

Restoration of deep-sea macrofauna after simulated benthic disturbance in the Central Indian Basin

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Abstract

Macrofaunal communities of the Central Indian Basin (CIB) were sampled with a spade before (June 1997), and immediately after (August 1997), and 44 months (April 2001) after a simulated benthic disturbance for polymetallic nodule mining. The average density recorded down to a sediment depth of 40 cm ranged from 89 to 799 ind. m⁻² (mean: 373 ± 221 SD; n=12) and 178-1066 ind. m⁻² (mean: 507 ± 489 SD; n=3) in the test and reference area, respectively.

Most of the macrobenthic animals (64%) were concentrated in the upper 0 to 2 cm sediment layers, whereas, sizeable fauna (6%) inhabited in 20 cm (20-40) sediment section and deepest 5 cm (35-40) section contributed only about 2% to the total population density. The fauna comprised of twelve groups, by the nematodes, which constituted 54% of the total population. The macrofaunal density in the test site showed significant increase (x:400 ind.m⁻²) 44 months post-disturbance sampling (x:320 ind.m⁻²).

The population of nematodes and oligochaetes were nearly restore at 44 months, but the polychaetes and crustaceans did not reach baseline populations (June 1997). Vertically, the top 0-2 cm sediment layer was severely affected by disturber, as the density of macrofaunal organisms did not reach baseline levels even 44 months after the experimental disturbance. This study suggests that physically disturbed deep-sea macrofauna may require a longer period for restoration and resettlement than normally believed.

Keywords: Deep-sea macrofauna; environmental disturbance; restoration; Central Indian Ocean.

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1. Introduction

Due to the depleting land resources and increased demand, many developed countries as well as developing countries are looking for alternative sources, be it food, fuel, space or mineral resources. Exploratory surveys at sea, conducted worldwide have revealed large mineral deposits in the intertidal, shallow sub-tidal and deep-sea areas.

Among different marine sectors, the deep-sea has attracted considerable commercial interest, as large deposits of polymetallic nodules have been identified in the world oceans (Glasby, 1977; Thiel, 2001). Nodules occur on the deep-sea floor in all the oceans, including Indian Ocean wherein one of the highest nodule concentrations is in the Central Indian Basin (CIB) [Qasim and Nair, 1988]. Although deep-sea mining may not be economically feasible at present due to low metal prices and expensive mining technology, it could be a reality in future. Mining activities in the deep-sea are expected to introduce a new set of environmental conditions to the benthic communities of the oceanic basin (Borowski, 2001).

The possible effects of mining are related to habitat changes, as a result of the movement of the nodule collector on the seabed. In this process, the burrowing benthic organisms can be churned and killed by the collector (Jumars, 1981; Borowski and Thiel, 1998; Ingole et al., 1999; Borowski, 2001), the motile ones that escape from it, migrate horizontally or vertically (Ingole et al., 2001) and the sessile organisms that live attached to nodules could get crushed during nodule lifting (Bluhm, 2001). Impact on benthic biota may also involve disruption of food chain, impairment of physiological functions of organisms as well as physical damage to them. These effects could be immediate and also long-term (Shirayama and Fukushima, 1997; Radziejewska, 1997; Ingole et al., 1999; 2000; Radziejewska and Stoyanova, 2000; Radziejewska and Rokicka-Praxmayer, 2001; Bluhm, 2001).

Disposal of mining waste including the discharge of mining waste on the near surface biota, and deposition of suspended sediment on the seafloor are the major potential sources of environmental hazards for the deep-sea benthic system. The experimental studies have suggested that mining will affect not only the biotic components but also the abiotic components of the water column and the seabed (Shriever et al., 1997; Desouza and Sardesai, 1999; Doi et al., 1999; Xia and Yang, 1999; Lokabharati et al., 2003).

It is important for future mining operations that the extent of environmental disturbance that are likely to be caused be assessed beforehand, so that suitable mining

technologies can be developed and the potential ill effects can be predicted and avoided, if possible. Since the deep-sea benthic environment is considered as rich in biodiversity (Rex et al., 1993), apprehension for conservation and efforts to evolve methods for conserving the same has led to several investigations on the effect of polymetallic nodule mining, such as: DISCOL (Schriever et al., 1997); BIE (Trueblood et al., 1997); JET (Shirayama, 1999); IOM (Radziejewska and Modlitba, 1999) and INDEX (Ingole et al., 1999). All these studies simulated deep-sea benthic disturbance by using different devices to assess its impact on benthic environment where nodules will be mined. This paper describes the effects and recolonisation of metazoan macrofauna during the Indian Deep-sea Environmental Experiment.

2. Study site, material and methods

2.1. The study area

The “INDEX” (Indian Deep-sea Environment Experiment) was launched by India in 1996 in the Central Indian Basin between latitude 10°02' -10°15' S, and longitude 75°59' -76°00'E. It was aimed at studying the potential effects of the future deep-sea mining on the environment. Under this programme a long-term, multidisciplinary oceanographic, program has been initiated by the National Institute of Oceanography to assess the effect of sediment redistribution and the restoration processes over a period of time. The actual benthic disturbance experiment was conducted in July-September 1997 with the help of a benthic disturber, named 'deep-sea sediment resuspension system (DSSRS)', developed by the Sound Ocean System Inc., (SOSI), USA (Brockett and Richards, 1994). The disturber created an artificial disturbance on the sea floor by fluidizing the bottom sediment as it moved on the sea floor, and discharged the sediment through a 5m high stack (Sharma et al., 2001).

Benthic sampling was conducted before (pre-disturbance - June 1997) and immediately after the disturbance (post-disturbance - August 1997) experiment and results of pre- and post-disturbance study have been discussed elsewhere (Ingole et al., 1999, 2000, Ansari, 2000; Ingole et al., 2001; Rodrigues et al., 2001). Monitoring of the deep-sea benthic environment in the CIB was conducted during III phase (April 2001 *i. e.* 44 months after the experiment) of the INDEX programme.

2.2. Sampling design and processing

Sediment samples were collected with a 0.25-m²-spade box corer (50x50x50 cm size) on board *R.V.A.A. Sidorenko* (cruise no. 34) from the randomly chosen localities in the CIB. A total of 12 stations were sampled in the test area between Lat. 10°02'– 10°05'S

and Long. 75°59' - 76°03'E (4 from south of the test site, 4 from north of the test site and 1 station either side of the test site and 2 stations with in the test site). In addition to this 5 stations were sampled in the reference area, located >70 km away from the test site, between Lat.10°09'-10°15' S and Long. 75°29' - 76°00'E. Locations of the sampling stations were same as that of pre- and post-disturbance and are given in table 1 and figure 1. Acoustic navigation system was used for position fixing of the sampling locations with respect to the test site. The sub-samples for macrofauna were taken with the help of PVC core tube (12.5 cm dia. 50 cm length from each box core; Fig. 2). The core samples were sub-sectioned at 0-2, 2-5, 5-10, 10-15, 15-20 cm and so on till the complete core length of \cong 40 cm. Sub-sectioning of the core sample was done with the help of locally developed core cutter. All the sub-samples were preserved in 5% formalin-Rose bengal solution prepared in filtered seawater. These samples were later sieved using 500 μ stainless steel sieves; the organisms retained on the 500 μ sieves were collected and sorted group-wise.

