

Effect of mining activities on the clam fisheries and bottom fauna of Goa estuaries

A H PARULEKAR, Z A ANSARI and B S INGOLE

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

MS received 6 April 1985; revised 30 July 1985

Abstract. Comparison of two clam beds and associated benthic fauna, in Mandovi and Cumbarjua canal estuarine system of Goa, severely affected by massive inputs of mining rejects, revealed that, in less than 10 years (1972–73 to 1982–83), high biotic variability induced by increasing environmental stress has caused irreversible ecosystem instability. Reduced dissolved oxygen concentration; high suspended solids and blanketing of bottom deposits by mining rejects, has resulted in more than 70% reduction in clam production; near extinction of resident fauna and the appearance of a low diversity bottom fauna, comprising of tolerant but vagrant species. Ever increasing entry of mining rejects, which has reduced the healthy and highly productive estuarine environment of 1972–73, into an impoverished biotope, in less than 10 years, unless prevented will result in the total extinction of estuarine life in the near future.

Keywords. Mining rejects; clam bed; benthic fauna; environmental variability; faunal diversity; biomass.

1. Introduction

The coastline of Goa (between lat. $14^{\circ}54'$ – $15^{\circ}48'N$ and long. $73^{\circ}41'$ – $74^{\circ}20'E$), measuring about 100 km in length, is characterized by estuaries of 7 rivers (figure 1). All these estuaries, providing sheltered habitat, harbour commercially important shellfish beds of clams, mussels and oysters, with an estimated yield of about 1000 tonnes/year (Parulekar and Qasim 1981). Being sessile and burrowing in habitat, the benthic or bottom dwelling organisms are the major casualties of any major environmental or man-made changes (Heip 1980).

A major contribution to the economy of Goa is from the export of over 10 million tonnes/year of iron and manganese ores from Marmugao port. All the ore extraction operations are carried out in the vicinity of river systems and, further the transport of ore for export shipment is done by mechanized barges, plying solely through the inland waterways of Mandovi-Cumbarjua canal—Zuari estuarine system (figure 1). Extraction of one tonne of export quality ore, generates about 1.5 tonnes of mining rejects and over the years, more than 300 million metric tonnes of rejects are estimated to have accumulated in the mining belt of Goa (Anonymous 1981). Due to heavy southwest monsoon rains, (average rainfall varying from 3 meters/year in the coastal areas to 3.75 meters/year in the hilly regions, where the mining areas are located) these mining rejects get eroded due to flooding, and are transported downstream the rivers, when about 11% of the mining rejects settle in the sediment at 0–5% salinity and about 21% are lost to bottom deposits at 15–20% salinity (Anonymous 1981). Thus, a substantial part of these mining rejects, ultimately settle in estuarine benthic

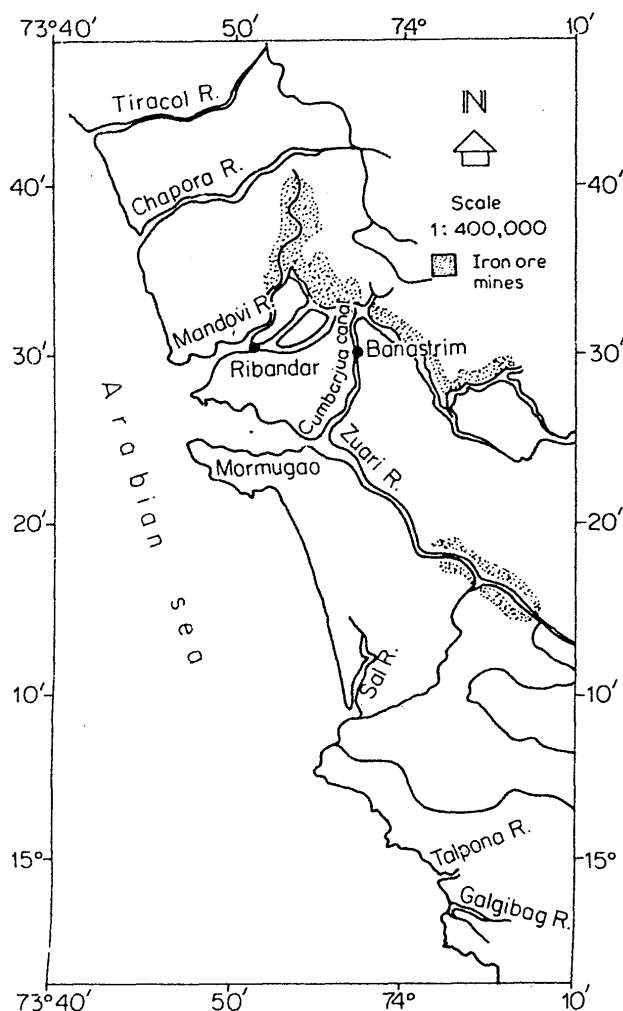


Figure 1. Map of Goa showing the mining area and the study area—Ribandar and Banastrim.

environment, having an extensive mesohaline (5–18%) and polyhaline (18–30%) salinity regime (Parulekar and Dwivedi 1974).

