

with *Thalassia* being more resistant to dispersed oil and oil alone than *Halodule* or *Syringodium*. From the results one can extrapolate LD₅₀ for *Thalassia* at about 125 ml dispersed oil in 100 l. seawater, and 75 ml dispersed oil for *Halodule* and *Syringodium*. The effect of Louisiana crude vs Murban (lighter) oil was of slightly lesser magnitude than differences between species created by concentrations and periods of exposure. Dispersed oil had a greater effect on the species growth than oil alone at higher concentrations and treatment periods. This may be due to an increased amount of oil (seen in chemical analyses) within the immediate environment of the blades for dispersed oil, rather than oil floating on a surface slick (oil alone). Note that dispersant alone had a significant impact on *Halodule* and *Syringodium*, but not on *Thalassia*. The higher concentrations tested, equivalent to 19.5 gal acre⁻¹ and 80 gal acre⁻¹ (Exxon, 1985), would not ordinarily be used in planned clean-up, but might accidentally occur as overdosage of dispersant in small spills. Further laboratory tests at intermediate concentrations to define these limits more carefully are now underway. Gilfilin & Page are testing *Zostera*, a temperate species, with a comparable methodology.

Field testing of these results is now necessary. Recommendations for dispersant use guidelines cannot be made from laboratory experiments alone. All three seagrasses form major habitats in various locations throughout the Greater Caribbean ranging from estuaries to coastal waters. Pre-spill planning sensitivity mapping for amounts of dispersants, dependent on seagrasses liable to be effected, appear necessary if field tests bear out laboratory toxicity differences to dispersed oil between seagrass species.

Since various Greater Caribbean seagrasses respond differently from one another to dispersed oil, it is not possible to extrapolate this information to other subtropical and tropical ocean basins all of which contain seagrass species different from the Caribbean.

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Effect of High Organic Enrichment of Benthic Polychaete Population in an Estuary

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The benthic polychaete fauna of an estuarine region receiving domestic sewage and wastes from a nearby fish landing jetty was compared to that of a site having normal organic enrichment. The population density, biomass and species diversity were greater at the sewage receiving site. Some species showed preference for sewage site and their number was significantly

greater at the sewage site while other species showed no differences. Total counts and the biomass were significantly higher at the site of organic enrichment. A quantitatively enhanced polychaete population indicates that input of high organic matter stimulate benthic productivity.

Organic wastes, such as domestic sewage, trash fish and washings from fishing boats, is essentially rich in nutrients and once introduced into the environment in large quantities may cause drastic changes in enclosed bays and estuaries (Bozzini, 1975). Benthos appear to respond in a characteristic manner with distance from the source of organic input or enrichment (Pearson & Rosenberg, 1978; Ansari *et al.*, 1984). Generally three zones are recognized in this environment: grossly polluted, polluted and unpolluted. Pearson & Rosenberg (1976) reported a fourth zone called enriched or transitory zone where individual number, biomass and species may increase above the levels encountered in the normal zone (Dauer & Connor, 1980).

James & Gibson (1980) have divided the effect of organic pollution into two components: stress and physical disturbance. Environmental stress leads to reduced productivity of the individuals. Disturbance on the other hand, leads to an unpredictable environment and favours the colonization by opportunistic species (Gray, 1979).

To evaluate the impact of high organic input (sewage effluent, trash fish and washing from fishing boats) on benthic macroinvertebrates, a study was undertaken at a site in the Mandovi estuary to examine the response of individual species as indicated by their population density, biomass and species diversity. Only polychaetes were analysed in this study since they tend to be the first macrobenthos inhabiting the stressed region of a pollution gradient (Pearson & Rosenberg, 1976).

Material and Method

The study site (Fig. 1) located in the Mandovi estuary of Goa, is characterized by the opening of an open drain (nullah) carrying sewage waste, from the residential areas of Altinho, Fontainhas and Santa Cruz, with a total population of 25 000 or more. Less than 100 m to the east of the opening of the nullah, is Pato Jetty where on an average 50–70 fishing trawlers land their catches daily. While the sampling site SW1 is located in the

estuary near the mouth of nullah, the control site SW2, on the opposite side was about $\frac{1}{2}$ km away from the SW1 site in the same estuary. Depth at the stations, was 6 ± 1.5 m (SW1) and 4 ± 1.5 m (SW2) respectively (Fig. 2).

