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Response of Trophic Groups of Macrobenthos to Organically Enriched Sediments: A Comparative Study between Temperate and Tropical Regions

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Abstract

This study is aimed to detect the level of environmental disturbance caused by farming activities using trophic groups of macrobenthic assemblages, with emphasizes the difference between temperate and tropical regions. The samples of macrobenthic assemblages were taken from 2 (two) farm sites, i.e. Southern Spencer Gulf, South Australia, where farming of southern bluefin tuna (*Thunnus maccoyii*) takes place, representing as a temperate region (Site I) and milk fish (*Chanos chanos*) farms and mangrove area at coastal region of Mngkang Kulon, Semarang, Central Java, Indonesia, representing as a tropical region (Site II). Macrobenthic abundance was categorised based on six major trophic groups.

Macrobenthic assemblages dominated by all polychaetes, they are Capitellidae, Cirratullidae, Lumbrineridae, Nephtyidae, and Spionidae at Site I (temperate region), owing to their relatively tolerance to organic enrichment, both at the farm sites and at control sites. Surface deposit feeders (SDF) dominated in abundance at both control and fish farm sites at Site I, whilst subsurface deposit feeders (SSDF) exhibited highest in proportion at Site II over the study period, in particular species of Capittelidae, indicating that both sites has been influenced by fish farm activities. The abundance of deposit feeders was significantly higher at the farm sites than at the reference sites. Organic carbon in the sediment surface is likely to correlate with deposit feeding and sub-surface deposit feeding species richness, whereas total and food particulate matter correlate with species diversity. The result of this comparative study implies that response of trophic groups of macrobenthos to environmental disturbance are considerably similar at both tropical and temperate regions.

Keywords: Organic enrichment, Farming activities, Trophic groups, Cacpitellidae, Surface deposit feeders, Sub-surface deposit feeders, Macrobenthic assemblages

1. Introduction

The trophic structure analysis on macrobenthic assemblages has been widely used as a method to determine energy flow in marine sediments owing to their sensitivity to multiple factors, including environmental disturbance. In most macrobenthic studies of soft-bottom sediments, relationships between sediment types and trophic structure are usually typical in that fine grained, muddy-sediments with high organic content are dominated by deposit-feeder organisms, whereas coarse-sandy sediments with low organic content and high energy environments are dominated by suspension feeders and carnivores (Diaz & Rosenberg, 1995; Gaston *et al.,* 1998; Rakocinski *et al*., 2000). Among macrobenthic animals, polychaetes are considered more sensitive organisms to organic enrichment by changing rapidly in diversity and abundance. They have been recognized as good indicators of environmental disturbance, owing to their trophic flexibility and life history traits as a pre-adaptation to the condition of disturbed habitats, and their high tolerance to stress associated with organic loading and low oxygen levels (Tomassetti & Porello, 2005). Single species, such as *Capitella capitata* (Capitellidae), *Polydora ciliata* (Spionidae) and *Hydrobia ulvae* (Bivalvia), have previously been used as indicators of organic enrichment. However, these species can also be found in areas with low organic content. Thus, the relative spatial and temporal abundance of groups of species are considered to be more useful to assess the level of organic enrichment than individual species.

Over the last two decades, researchers have been more focusing on the structure and interaction of functional groups, instead of the diversity, biomass, life forms and the niche analysis. It is considerably useful to determine the relationship among the diversity, community structure and function (Baoming *et al.*, 2008), thus their structure and interaction within functional groups contribute to the productivity and stability of the community. In terms of grouping macrobenthic community into functional groups and trophic structure by the feeding habit/trophic guilds, researchers commonly divide them into carnivores (C), omnivores (O), filter feeders (FF), surface deposit feeders (SDF), and sub-surface deposit feeders (SSDF) (Diaz & Rosenberg, 1995; Rakocinski *et al.*, 2000), planktophagous (Pl), phytophagous (Ph), detritivorous (D) groups (Baoming *et al.*, 2008), Herbivorous (H), filter feeders/detritivores (F/D)—alternate their feeding habits between filter feeders and detritivores, and carnivores/ detritivores (C/D)—alternate their feeding habits between carnivores and detritivores (Gaudencio & Cabral, 2007). Moreover, in order to define the ecological quality of the environment, trophic group has been used as one of the parameters in describing the ecological functioning of the communities in Biological Traits Analysis (Paganelli *et al.*, 2012). The other biological traits in determining functional characteristics of the soft-bottom macrobenthic community were growth form, type of movement, habit, adult mobility, method of bioturbation, reproductive strategy, patterns of development, life span and substratum affinity. These traits have been selected mainly due to their importance for the ecological functioning of the benthic ecosystem and their meaningful responses of species to the environment. Furthermore, Rakocinski (2012) found that higher biodiversity corresponds with a more even distribution of production potential among a wider range of trophic groups.