Earlier in 1972–73, a detailed study on the ecology of clam beds and associated fauna, at Ribandar, in Mandovi River and Banastrim, in Cumberjua Canal, was carried out (Parulekar *et al* 1973). Recently, i.e. in 1982–83, the clam beds at Ribandar and Banastrim were again studied and the changes observed in environmental and biotic components are presented and discussed in relation to mining activities.

2. Material and methods

Clams, *Meretrix casta* (Chemnitz), were collected at fortnightly interval (1982–83) from the subtidal clam beds at Ribandar and Banastrim (figure 1). Both the sites were sampled on the same day and during the same tidal phase, by using a Van Veen grab,

having a substrate coverage of 0.1 m², upto a penetration depth of 10 cm. Samples were collected in replicate of 5 and the mean value of biomass (wet weight) and population density was estimated.

After removing clams, the remaining sediments were sieved through a 0.5 mm mesh screen and the fauna retained in the sieve was preserved in 5% seawater—formaline—Rose Bengal solution, for observations on the distribution, abundance and species composition of benthic fauna associated with the clam bed. Environmental data on temperature, salinity, dissolved oxygen and suspended solids in the bottom waters, about 30 cm above the clam bed, was collected during each sampling trip. Temperature and salinity were recorded directly on a NIO (India) design Temperature-Salinity bridge. Dissolved oxygen was estimated by winkler method (Strickland and Parsons 1972) and the amount of suspended solids, was determined by filtering one litre of near bottom water through a pre-weighed Whatman GF/A filter paper, which was dried at 105°C and reweighed. Organic carbon in sediments was estimated by the method of El Wakeel and Riley (1956).

As biomass and population density counts are usually found to be skewed in benthic surveys, a log transformation [$\log(x + 1)$] of biotic parameters was carried out, for statistical treatment (Gage and Tett 1973). Similarly, the interpretation of data, pertaining to two different periods of observations i.e. 1972–73 and 1982–83, were tested for the magnitude of interaction and significance of relationship, by calculating the correlation coefficient (r) and testing it by t -test ($P < 0.05$). Data on environmental and biotic variables, is presented (range, mean and 95% confidence limit) by Dice-Lerass diagrams. Species diversity was estimated by using the index of diversity (Margalef 1958).

3. Results and discussion

3.1 Environmental features

The average depth at the sampling sites varied from 2.2–3.5 m (Ribandar) to 2.6–3.3 m (Banastrim) and the variations were relevant to tidal phase and seasonal flooding due to land run-off. As compared to 1972–73, no major changes, in depth over the clam beds, were observed (Parulekar *et al* 1980).

Bottom water temperatures (0.3 m above the clam bed) displayed a comparable trend in range, mean and variability, both in 1972–73 and 1982–83. Though no major changes were observed in 1982–83, the maximum temperature, both at Ribandar and Banastrim, was almost 4°C higher than in 1972–73 (figure 2).

Range of salinity values at Ribandar in 1982–83 was relatively small and of lower magnitude than in 1972–73, and consequently the observed variability was more intense in 1972–73 than in 1982–83 (figure 2). In contrast, the range, mean and magnitude of variability, in salinity values at Banastrim, was comparable in both the periods of observations.

Dissolved oxygen concentration in 1982–83 showed major changes in range, mean and magnitude of variability, at both the sampling sites (figure 2). While the range and mean values, in 1972–73 at Ribandar and Banastrim, were uniformly high but with small variability, by 1982–83, the range and mean values though of low magnitude, showed relatively high variability, especially at Ribandar. Mean values of 2.69 ml/l

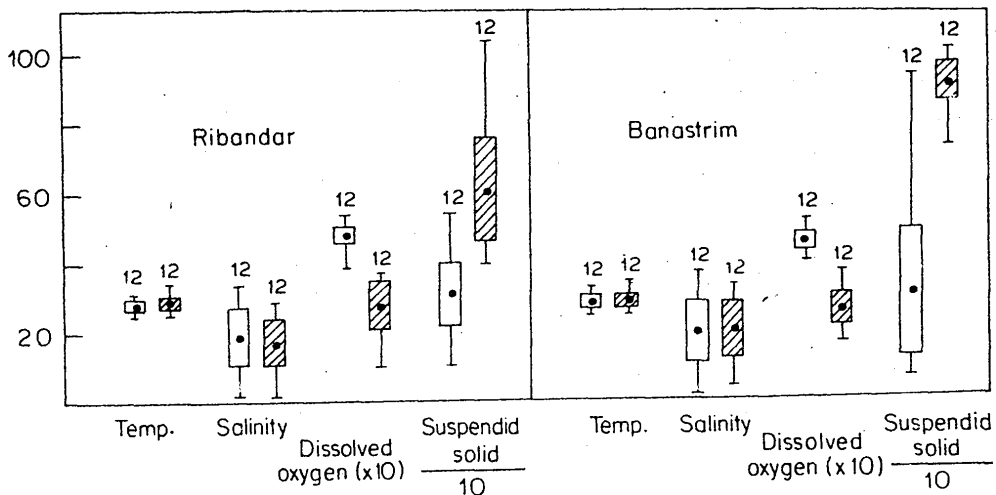


Figure 2. Range, mean and variability in environmental factors at Ribandar and Banastrim in 1972-73 and 1982-83 (stippled).

