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BENTHIC FORAMINIFERAL BIOCOENOSES IN THE ESTUARINE REGIMES OF GOA

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Abstract. Benthic Foraminifera are highly responsive to subtle changes in the estuarine environment. Keeping this in view, a qualitative analysis of living benthic Foraminifera was made of the samples collected from the Mandovi—Zuari estuaries and the connecting long and narrow Cumbarjua canal of Goa. The lower reaches of the rivers are paved with a substrate consisting mostly of sand while it is silty—sand in the upper estuarine zones and clayey in the canal zone. The living Foraminifera are abundant in the upper estuarine zones of the rivers and the Cumbarjua canal junction zones, and characterised by the *Ammonia—Trochammina* suite with *Miliammina fusca*; while the canal zone is enriched by agglutinated formes. The *Ammonia—Elphidium* suite dominates the lower estuarine zones indicating a typical marine environment. The high organic matter content particularly in the Canal Zone is due to the inflow of pollutants from the nearby pesticide factory and the constant contaminating discharge of navigating barges and other mechanised boats of the fishing industry. *Ammonia* sp. and its variants and other agglutinated species become dominant here. The decline in calcareous species and thinning of the dead tests leading to their eventual destruction may be attributed to their susceptibility to acidity in the waters.

Introduction.

Estuaries are generally considered in terms of salinity regimes and the basis of their classification is the spatial distribution of salinity, with fresh water rivers and saline oceanic waters as two end members. Benthic Foraminifera have been used (1) to differentiate estuarine water masses and as environmental indicators (Nichols, 1974), (2) to define depth stability and open ocean influences (Scott et al., 1976), (3) to delimit modal circulation patterns (Scott et al., 1977), and (4) to characterise spatial distribution of salinity (Scott et al., 1980). Furthermore, benthic Foraminifera are known to be highly responsive to the subtle changes in the estuarine environment. Thus, using benthic foraminiferal assemblages as indicators, it is possible to differentiate estuarine salinity distribution. It is in this context that a qualitative analysis of living foraminiferal response of the Mandovi—Zuari—Cumbarjua canal estuarine complex was made.

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Among the several estuarine complexes in Goa, the two major estuaries are those of Mandovi and Zuari rivers. These two rivers are connected by a narrow Cumbarjua canal, 15 km upstream of Mandovi (Fig. 1). These rivers and the canal are navigable throughout the year, and there is a continuous traffic of iron and manganese ore–laden barges commuting between Marmagoa Harbour, larger ships anchored out in the ore loading terminals upstream. Besides, the mechanical boats and trawlers haul their fish catch from the sea to points farther inland through these estuaries during high tides and the navigation channels. These estuaries represent a complex and dynamic ecosystem; they are being highly polluted by ore, barge waste, and fish–refuse disposals. Physical, chemical biological and hydrological aspects of this region were studied earlier (Murty & Das, 1972; Anand, 1973; Parulekar et al., 1973; Rao, 1974).

