Does temperature affect dimorphic reproduction in benthic foraminifera? A culture experiment on *Rosalina leei*

Rajiv Nigam*,† and David A. Caron#

*Geological Oceanography Division, National Institute of Oceanography, Dona Paula, Goa 403 004, India
#Biology Department, Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA

The possible effects of environmental factors on the dimorphic mode of reproduction in benthic foraminifera have been reported in the literature. Published observations based on field samples have indicated an inverse relationship between the ratio of microspheric/megalospheric forms and temperature or salinity. These findings imply their potential use in palaeoclimatic studies. Two experiments were conducted on the benthic foraminifera *Rosalina leei* (Hedley and Wakefield) collected from Vineyard Sound near Woods Hole, Massachusetts, USA. In the first experiment, a large number of specimens were maintained at four different temperatures (5, 15, 20 and 25°C) and observations were made on the frequency of pairing (an indication of sexual activity). The percentage of pairs formed was directly related to the temperature, i.e. 0 pairs at 5°C to 19.3% pairs at 25°C. In the second experiment, paired and unpaired specimens were maintained separately at three different temperatures (15, 20 and 25°C). Nearly one-half of the unpaired specimens reproduced at all three temperatures, while none of the paired specimens reproduced. Type and frequency of feeding were common in all the experiments. We surmised that dimorphic reproduction in *R. leei* requires a different environment.

STUDIES on the life cycle or differential mode of reproduction in benthic foraminifera have been of utmost importance and they have been investigated by many workers[1–6]. Boltovskoy and Wright[7] in a review, indicated that microspheric and megalospheric generations in foraminifera might have different environmental requirements. Later, attempts were made to correlate dimorphic test ratios with climatic changes, suggesting their utility in palaeoclimatic applications[8–12]. However, Nigam and Khare[11] suggested that this approach must be tested through laboratory experiments. Therefore, we have attempted to study *Rosalina leei*[13] species of benthic foraminifera in laboratory culture to see whether microspheric and megalospheric forms required different environmental conditions. The selection of *Rosalina* species was based on its availability in field collections and that it is known to have a dimorphic life cycle[14,15].

†For correspondence. (e-mail: nigam@csnio.ren.nic.in)

First, a preliminary survey was made for collection of benthic foraminifera from sea grasses and surface sediment samples from three locations near Woods Hole, Massachusetts, USA, viz. (i) Vineyard Sound at the shore lab facility of WHOI, (ii) Buzzard Bay at the Marine Biological Laboratory and (iii) Woods Hole (near Redfield Laboratory). Based on the richness of the foraminiferal fauna, the first location was selected as a permanent station for sample collection. The species *R. leei* was selected for future experiments. Foraminiferal specimens were obtained by vigorous shaking of *Sargassum* into a plastic bucket filled with sea water. The residue was passed through a 63 ìm opening sieve. The > 63 ìm fraction was kept in a jar filled with sea water and the specimens were sorted out with a pipette. Filtered (0.22 µm Millipore filtered) sea water was used as culture medium and changed every alternate day.

A mixture of three microalgae was cultured separately and used as food (every alternate day) for living specimens of foraminifera. The following species (for which stock cultures were available at Woods Hole Oceanographic Institution) were cultured: (i) *Isochrysis galbana* [clone T-ISO]; (ii) *Chlorella capsula* [clone FLA-E]; and (iii) *Minutocellus polymorphus* [clone Minuto]. All the species were cultured in F-2 medium.

With the objective to check the effect of temperature on inducing pairing of two gamonts by their ventral side for sexual reproduction[16], the picked specimen were kept in one large jar at four different temperatures (5, 15, 20 and 25°C). The percentage of specimens making pairs has been calculated in each case.

In another experiment, a large number of specimens were kept in a jar at 20°C. Paired and unpaired specimens were picked after a week and kept one each in six well-sterilized culture dishes. A total of 36 pairs and 36 single specimens were used in this experiment. Mixed prey (one drop) was added every alternate day. This experiment was conducted at three different temperatures, i.e. 15, 20 and 25°C. The objective was to study differences in sexual and asexual reproduction.

When a large number of specimens was kept in a container, many of them formed pair. The experiment conducted (Table 1) to study the effect of temperature on their behaviour indicated that an increase in temperature

Table 1. Effect of temperature on frequency of pairing (an indication of sexual activity)

Temperature (°C)	No. of specimens kept in experiment	No. of pairs after a week	Pairs (%)
5	61	0	0
15	39	6	15.3
20	64	11	17.0
25	26	5	19.3

Table 2. Effect of temperature on single specimens and paired specimens

	Single specimen		Paired specimen		
Temperature (°C)	No. of specimens	No. of reproduced specimens	No. of pairs	No. of separated pairs	No. of reproduced pairs
15	12	5	12	2	0
20	12	5	12	4	0
25	12	6	12	5	0

resulted in more specimens forming pairs and thus represents increased tendency for sexual reproduction.