(Ribandar) and 2.55 ml/l (Banastrim) in 1982-83 observations, clearly indicate that an overall 66-67% depletion in dissolved oxygen, has taken place in the clam bed environment, in a span of 10 years (1972-73 to 1982-83).

Major changes in the suspended solid content of the bottom waters overlying the clam bed, were evident (figure 2). At Ribandar, the range, mean and variability was higher in 1982-83 than in 1972-73. In contrast, at Banastrim, while the range of values and the magnitude of variability, was rather wide in 1972-73, the mean value as well as the range, was many times more, but with less variability in 1982-83. It suggests that, while the suspended solids in the water column at both the clam beds, have increased considerably within 10 years, the relative increase at Banastrim is more consistent and of higher magnitude than at Ribandar. This is attributed to the flow characteristics wherein flow of water is from Zuari estuary into the Cumbarjua canal (Das *et al* 1972).

Retrogressive changes, in the composition of bottom deposits, were observed. In 1971-73, the type of bottom deposits, at Ribandar and Banastrim, were characterized as sandy to muddy sand, with mean grain size of 0.5-0.25 mm and 0.25-0.125 mm, respectively (Parulekar *et al* 1980). However, in 1982-83 survey, the sandy and the muddy sand type of bottom deposits, were observed to be covered with red clay and further blanketed by cobble and pebbles of lateritic origin (figure 3).

Organic carbon content of bottom deposits in 1972-73 varied from 0.11-2.55% with a mean value of 0.78% at Ribandar and from 0.24-1.8%, with a mean value of 1.0% at Banastrim (Parulekar *et al* 1980). In spite of a marginal increase in annual mean of 0.04% at Ribandar and 0.02% at Banastrim, the range (0.1-2.72%) and the magnitude of variability in 1982-83, was almost similar to that in 1972-73. It means that there was no substantial increase in the organic enrichment of clam habitat, in the last 10 years.

3.2 Biotic characteristics

The clam biomass (figure 4) in two different periods of observations, showed overall decrease in range, mean and variability. At Ribandar, in 1972-73, the biomass values,

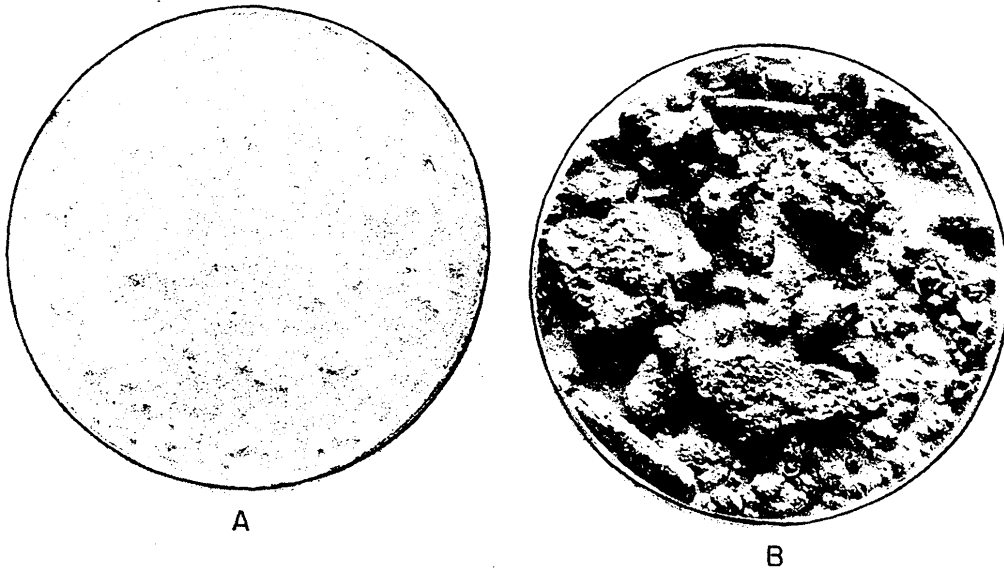


Figure 3. Bottom deposits at clam bed. **A.** Sandy-mud type of bottom, as occurred in 1972–73. **B.** Sandy-mud bottom deposits covered by cobble and pebbles as in 1982–83.

while varying between 133.9 and 2381.3 g^{-2} ($\bar{x} = 538.4 \text{ g}^{-2}$), displayed a high magnitude of variability. By 1982–83, not only the range and mean value ($0.1\text{--}38 \text{ g}^{-2}$; $\bar{x} = 10 \text{ g}^{-2}$) but also the variability declined considerably. At Banastrim, almost similar depletory trend was observed. The high range and high mean value ($149.2\text{--}3060.5 \text{ g}^{-2}$; $\bar{x} = 779.7 \text{ g}^{-2}$) as observed in 1972–73 decreased, both in range ($4.4\text{--}392.2 \text{ g}^{-2}$) and mean value (151 g^{-2}) in 1982–83. Consequently, the high magnitude of variability in clam biomass, as observed in 1972–73, reduced to a low level in 1982–83 (figure 4).