Benthic samples were collected using a Van Veen grab of 0.04 m^2 area. Replicate samples were collected monthly at each site from July 1982 through June 1983. Details of methodology for further analysis of benthic samples are same as reported elsewhere (Parulekar *et al.*, 1976). Faunal elements were fixed in 5% formalin to which rose Bengal was added. All polychaetes were sorted and identified to the species level, if possible, from each sample and their biomass (dry wt) determined.

Analysis of bottom water for salinity, dissolved oxygen and BOD_5 was done by standard methods. Various sediment parameters were calculated using the formulae given by Folk (1974). The organic content of the sediments was determined by the method of El Wakeel & Riley (1956). A species diversity index (H') (Shannon & Weaver, 1949) and the evenness (E) (Heip, 1974) of numerical abundance were calculated.

Results

Environmental Parameters

Table 1 summarizes the environmental parameters studied at the two sites. Both sites were situated in shallow waters, the bottom having moderately sorted fine median particles with high percentage of silt clay. The percentage organic matter of the sediment was higher at SW1 than at site SW2. The salinity and dissolved oxygen values of the bottom water at the two sites were sufficiently similar while the BOD_5 values indicated higher microbial activity at SW1 site. In general the environmental parameters did not vary significantly and therefore the two sites are comparable. It may be pointed here that the organic matter and BOD values do not suggest any severe pollution due to



Fig. 1 Photograph of site SW1 showing the opening of the nullah and the fishery jetty.

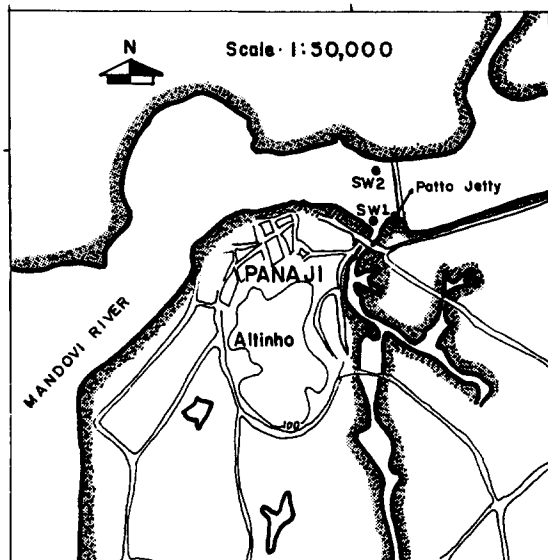


Fig. 2 Location of sampling sites SW1 and SW2.

sewage input and waste from fishing boats including trash fish at site SW1.

Fauna

A systematic list of polychaete species collected during the study period is presented in Table 2. Very dense assemblage of polychaetes, dominated by spionid, nereid and capitellid worms, was present throughout, except during the active monsoon season. A total of 17 090 individuals representing 15 genera and 17 species were collected from both the sites. The most numerous species collected were *Dendronereis aestuarina*, *Glycera alba*, *Prionospio polybranchiata*, *Nephtys polybranchia* and *Lumbriconereis polydesma* at site SW1 and *Diopatra neapolitana*, *G. alba* and *Lepidonotus tenuisetosus* at site SW2. Highest infaunal density (1925 m^{-2}) were recorded at SW1 during March while the maximum density (950 m^{-2}) at SW2 was observed in January. Total number of species collected at SW1 and SW2 were 14 and 10 and the total number of individuals 11 370 and 5720 respectively. Total biomass (g m^{-2}) was 13.43 and 5.24 at SW1 and SW2, respectively. Seven species were common to both the sites. The fauna showed seasonality in their abundance. Species were poorly represented during the monsoon season.

A comparison of the community data at two sites is given in Table 3. The mean biomass and number of individuals showed a fluctuating trend as indicated by high standard deviation. However, the species do not vary much at the two sites indicating their consistent occurrence. The species diversity (H') and evenness (E) were higher at SW1 site. The presence of few species in large number resulted in some what depressed H' and E values.