2.3. Data analysis

Subsequently specimens were identified as far as possible under stereoscopic microscope. All unidentified specimens are referred by their generic/family names and are considered in single taxonomic categories. Macrofaunal group diversity (H') was measured by using Shannon-Weaver diversity (H') function, Evenness (Pielou, 1966) and group level richness (\square) (Margalef, 1968) was calculated based on group abundance by the function $s-1/\ln N$, where s is the number of genus and N the total number of individual in a sample. Analysis of variance (ANOVA) was used as a global significance test for difference between the total abundance of macrofauna at the different sites as well as different sampling phases.

3. Results

3.1. Faunal composition and abundance in the disturbance area

Abundance of macrofauna in the disturbed area during monitoring phase shows that the average density recorded up to a sediment depth of 0-40 cm ranged from 89 to 799 ind.m⁻² (mean: 373 \pm 221SD; n=12;Table 2). The highest population density was recorded at station 4, located NW of the test site. The macrofaunal density showed significant increase (mean: 400 ind.m⁻²) on the test site when compared to the post-disturbance value (mean: 320 ind.m⁻²). As shown in table 2, the mean macrofaunal density was highly variable between the sampling stations demonstrating patchy distribution of macrofauna. In general, the faunal abundance was higher in north of the test site (stn. 4, 8, 11, 12 and 13) as compared to the test site (stn.2 and 5) and south of the

test site (stn. 6, 7, 14, 15, 18). A similar trend was observed in the pre-disturbance phase (Fig. 3), which was changed in post-disturbance due to the physical disturbance. The fauna was comprised of twelve macrofaunal groups and was mainly dominated by the nematodes that constituted 54% of the total population (Table 3). The nematodes belonging to the family Microlaimidae, Marinermithidae, Chomadoridae, Comesomatidae and Molgolaimus were most dominant. Next in order of abundance were the polychaetes (19%) - belong to seven family viz, Spionidae, Paranoidae, Aricidae, Maldanidae, Nereidae,, Nephtyidae and Flabelligeridae, followed by the crustaceans (13%). Isopods (Cirolanidae), harpacticoids (Tetragoniciptidae), cumaceans, amphipods and tanaidacea represented Crustacea. Other taxa included oligochaetes (4%) and Ophiopluteus larvae (2%). The remaining 8% was made up of unidentified forms.

3.2. Faunal abundance in the reference area

The reference stations in area T1 (Sharma et al., 1999), which were located >70 km away at western side of the disturbed zone, showed similarity with test area in terms of faunal diversity. However, the mean faunal abundance was much higher in the reference area and ranged from 178 - 1066 ind. m⁻² (mean: 507 ± 489; n=3, Table 2 and 3) as compared to the test site and showed significant variation (*t* test; *t*=0.09; *p*<0.04, *df*=3). The fauna was dominated by nematodes (268 ind. m⁻²) followed by polychaetes (119 ind. m⁻²), amphipods (60 ind. m⁻²), isopods (30 ind. m⁻²) and unidentified forms (30 ind. m⁻²). Polychaetes were found only in the top 0-5 cm sediment layer whereas; nematodes were recorded in deeper sediment depths (30-35 cm).

3.3. Vertical distribution of macrofauna

Distribution of macrofauna in the top 20 cm sediment depth of the test area showed that majority of macrofauna (66.3%) concentrated in the top 0-5 cm sediment layer (Fig. 4). When the top 5 cm layer was subdivided into 0-2 cm and 2-5 cm, 35% macrofauna was observed in the top 0-2 cm and remaining (33.3%) in 2-5 cm sediment layer (Table 4). The crustaceans being epibenthic and detritivores were higher in top 5 cm layer, whereas polychaetes and nematodes were continually found at deeper depths. The sediment samples taken down to the depth of ≈40 cm showed steady decline in faunal density with increasing sediment depth. The deepest sediment section (35-40 cm) contributed over 2% of the population density (Fig. 4). The nematodes were observed down to the depths of 30-35 cm whereas; polychaetes were recovered in 35-40 cm sections (Table 2).

The presence of live burrows in 20-25 cm sediment layer (Fig. 5) suggested the possibility of live organisms in the deeper layers. Therefore, the macrobenthic samples during the monitoring cruise were collected up to the sediment depth of ≈ 40 cm. The data depicted in table 2 confirmed the presence of burrowing polychaetes and nematodes in the deeper (30-40 cm) sediment layer. When the entire sediment section of 40 cm was considered the percent composition as well as vertical distribution of macrofauna did not deviate from that of the observed trends. During the pre- and post-disturbance study, sampling was confined to the sediment depth of 0-20 cm, and therefore for the comparison purpose macrofaunal data of monitoring phase was sub-divided into two sets, i) as the faunal abundance in 0-20 cm and ii), in 20-40 cm. A total of 352 ind. were observed in 0-20 cm sediment layer (Table 4), whereas additional 21 ind. were obtained from 20-40 cm layer *i.e* a total of 373 ind. m^{-2} were observed in the entire 0-40 cm layer (Table 3). It means $\geq 6\%$ fauna actually occurred in the deeper 20 cm section (*i.e.*, 20-40 cm layer) and comprised mainly of burrowing polychaetes and nematodes.

3.4. Comparison with pre and post-disturbance

During the pre-disturbance study, the macrofaunal communities were dominated by polychaetes, which constituted $>65\%$ of the total population (Table 5) and crustaceans with 32%. Polychaetes were present throughout the sediment depth with 100% prevalence (Table 5). The other taxa included Mollusca (1.5%) and Sipunculida (1.4%). In the post-disturbance, there was major shift in the relative proportion of major taxa. The deposit feeding polychaetes showed significant reduction whereas the scavengers such as natantian decapods showed resistance to the changed conditions. The monitoring study showed that majority of the organisms were concentrated in the upper 0-5 cm sediment layers with maximum density occurring in the top 0-2 cm layer (Table 4). The comparison with pre-disturbance data, showed that organisms are being restored in the top sediment layer as only 35% fauna was recorded in the 0-2 cm section in the monitoring phase, against 60% during pre-disturbance phase (Table 4). Nonetheless, there was a substantial increase in the benthic abundance in the sub-surface sediment layer of 2-5 cm. In the post-disturbance phase the dominant organisms were nematodes (33%) and crustaceans (28%). The usually dominated polychaetes were shifted down in order of dominance in post-disturbance and were taken over by crustaceans (Fig. 6). The polychaetes showed 100% prevalence in pre-disturbance was decreased to $\approx 93\%$ and 67% during post-disturbance and monitoring phase, respectively (Table 5). Although the frequency of occurrence as well as prevalence of crustaceans (cumaceans and isopods) increased

considerably during the post-disturbance, it showed marginal decrease in the monitoring phase.