Population density of clams, in space and time, revealed (figure 4) that from the high range and high mean value of $150\text{--}2075/\text{m}^2$ ($\bar{x} = 893/\text{m}^2$) and $450\text{--}22012/\text{m}^2$ ($\bar{x} = 3969/\text{m}^2$) in 1972–73 at Ribandar and Banastrim, respectively, the observed decline in 1982–83, ranged from $3\text{--}98/\text{m}^2$ ($\bar{x} = 36/\text{m}^2$) at Ribandar to $90\text{--}720/\text{m}^2$ ($\bar{x} = 360/\text{m}^2$) at Banastrim. Magnitude of variability, which was very high in 1972–73 at Ribandar, reached very low level in 1982–83, with range and mean value at their lowest. Total absence of clams, in the month of March, November and December at Ribandar and in the month of July at Banastrim, was also observed in 1982–83.

Benthic standing crop, estimated as benthic biomass, varying from $0.1\text{--}228.9 \text{ g}^{-2}$ ($\bar{x} = 56.8 \text{ g}^{-2}$), but with moderately high variability (figure 4), as observed in 1972–73 at Ribandar, declined to $0.5\text{--}190.6 \text{ g}^{-2}$ ($\bar{x} = 23.8 \text{ g}^{-2}$) with low variability in 1982–83. Similarly, at Banastrim, the high range ($33.1\text{--}876.9 \text{ g}^{-2}$) with relatively high variability and high mean value of 339.6 g^{-2} in 1972–73, while displaying almost 50% reduction, both in range ($0.8\text{--}331.6 \text{ g}^{-2}$) and mean value (153.2 g^{-2}) in 1982–83, had comparable magnitude of variability (figure 4) as in 1972–73.

Population density of benthic fauna at Ribandar, which declined from $648\text{--}3900/\text{m}^2$ ($\bar{x} = 1864/\text{m}^2$) in 1972–73 to $200\text{--}1500/\text{m}^2$ ($\bar{x} = 831/\text{m}^2$) in 1982–83, displayed comparable magnitude of variability during both the periods of observations (figure 4).

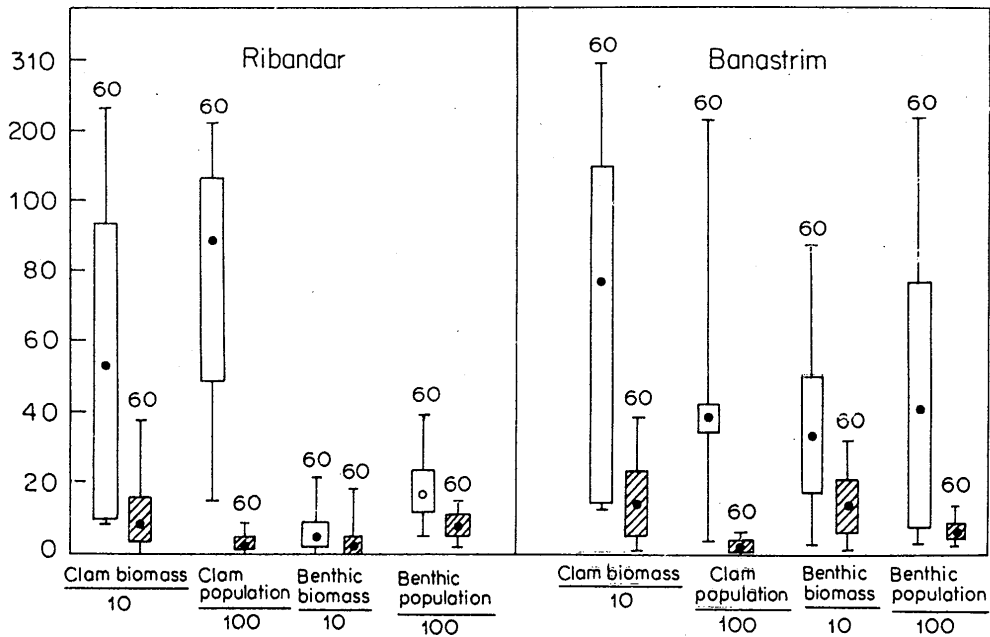


Figure 4. Range, mean and variability in biotic characteristics at Ribandar and Banastrim in 1972-73 and 1982-83 (stripped).

In contrast, at Banastrim, the population density, which exhibited high range (875–22350/m²), high mean value (4274/m²) and high magnitude of variability in 1972-73, decreased considerably in range (50–1575/m²), mean (750/m²) and variability in 1982-83 (figure 4).

Faunal composition at two sampling sites during the two periods of observations, indicated (table 1) that while the prevalence of a particular faunal taxa underwent minor changes, within a span of 10 years, there were noticeable changes, both qualitative and quantitative, in the presence or absence of species. While the number of species at Ribandar increased from 24 in 1972-73 to 30 in 1982-83, the number of species at Banastrim, decreased from 15 in 1972-73 to 12 in 1982-83. The total number of species at Ribandar and Banastrim, was 46 and 23, respectively. The break-up of 8 common species at Ribandar was, 6 species of polychaetes (*Nereis capensis*, *N. mirabilis*, *Perinereis nuntia*, *Prionospio cirrifera*, *Diopatra neapolitana* and *Marphysa sanguinea*) and a species each of pelecypoda (*Meretrix casta*) and amphipoda (*Corophium* sp.). At Banastrim, the 4 common species were 2 polychaete species (*Lepidonotus carinulatus* and *Diopatra neapolitana*) and a species each of gastropoda (*Cerithidea fluviatilis*) and pelecypoda (*Meretrix casta*).

