerged is as follows—

- Most of the studies were done by biologists who were interested in studying the soft part of foraminifera.
- Studies dealing with the hard part of foraminifera were comparatively less and the proper understanding of the parameters affecting the morphology of the benthic foraminifera is still lacking.
- Exact mechanism leading to the test deformities is yet to be explored
- Characterization of foraminiferal response to pollutants so as to effectively use it as a proxy for marine pollution studies.

Taking these facts in to account, I decided to work on laboratory culture experiments on benthic foraminifera for the doctoral thesis and the following objectives were set—

- To establish culture program and to observe life span and mode of reproduction of selective foraminiferal species
- To observe the response of benthic foraminifera to specific pollutants
- To characterize type of abnormalities (if any) in benthic foraminifera as a result of different pollutants
In Chapter 3, a detailed sketch of general methodology involved in the laboratory culturing of coastal benthic foraminifera is given. The experimental set-up of different experiments is discussed in the respective chapters for better understanding of the procedures. This chapter mainly deals with the field collection and preparation of samples for live culturing, separation of live specimens, maintenance in the laboratory, etc. Working photographs are included to understand the field and field procedures better.

Discussion on the experimental studies carried out on benthic foraminifera starts with Chapter 4. In this chapter the growth, reproduction and lifespan of 2 benthic foraminiferal species viz. *Strebloides advena* and *Rosalina leei* are discussed. Observations from consecutive generations revealed the length of the reproductive span of these species as 17-19 days for *Strebloides advena* and 105-109 days for *Rosalina leei* and previous studies confirm that these are the first report of lifespan of *Strebloides advena*.

In Chapter 5, foraminiferal responses to varying levels of oxygen is discussed with the help of an experiment conducted onboard ORV Sagarkanya, followed by subsequent observations in container lab brought from NIOO, The Netherlands. The main findings indicate that genera like *Fursenkoina* and *Nonion* showed more adaptive values to changing oxygen conditions and migrated to more oxygenated surface layers, whereas the *Rotalids* and *Bolivinids* died out showing poor adaptation to such stress conditions. The results thus obtained will be useful to explain the occurrence/abundance of certain foraminiferal species under oxygen minima conditions in the past.

Chapter 6 discusses foraminiferal response to anthropogenic stress by citing examples of two common heavy metal pollutants along our coast line viz. Mercury (Hg) and Cadmium (Cd). Experiments conducted on benthic foraminiferal species *Rosalina leei* to study their response to different levels of heavy metal Mercury is included in the beginning of the chapter followed by the experiments on *Pararotalia nipponica* with heavy metal cadmium. The results from the experiments confirm the effective application of foraminiferal proxies for marine pollution studies.

After learning the morphological responses of foraminifera to different stress conditions, attempts were made to understand the production of stress proteins in
benthic foraminifera (Chapter 7). The total protein content per individual was also determined for the benthic foraminiferal species under study.

The last experiment (Chapter 8) included in the thesis deals with the response of benthic foraminiferal response to $^{13}$C labeled algal feed. Experiments were conducted on benthic foraminiferal species *Ammonia tepida* and the results show the preference of this species to fresh organic matter and its pattern of food uptake with time.

Thesis is concluded with Chapter 9 which summarizes the major findings of the present work and indicates the potentials of future research in this direction. References cited in the thesis are included as a separate list after this chapter. The list of publications and the certificates of merit are enclosed as Annexures.