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Impact of bottom trawling on the epifauna off Veraval coast, India

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Experimental bottom trawling was conducted from MFV *Sagarkripa* at five transects of water depths 15-20 m, 21-25 m, 26-30 m, 31-35 m and 36-40 m in commercial trawling grounds to assess the impact of bottom trawling on the epifauna off Veraval coast. Trawling was conducted for 17 months in a span of 20 months (September 2005-April 2007) excluding the trawl ban period (June to August). Altogether 41 species of *gastropods*, 1 species of *scaphopod*, 19 species of *bivalves*, 3 species of *crab*, 3 species of *shrimps*, 2 species of *Balanus*, 1 species of *stomatopod*, 4 species of *finfishes*, 2 species of *brown algae* and 4 species of *octocorals* were identified. The soft corals found were *Litophyton* sp. and *Studeriotes* sp. (Christmas tree soft coral). The gorgonians collected were young stages of *Subergorgia suberosa* and *Juncella juncea* (Whip coral). The presence of octocorals recorded in the month of October, immediately after the closed season (June to August) when the sea bottom is not heavily trawled suggests that this area is an abode of corals and a favourable site for coral reef formation. But intense trawling in the succeeding months destroys these valuable entities of ecosystem and the samples were not encountered in the subsequent months. The changes before and after trawling in biodiversity indices were significant at 15-20 m. The abundance-biomass curve showed that the rate of stress increased with water depth. The shallow depths are lightly trawled due to intermittent rocky nature of bottom and as water depth increases, the trawling intensity increases. The analysis of similarity of percentages in Simper showed that the dissimilarity of fauna before and after experimental trawling was more evident in lightly trawled area and remained masked in heavily trawled area. Suggestions are made for the promotion of eco-friendly gears and for conducting studies on appropriate un-trawled control sites for comparative assessment. Management strategies have to be adopted for the conservation and biodiversity protection of octocorals.

[**Keywords:** Epifauna, Bottom trawling, Veraval, India]

Introduction

The commercial trawling fleet of India consists of 29,241 small and medium-fishing boats[1]. Northwest coast of India has the highest number (23,618) of mechanized vessels operated in the Arabian Sea[2]. Recommended optimum fleet size of Gujarat is 1,473 mechanised trawlers[3]. However, presently 7402 commercial trawlers are operating in Gujarat waters[4]. Veraval is an important fishing port of Gujarat from where 2793 trawlers are being operated[4].

Epifauna are more vulnerable to fishing disturbance and changes in the occurrence or abundance of epifaunal species are among the first indications of fishing disturbance on benthic communities[5]. Fishing activities causes direct mortality of epibenthos as bycatch and net damaged organisms[6]. Complex seafloor habitats of seagrasses, seamounts and coral reefs that provide food, nurseries and shelter for a variety of marine organisms are destroyed by bottom trawling activities[7,8]. A large-scale mortality of invertebrate species occur either as a result of direct mortality by the passage of the trawl or indirectly owing to disturbance, exposure and subsequent predation[9]. In India, studies that have been conducted to study the impact of trawling on epifauna

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Tel.: Off: 91 484 2666845; Fax: 91 484 2668212 have mostly enumerated the impact by quantifying and characterising the proportion of epifauna in bycatch and discards[10,11,12,13,14,15,16]. Present study consists the possible impact of bottom trawling on epifauna in the commercial fishing grounds, off Veraval coast (Gujarat, India).

Materials and Methods

Experimental bottom trawling was carried out monthly, for 20 months (September 2005- April 2007) excluding the trawl ban period (June to August) in the fishing ground off Veraval (20°54′40″N lat and 70°22′12″E long) (Gujarat, India). Trawling was carried out from CIFT Research vessel MFV *Sagarkripa* (15.5 mL_{OA}; 125 hp stern trawler), along five transects representing five water depth zones ranging from 15 to 40 m. This is the commercial fishing ground for traditional and mechansied fishing vessels conducting single day fishing. Transect, corresponding to a particular depth zone was fixed using a Garmin GPS (with an accuracy of 4-6 m) installed onboard the vessel and coordinates were stored for navigation to the respective stations for sample collection. A 50/200 dual frequency Simrad fish finder was also used to fix transects by avoiding areas with rocky bottom and other physical disturbances. Five transects of study area included the five depth zones of 15-20 m, 21-25 m, 26-30 m, 31-35 m and 36-40 m in the commercial trawling grounds (Fig. 1). From the point fixed in the pre-identified depth zone, epifauna were collected using a dredge before and after experimental trawling. A 0.9 x 0.4 x 0.5 m rectangular dredge (with 100 cm long net and mesh size of 6 mm) was operated to collect the epifauna. A 34 m head rope four seam high opening bottom trawl net rigged with 23 kg of sinkers in the foot rope, seven numbers of 150 mm Ø plastic floats in the head rope and a pair of V-form steel otter boards (80 kg each) was used for fishing operations. Mesh sizes ranged from 400 mm in the wing sections, 300 to 90 mm in the belly sections and 40 mm in the codend (Fig. 2). This type of trawl net is commonly used by fishermen of Veraval. Trawling intensity was fixed as one tow for one hour and this was repeated at each depth zone for 17 months.