Changes in species composition, in a span of 10 years, was further investigated by studying the composition of feeding types in the fauna (table 1). At Ribandar clam bed; the benthic fauna in 1972-73, was characterized by the dominance of filter feeding and detritus feeding species, basically infaunal in habitat. It reflects on the availability of the food material, both in the overlying water column as also on the surface of the bottom deposits. However, by 1982-83, with alarming increase in the amount of inorganic suspended solids, the food supply was drastically cut and accordingly, the scavenger species, epibenthic or migratory in habitat, attained the dominance. Similarly, at

Banastrim, the dominance of filter feeders and detritus feeders in 1972–73, was replaced by the overwhelming dominance (83.4%) of scavenger species in 1982–83.

Species diversity index describes the effect on the fauna by changes in the environment. The index of diversity (table 2), as assessed from the temporal variations in the distribution and abundance of species, at Ribandar and Banastrim, during 1972–73 and 1982–83, revealed that, in accordance with the high magnitude of variability in environmental factors, there was higher species diversity in 1972–73 than in 1982–83, at Ribandar. At Banastrim, while the index of diversity was higher in 1972–73 than in 1982–83, the magnitude of variability, surprisingly, was more intense in 1982–83 than in 1972–73. It indicates that the epibenthic or vagrant species are not present throughout the year. Number of species and the number of specimens, at both the sampling sites and in two different periods of observations, showed a declining trend, during the different months of monsoon season (June–September), apparently because of lowering of salinity due to heavy land run-off; and consequently, the species diversity, attained its lowest, during June–September period, depending upon the year-to-year variations in rainfall and flooding. As assessed from the annual mean (table 2), it may be inferred that the faunal diversity, over the years, decreased considerably, from 5.4 ± 0.91 (1972–73) to 4.1 ± 0.61 (1982–83) and from 2.8 ± 0.43 (1972–73) to 1.5 ± 0.53 (1982–83), at Ribandar and Banastrim, respectively. The changes in diversity can be correlated to simultaneous changes in the suspended solids and sediment composition which made benthic environment unsuitable for colonization by many sensitive and rare species and were duly replaced by a few tolerant species. Such striking decline in species diversity, is a reflection of environmental perturbation and the response of biota, over the span of 10 years (Lie 1968).

The magnitude of interaction between environmental and biotic variables, determines the quality and quantity of the biota and, therefore the relationship between them was attempted (table 3). The correlation coefficient (r), which measures the magnitude of interaction, was tested by t -test ($p < 0.05$). The significant correlation, observed between abiotic and biotic variables was as summarized below:

	1972–73	1982–83
Ribandar	Salinity-benthic biomass	Salinity-benthic population density
	Salinity-No. of species	Salinity-No. of species
	Suspended solids-benthic biomass	Suspended solids-benthic biomass
	Suspended solids-benthic population density	Suspended solids-benthic population density
	Suspended solids-No. of species.	Suspended solids-No. of species
Banastrim	Salinity-clam biomass	
	Salinity-No. of species	Dissolved oxygen-No. of species
	Suspended solids-benthic biomass	
	Suspended solids-benthic population density	

These relationships indicated that salinity-especially during the monsoon season (June–September) and suspended solids, both were related to the occurrence of number of species, at Ribandar and Banastrim, in 1972–73. Suspended solids, in the overlying water column above the clam beds, showed significant relationship with benthic biomass, benthic population density and number of species at Ribandar, both in

Table 2. Number of species, population density and index of diversity in associated fauna of clam beds at Ribandar and Banastrim in 1972-73 and 1982-83.

Month	Ribandar						Banastrim					
	1972-73			1982-83			1972-73			1982-83		
	Species	Popula- tion density	Index of diversity	Species	Popula- tion density	Index of diversity	Species	Popula- tion density	Index of diversity	Species	Popula- tion density	Index of diversity
Jan.	23	1200	7.1	12	1075	3.6	13	4987	3.2	6	1300	1.6
Feb.	21	1780	6.1	11	1475	3.1	14	1538	4.0	6	225	2.1
Mar.	22	1300	6.7	17	1025	5.3	12	1200	3.5	8	600	2.5
Apr.	24	1975	6.9	16	725	5.2	10	2887	2.6	4	300	1.2
May	21	2225	5.9	17	1125	5.2	12	22350	2.5	5	1225	1.2
June	17	725	5.6	10	200	3.9	12	875	3.7	7	650	2.1
July	9	648	2.8	11	425	3.8	7	1675	1.8	3	50	1.1
Aug.	10	2750	2.6	7	250	2.5	8	3112	2.0	2	350	0.4
Sept.	16	1325	4.8	9	475	2.9	11	2812	2.9	2	875	0.3
Oct.	19	2687	5.2	16	1125	4.9	10	2700	2.6	4	1575	3.2
Nov.	22	3900	5.8	15	1500	4.4	9	1800	2.4	5	1050	1.3
Dec.	22	1855	6.4	13	575	4.3	14	5362	3.4	7	800	2.0
Mean			5.4			4.1						2.8
95% confidence limit ±			0.91			0.61						0.43

Table 3. Magnitude of interaction between environmental parameters and biotic components at Ribandar and Banastrim in 1972-73 and 1982-83.