A comparison of the average density of the top

TABLE 1

Comparison of environmental parameters at the two sites

Parameters	SW1	SW2
Depth	6 ± 1.5	4 ± 1.5
Mean grain size (mm)	0.052	0.059
Sorting coefficient	0.33	0.41
Percentage silt clay	69.00	55.00
Percentage organic matter	2.6	1.2
Salinity (‰)	26.12	27.76
Dissolved oxygen ml l^{-1}	3.79	4.63
$\text{BOD}_5\text{ mg l}^{-1}$	9.92	6.56

TABLE 2

Abundance (+ present, - absent) of polychaete species at SW1 and SW2

Species	SW1	SW2
<i>Dendronereis aestuarina</i> Southern	+	+
<i>Prionospio polybranchiata</i> Fauvel	+	+
<i>P. tridentata</i> Wiren	+	-
<i>Polydora</i> sp.	+	-
<i>Cirratulus</i> sp.	+	-
<i>Perinereis nuntia</i> Savigny	+	+
<i>Nereis</i> sp.	+	-
<i>Lumbriconereis polydesma</i> Southern	+	+
<i>L. simplex</i> Southern	+	-
<i>Glycera alba</i> (Muller)	+	+
<i>Nephtys polybranchia</i> Southern	+	+
<i>Heteromastus filiformis</i> Southern	+	+
<i>Diopatra neapolitana</i> Delle Chiaje	-	+
<i>Marphysa</i> sp.	-	+
<i>Phyllodoce</i> sp.	+	-
<i>Lumbrinereis</i> sp.	-	+
<i>Onuphis</i> sp.	+	-
Total No. of species	14	10
Total No. of individuals m^{-2}	11 370	5720
Total biomass g m^{-2}	13.43	4.24

ranked polychaete species was attempted by using Mann-Whitney 'U' test (Table 4). The eight species shown in the Table accounted for an average of 86 and 77% of the total polychaete individuals and 79 and 67% of the total polychaete biomass at SW1 and SW2, respectively. These data clearly indicate the influence of organic enrichment on the fauna. Of the eight species, four density dominant, showed significantly higher density at the SW1 site, an organic rich habitat. *Nephtys polybranchia* and *Heteromastus filiformis* did not produce significant results mainly because their variability from month to month was so great that no statistically significant difference was detected. *Diopatra neapolitana* was highly abundant at SW2 site but absent at SW1 site throughout the study period.

Comparison of the total polychaete population and their biomass was also made by ANOVA and the results are presented in Table 5. It shows statistically significant differences in the mean number and biomass between the two sites, although the presence of large number of few species specially at SW1 site, presumably reflect its numerical dominance on other species.

TABLE 3

Comparison of community variables (m^{-2}) between two sites. Values given are \pm S.D.

Site	Biomass	No. individuals	No. species	H'	E
SW1	1.19 ± 0.75	947 ± 284.4	9.82 ± 1.80	2.792 ± 0.66	2.89 ± 0.32
SW2	0.35 ± 0.27	476 ± 162.2	7.25 ± 1.04	2.259 ± 0.61	2.27 ± 0.26

TABLE 4

Comparison of average density (individuals m^{-2}) of the top ranked species at the two sites. Density values compared using Mann-Whitney 'U' test.

Species	SW1	SW2
<i>Dendronereis aestuarine</i>	206*	34
<i>Prionospio polybranchiata</i>	187*	39
<i>Nephtys polybranchia</i>	168	45
<i>Perinereis nuntia</i>	120*	21
<i>Lumbriconereis polydesma</i>	144*	35
<i>Glycera alba</i>	114	45
<i>Heteromastus filiformis</i>	112	42
<i>Diopatra neapolitana</i>	0	90*

*Significant at 5% level.

Discussion

Introduction of organic rich sewage effluent into marine and estuarine water, and whether its effects are harmful or beneficial on biota, is determined by the circumstances of the specific situation. O'Sullivan (1971) has reviewed the polluting effect of sewage in marine environment. Estuarine wetlands have several characteristics which indicate that they may have a high capacity to assimilate sewage effluent. Their high primary productivity, high decomposer activity and large adsorptive capacity of associate sediments are some of the characteristics that have stimulated interest in using these areas as a suitable site for nutrient rich effluent discharge (Dauer & Conner, 1980). The gradual increase in the organic input to the sediment which results in progressive build up of anoxic conditions may be regarded as the gradient of increasing stress in the benthic environment. Such conditions if developed, will lead in progressively eliminating all but those few species with the capacity to survive the stress. It has been demonstrated, that response of an individual species to organic enrichment may be variable (Pearson, 1975).