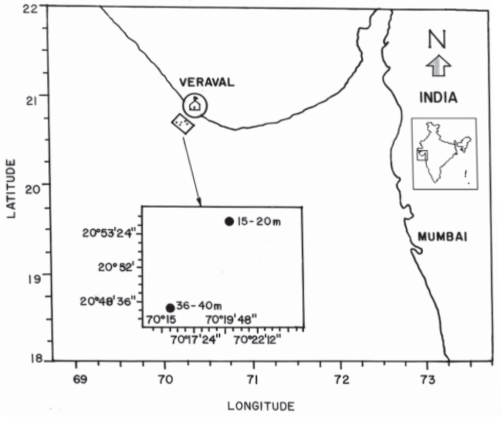

Fig. 1—Map showing study sites

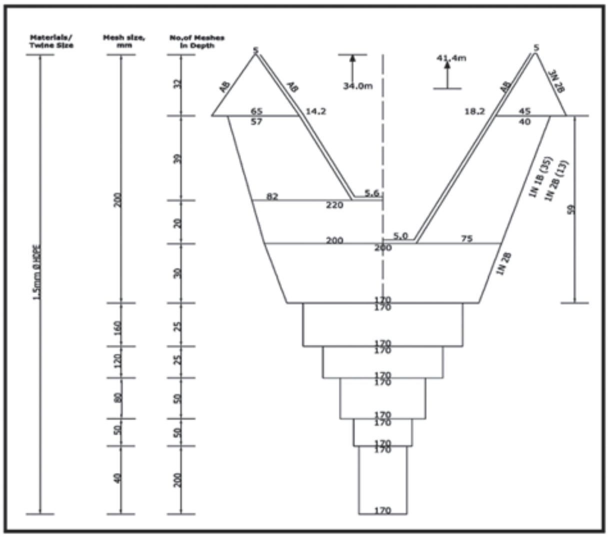

Fig. 2—Design of gear operated

The epifauna collected were sorted and identified to generic/species level as far as possible. Octocorals, seaweeds and molluscs were identified using standard references and published literature[17,18,19,20]. Crustaceans and fishes were also identified[21]. Numerical abundance and wet weight were noted. Numerical abundance is noted as number/haul and biomass in gram/haul. Diversity indices of epifaunal organisms before and after trawling were calculated using PRIMER v5 software package (Version 5.2.9; Plymouth Marine Laboratory, Plymouth, UK)[22]. The biodiversity indices such as species (S), number (N), Margalef index (d), Pielou's evenness index (J'), Brillouin index (H), Fisher's Alpha (α), Shannon index (H'), Hill's number (N_1 and N_2), Simpson's index (1-λ'), taxonomic diversity index (Δ^{*}), taxonomic distinctness index (Δ), average taxonomic diversity index (Δ+or AvTD), total taxonomic distinctness

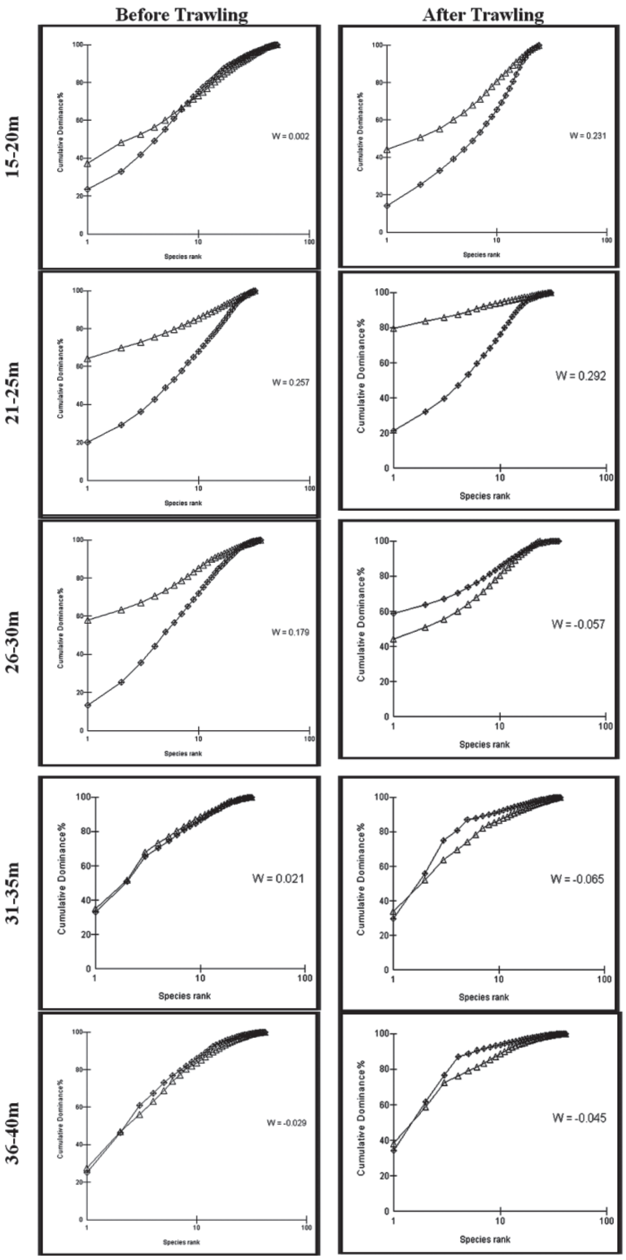

Fig. 3—⊕ Abundance ∆ Biomass Comparison curves for total epifauna

(sΔ^+ or TTD), variation in taxonomic distinctness (Lambda+ or VarTD), average phylogenetic diversity (ϕ+ or AvPD) and phylogenetic diversity (Sϕ+ or PD) were analysed. The $\log_{10}$ (X+1) transformed indices were used for one way ANOVA of SPSS 12.0 to find out the significance of difference in the mean value of the indices before and after trawling in each depth zone. Abundance-Biomass Comparison (ABC) curves were plotted in order to ascertain whether the benthic communities undergone any stress due to trawling pressure. SIMPER analysis revealed the most abundant species in each depth zone before and after trawling.