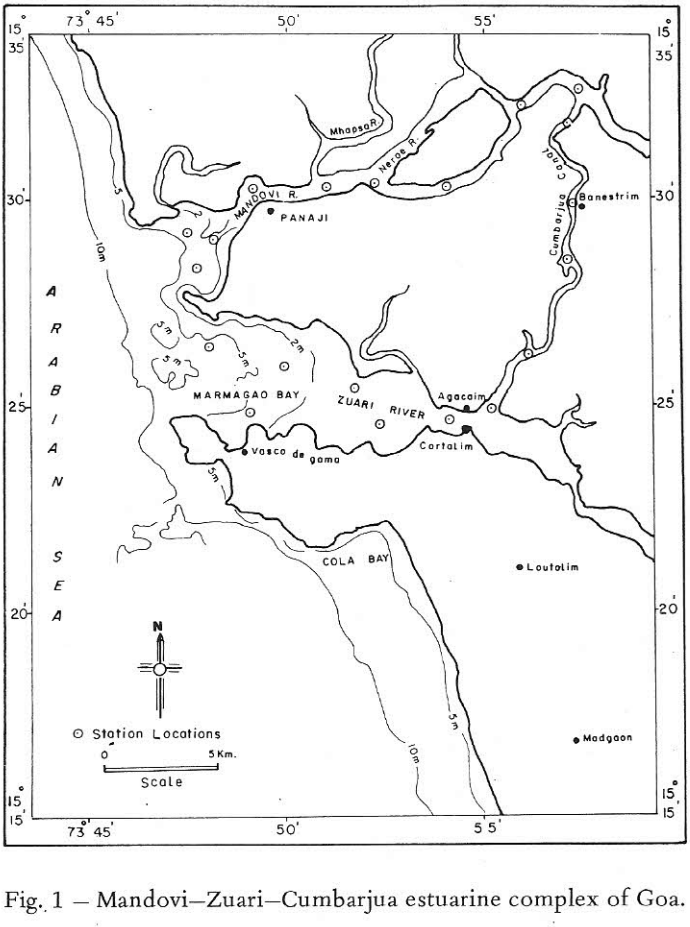

Fig. 1 – Mandovi–Zuari–Cumbarjua estuarine complex of Goa.

Setting.

The mouths of the two rivers adjoining the Arabian Sea are quite wide and they are separated only by a narrow promontory. More fresh water, especially during monsoon, flows through the Mandovi as it has several tributaries. In the Zuari the tidal influences show predominance over the river discharges, thus the marine factor becomes dominant giving rise to an accentuated marine estuarine zone. Therefore, these two estuaries can be classified as vertically Homogeneous (Type C) Estuary and sectionally Homogeneous (Type D) Estuary of Schubel and Pritchard (1972) respectively. The Cumbarjua canal is highly influenced by marine conditions through the Zuari river (Fig. 1).

Domestic and industrial effluents (pesticide rejects from Ciba–Geigy, oil and other wastes from Goa Shipyard and other ship repairers), spillage from barges, sewage disposal at various points along the rivers, ore and other wastes from the Port, plant debris contributed by swamps and mangroves along their path are the major pollutants into these river estuaries.

The tides in the estuaries are semi–diurnal having an amplitude of 230 cm and the effect is observed upstream as far as 30–40 km in the interior (Dwivedi et al., 1974). The surface temperature varies from 26.1°C to 30.1°C during high and low tides whereas the bottom temperature ranges from 23.5°C to 30.4°C. Salinity is highly influenced by monsoon and tidal effect. The surface salinity in the Mandovi ranges from 0.12 to 30.2‰, while in the Zuari it is from 0.21 to 32.9‰. In the canal region it ranges from 0.12 to 15.66‰. Close to the sediment–bottom water interface the salinity averages from 0.12 to 33.58‰ (Dwivedi et al., 1974).

The influx of seawater entering the rivers as a wedge through the bottom, on gradual mixing in the upstream turns to brackish or hyposaline condition. Therefore, based upon the salinity gradient, the estuarine complex of Goa region may be divided broadly into four zones: (1) Mandovi upper estuarine zone and Zuari upper estuarine zone, (2) Cumbarjua canal zone, (3) Mandovi canal junction zone and Zuari canal junction zone and (4) Mandovi lower estuarine zone and Zuari lower estuarine zone adjoining the sea. More precise salinity limits are difficult to assign because of the high degree of salinity variation at any one point in an estuary. Nevertheless, biological but more particularly living foraminiferal response at these zones is observed to be varied and significant.

Methods and materials.

Fourteen bottom sediment samples were collected, from upstream regions of both the rivers at the junctions and along the canal using a van veen grab. The top one centimeter of sediment was separated from the bulk sample through a plastic liner and immediately treated with 5N rose bengal—formalin solution for foraminiferal studies. The rose bengal technique (Walton, 1952) differentiates the living Foraminifera from the dead ones. Thirty eight species of Foraminifera were identified overall, but only nineteen were found to be living at the time of collection. Only the hyposaline and tolerant species survived as they adapted to the deteriorated environment.