When paired and unpaired specimens were kept in individual culture dishes at temperatures of 15, 20 and 25°C, none of the paired specimens reproduced (Table 2). In addition, when kept for a prolonged period, paired specimens showed a tendency to separate at higher temperature, indicating death without reproduction. Whereas, in similar conditions, reproduction was observed at all the temperatures in single specimens (Table 2). In this case, a single specimen produced as many as 39 young ones.

We surmise that dimorphic reproduction in benthic foraminifera (at least in the case of *R. leei* species) requires different environmental factors to complete the life cycle. An increase in temperature resulted in an increase in tendency for sexual reproduction. However, we are yet to obtain optimum environmental conditions, (including type of food) in which paired specimens can reproduce. The study suggests the need for more experiments with different benthic foraminiferal species at different temperatures with varieties of prey.

1. Lister, J. J., *Philos. Trans. R. Soc. London, B*, 1895, **186**, 401–453.
2. Leutenegger, S., *Utrecht Micropaleontol. Bull.*, 1977, **15**, 26–34.
3. Rottger, R., Fladung, M., Schmaljohann, R., Spindler, M. and Zacharias, H., *J. Foram. Res.*, 1986, **16**, 141–149.
4. Harney, J. N., Hallock, P. and Jalge, H. K., *J. Foram. Res.*, 1998, **28**, 141–147.
5. Lee, J. J., Walter, W. F. Jr., Anderson, O. R. and Pawlowskoi, J., in *Biology of Foraminifera* (eds Lee, J. J. and Anderson, R.), Academic Press, London, 1991, pp. 285–334.
6. Goldstein. S. T. and Moodley, L., *J. Foram. Res.*, 1993, **23**, 213–230.
7. Boltovskoy, E. and Wright, W. R., *Recent Foraminifera*, Dr. W. Junk b. v.-Publisher, The Hague, 1976, p. 515.
8. Nigam, R., *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1986, **53**, 239–244.
9. Nigam, R. and Rao, A. S., *Estuar. Coast. Shelf Sci.*, 1987, **4**, 649–655.
10. Nigam, R., *Proc. Indian Natl. Sci. Acad.*, 1988, **54**, 574–583.
11. Nigam, R. and Khare, N., *Geomar. Lett.*, 1995, **15**, 45–50.
12. Nigam, R., Khare, N. and Nair, R. R., *J. Coast. Res.*, 1995, **11**, 1099–1107.
13. Hedley, R. H. and Wakefield, J. S. J., *J. Mar. Biol. Assoc., UK*, 1967, **47**, 121–128.
14. Bock, W., Hay, W. and Lee, J. J., in *Illustrated Guide to the Protozoa* (eds Lee, J. J., Hunter, S. H. and Bovee, E. C.), Society of Protozoologists, Lawrence, 1985, pp. 252–273.
15. Lee J. J., Freudenthal, H. D., Muller, W. A., Kossoy, V., Pierce, S. and Grossman, R., *Micropaleontology*, 1963, **9**, 449–466.
16. Lee Calvez, J., *Arch. Zool. Exp. Gen.*, 1950, **87**, 211–243.

ACKNOWLEDGEMENTS. We are grateful to Dr Elain Lim for her help in the laboratory and the Department of Science and Technology, Govt. of India for providing financial assistance to R.N. in the form of BOYSCAST Fellowship. Dr E. Desa, Director NIO is sincerely acknowledged for his keen interest in this study.

Received 27 June 2000; revised accepted 9 August 2000

A common spatial mode for intra-seasonal and inter-annual variation and predictability of the Indian summer monsoon

R. S. Ajaya Mohan and B. N. Goswami*

Center for Atmospheric and Oceanic Sciences, Indian Institute of Science, Bangalore 560 012, India

How and to what extent the intra-seasonal oscillations (ISOs) of the Indian summer monsoon influence the seasonal mean and its inter-annual variability is investigated using long records of daily circulation data (1956–1997) and outgoing long wave radiation (OLR) data (1974–1997). The underlying spatial structure of a typical ISO cycle that is invariant from event to event and year to year is brought out. It is shown that the intra-seasonal and inter-annual variations are governed by a common mode of spatial variability. A higher frequency of occurrence of 'active' ('break') conditions within a monsoon season, therefore, could result in a 'strong' ('weak') summer monsoon. Two-dimensional probability density function estimates of the ISOs show that 'strong' ('weak') monsoon years are indeed associated with higher probability of occurrence of 'active' ('break') conditions. For the first time, these results show that the frequency of chaotic ISO regimes determine the seasonal mean monsoon, thereby setting a limit on monsoon predictability.

WHILE conceptual basis for predicting the tropical climate in general has been established[1], the prediction of the Indian summer monsoon variability remains

*For correspondence. (e-mail: goswamy@caos.iisc.ernet.in)