Results and Discussion

Altogether 41 species of gastropods (molluscs), 1 species of scaphopod (mollusc), 19 species of bivalves (molluscs), 3 species of crab (crustacean), 3 species of shrimps (crustacean), 2 species of balanus (crustacean), 1 species of stomatopod (crustacean), 4 species of finfishes, 2 species of brown algae and 4 genera of octocorals were identified. Gastropods belonged to 20 families, bivalvia to 9 families, crustaceans to 5 families, octocorals to 4 families, finfishes to 4 families and brown algae to 2 families. Occurrence of sessile fauna was found to be very less in the study area. *Balanus* spp., hydroids, bryozoans, molluscan eggs, seaweeds, octocorals etc were the sessile fauna encountered during the study. Of these, except *Balanus* spp. and sedentary polychaetes all of them were observed only at 15-20 m depth before experimental trawling. Sessile fauna were destroyed after experimental trawling. Hydroids and eggs of molluscs abundant before trawling at 15-20 m water depth (just after trawl ban) were destroyed during trawling. Hydroids, octocorals and bryozoans abundant in September (just after trawl ban) were found destroyed after trawling.

Analysing the species/group identified, the changes before and after trawling in diversity indices viz., S (species) & N (number) were significant at 15-20 m (Table 1). This result can be attributed to the damage inflicted to sedentary fauna like octocorals, hydroids, bryozoans etc. The diversity indices were not significantly different before and after trawling at 21-25m (Table 2), 26-30 m (Table 3), 31-35 m (Table 4) and 36-40 m (Table 5). As the large bodied epifauna have been affected by intense trawling prevalent in these areas, the impact is not evident in heavily trawled areas. Since 15-20 m is lightly trawled, the impact is more evident. Jennings and Reynolds (2000) enumerated the impacts of fishing on species diversity in the northeast Atlantic[23]. A reduction in diversity resulted from the direct mortality of target species and a reduction in invertebrate diversity resulted from the effects of towed gears on the seabed. In unfished sheltered

Scottish sea loch, the epifaunal diversity indices Shannon's H', Simpson's reciprocal D and evenness decreased in the trawled area relative to the reference site[24].

In the present study, octocorals were encountered in the dredge operated at a depth of 15-20 m (latitude 20°54′13″ N and longitude 70°22′18″) in October 2005 and October 2006 before experimental trawling. Four genera of octocorals were recorded at 15-20 m depth. Soft corals found were *Litophyton* sp. and *Studeriotes* sp. (Christmas tree soft coral). The gorgonians collected were young stage of *Subergorgia suberosa* (Pallas) and *Juncella juncea* (Pallas) (Whip coral). Present study confirmed the possibility of finding corals in the sub-tidal waters of Veraval, by recording soft corals and gorgonians[25]. Adult forms of these corals were not recorded during the study period which made species level identification difficult. During monthly trawling experiments the epifaunal corals were not observed in other transects. At 15-20 m depth there was no incidence of corals in the pre-trawl ban period. Presence of epifaunal octocorals recorded in the sub-tidal region of Veraval in the month of October, immediately after the closed season (June to August) when the sea bottom is not heavily trawled suggests that this area is an abode of corals and a favourable site for coral reef formation. But intense trawling in the succeeding months destroys these valuable entities of ecosystem and the samples were not encountered in the subsequent months. Thus encrusting forms and alcyonarian were destroyed[26].

The impact of bottom trawling on coral reefs has been studied in different parts of the world where it is mentioned that bottom trawling crushed or buried corals leading to increased mortality of coral populations[27,28]. They have cautioned that the destruction of the corals will also affect the associated fauna of fishes and invertebrates, which was evident from the complete loss of associated community from the shallow heavily fished seamounts of Tasmania[27]. Lokkeborg (2005) on reviewing the studies conducted for the past 15 years reported that the sessile organisms like sponges and corals decreased considerably at the passage of otter trawl[29]. At seamounts of Tasmania the dominant colonial coral, *Solenosmilia variabilis* and its associated fauna were eliminated from the shallow, heavily fished seamounts[27]. Kaiser *et al*. (2000) reported off Start Bay, Devon, United Kingdom that the biomass of soft corals was higher in the areas closed to fishing gear than those areas under bottom-fishing pressures even at a small scale[30]. In the mid Norwegian continental shelf the trawlers damage the deep-water corals *Lophelia pertusa* significantly lowering the inhabitant fishery[28]. There was a significant decrease in density of sponges and anthozoans in trawled hard-bottom seafloor versus reference transects in the Gulf of Alaska[31]. In the Great Barrier Reef of Australia, ascidians, sponges, echinoids, crustaceans and gorgonians were depleted by 74-86%[32]. The complex habitats like coral reefs have the longest recovery rate and take years to recolonise[7,8].

According to Jennings *et al*. (2001) infrequently fished areas were characterized by abundant growth of bryozoans, hydroids and tube worms[5]. Investigations on the short-term destructions imparted by trawlers in the Gulf of Alaska indicated that 14-67% of large sessile epifauna was damaged and densities of these epifauna were significantly higher in unfished reference sites. Motile invertebrates were not affected[31]. Experimental trawling conducted in areas untrawled for 15-20 years in Gulf St. Vincent, South Australia showed that most taxa of sessile benthic assemblages declined significantly in trawled areas compared with untrawled areas. In contrast to this, the recruitment rates of several taxa into the visible size classes increased after trawling, presumably because of a reduction in competition. Epifauna at trawled sites decreased in abundance by 28% within 2 weeks of trawling and by another 8% in the following 2-3 months[7]. Gravel sediment habitat of Georges Bank (East coast of North America) is an important nursery area for juvenile fish and the site of a productive scallop fishery. Colonial epifauna (bryozoans, hydroids and worm tubes) of this area provide a complex habitat for shrimp, polychaetes, brittle stars and small fish at undisturbed sites. Otter trawling and scallop dredging in this area removed this epifauna, thereby reducing the complexity and species diversity of the benthic community[33]. Sessile animals were relatively more abundant in lightly trawled areas of North Sea, while areas with higher levels of trawling were characterized by a higher relative biomass of mobile animals[34].