		Banastrim							
	Temperature (°C)	Salinity (‰)	Dissolved oxygen (ml/l)	Suspended solids (mg/l)	Clam biomass (g ⁻²)	Clam population (n/m ²)	Benthic biomass (g ⁻²)	Benthic population density (n/m ²)	No. of species
Temperature (°C)	1972-73	0.41	0.29	-0.44	-0.14	-0.17	0.02	0.18	-0.10
	1982-83	0.60 ^a	-0.48	-0.44	-0.12	0.24	-0.04	0.33	0.06
Salinity (‰)	1972-73	1.00	-0.55 ^a	-0.83 ^a	-0.73 ^a	0.21	0.15	0.18	0.62 ^a
	1982-83	1.00	-0.61	-0.73 ^a	0.01	0.33	-0.02	0.33	0.42
Dissolved oxygen (ml/l)	1972-73	-0.10	1.00	0.33	0.47	-0.15	-0.11	-0.29	-0.29
	1982-83	-0.58 ^a	1.00	0.81	0.22	-0.12	0.23	-0.09	-0.60 ^a
Suspended solids (mg/l)	1972-73	-0.58 ^a	0.74 ^a	1.00	0.39	-0.38	0.54 ^a	-0.55 ^a	-0.70 ^a
	1982-83	-0.91 ^a	0.55 ^a	1.00	0.04	-0.25	0.05	-0.23	-0.42

Clam biomass (g ⁻²)	1972-73	0.22	-0.33	-0.16	0.21	1.00	0.19	-0.09	0.25	-0.26
	1982-83	0.11	0.16	0.08	-0.19	1.00	0.81	0.96 ^a	0.78 ^a	-0.02
Clam population (n/m ²)	1972-73	-0.47	-0.44	-0.27	-0.15	0.32	1.00	0.43	0.68 ^a	0.37
	1982-83	0.31	-0.02	-0.14	0.04	0.59 ^a	1.00	0.81	0.92 ^a	0.29
Benthic biomass (g ⁻²)	1972-73	-0.22	0.62 ^a	-0.35	-0.61 ^a	-0.47	-0.42	1.00	-0.54 ^a	0.30
	1982-83	-0.09	0.46	-0.08	-0.53 ^a	0.81	0.28	1.00	0.83 ^a	-0.01
Benthic population density (n/m ²)	1972-73	0.31	0.33	-0.38	-0.57 ^a	-0.22	0.11	0.74 ^a	1.00	0.49
	1982-83	-0.24	0.53 ^a	-0.01	-0.53 ^a	-0.16	-0.46	0.26	1.00	0.27
No. of species	1972-73	0.31	0.87 ^a	-0.32	-0.69 ^a	-0.53 ^a	-0.43	0.71 ^a	0.32	1.00
	1982-83	0.38	0.75 ^a	-0.32	-0.63 ^a	-0.23	-0.24	-0.03	0.52	1.00

^ap < 0.05.

1972–73 and 1982–83. At Banastrim, in 1972–73, the suspended solids displayed a significant relationship with benthic biomass and benthic population density, as against the only significant relationship between dissolved oxygen and number of species, in 1982–83. From table 3, it may be deduced that at Banastrim, in a span of 10 years, between 1972–73 and 1982–83, severe destruction accompanied by complete instability of the clam bed ecosystem has taken place, and consequently, the magnitude of interaction between environmental variables and biotic variables has become insignificant. At Ribandar, on the otherhand, the interaction, especially between the suspended solids and the biotic variables of the clam bed ecosystem, is significantly maintained even in 1982–83. It indicates that while the assimilative capacity of clam bed ecosystem at Ribandar, as evidenced from the considerable impoverishment of biota, is on decline, the overall stability is still being maintained, though at a much lower level than in 1972–73. However, with the continuing deterioration in the environmental quality, it is only a matter of time, before the total disintegration of assimilative capacity and instability of clam bed ecosystem, takes place.

Field measurement of biological impact of pollutants, as in the present study, has a significant role in the management and conservation of sensitive but highly productive estuarine environment. The monitoring of the biological effects of marine pollution, can be carried out at any level of biotic organization, from the ecosystem, community, population density, organismic down to the cellular levels, by undertaking comparative studies on distribution, abundance and structure of a population (Widdows 1983). Measurement at community and population structure level provides an assessment of impact of the long term consequences of high levels of chronic pollution. Though, quite a few studies on the long term effects of pollutants on estuarine and marine biota have been reported (Bayne 1978; Parulekar *et al* 1985), very little (Norris *et al* 1982) is known about the long term effects of onshore mining on the biota of coastal ecosystems.