4. Discussion

The total density of macrofauna increased from 335 ± 464 SD to 392 ± 512 SD in test area immediately after the disturbance (post-disturbance) experiment. This abrupt increase was certainly due to the physical disturbance which might have created space for rapid colonizing opportunistic species (Sousa, 1984; Connell and Keough, 1985). However, there was a considerable reduction in the total density during the monitoring in the area south of test site as compared to the post-disturbance values (Table 4). The mean density values showed higher variation between the stations and there was a considerable increase in variance to mean ratio (Table 6) during monitoring (1:1552) as compared to pre-disturbance data (1:149). Results of the ANOVA also showed significant variation in the mean abundance of macrofauna between all three INDEX phases (Table 6). Such high variability, between the sampling stations, persisting over a period of time, could be owing to the sedimentary cover on the test area (Sharma et al., 2001), caused due to the relatively strong near bottom currents (McPhee et al., 1998; Murty et al., 2001). Additionally, the sublethal disturbance is known to effect the reproductive output of benthic organisms (Lawrence and Vasquez, 1996). The environmental conditions (temperature, salinity, dissolved oxygen and food availability) fluctuate within a very narrow range at abyssal depths as compared to the shallow-subtidal areas (Marshall, 1979; Pfannkuche, 1993); hence any change or disturbance caused to the deep-sea environment may lead to high stress condition on the abyssal communities, already adapted to the relatively stable (Grassle and Sanders, 1973) deep-sea environment.

Polychaetes generally have been found to be abundant in the deep-sea benthic environment (Gage, 1978; Parulekar, et, al., 1992; Ingole, et. al., 1992; Borowski and Thiel, 1998; Ansari 2000; Ingole, et. al., 2001; Ingole, 2003). This trend was also observed in the present study where burrowing polychaetes constituted over 65% of the macrofaunal abundance during the pre-disturbance (June 1997). High burrow density up to 6.41 ± 1.76 (n=6) burrows m^{-2} (probably belong to burrowing polychaetes and crustaceans) observed on deep-sea photographs (Fig. 7 and 8) and presence of live burrow in 20-25 cm sediment section (Fig. 5) as well as polychaete specimens in 30-40 cm sediment layer confirm the abundance of polychaetes in the CIB area. The composition and abundance of macrofauna was totally changed during the post-disturbance (July 1997), where mobile crustaceans dominated the macrofauna (Ingole et al., 2001). The comparison of pre- and post-disturbance data with monitoring phase

(present study), showed improvement in the polychaete density, especially the juvenile population, signifying the possibility of polychaete recruitment in the test area. Most of the cores showed presence of oval structures and mottled surfaces suggesting variable degree of bioturbation in deeper (≥ 25 cm) sediment layers. The textural and biochemical analysis of the CIB sediment showed considerable increase in the clay content, labial organic matters, carbohydrates and proteins in 44 months (Raghukumar et al., 2003; Nath et al., 2003). Thus, the sediment analysis suggests a pragmatic improvement in the biochemical parameters and undoubtedly advocate for enhanced food conditions for benthos.

Since the deep-sea polychaetes are known to respond quickly to the improved food supply (Vanreusel et al., 2001), therefore the recruitment of benthic polychaete in CIB area may have been stimulated due to the augmented food material. Hence, the decrease in polychaete density immediately after the disturbance is largely attributed to the heavy sedimentation (Tkatchenko and Radziejewska, 1998) and exposure of burrowing fauna to the predatory megabenthos (Billett et al., 2001). The immediate impact of sediment disturber at CIB appears to be similar to the impact of bottom trawling on benthic fauna where, otter boards penetrate several centimeters into soft sediment, kill the benthic organisms and re-suspend the top sediment layer (Bergman and Hup, 1992; Lindeboom and Groot, 1998). Despite the fact that the deep-sea mining will potentially affect the benthic fauna only once at a given location, recovery of the affected communities would take years to decades. As exhibited in table 5, the abundance of nematodes and oligochaetes has already approached the pre-disturbance level, whereas the density of polychaetes and harpacticoid copepods showed slower recovery rate. The harpacticoid copepods are very sensitive to environmental changes (Raffaelli and Mason, 1981), whereas nematodes are resistant to the rapidly changed environment (Moore and Bett, 1989; Ansari and Ingole, 2002). Therefore, it is concluded that those organisms (polychaetes and harpacticoids in present case) sensitive to local disturbance will require more time for resettlement unlike those (nematodes) which are resistant to stress conditions.

The top few centimeters ($\cong 5$ cm) of the deep-sea sediment layer are considered most important layer for food availability and benthic recruitment (Shirayama, 1984; Grehan et al., 1994; Witte, 2000). Intensive activity (possibly feeding) of motile megafauna with general increase in their abundance at INDEX test site was observed during present study (Ingole et al., 2003). Megabenthos prefer to feed in the uppermost layer of the sediment (Ginger et al., 2002) and majority of them are known to potentially feed on

macrofauna (Briggs, 1985). Further, it has been observed that predatory deep-sea communities are instantly attracted to the exposed prey items (Hargrave, 1985; Henriques et al., 2002), hence the increased megabenthic population, in the test area reported by Ingole et al (2003), may possibly amount some additional feeding pressure on the macrofauna. Predatory megafauna are known to affect the reproductive output on the prey items by diverting energy to regeneration of body parts, thereby reducing the energy available for reproduction (Lawrence and Vasquez, 1996). In addition, the migration of mobile fauna and mortality of some macrofauna due to the discharged sediment plume on the near-surface biota cannot be ruled out (Morgan et al., 1999).

Macrofaunal abundance during the monitoring phase was compared with the pre-disturbance phase. There was substantial increase (>28%) in the mean macrofaunal density during the monitoring phase over the pre-disturbance phase and the density values differed significantly within the sampling stations ($F=0.33$; $p=0.58$; $df=9$, Table 6). This possibly could have happened due to the faunal colonization in the disturbed area. Generally, the abundance of macrofauna was high in the north of test site during pre-disturbance phase (Ingole et al., 2001). This situation was radically changed during the post-disturbance and the maximum concentration of macrofauna was seen in an area south of the test site. Bottom currents in the test area change periodically (Murthy et al., 2001). The sediment plume, which was deposited to the southern side of the disturbed zone and was responsible for increased macrofaunal abundance in this area after the disturbance (Ingole et al., 2001), must have been again shifted to the northern side of the test site (Fig. 3). It indicates that increased faunal density, on either side of the test site (Fig. 3), immediately after the disturbance was a temporary phase, caused due to human interference. This supports the earlier finding of Thiel (1992) and others that physical disturbance caused due to the sediment disturber have a long-term effect on sedimentation process and associated benthic fauna. Although, the heavy particles of the disturbed sediment plume could settle immediately, the fine particles may remain suspended in the bottom water (sediment-water interface) for longer duration and may take longer time for settling. During this time, the current direction may have changed in the area (Murthy et al, 2001), affecting the particle settlement. Since, the re-suspended sediment particles will take longer time for settling down, particularly if the current pattern changes periodically (as observed in the present case). Therefore, the seasonal pattern of bottom current in the INDEX area may affect the benthic recruitment up to certain extent.