Abundance biomass comparison (ABC) curve for total epifauna is given in Fig. 3. ABC plots were built and difference between biomass and abundance curves was quantified by the measure of w. According to the theory, the fauna is unstressed, when the abundance curve lies below biomass curve (w>0). Fauna is moderately stressed when the abundance curve and biomass curve lie close together (w=0). Fauna is grossly stressed when biomass curve lie below abundance curve (w<0). At 15-20 m, the k-dominance curve was more or less unstressed or moderately stressed. At 26-30 m before trawling the curve showed unstressed fauna. But after trawling, the curve indicated grossly stressed fauna. Similarly at 31-35 m and 36-40 m, the k-dominance curve was observed to be moderately stressed before trawling and grossly stressed after trawling. Rate of stress increased with water depth as shallow depths are lightly trawled and as water depth increases the trawling intensity increases.

The epifauna collected in dredge mainly composed of dead and damaged molluscan shells that can be attributed to as an impact of trawling. Proportion of damaged shells showed increase in weight after trawling. This was evident at 26-30 m, 31-35 m and 36-40 m depths. Highest variation observed was at 36-40 m depth with an average increase of 344 gm/haul after trawling. This is in conformity with the reports of Raman (2006)[14]. Damage inflicted to epifauna was clearly evident from the enormous amount of dead shells obtained in trawled areas off Vishakapatanam comparing to untrawled areas[14]. In the present study, at 15-20 m water depth *Tibia curta* and *Anadara* spp. were found to be the most dominant species before and after trawling. At 26-30 m *Anadara* spp. was the most dominant and at 31-35 m and 36-40 m *Paphia textile* was the most dominant species observed. Species dominant in trawling grounds can be opportunistic species resistant to trawling disturbance. *Paphia textile* dominant in heavily trawled area is small in size compared to large sized *Tibia curta* dominant at 15-20 m (lightly trawled). Gradual replacement of fauna by small opportunistic species resistant to trawling is a marker of stressed areas[5].

The gastropods suffered the greatest depletion as 95% were removed by the combined effect of 13 trawls on the same track in the Great Barrier Reef of Australia[32]. In megafaunal species of North Sea, trawling induced direct mortalities were found to be up to 68% for bivalves[35].

Polychaete tubes abundant before trawling showed reduction. This decrease was more evident at 15-20 m depth where they were relatively abundant. On an average, the highest reduction was noted as 31 gm/haul after trawling. Rosenberg *et al*. (2003) on carrying out experimental trawl study in the northwest Mediterranean found that the polychaete tubes were either rare or not observed at all on trawled sediment surfaces[36]. Jennings *et al*. (2001) studied the effects of bottom trawling on the trophic structure of epifaunal benthic communities in two regions - Silver Pit and Hills of the central North Sea. Impacts of fishing were most pronounced in the Silver Pit region, where the range of trawling disturbance was greater. Epifaunal biomass decreased significantly with trawling disturbance[5].

The short term changes due to trawling are evident from damage to molluscan shells and polychaete tubes after experimental trawling. Long term impact is less explained by experimental trawling. But ABC curve reveal long-term impact by showing unstressed fauna in lightly trawled areas and grossly stressed fauna in heavily trawled area. In unfished sheltered Scottish sea loch, the ABC plots confirmed that epifaunal community changes occurred following trawling disturbance, with impact visible after 18 months of recovery[24].

Wilcoxon Signed rank test revealed no significant difference in before trawling-after trawling W statistic value for each depth zone (asymp. Sig. 2 tailed: 0.686) analyzing for all the species identified. On including polychaete tubes and damaged molluscan shells also, Wilcoxon Signed rank test was found to be significant (p=0.043). This can be attributed to the increase in the proportion of damaged shells and decrease in proportion of polychaete tubes after trawling. The w-statistic values were found to be negative in heavily trawled areas (26-30 m, 31-35 m and 36-40 m) and positive in lightly trawled areas (15-20 m and 21-25 m) (Fig. 3). In the present investigation it is difficult to conclude whether negative values of the w-statistic relates to an acceptable trawling impact or to an unacceptable chronic trawling. This situation may be partly due to limited number of comparable studies in a small area, but also due to the complexity of the problem. Analysis of time-series data that encompasses the whole range of ecological states (i.e. virgin state to heavily trawled) and comparisons among similar assemblages from different areas subject to different levels of stress have to be performed.

SIMPER analysis considering different species of epifauna revealed the most abundant species in each depth zone before and after trawling. The major species contributing to the dissimilarity before and after trawling at each depth zone were *Anadara spp*. at 15-20 m (Table 6); *Tibia curta* at 21-25 m (Table 7); *Paphia textile* at 26-30 m (Table 8) and *Chlamys spp*. at 31-35 m (Table 9) and 36-40 m (Table 10). The average dissimilarity between before and after trawling is highest at 15-20 m water depth i.e. lightly trawled area (Table 6). This dissimilarity decreased with increasing water depths and was observed to be lowest at 36-40 m i.e. heavily trawled area (Table 10). The order of average dissimilarity is 15-20 m (91.16) > 21-25 m (70.19) > 26-30 m (62.03) > 31-35 m (57.41) > 36-40 m (52.28). Dissimilarity of fauna before and after experimental trawling is more evident in lightly trawled area and remains masked in heavily trawled area. Tuck *et al*. (1998) used SIMPER test to identify the epifaunal species that contributed to the similarity or dissimilarity between two sites studied to interpret bottom trawling impact in Scottish sea loch[24]. SIMPER analysis was used to describe a reduction in the abundance of megafaunal slow-moving polychaetes that contributed most to the dissimilarity between trawled and control areas off the northwest coast of Anglesey, Liverpool Bay[37].