The benthic polychaete fauna in the present study comprised a limited number of species represented by both species of disturbed and polluted environment and those very sensitive to environmental changes. The spionids (*Prionospio polybranchiata*, *Cirratulus* sp.), capitellids (*Nephtys polybranchia*, *Phyllodoce* sp.) and nereid (*Dendronereis aestuarina*), which are either selective deposit feeder or burrowing forms, appears to gain advantage from changes in the substratum. Their dominance at site SW1 showed their preference for such habitat as is observed by Remani *et al.* (1983) in Cochin Backwater. Despite the considerable range of polychaete species at the two sites, much of the variation may be attributed to changes in the occurrence of a comparatively few dominant species.

A survey of the Mandovi estuary earlier (Anon, 1979) showed no effects of sewage pollution. Although the addition of nutrients to estuarine system may not always enhance biological productivity, the addition of domestic sewage in the Mandovi estuary seems to have a biostimulating effect resulting in high density and biomass of benthic polychaetes at the SW1 site. It may be mentioned here that Mandovi estuary is stratified during monsoon (June–September); partially mixed in

TABLE 5

Analysis of variance table for total count and biomass (after log (x+1) transformation)

Source	SS	df	MS	F ratio
Total count				
Between sites	0.70177	1	0.70177	6.959*
Within sites (residual error)	2.21893	22	0.10086	
Total biomass				
Between sites	0.5263	1	0.5263	9.8742*
Within sites (residual error)	1.1729	22	0.0533	

* $P(F) < 0.05$.

postmonsoon (October–January) and well mixed during the premonsoon i.e. February–May, with strong bottom currents having peak values of 160 cm s^{-1} (Varma *et al.*, 1975). This may bring considerable dilution due to flushing of sewage with a high organic load leading to an environment favourable for high benthic production. Other studies which have recorded enhanced density and biomass in association with increased input or organic material are mainly due to enhancement of few opportunistic species (Mearns & Greene, 1976; Dauer & Conner, 1980). In organically enriched areas some species take advantage of the changed conditions such as changes in physical and chemical properties of the sediment, enhanced food supply consisting of microbes associated with detritus and reduced biological interactions and develop large populations.

It has been shown by McIntyre (1977) that organic enrichment on a sewage sludge dump site increased the rate of carbon input to the subtidal benthos approximately 55 times the natural rate. He reported high density and biomass at the dump site as compared with an unaffected area, as is observed in the present study. Goving & Hulings (1976) found high meiofaunal density and diversity on a sandy beach affected by sewage pollution. They suggested that the sewage input on the beach was not sufficiently high to have a negative effect on the fauna.

Among the environmental parameters, sediment and salinity are of primary importance to estuarine benthos. In the Mandovi estuary Parulekar *et al.* (1980) have reported large seasonal changes, ranging from 0.12 to 35.55‰ in bottom salinity, mainly due to heavy monsoonal precipitation. Further, they also observed considerable decrease in the qualitative and quantitative distribution of benthic fauna in relation to salinity variations. In another study, Parulekar & Dwivedi (1974) have observed high sediment content in the near-bottom water and striking seasonality in the suspended sediments in the Mandovi estuary. Considerable sedimentary or salinity changes may alter the course of benthic succession even under high organic input level, as is shown by Tulkki (1968), in estuarine areas. This may be the reason for the low population density during Monsoon, when considerable reduction in salinity of the Mandovi estuary has taken place. The high percentage of fine particles (silt and clay) is expected to hold a high concentration of nutrients with

their great sorptive capacity. The colonization of benthos, in particular polychaetes, as in the present case, is due to the enriched sediment. Such patchy dispersion of benthic polychaete in the organically rich estuarine mud has been well documented (Gray, 1976; James & Gibson, 1980).

Mechanical disturbance imposed by fishing trawlers and effluent (trash fish, wastings) from the fishery jetty dumped in the vicinity of the SW1 site, will tend to lead to an unpredictable and physically unstable habitat. Yet the very instability of the sediment appears to favour the opportunistic species like *Prionospio polybranchiata*, *Dendronereis aestuarina*, *Lumbrioceneris simplex*, *L. polydesma*, *Phylloce* sp., *Onuphis* sp. and *Cirratulus* sp., mainly because of the enriched sediment which attracts such species (Gray, 1979). Thus it appears that the organic input via domestic sewage and wastings from the fishing boats has a range of biostimulation that can enhance benthic productivity without eliminating major species in the Mandovi estuary.

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