Vertically only 35% macrofaunal population was recorded in the top (0-2 cm) sediment layer during the monitoring phase as against 60% during the pre-disturbance

phase (Table 3 and 4). Nevertheless, these values were much higher as compared to the post-disturbance values (23%, Table 4). According to Flach and Heip (1996) and Witte (2000) almost 80% of the macrofauna was concentrated in the upper 5 cm sediment layer of North Atlantic (4400 m) and Arabian Sea (3190-4420 m). As shown in table 4, about 71% of the macrobenthic population was concentrated in the top 5 cm surface sediment during the pre-disturbance. However, this was reduced to 59% in post-disturbance, mainly due to the physical disturbance (Ingole et al., 2001). Monitoring of the disturbed area conducted after 44 months confirmed overall 15% increase (59% to 68%) in macrobenthic population in top 5 cm sediment layer (Table 4) in the test area, may be due to improved environmental conditions. Additionally, the abundance of macrofauna was also higher in the sub-surface (2-5 cm) layer of the sediment samples collected from reference site (Table 5). The depth-integrated abundance was also considerably higher at reference area than that of the test area (Table 3). However, the value for Shannon-Weaver diversity index (H) calculated for test area, showed marginal decrease during the monitoring phase (Fig. 9). All the above finding leads to conclude that although the abundance of the macrofauna was being restored, the diversity was reduced and the density values were much less in the test area than that of the reference area. This re-emphasizes that even though the environmental conditions were improved in the INDEX area, it has not reached the reference level.

Conclusion

Macrofauna are highly sensitive group of metazoans and a slight change in their natural environment could induce a high stress on the organisms already adapted to the stable deep-sea conditions. The physical disturbance to the deep-sea sediment may have long-term effect on the benthic biota and restoration of the disturbed benthic habitat may take few decades to achieve the initial baseline levels. The present study clearly highlight that recolonisation of macrofauna was certainly in progress in INDEX area, but at slower rates. Their slow recovery apparently was due to the predatory pressure. Hence the physically disturbed deep-sea habitat may require a longer period for restoration than commonly believed.

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Legends to the figures

Fig. 1: Locations of the sampling stations.

Fig.2. Sub-sampling of macrofauna from the box corer.

Fig. 3, Abundance of macrofauna on and around the test site during the three INDEX phases.

Fig. 4, Vertical distribution of macrofauna in the disturbance area.

Fig.5, Live burrow observed in 20- 25 cm sediment section of stn. 14-M

Fig.6, Macrofaunal composition (%) during three INDEX phases.

Fig.7 and 8, Live burrows of the benthic organisms seen on the sediment surface.

Fig. 9, Diversity indices of macrofauna.

Table 1: Geographical position of the sampling locations during the monitoring cruise (April 2001).

Station No.	Geographical position		Depth (m)	Sediment texture
	Latitude (⁰ S)	Longitude (⁰ E)		
M-2	10 ⁰ 02.311	76 ⁰ 01.061	5330	Silty clay
M-4	10 ⁰ 01.497	75 ⁰ 59.673	5249	Silty clay
M-5	10 ⁰ 01.786	76 ⁰ 06.120	5306	Silty clay
M-6	10 ⁰ 02.651	76 ⁰ 01.625	5311	Silty clay
M-7	10 ⁰ 02.320	76 ⁰ 00.470	5350	Silty clay
M-8	10 ⁰ 01.788	76 ⁰ 00.762	5330	Silty clay
M-11	10 ⁰ 02.074	76 ⁰ 01.242	5298	Silty clay
M-12	10 ⁰ 01.328	76 ⁰ 00.564	5254	Silty clay
M-13	10 ⁰ 01.510	76 ⁰ 00.350	5286	Silty clay
M-14	10 ⁰ 02.200	76 ⁰ 00.148	5273	Silty clay
M-15	10 ⁰ 02.418	75 ⁰ 59.939	5240	Silty clay
M-18	10 ⁰ 02.729	76 ⁰ 00.620	5315	Silty clay
T1/A*	10 ⁰ 10.836	75 ⁰ 22.111	5240	Silty clay
T1/B*	10 ⁰ 06.873	75 ⁰ 10.638	5292	Silty clay
T1/C*	10 ⁰ 00.933	75 ⁰ 21.210	5260	Silty clay

* These are reference stations.

Table 2: Abundance of macrofauna (ind.m⁻²) at test and reference stations studied during the monitoring phase

Sediment Depth (cm)	Taxon	Test area											Reference area			
		M-2	M-4	M-5	M-6	M-7	M-8	M-11	M-12	M-13	M-14	M-15	M-18	T1/A	T1/B	T1/C
0-2	Harpacticoida	89	0	0	0	0	89	0	0	0	0	0	0	0	0	0
	Nematoda	89	0	0	0	0	177	177	354	0	0	0	0	0	0	0
	Isopoda	0	0	0	0	89	0	0	0	0	0	0	0	0	0	0
	Unidentified	89	0	0	0	0	89	0	0	0	0	0	0	0	0	0
	Polychaeta	0	0	0	89	0	0	0	0	0	0	0	0	0	89	0
	Ophiopluteus larva	89	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Amphipoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	89
2-5	Oligochaeta	0	0	0	0	0	0	0	0	89	0	0	0	0	0	0
	Polychaeta	0	0	89	0	89	0	0	89	0	0	89	89	266	0	0
	Nematoda	0	177	0	0	177	0	89	177	0	0	0	0	266	177	0
	Unidentified	0	0	0	89	0	0	0	0	0	0	0	0	89	0	0
	Harpacticoida	0	89	0	0	0	89	0	0	0	0	0	0	0	0	0
	Tanaidacea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	89
5-10	Oligochaeta	0	0	0	0	0	89	0	0	0	0	0	0	0	0	0
	Polychaeta	0	0	89	0	0	0	0	0	0	0	89	0	0	0	0
	Nematoda	177	89	0	89	0	0	0	0	89	0	0	0	0	0	0
	Isopoda	0	0	89	0	0	0	0	0	0	0	0	0	0	0	0
	Unidentified	0	89	0	0	0	0	0	0	0	0	0	0	0	0	0
10-15	Nematoda	0	177	0	0	89	0	0	0	0	0	0	89	89	0	0
	Amphipoda	0	0	0	0	0	0	0	0	0	0	0	0	89	0	0
15-20	Polychaeta	0	89	0	0	0	0	0	0	0	0	0	0	0	0	0
	Nematoda	0	0	0	0	0	0	0	0	0	0	0	0	89	0	0
20-25	Nematoda	0	89	0	0	0	0	0	0	0	0	0	0	0	0	0
	Polychaeta	0	0	0	0	89	0	0	0	0	0	0	0	0	0	0
25-30	Nematoda	0	0	0	0	0	0	0	0	0	0	0	0	89	0	0
30-35	Nematoda	0	0	0	0	0	0	89	0	0	0	0	0	89	0	0
35-40	Polychaeta	0	0	0	0	0	0	0	0	0	89	0	0	0	0	0
Total density		533	799	267	267	533	533	355	620	178	89	178	178	1066	266	178

Table 3: Cumulative abundance (no m⁻²) and composition of macrofauna at test and reference site during the monitoring phase.