Conclusion

Impact of bottom trawling on octocorals was evident in lightly trawled areas of 15-20 m water depth where bottom trawling is not prevalent due to rocky nature of seabed. Abundance biomass comparison curves and similarity of percentage analysis have proved to be a powerful indicator of impact of trawling disturbance on epifaunal communities of the area studied. Epifaunal abundance-biomass curve showed that the rate of stress increased with water depth. Shallow depths are lightly trawled due to intermittent rocky nature of bottom and as water depth increases, the trawling intensity increases. The *W* statistic which is a synoptic descriptor of abundance-biomass curve were found to be negative in heavily trawled areas (26-30 m, 31-35 m and 36-40 m) and positive in lightly trawled areas (15-20 m and 21-25 m). By using the similarity of percentages in the SIMPER routine, the average epifaunal dissimilarity between before and after trawling was highest at 15-20 m water depth. This dissimilarity decreased with increasing water depths and was observed to be lowest at 36-40 m. Dissimilarity of fauna before and after experimental trawling was more evident in lightly trawled area and remained masked in heavily trawled area. Short-term effects were damage to molluscan shells and polychate tubes. The long term effects were evident on comparing lightly and heavily trawled areas.

The excess number of bottom trawlers operated in the study area has to be controlled. To conduct studies on trawling impacts, appropriate untrawled control sites are very much necessary for comparative assessment. Continuous monitoring of epifauna for a long period will bring to light the precise impact. This will lead to management issues of mapping the areas where corals thrive and limiting or closing bottom trawling in these regions. Management strategies have to be adopted for the conservation and biodiversity protection of octocorals. This study indicates the need for the promotion of eco-friendly trawls with light rigging to minimize physical disturbance to the epifauna. Semi-pelagic trawls have to be popularized for off-bottom resources.

Table 1—Diversity indices of total epifauna at 15-20 m.
*Significant difference of the Index before and after trawling (P<0.05)

Diversity Index	Before Trawling				After Trawling			
	Minimum	Maximum	Mean	S.E.	Minimum	Maximum	Mean	S.E.
S*	2.00	33.00	11.13	3.45	1.00	8.00	3.67	0.76
N*	7.00	281.00	92.50	33.80	2.00	47.00	14.78	4.77
Margalef	0.51	6.16	2.28	0.64	0.00	1.82	1.06	0.21
Pielou	0.59	0.95	0.77	0.05	0.69	1.00	0.90	0.03
Brillouin	0.28	2.44	1.42	0.24	0.00	1.69	0.77	0.18
Fisher	0.93	11.85	3.94	1.27	0.38	3.98	1.83	0.41
Shannon	0.41	2.69	1.62	0.26	0.00	1.93	1.00	0.20
Simpson	0.29	0.92	0.70	0.07	0.00	1.00	0.65	0.10
Hill’s N1	1.51	14.80	6.31	1.59	1.00	6.88	3.19	0.63
Hill’s N2	1.32	9.84	4.58	1.06	1.00	5.83	2.88	0.53
Tax_div	15.25	58.40	35.65	5.71	0.00	83.33	39.52	7.84
Tax_dist	24.56	66.67	50.72	5.30	0.00	83.33	53.52	8.61
AvTD	27.78	75.25	56.44	5.22	0.00	83.33	54.36	8.63
TTD	83.33	2111.46	676.18	231.45	0.00	442.86	212.17	47.37
VarTD	0.00	640.42	266.03	69.45	0.00	555.56	173.51	70.35
AvPD	38.89	83.33	50.76	5.11	47.92	100.00	71.59	6.18
PD	150.00	1300.00	497.92	131.36	100.00	383.33	231.48	33.04

Table 2. Diversity indices of total epifauna at 21-25 m

Diversity Index	Before Trawling				After Trawling			
	Minimum	Maximum	Mean	S.E.	Minimum	Maximum	Mean	S.E.
S	2.00	13.00	6.18	0.95	1.00	17.00	8.00	1.62
N	4.00	136.00	30.91	10.97	7.00	169.00	42.33	16.61
Margalef	0.69	2.44	1.63	0.20	0.00	3.20	1.99	0.37
Pielou	0.72	1.00	0.91	0.03	0.75	0.98	0.88	0.03
Brillouin	0.45	2.08	1.23	0.13	0.00	2.52	1.33	0.23
Fisher	1.03	14.12	3.72	1.10	0.29	19.95	5.41	1.96
Shannon	0.69	2.23	1.52	0.13	0.00	2.70	1.61	0.25
Simpson	0.67	0.93	0.79	0.03	0.00	0.95	0.72	0.10
Hill’s N1	2.00	9.31	4.94	0.62	1.00	14.83	6.19	1.31
Hill’s N2	2.00	7.99	4.36	0.53	1.00	13.56	5.18	1.24
Tax_div	31.62	63.33	45.77	2.88	0.00	79.37	44.32	7.18
Tax_dist	44.05	67.86	57.72	2.41	0.00	83.33	53.85	7.57
AvTD	44.44	66.67	57.04	2.37	0.00	83.33	54.95	7.51
TTD	133.33	708.33	352.11	54.35	0.00	1100.00	483.55	105.23
VarTD	0.00	555.56	298.94	54.28	0.00	424.38	227.80	43.32
AvPD	38.46	83.33	56.10	3.79	40.91	100.00	59.09	6.63
PD	166.67	500.00	316.67	32.64	100.00	733.33	403.70	62.53

Table 3. Diversity indices of total epifauna at 26-30 m.
*Significant difference of the index before and after trawling (P<0.05)