Living benthic Foraminifera	Upper estuarine zone of Mandovi	Upper estuarine zone of Zuari	Cumbarjua canal zone	Mandovi-canal junction zone	Zuari-canal junction zone	Lower estuarine zone of Mandovi	Lower estuarine zone of Zuari
Ammobaculites crassus		C	C			F	F
A. salsus	A	A					
Ammonia parkinsoniana		A	C		A		
A. tepida	C	C	F	A	F	A	A
Ammotium salsum	A	A	C				
Arenoparella mexicana			C	F		F	F
Bolivina lowmani			F		A	C	C
Elphidium clavatum				F		A	A
E. excavatum	C	C		A	F		
Florilus boueanum			F		A	C	C
Haplophragmoides wilberti		C	C				
Jademmina polystoma	F	F	C				
Miliammina fusca	A	A	A	A	F		F
Nonion depressulum	C	C		A		F	
Quinqueloculina seminulum			F	F	F	C	C
Reophax subfusiformis		F				C	C
Textularia earlandi						C	C
Trochammina globigeriniformis			C		F		
T. inflata	A	A	A	A			F

A = Abundant (>20) C = Common (5–10) F = Frequent (<10)

Fig. 2 — Living benthic foraminiferal distribution in the four estuarine zones of Mandovi–Zuari–Cumbarjua canal region of Goa.

Results.

Figure 2 shows that the Mandovi upper estuarine zone and the Zuari upper estuarine zone have a similar fauna. In the Zuari the typical marine forms *Ammonia parkinsoniana*, *Haplophragmoides wilberti*, *Reophax subfusiformis* and *Ammobaculites crassus* are also present. The Cumbarjua canal zone is largely dominated by agglutinated species. The species patterns of the Mandovi–canal junction and Zuari–canal junction zones differ since the salinity gradient in these two regions is variable i. e., in the former, there is more freshwater inflow and thereby the region is less saline whereas in the latter there is more marine water influence hence tending to be more saline. The lower zones of both the Mandovi and Zuari estuaries become typically marine, and the species composition is similar. The *Ammonia – Elphidium* suite predominates, with large chambered forms, associated with nearshore forms.

Discussion.

Temperature, although variable, is more stable in these two estuaries. Salinity barriers impair adaptation of faunal mixing because organisms are sensitive to salinity changes. Though faunal diversity is low in these brackish or estuarine regimes the assemblages are quantitatively rich (Rao, 1974; Boltovskoy & Wright, 1976).

The faunal composition of both upper estuarine zones is similar whereas in the Zuari upper estuarine zone typical marine forms are also present. *Ammonia tepida, Nonion depressulum, Elphidium excavatum, Jademmina polystoma, Ammobaculites salsus, A. crassus, Ammotium salsum, Haplophragmoides wilberti, Miliammina fusca* and *Trochammina inflata* have living representatives in the upper estuarine zones of Mandovi and Zuari rivers receiving tidal marine waters. Similar observations were made by Boltovskoy and Boltovskoy (1968) from their studies in the Quepem Grande river estuary of Argentina, and Mississippi Sound near Mobile Bay (Anderson, 1968). According to Boltovskoy and Wright (1976) *Nonion depressulum, Elphidium excavatum, Trochammina inflata, T. globigeriniformis, Miliammina fusca, Ammotium salsum, Ammonia, Ammobaculites* and *Quinqueloculina seminulum* are typical estuarine forms.

Miliammina fusca and *Ammotium salsum* are capable of tolerating extreme ecological changes (hyposaline to hypersaline 0–50‰S) and known to have the ability to live even in lacustrine conditions (Murray, 1973). Scott et al., (1980) consider them as key estuarine species. *A. salsum* and *M. fusca* are numerically dominant in this assemblage. However, *A. salsum* is very abundant in the canal zone only. These species are thus relatively ubiquitous and abundant in both upper estuarine zones of the Mandovi and Zuari rivers and in the entire canal zone. Such a condition is also reported for Chezzetcook Inlet, Miramichi estuary and Restigouche estuary of Canada (Schafer & Cole, 1974). Similarly, *Arenoparella mexicana* (0–28‰S) appears to be another estuarine indicator species. Brady (1874) noticed the occurrence of *Nonion depressulum* even in fresh water, but recent work has delineated its tolerance limit to 30–4–6‰S (Rottgardt, 1952; Voorthuysen, 1960; Pujos, 1973). These species are quite common in the upper estuarine zones of Mandovi and Zuari rivers.