Sediment Depth (cm)	Taxon	Test site (n=12)				Reference site (n=3)			
		Mean	±SD	%	% of each Sed.section	Mean	±SD	%	% of each Sed.section
0--2	Harpacticoida	15	35	4.0	33.4	0	0	0	11.8
	Nematoda	66	114	17.7		0	0	0	
	Isopoda	7	26	1.9		0	0	0	
	Unidentified	15	35	4.0		0	0	0	
	Polychaeta	7	26	1.9		30	51	5.9	
	Ophiopluteus larva	7	26	1.9		0	0	0	
	Oligochaeta	7	26	1.9		0	0	0	
	Amphipoda	0	0	0		30	51	5.9	
2--5	Polychaeta	37	46	9.9	31.6	89	154	17.6	58.5
	Nematoda	52	80	13.9		148	135	29.1	
	Unidentified	7	26	1.9		30	51	5.9	
	Harpacticoida	15	35	4.0		0	0	0	
	Tanaidacea	0	0	0		30	51	5.9	
	Oligochaeta	7	26	1.9		0	0	0	
5--10	Polychaeta	15	35	4.0	17.7	0	0	0	0
	Nematoda	37	59	9.9		0	0	0	
	Isopoda	7	26	1.9		0	0	0	
	Unidentified	7	26	1.9		0	0	0	
10--15	Nematoda	30	58	8.0	8.0	30	51	5.9	11.8
	Amphipoda	0	0	0		30	51	5.9	
15--20	Polychaeta	7	26	1.9	3.8	0	0	0	5.9
	Nematoda	7	26	1.9		30	51	5.9	
20--25	Polychaeta	7	26	1.9	1.9	0	0	0	0
25-30	Nematoda	0	0	0	0	30	51	5.9	5.9
30-35	Nematoda	7	26	1.9	1.9	30	51	5.9	5.9
35--40	Polychaeta	7	26	1.9	1.9	0	0	0	0
Total density		373	221	100	100	507	489	100	100

Table 4: Mean density (ind.m⁻²) and composition (%) of major macrofaunal groups in the sediment layer during the three cruises

Sediment Depth (cm)	Taxon	Pre-disturbance (June 1997)		Post-disturbance (August 1997)		Monitoring (April 2001)	
		Density	%	Density	%	Density	%
0--2	Annelida	144	43.0	49	12.4	80	22.7
	Crustacea	48	14.3	29	7.3	22	6.2
	Mollusca	0	0	10	2.5	0	0
	Holothuria	0	0	2	0.5	0	0
	Sipunculida	5	1.4	0	0	0	0
	Echinodermata	0	0	0	0	7	1.9
	Unidentified	5	1.4	0	0	15	4.2
2-- 5	Annelida	24	7.1	84	21.3	96	27.2
	Crustacea	11	3.3	47	11.9	15	4.2
	Mollusca	0	0	11	2.8	0	0
	Holothuria	0	0	2	0.5	0	0
	Unidentified	0	0	0	0	7	1.9
5 -- 10	Annelida	32	9.5	82	20.7	52	14.7
	Crustacea	21	6.2	18	4.5	7	1.9
	Mollusca	0	0	19	4.8	0	0
	Unidentified	0	0	0	0	7	1.9
10 -- 20	Annelida	13	3.9	27	6.8	44	12.5
	Crustacea	27	8	15	3.8	0	0
	Mollusca	5	1.5	0	0	0	0
Total		335	100	395	100	352	100

Table 5: Comparison of the macrofaunal data during three INDEX cruises

Taxon	Pre-disturbance (n=6)		Post-disturbance (n=15)		Monitoring (n=12)	
	No. of occurrence	Prevalence %	No. of occurrence	Prevalence %	No. of occurrence	Prevalence %
ANNELIDA						
Polychaeta	6	100	14	93.3	8	66.7
Oligochaeta	1	16.7	0	0	2	16.7
NEMATODA	6	100	14	93.3	9	75
SIPUNCULIDA	1	16.7	0	0	0	0
CRUSTACEA						
Harpacticoida	5	83.3	14	93.3	3	25
Isopoda	0	0	0	0	2	16.7
Tanaidacea	5	83.3	0	0	0	0
Cumacea	1	16.7	13	86.7	0	0
Amphipoda	0	0	0	0	2	16.7
Ostracoda	1	16.7	0	0	0	0
ECHINODERMATA						
Ophiuroidea	0	0	0	0	1	8.3
Holothuria	0	0	1	6.7	0	0
MOLLUSCA						
Gastropoda	1	16.7	5	33.3	0	0
Bivalvia	0	0	7	46.7	0	0
Unidentified	1	16.7	0	0	3	50

Table 6, Analysis of variance - One-Way ANOVA test between three different data sets.

Anova: Single Factor for post-disturbance and monitoring						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Post-disturbance	11	4256	386.9091	88976.29		
Monitoring	11	3997	363.3636	51019.05		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3049.136	1	3049.136	0.043561	0.836784	4.35125
Within Groups	1399953	20	69997.67			
Total	1403003	21				
Anova: Single Factor for pre- and post- disturbance						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Pre-disturbance	6	2016	336	48332.8		
Post-disturbance	6	1696	282.6667	15633.07		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	8533.333	1	8533.333	0.266809	0.61671	4.964591
Within Groups	319829.3	10	31982.93			
Total	328362.7	11				
Anova: Single Factor for pre-disturbance and monitoring						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Pre-disturbance	5	1824	364.8	54195.2		
Monitoring	5	1420	284	44608.5		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	16321.6	1	16321.6	0.330384	0.581233	5.317645
Within Groups	395214.8	8	49401.85			
Total	411536.4	9				