Diversity	Before Trawling				After Trawling			
Index	Minimum	Maximum	Mean	S.E.	Minimum	Maximum	Mean	S.E.
S	1.00	23.00	10.70	2.20	6.00	24.00	14.33	1.86
N	5.00	248.00	70.80	23.33	26.00	2135.00	319.33	228.28
Margalef	0.00	5.44	2.39	0.49	1.54	3.84	2.85	0.28
Pielou	0.87	1.00	0.93	0.02	0.36	0.97	0.81	0.06
Brillouin	0.00	2.42	1.69	0.22	1.12	2.64	1.84	0.16
Fisher	0.38	14.33	4.78	1.29	2.09	6.99	4.78	0.59
Shannon	`0.00	2.89	1.95	0.25	1.15	2.84	2.07	0.17
Simpson	0.00	0.95	0.79	0.09	0.39	0.93	0.80	0.06
Hill’s N1	1.00	18.04	8.63	1.55	3.14	17.13	8.87	1.41
Hill’s N2	1.00	14.07	7.18	1.11	1.64	13.77	6.97	1.27
Tax_div	0.00	54.89	43.88	5.02	22.06	61.54	48.71	4.12
Tax_dist	0.00	62.14	49.72	5.62	51.76	68.09	60.40	1.92
AvTD	0.00	64.35	50.73	5.74	55.19	64.14	58.30	0.97
TTD	0.00	1259.09	596.97	126.25	333.33	1420.29	841.54	113.87
VarTD	0.00	427.66	266.24	37.47	202.53	461.40	308.98	27.42
AvPD	34.06	100.00	50.11	5.94	36.46	50.00	42.72	1.63
PD	100.00	783.33	448.33	66.60	300.00	883.33	590.74	58.08

Table 4. Diversity indices of total epifauna at 31-35 m

Diversity	Before Trawling				After Trawling			
Index	Minimum	Maximum	Mean	S.E.	Minimum	Maximum	Mean	S.E.
S.	1.00	19.00	11.71	2.60	5.00	27.00	14.56	2.46
N.	4.00	454.00	230.57	59.32	12.00	2503.00	741.22	328.38
Margalef	0.00	3.51	1.97	0.49	0.97	3.75	2.47	0.34
Pielou	0.51	0.97	0.80	0.08	0.52	0.94	0.77	0.05
Brillouin	0.00	2.57	1.62	0.34	1.05	2.34	1.78	0.17
Fisher	0.43	6.03	2.90	0.76	1.19	5.97	3.80	0.57
Shannon	0.00	2.76	1.71	0.36	1.14	2.52	1.93	0.17
Simpson	0.00	0.94	0.68	0.12	0.65	0.92	0.80	0.03
Hill’s N1	1.00	15.76	7.61	2.16	3.14	12.47	7.67	1.16
Hill’s N2	1.00	14.77	6.20	1.92	2.74	10.61	5.61	0.86
Tax_div	0.00	55.69	34.14	7.19	22.75	56.69	42.87	4.30
Tax_dist	0.00	59.10	42.17	7.57	35.23	64.58	52.57	3.82
AvTD	0.00	60.29	48.76	8.16	52.78	61.48	56.71	1.03
TTD	0.00	1059.26	657.55	153.71	266.67	1553.85	832.35	143.81
VarTD	0.00	347.46	210.90	39.18	209.88	424.82	299.16	24.64
AvPD	37.72	100.00	51.55	8.57	34.57	52.78	41.95	2.33
PD	100.00	716.67	488.10	87.04	250.00	933.33	570.37	75.65

Table 5. Diversity indices of total epifauna at 36-40 m

Diversity Index	Before Trawling				After Trawling			
	Minimum	Maximum	Mean	S.E.	Minimum	Maximum	Mean	S.E.
S	9.00	25.00	16.10	1.74	7.00	29.00	16.00	2.09
N	35.00	708.00	254.80	62.52	34.00	3261.00	790.73	348.51
Margalef	1.62	4.70	2.91	0.32	1.24	3.72	2.49	0.24
Pielou	0.60	0.94	0.79	0.03	0.28	1.00	0.68	0.07
Brillouin	1.68	2.46	1.98	0.07	0.54	2.40	1.68	0.16
Fisher	2.14	8.17	4.60	0.68	1.52	5.57	3.41	0.35
Shannon	1.72	2.68	2.14	0.09	0.58	2.48	1.78	0.17
Simpson	0.71	0.90	0.83	0.02	0.25	0.90	0.74	0.06
N1	5.59	14.57	8.78	0.80	1.78	11.99	6.70	0.95
N2	3.46	9.54	6.36	0.60	1.33	8.61	5.06	0.71
Tax_div	29.35	60.03	43.00	2.60	14.10	49.38	36.28	3.48
Tax_dist	40.19	66.51	51.35	2.29	34.71	57.26	48.77	2.08
AvTD	50.46	63.68	56.96	1.25	52.35	61.31	55.76	0.91
TTD	454.17	1473.61	925.11	107.32	366.67	1619.05	904.18	125.32
VarTD	190.13	406.89	306.73	19.42	222.75	430.84	295.63	18.95
AvPD	34.03	46.15	39.30	1.12	34.48	45.83	40.34	1.05
PD	383.33	900.00	620.00	53.62	316.67	1000.00	624.24	67.66

Table 6. SIMPER analysis of epifaunal abundance data for 15-20 m depth. The average dissimilarity between before and after trawling was 91.16