Benthic macroinvertebrates, as a group of organisms, having infaunal and/or epifaunal habitat, are very sensitive to changes in the environment, as they integrate the combined effect of many stresses through changes in their ecology, morphology and physiology (Ketchum 1973). As a group, they are amenable to numerical quantification and hence, they are ideally suited for assessing the impact of pollution in estuarine and marine environment (McIntyre and Pearce 1980).

Amongst the multitude of benthic organisms, bivalve molluscs, like clams, mussels and oysters, have widely been used as sentinel organisms, for assessing and monitoring the chemical and biological effects of marine pollution (Hung *et al* 1975). Besides, being commercially important and also the dominant members of coastal and estuarine ecosystem, the bivalves being sessile in habit, passively experience the varying conditions in the overlying water column. As they pump large quantity of water, for feeding and respiration, they accumulate contaminants and are reported to be responsive to many of the environmental pollutants, without showing a prolonged stress (Widdows *et al* 1980).

Environmental and biological parameters, studied during the course of the present study, are essential to correlate the frequency of occurrence, faunal composition, standing crop and community structure of the clam bed ecosystem, in relation to changes in the physical, chemical and geological characteristics, over a period of 10 years, from 1972–73 to 1982–83. Relative abundance and changes in spatial and temporal distribution of clams and the associated benthic fauna, gives a good indication of the magnitude of environmental changes, principally, brought about by the entry of mining

rejects, on an everincreasing scale, in the Mandovi-Cumbarjua canal-Zuari estuarine system of Goa.

Mining activities are about double as much along the Mandovi river than along the Zuari river (Anonymous 1979) and accordingly, the ecosystems in Mandovi estuary, receive the maximum adversity, due to mining rejects. Kamat and Sankaranarayana (1974) observed high value of 40.3 mg/l of particulate iron in the nearbottom water at Ribandar as compared to 6.6 mg/l at Banastrim and further reported that about 70,000 tonnes of iron, in particulate form, gets annually deposited in Mandovi river. Based on a 1977-78 study, significantly high concentration of iron and manganese in the sediments of Mandovi and Zuari river, with moderate concentrations in the interconnecting Cumbarjua canal have been reported (Anonymous 1979).

The fate, and the probable effects on the benthic fauna, of a metal, from particulate to dissolved state, in interstitial waters within the sediments, vary greatly (Krom and Sholkovitz 1978). For, iron and manganese, there is a significant release from the interstitial waters in response to the degradation of organic matter (Lu and Chen 1977) and further conversion to dissolved state in the overlying oxygenated water and dispersal by physical forces of currents and tides (Bertine 1982; Gideiri 1984). While explaining the causes for the considerable depletion of dissolved oxygen (66-67%), as observed in the present study, also provides a clue for the non-toxic effects of mining rejects to the benthic fauna.

Besides the overall decrease in the dissolved oxygen concentration, other obvious reasons for the decline in the clam resources are due to the immense increase in the quantity of suspended solids and structural deformation of bottom deposits (figure 3).

An ideal habitat for burrowing organisms, like clams is of soft sediments, a combination of sand and silt. Any change to red clay, cobbles and pebbles, as observed in the present study, will deter the settlement and growth of suspension feeders, like clams and a majority of infaunal benthic invertebrates. Even if the pelagic larvae of clams, succeed in settling on the altered bottom deposits, then the observed, alarming increase in the suspended solids, principally of inorganic origin, while reducing the availability of conventional suspended organic matter, will also result in the choking of filtration apparatus, with possible mortality of the infaunal assemblages. As a consequence, the dominant filter feeding and detritus feeding species of 1972-73 have been replaced, in reduced population density and biomass, by scavenger or migrant species, comprising of opportunistic organisms like amphipods, alpheids and errant polychaetes (table 1). It gave rise to the observed low faunal diversity, due to the replacement of multispecies infaunal assemblages of resident fauna of 1972-73 by few tolerant, but epifaunal and migrant species of 1982-83.

Evidently, the red clay particles, both in suspension as also settled on the bottom deposits alongwith the lateritic cobble and pebbles strewn in the clam beds, are of terrigenous origin, and have entered the estuarine environment through land run-off from the mining rejects and due to spilling, handling mishaps and washings from mechanized barges, transporting iron ores, from mine head to the shipment point. Such massive inorganic inputs, estimated to be about 70,000 tonnes of iron, in particulate form, getting deposited annually in the Mandovi river (Kamat and Sankaranarayana 1974), has resulted in the considerable reduction of the assimilative capacity of the clam bed ecosystem at Ribandar and serious ecosystem instability at Banastrim clam bed. These deleterious man-made changes though gradual are recurring in nature and unless abated, the total extinction of estuarine living resources, is evident.

Acknowledgements

Thanks to Dr V V R Varadachari and T S S Rao for the facilities. Able assistance by Dr S G Dalal in statistical treatment of data is gratefully acknowledged.