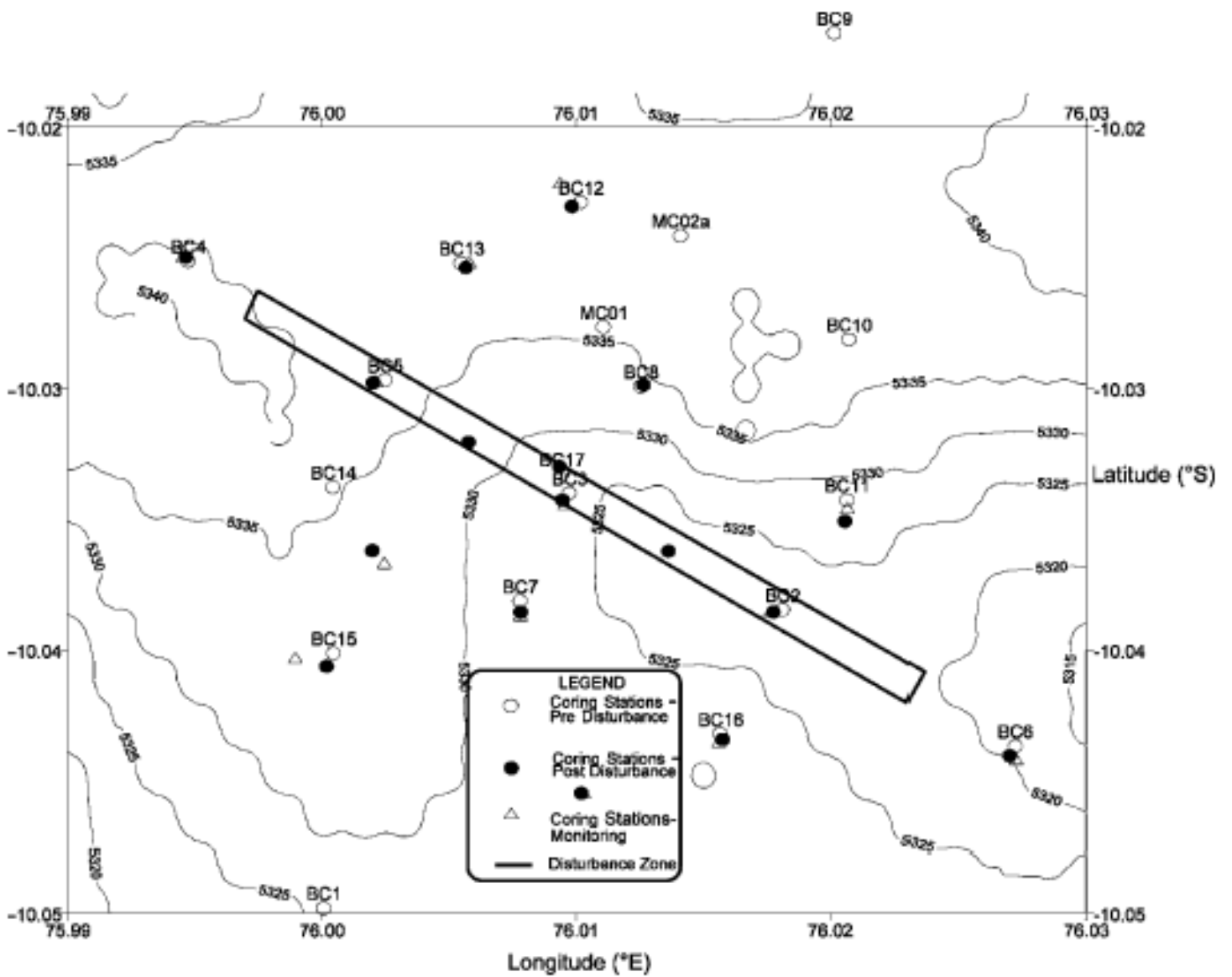


Fig. 1: Locations of the sampling stations.

Fig. 2,
Macrofaunal
sub-sampling



Fig.2. Sub-sampling of macrofauna from the box corer.

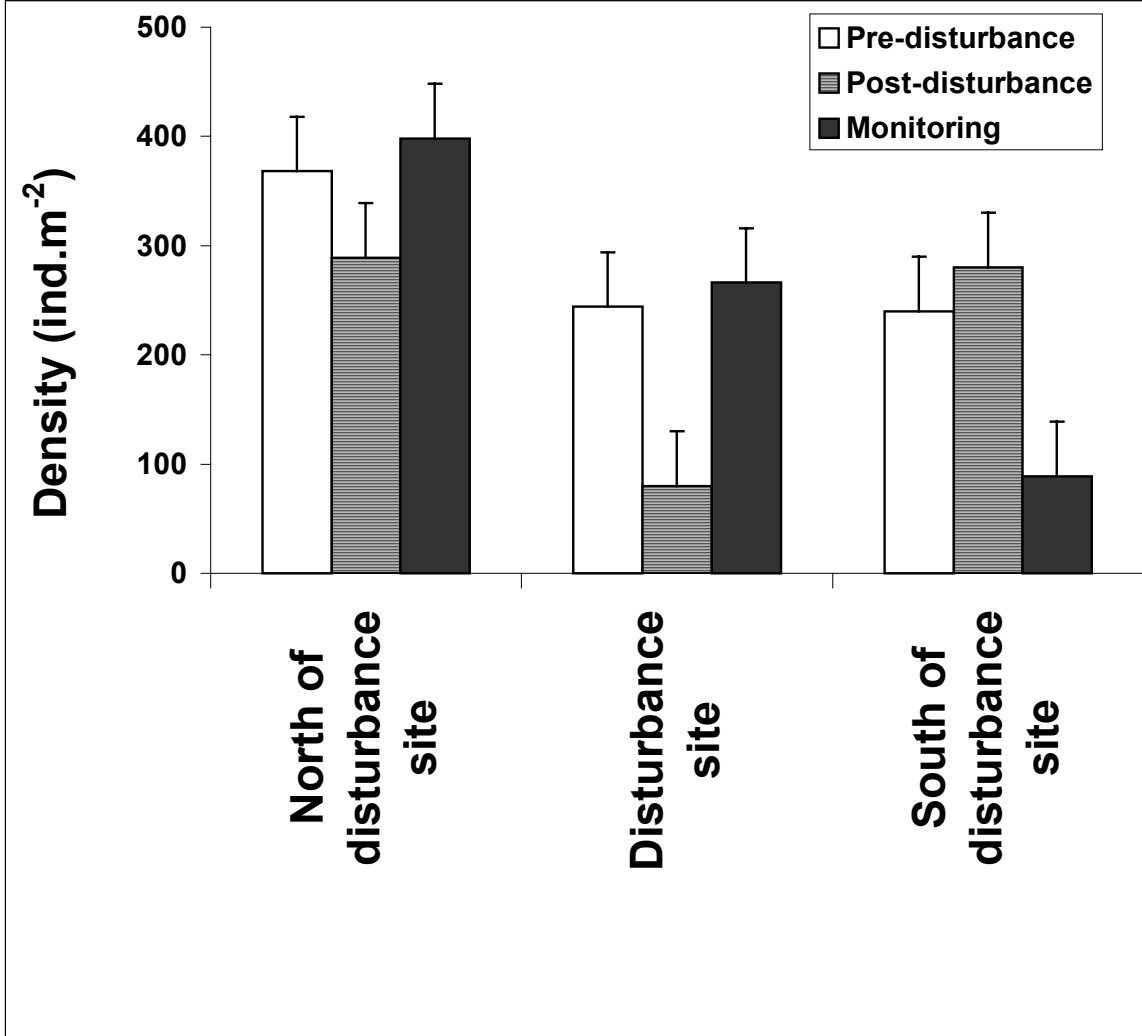


Fig. 3, Abundance of macrofauna on and around the test site during the three INDEX phases.