As these species have a wide range of salinity tolerance, the bottom salinity variation all the year round (including monsoon period) in the entire region does not have any significant effect on them.

The Cumbarjua canal zone is rich in agglutinated forms (Fig. 2). They include typical estuarine species. *Ammonia parkinsoniana*, *Bolivina lowmani* and *Quinqueloculina seminulum* are also present. *A. parkinsoniana* is typically a marsh, lagoonal and beach form living in regions receiving tidal marine waters and *Bolivina lowmani* is a marginal marine form tolerating 1.32‰S. Thus their occurrence in this zone is in conformity with the other key estuarine species.

The faunal assemblage at the Mandovi–canal junction zone where the mixed water is less saline due to the large inflow of fresh water from the Mandovi river includes the key estuarine species (*Ammonia tepida*, *Elphidium excavatum*, *Nonion depressulum* and *Trochammina inflata*) dominating. But at the Zuari–canal junction zone, where the mixed water is more saline due to the tidal effect and less freshwater inflow, *Ammonia parkinsoniana*, *Florilus boueanum* and *Bolivina lowmani* dominate. These species are typical lagoonal, normal marine and marginal marine forms. The variation recorded at the two junctions documents the salinity gradient.

The lower estuarine zones of the Mandovi and Zuari rivers include the species tolerant to salinity fluctuations wherein the *Ammonia–Elphidium* suite predominates consisting of large chambered, typical nearshore forms. The presence of *Elphidium clavatum* (> 15‰S), *Textularia earlandi*, *Reophax subfusiformis* in this zone indicates the vicinity of the sea.

As marsh and estuarine environments intergrade with each other in the Mandovi–Zuari–canal estuarine complex, *Arenoparella mexicana*, *Miliammina fusca* and *Trochammina inflata* occur very commonly. It is known that several species which are endemic to marshes are commonly washed into the estuarine environment, thus showing an intimate association.

The substratum of the lower estuarine zones of the Mandovi and Zuari rivers is mostly sandy while it is silty–sand to silty–clay at the upper reaches. The lower zones are not very rich in living Foraminifera but comparatively they are richer than those of upper zones. The muddy/clayey substrate of the canal is dominated by *Trochammina inflata*, *T. globigeriniformis* and *Miliammina fusca* which are edaphic in character. Though *Ammonia* spp. is present in this substrate, it occurs in smaller size and low in population. The edaphic nature of *Ammonia*, *Ammobaculites* and miliolids being specific to sandy or silty sand and *Florilus* and *Elphidium* to silty–clay indicates microenvironments (Setty & Nigam, 1980). Howewer, *Elphidium clavatum* which dominates in salinities $> 14‰$ is present in lower estuarine zones where a more diverse fauna is present.

The organic matter content in the sediment varies considerably. The important factors that govern the concentration of organic matter and the sediment grain size, are the hydrodynamic condition, the source and rate of sedimentation. It ranges from 0.60% at the mouths of the rivers to 16.5% in the lower estuarine zones of Zuari but is as high as 21.90% in the canal zone (Dwivedi et al., 1974). Sewage along the paths of the rivers, spillage from the navigation barges, mechanised boats and the fish canning industries along the banks are the contributing factors. Besides, they include pollutants from various factories located along the rivers. The effects of toxic effluents discharged bears direct relationship with the fluctuation of the tolerance level and increased destruction of living forms in the environments. This is indicated in a rich living faunal assemblage in the canal zone. Bordovskiy (1965), Setty (1976) and Setty and Nigam (1982) noted a high benthic biomass (including foraminiferal populations) when the organic matter content in the substrate is low. Though a variety of living benthic Foraminifera are present in the canal zone and the lower estuarine zone of the Zauri due to the high organic carbon contents and the substrates being clayey and silty clay the population is very low. The edaphic character, high organic matter content and salinity variation are the important variables affecting the density of the population. However, in this environment *Ammonia* spp. and its variants and other agglutinated species assume a dominant role (Setty, 1976; Schafer & Cole, 1974). The decrease in the calcareous species and the thinning in the dead tests with their eventual destruction here may be attributed to their susceptibility to acidity. Several zones of microenvironments and faunal facies (Setty & Nigam, 1980) can thus be delineated within the area.

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