Species	Average AbundanceBT	Average AbundanceAT	Average Dissimilarity	Dissimilarity / s.d.	Contribution (%)	Cumulative (%)
Anadara spp.	3.38	2.11	6.49	0.77	7.11	7.11
Nassarius arcularis	8.63	0.56	4.61	0.85	5.05	12.17
Tibia curta	2.88	0.78	4.46	1.07	4.89	17.06
Metapenaeus monoceros	0.25	0.89	4.42	0.53	4.84	21.90
Chicoreus sp.	1.50	0.00	3.65	0.67	4.00	25.90
Paphia textile	5.75	0.11	3.45	0.82	3.79	29.69
Balanus amphitrite	6.88	1.11	3.18	0.61	3.48	33.17
Murex sp	0.75	0.00	3.10	0.57	3.40	36.58
Metapenaeus dobsoni	0.25	0.67	3.09	0.54	3.39	39.96
Chlamys tranquebaricus	21.88	0.00	3.07	0.56	3.36	43.33
Babylonia spirata	2.63	0.11	2.85	0.50	3.13	46.46
Arca navicularis	0.00	0.67	2.79	0.46	3.07	49.52
Trisodos tortuosa	4.50	0.56	2.70	0.73	2.96	52.49
Balanus reticulatus	5.00	0.56	2.70	0.63	2.96	55.45
Conus eldredi	1.50	0.00	2.67	0.40	2.93	58.38
Chlamys singaporina	8.13	0.00	2.40	0.56	2.64	61.02
Calappa lophos	0.00	0.44	2.40	0.46	2.64	63.66
Donax sp.	1.75	0.22	2.26	0.80	2.47	66.13
Bursa echinata	0.63	0.33	2.14	0.61	2.34	68.47
Dosinia cretacea	0.63	0.67	2.07	0.62	2.28	70.75
Conus betulinus	0.63	0.00	2.05	0.37	2.25	73.00
Portunus sanguinolentus	0.00	0.33	1.88	0.33	2.06	75.06
Mitra eremiatrum	1.63	0.00	1.78	0.51	1.95	77.01
Oratosquilla nepa	0.38	0.11	1.42	0.50	1.56	78.57
Bursa spinosa	2.13	0.00	1.32	0.55	1.45	80.02
Litophyton sp.	1.50	0.00	1.30	0.54	1.43	81.45
Scarpha inaequivalvis	1.25	0.00	1.24	0.54	1.36	82.81
Studeriotes sp.	1.00	0.00	1.10	0.53	1.20	84.01
Charybdis lucifeara	0.13	0.56	1.09	0.38	1.19	85.20
Paphia papilionis	0.00	1.67	1.05	0.34	1.15	86.35
Nassarius spp.	0.63	0.56	1.04	0.47	1.14	87.49
Architectonica laevigata	0.38	0.00	1.01	0.47	1.10	88.59
Thais bufo	0.13	0.56	0.84	0.40	0.92	89.51
Donax scortum	0.63	0.00	0.80	0.37	0.88	90.39

Table 7. SIMPER analysis of epifaunal abundance data for 21-25 m depth. The average dissimilarity between before and after trawling was 70.19

Species	Average	Average AbundanceBT	Average AbundanceAT	Dissimilarity / s.d. Dissimilarity	Contribution (%)	Cumulative (%)
Tibia curta	2.00	4.44	5.88	1.07	8.37	8.37
Anadara spp.	6.18	9.11	5.12	0.82	7.29	15.66
Bursa spinosa	0.82	2.56	3.96	0.82	5.65	21.31
Scarpha inaequivalvis	0.27	3.11	3.91	0.82	5.57	26.88
Turricula javana	0.64	3.22	3.86	1.19	5.50	32.38
Paphia textile	2.82	1.33	3.35	0.95	4.77	37.15
Nassarius suturalis	1.36	0.22	3.22	0.71	4.59	41.74
Donax scortum	0.27	1.33	3.02	0.80	4.31	46.05
Bursa echinata	0.64	1.78	2.86	0.88	4.08	50.13
Murex acanthostephes	0.91	0.56	2.59	0.56	3.70	53.83
Nassarius thersites	1.91	1.67	2.02	0.67	2.87	56.70
Arca navicularis	0.64	0.11	1.86	0.60	2.65	59.35
Balanus reticulates	0.73	1.11	1.75	0.55	2.49	61.84
Natica didyma	0.45	0.11	1.74	0.67	2.47	64.31
Chlamys tranquebaricus	1.36	2.78	1.73	0.60	2.46	66.77
Balanus amphitrite	0.64	1.44	1.71	0.58	2.43	69.21
Oratosquilla nepa	0.09	0.11	1.61	0.46	2.29	71.50
Rampana bulbosa	0.64	0.11	1.60	0.53	2.28	73.78
Donax sp	0.00	0.56	1.50	0.65	2.14	75.92
Chlamys singaporina	0.91	2.00	1.48	0.60	2.11	78.02
Nassarius spp.	0.73	0.00	1.31	0.30	1.87	79.89
Dosinia cretacea	0.00	1.67	1.23	0.51	1.75	81.64
Dosinia gibba	1.36	0.56	1.20	0.46	1.72	83.36
Pholas sp.	0.55	0.33	1.01	0.39	1.44	84.80
Natica lineata	0.36	0.00	0.96	0.44	1.36	86.17
Trypauchen vagina	0.00	0.11	0.95	0.35	1.35	87.52
Sargassum wightiii	0.00	0.11	0.95	0.35	1.35	88.86
Cystoseira trinodis	0.00	0.11	0.95	0.35	1.35	90.21

Table 8. SIMPER analysis of epifaunal abundance data for 26-30 m depth. The average dissimilarity between before and after trawling was 62.03

Species	Average	Average AbundanceBT	Average AbundanceAT	Dissimilarity / s.d. Dissimilarity	Contribution (%)	Cumulative (%)
Paphia textile	5.30	188.22	3.58	1.10	5.77	5.77
Tibia curta	3.30	4.11	3.36	0.87	5.42	11.19
Scarpha inaequivalvis	6.00	7.78	3.14	1.07	5.05	16.25
Anadara spp.	8.60	15.89	3.05	0.86	4.92	21.17
Donax scortum	2.70	2.78	3.04	1.19	4.90	26.07
Bursa echinata	2.30	10.44	2.90	1.19	4.67	30.74
Bursa spinosa	2.60	5.56	2.74	1.07	4.41	35.15
Balanus reticulates	0.90	6.22	2.70	1.00	4.35	39.50
Chlamys tranquebaricus	9.40	10.56	2.57	0.87	4.14	43.63
Dentalium aprinum	1.70	6.78	2.51	1.15	4.05	47.68
Turricula javana	0.60	4.78	2.46	1.14	3.96	51.65
Dosinia cretacea	2.20	10.22	2.34	1.11	3.78	55.42
Nassarius thersites	3.50	8.56	2.28	1.08	3.67	59.09
Donax sp.	1.50	1.89	2.27	0.96	3.66	62.76
Balanus amphitrite	0.90	4.11	2.25	1.01	3.62	66.38
Chlamys singaporina	7.30	7.67	2.25	0.79	3.62	70.00
Nassarius suturalis	2.00	1.67	2.09	0.96	3.37	73.36
Natica didyma	1.10	4.56	1.68	1.08	2.70	76.07
Arca navicularis	1.10	1.56	1.63	0.79	2.62	78.69
Murex carbonnieri	0.30	1.22	1.51	0.68	2.43	81.12
Surcula amicta	1.60	3.00	1.32	0.71	2.12	83.24
Murex acanthostephes	0.80	1.11	1.30	0.89	2.10	85.34
Rampana bulbosa	1.10	3.78	1.11	0.67	1.78	87.12
Natica ineate	0.20	0.67	1.08	0.69	1.74	88.86
Umbonium vestiarium	0.80	0.00	0.99	0.43	1.59	90.45