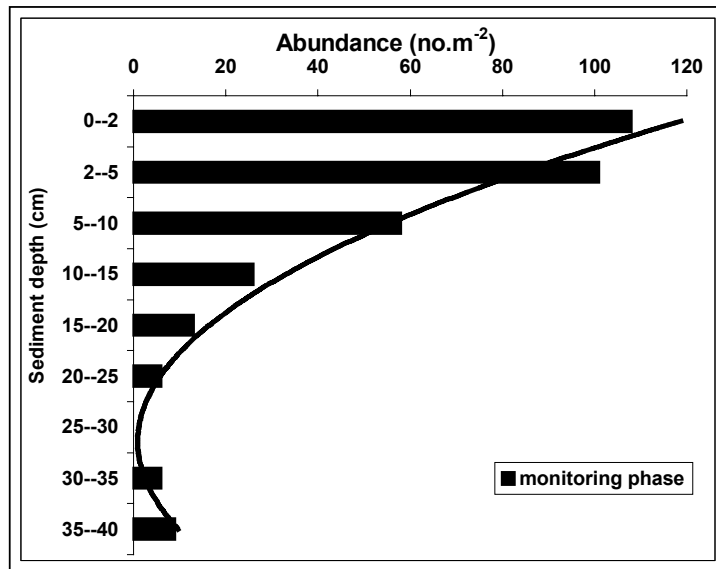


Fig. 4, Vertical distribution of macrofauna in the disturbance area.

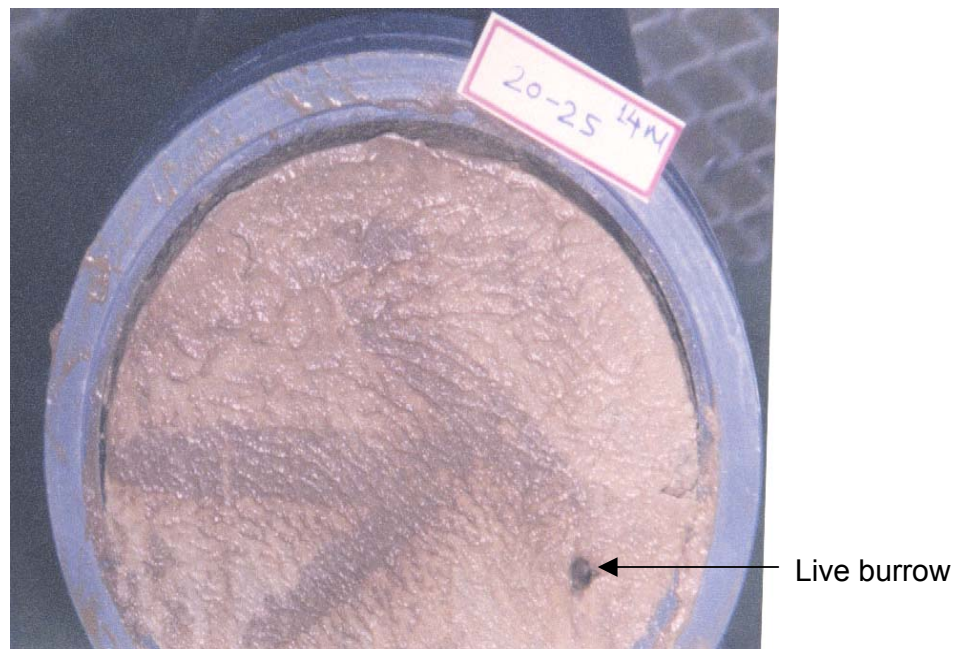


Fig.5, Live burrow observed in 20- 25 cm sediment section of strn. 14-M

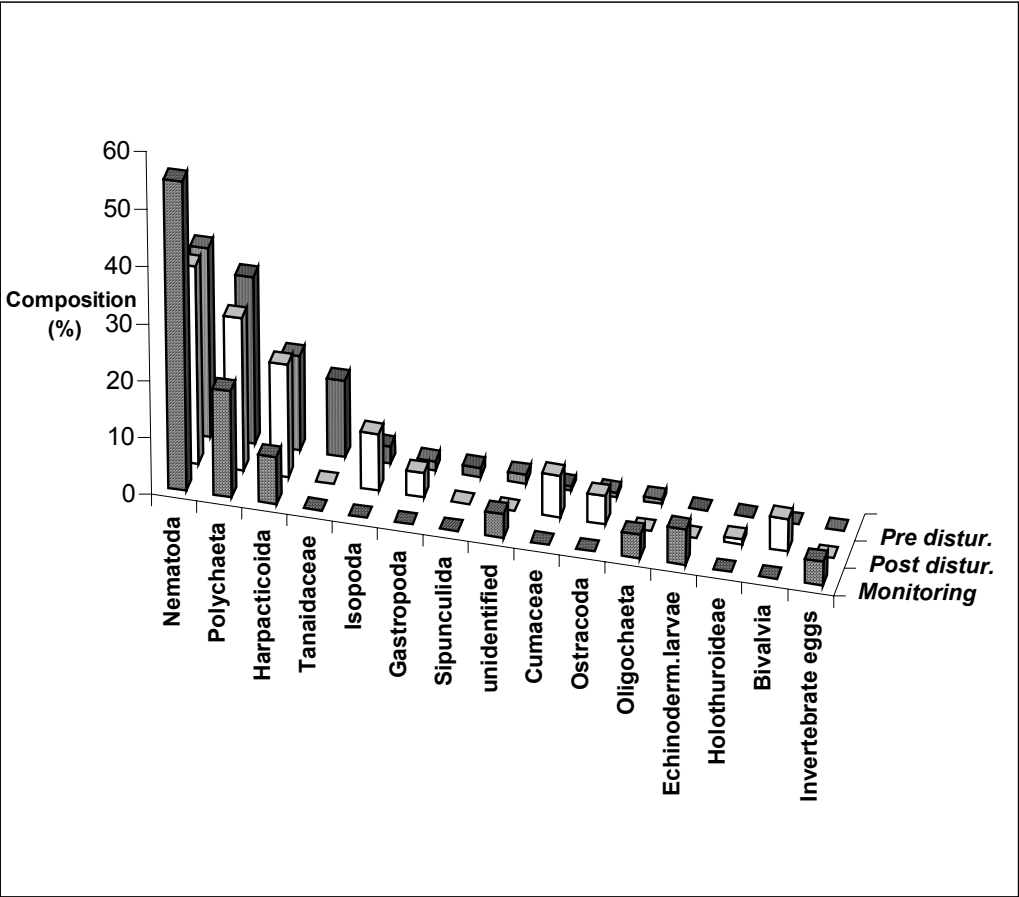


Fig.6, Macrofaunal composition (%) during three INDEX phases.