References

- Anonymous 1979 *Master Plan for Pollution Control of the Rivers Zuari and Mandovi* (NIO Technical Report No. 02/79) p 114 (Mimeo)
- Anonymous 1981 *Eco-Development Plan For Goa* (Report of Task Force on Coastal Area Planning), p. 42 (Mimeo)
- Bayne B L 1978 Assessing effects of marine pollution; *Nature (London)* **280** 14–15
- Bertine K K 1982 Metals and metalloids in oxic and anoxic environments; in *Assimilative Capacity of the Oceans For Man's Wastes*, (eds) Jong-Chin Su and Tsu-Chang Hung (SCOPE/ICSU, Academia Sinica, Taipei, Republic of China) pp 51–68
- Das P K, Murthy C S and Varadachari V V R 1972 Flow characteristics of Cumbarjua Canal connecting the two estuaries of Mandovi and Zuari; *Indian J. Mar. Sci.* **1** 95–102
- El-Wakeel S K and Riley J P 1956 The determination of organic carbon in marine muds; *J. Cons. Perm. Inst. Explor. Mar.* **22** 180–183
- Gage J D and Tett P B 1973 The use of log-normal statistics to describe the benthos of Loch Etive and Crenan; *J. Anim. Ecol.* **42** 373–382
- Gideiri Y B A 1984 Impact of mining in Central Red Sea environment; *Deep-Sea Res.* **31** 823–827
- Heip C 1980 Meiobenthos as a tool in the assessment of marine environmental quality; in *Rapport et Process-Verbaue des Reunions Conseil International pour l'exploration de la mer* (eds) A D McIntyre and J B Pearce (Copenhagen: ICES) No. 169 pp 182–187
- Hung T C, Chen J C, Lin L P and Liang N K 1975 Pollution studies in shellfish cultivating area of Taiwan western coast; *Spl. Publ. (Inst. Oceanogr., National Taiwan Univ.)* No. 6 p 60
- Kamat S B and Sankaranarayanan V N 1974 Concentration of particulate iron in estuarine and coastal waters of Goa; *Indian J. Mar. Sci.* **3** 34–38
- Ketchum Bostwick H 1973 Ecological effects of marine pollution; in *Special Publication Dedicated to Dr N K Panikkar* (A Marine Biological Association of India Publication) pp 7–28
- Krom M D and Sholkovitz G R 1978 On the association of iron and manganese with organic matter in anoxic marine pore waters; *Geochim. Cosmochim. Acta* **42** 607–611
- Lie U 1968 A quantitative study of benthic infauna in Puget Sound; *Fiskeridir. Skr. Ser. Havunders.* **14** 229–256
- Lu J C S and Chen K Y 1977 Migration of trace metals in interfaces of seawater and polluted surficial sediments; *Environ. Sci. Technol.* **11** 174–182
- Margalef R 1958 Temporal succession and spatial heterogeneity of phytoplankton; in *Perspectives in Marine Biology*, (ed.) A A Buzzati-Traverso (Univ. California Press, Berkeley and Los Angeles) pp 323–349
- McIntyre A D and Pearce J B 1980 Foreword. in *Rapport et Process-Verbaue des Reunions Conseil International Pour l'exploration de la Mer* (Copenhagen: ICES) No. 179, pp 5–11
- Norris R H, Lake P S and Swain R 1982 Ecological effects of mine effluents on the South Elk River, north-eastern Tasmania. III-Benthic macroinvertebrates; *Aust. J. Mar. Freshwater Res.* **33** 789–810
- Parulekar A H and Dwivedi S N 1974 Benthic studies in Goa estuaries: Part I-standing crop and faunal composition in relation to bottom salinity distribution and substratum characteristics in the estuary of Mandovi river; *Indian J. Mar. Sci.* **3** 41–45
- Parulekar A H and Qasim S Z 1981 Molluscan Culture; in *Status Report on Coastal Aquaculture in India* (NIO Tech. Rep.) pp 32–42
- Parulekar A H, Dwivedi S N and Dhargalkar V K 1973 Ecology of clam beds in Mandovi, Cumbarjua Canal and Zuari estuarine system of Goa; *Indian J. Mar. Sci.* **2** 122–126
- Parulekar A H, Dhargalkar V K and Singbal S Y S 1980 Benthic studies in Goa estuaries: Part III-Annual cycle of macrofaunal distribution, production and trophic relations; *Indian J. Mar. Sci.* **9** 189–200
- Parulekar A H, Ansari Z A, Harkantra S N and Rodrigues C L 1985 Long term variations in benthic macroinvertebrate assemblages off Bombay; in *Biology of Marine Benthic Organisms: Techniques and Methods as Applied to the Indian Ocean*, (ed.) R Nagabhushanam (New Delhi: Oxford-IBH Publ. Co.) pp 118–131

- Strickland J D H and Parsons T R 1972 A Manual of Sea Water Analysis; *Bull. Fish. Res. Board Can.*, No. 125, pp 185
- Widdows T 1983 Field measurement of the biological impacts of pollutants; in *Assimilative Capacity of the Oceans for Man's Wastes* (eds Jon-Ching Su and Tsu-Chang Hung (SCOPE/ICSU Academia Sinica, Taipei, Republic of China) pp 111-129
- Widdows J, Salkeld P N, Moore M N and Livingstone D R 1980 The ecological effects of sublethal stress and pollution in estuarine invertebrates; in *Environment and Quality of Life: Second Environmental Research Programme 1976-80* (Brussels: Commission of the European Communities) pp 624-627