Table 9. SIMPER analysis of epifaunal abundance data for 31-35 m depth. The average dissimilarity between before and after trawling was 57.41

Species	Average Abundance BT	Average Abundance AT	Average Dissimilarity	Dissimilarity/ s.d.	Contribution (%)	Cumulative (%)
Chlamys tranquebaricus	76.43	194.22	4.46	0.94	7.77	7.77
Tibia curta	4.43	5.33	4.09	0.76	7.13	14.90
Chlamys singaporina	33.57	139.44	4.05	0.96	7.05	21.95
Anadara spp.	11.57	45.11	3.56	1.01	6.20	28.15
Paphia textile	40.57	220.89	3.12	0.74	5.43	33.59
Dosinia cretacea	7.71	44.44	2.87	1.12	4.99	38.58
Nassarius thersites	9.86	8.33	2.86	1.07	4.98	43.56
Bursa spinosa	4.14	6.00	2.50	1.04	4.35	47.90
Bursa echinata	1.57	5.78	2.35	1.19	4.09	51.99
Dentalium aprinum	6.43	5.89	2.13	1.03	3.71	55.70
Turricula javana	4.57	7.44	2.09	1.09	3.64	59.34
Balanus reticulatus	0.71	7.78	1.84	0.74	3.21	62.55
Scarpha inaequivalvis	4.29	1.44	1.82	0.90	3.17	65.72
Nassarius suturalis	2.86	1.78	1.71	0.76	2.98	68.70
Donax sp.	2.43	2.78	1.65	0.88	2.87	71.57
Balanus amphitrite	0.43	5.00	1.54	0.70	2.69	74.26
Natica didyma	3.71	4.89	1.48	1.05	2.58	76.84
Donax scortum	1.86	1.11	1.21	0.67	2.11	78.95
Surcula amicta	0.71	2.78	1.19	0.69	2.07	81.02
Murex acanthostephes	2.57	1.33	1.18	0.84	2.06	83.08
Dosinia gibba	1.43	4.00	1.12	0.81	1.95	85.03
Trisodos tortuosa	2.00	2.78	0.96	0.89	1.67	86.70
Xenophora solaris	1.57	3.33	0.90	0.67	1.56	88.26
Natica vitellus	0.71	0.44	0.77	0.64	1.34	89.60
Natica lineata	1.43	0.56	0.75	0.67	1.31	90.91

Table 10. SIMPER analysis of epifaunal abundance data for 36-40 m depth. The average dissimilarity between before and after trawling was 52.28

Species	Average Abundance BT	Average Abundance AT	Average Dissimilarity	Dissimilarity / s.d.	Contribution (%)	Cumulative (%)
Chlamys singaporina	37.00	118.18	3.51	1.34	6.72	6.72
Chlamys tranquebaricus	64.00	79.91	3.06	1.04	5.85	12.57
Dosinia cretacea	16.30	217.82	2.87	1.17	5.50	18.06
Anadara spp.	14.50	15.45	2.83	1.20	5.41	23.48
Tibia curta	4.40	6.00	2.40	1.28	4.60	28.08
Paphia textile	54.50	270.91	2.38	0.97	4.55	32.63
Nassarius thersites	9.10	13.82	2.31	1.35	4.42	37.05
Umbonium vestiarium	4.40	3.64	2.03	1.13	3.88	40.93
Dosinia gibba	7.40	8.27	2.01	1.12	3.85	44.78
Donax sp	6.00	0.91	1.95	0.92	3.74	48.52
Bursa spinosa	2.70	4.55	1.93	1.12	3.69	52.20
Dentalium aprinum	4.70	5.73	1.87	1.27	3.57	55.77
Scarpha inaequivalvis	3.60	1.55	1.83	1.00	3.50	59.27
Natica didyma	0.70	2.73	1.73	0.82	3.31	62.58
Trisodos tortuosa	5.20	3.36	1.64	0.80	3.13	65.71
Turricula javana	1.70	3.00	1.49	0.93	2.84	68.55
Bursa echinata	1.10	4.64	1.43	1.00	2.73	71.29
Balanus amphitrite	1.60	1.45	1.34	0.77	2.57	73.85
Murex acanthostephes	4.00	1.09	1.27	0.97	2.44	76.29
Natica vitellus	1.30	1.73	1.15	1.01	2.20	78.48
Xenophora solaris	0.40	5.27	1.09	0.99	2.09	80.58
Balanus reticulatus	1.10	2.00	1.09	0.84	2.09	82.67
Nassarius suturalis	0.80	0.45	1.08	0.66	2.06	84.73
Paphia papilionis	1.70	1.00	0.93	0.57	1.77	86.51
Rampana bulbosa	0.90	3.09	0.92	0.83	1.75	88.26
Babylonia spirata	0.30	3.18	0.87	0.86	1.67	89.93
Natica lineata	0.70	1.09	0.76	0.69	1.46	91.38

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