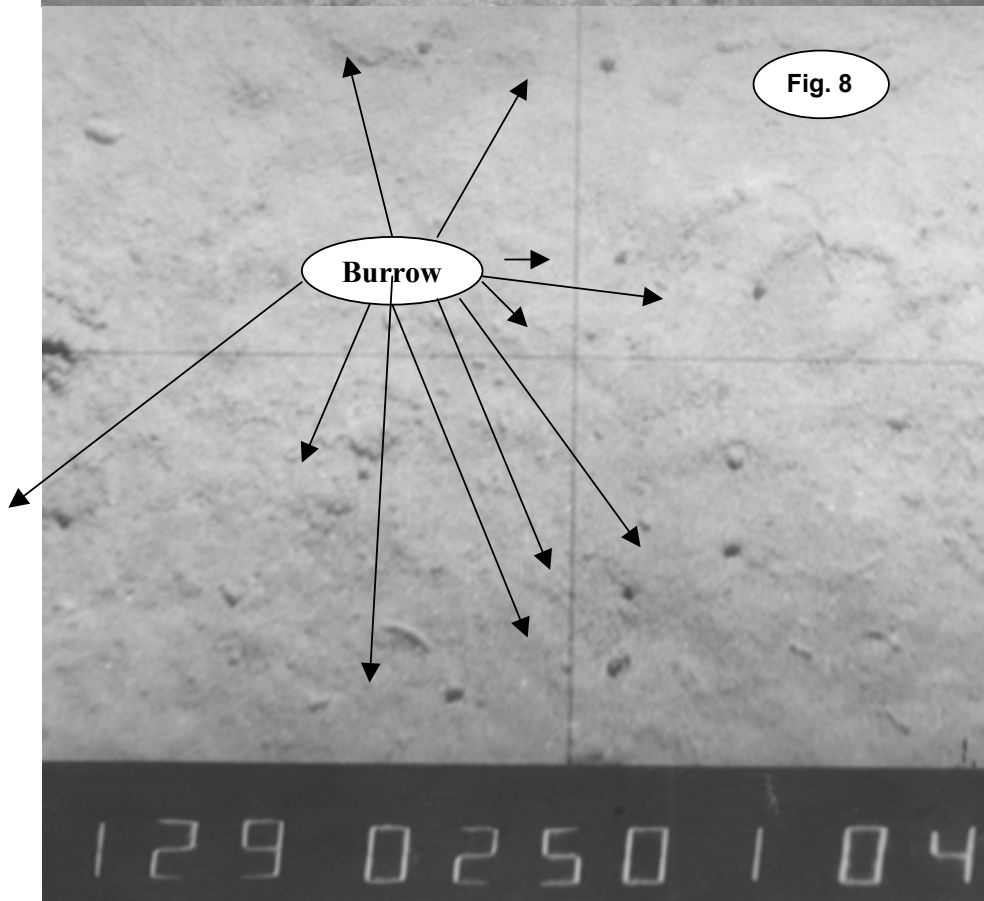
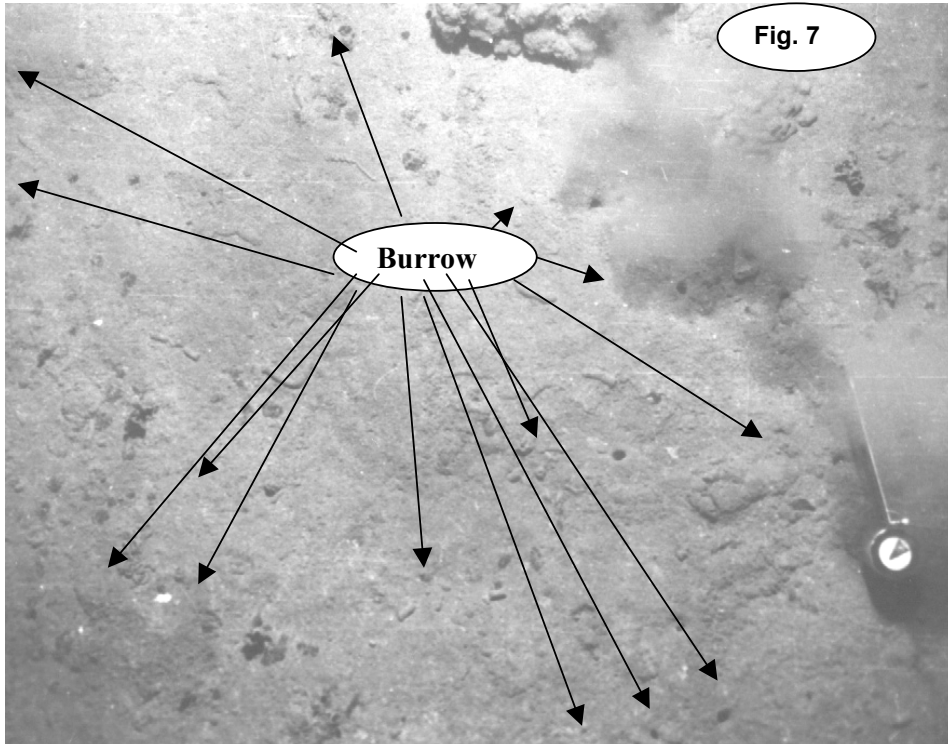


Fig.7 and 8, Live burrows of the benthic organisms seen on the sediment surface.

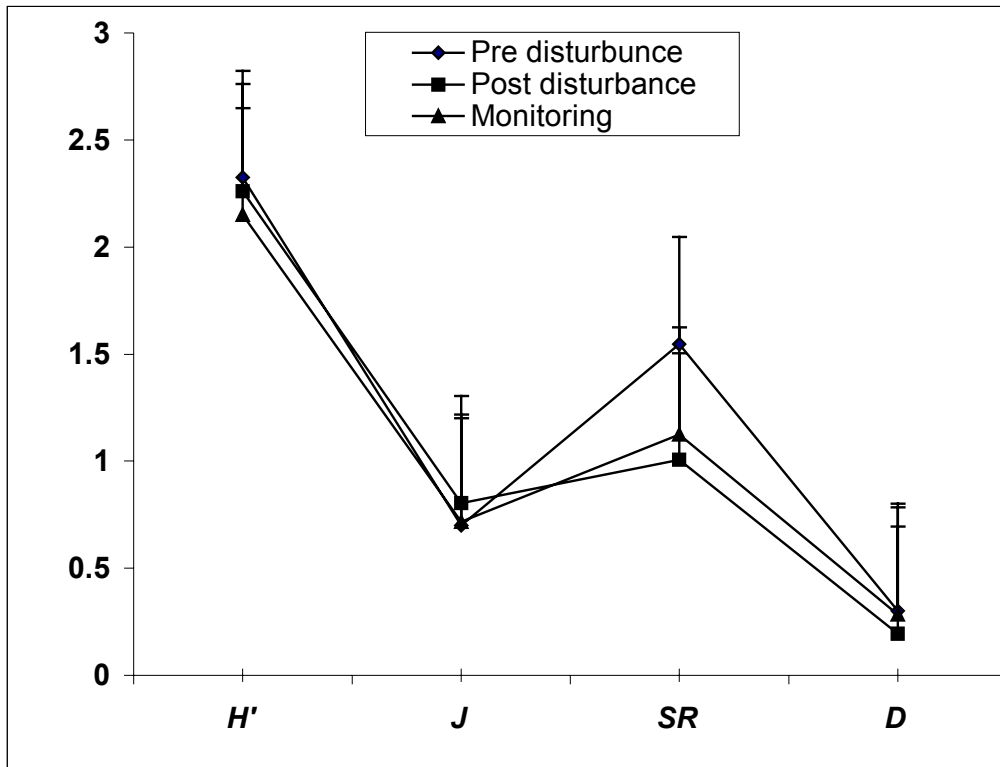


Fig. 9, Diversity indices of macrofauna.