The ability of macrobenthic animals to establish themselves is generally influenced by feeding patterns and food availability (Roth & Wilson, 1998). Physico-chemical factors, such as water stability, salinity, sediment characteristics, organic content, dissolved oxygen, particle size and microbiomass, are considered as significant factors influencing trophic composition of benthic assemblages (Gaston *et al.*, 1998). Other studies emphasized the significant role of tidal currents in food availability for benthic suspension feeders through turbulent diffusion, allowing pelagic production to be available for benthic suspension/filter feeders. Food quality and quantity can thus be a limiting factor for suspension-feeders. Because a significant relationship between benthic trophic structure, sediment contaminants and environmental variables have been observed (Gaston *et al.*, 1998), changes in trophic structure can be used as an indicator of disturbance. Reduction in trophic complexity in organically-enriched and chemically-contaminated sediments, in which the benthic assemblages were dominated by opportunistic species, has been observed by several authors (Diaz & Rosenberg, 1995; Gaston *et al.,* 1998; Rakocinski *et al.*, 2000; Davault & Gounin, 1995). It has been reported that sub-surface deposit feeders dominated sediments at high accumulation of organic matter, whereas carnivores, filter feeders, and surface deposit feeders decreased (Diaz & Rosenberg, 1995; Rakocinski *et al.*, 2000).

2. Materials and Methods

2.1 Sampling Procedure

The samples of macrobenthic assemblages were taken from 2 (two) farm sites, i.e. Southern Spencer Gulf, South Australia, where farming of southern bluefin tuna (*Thunnus maccoyii*) takes place, representing as a temperate region (Site I) and milk fish (*Chanos chanos*) farms and mangrove area at coastal region of Mangkang Kulon, Semarang, Central Java, Indonesia, representing as a tropical region (Site II). The sampling sites of Site I are relatively strong microtidal (<2 m) currents with an average current velocity of 5-10 cm s^{-1}. The seawater temperatures fluctuate from 14^{o}C in winter to 25^{o}C in summer. Samples were subsequently collected five times. The depth of sediment collected varied between 25 – 75 mm (mean = 40.9 mm) at control sites and between 22 – 85 mm (mean = 44.9 mm) at farm sites. Cores were collected using HAPS corer at eight fish farms and control sites. The sampling sites of Site II are relatively weak microtidal (<1 m) currents with an average current velocity of 3-5 cm s^{-1}. The seawater temperatures fluctuate from 25^{o}C to 32^{o}C. Samples were subsequently collected five times. The depth of sediment collected using Eckman Grab with the average depth 25mm at both farm sites and mangrove sites. Sediment was classified according to the Wentworth scale and characterized by its percentage of silt and clay (<63 lm), very fine sand (63 – 125 lm), fine sand (125–250 lm), medium sand (250–500 lm), coarse sand (500–1,000 lm), very coarse sand (1,000–2,000 lm), gravel (>2,000 lm) and by the median of grain size diameter.

2.2 Laboratorium Procedures

Sediment samples were fixed in Bennett's solution and stored in 2 l plastic jars. The samples were then sieved through a 1.0 mm mesh. The macrobenthic animals from the sediment retained by the sieve were sorted under a binocular microscope. The sorted fauna was preserved in 70% ethanol for further analyses. For Site I's samples, enumeration and identification of benthic animals were carried out at family level for polychaetes and bivalves. Other animals were identified to higher taxa. Or Site II's samples, enumeration and identification were done only for polychaetes at species level.

Because of the complexity of functionally grouping of benthic fauna, which ideally involves the assessment of motility and feeding patterns, macrobenthic abundance was categorised based on six major trophic groups: carnivores (CAR), herbivores (HER), omnivores (OMN), suspension feeders (SF), surface deposit feeders (SDF), and subsurface deposit feeders (SSDF) using literature descriptions of feeding behaviour (Jones & Morgan, 2002; Pardo & Dauer, 2003; Rouse & Pleijel, 2001). The proportion of each trophic group was then calculated for each sampling site and time. For samples of Site I, changes of the composition of trophic groups over the study period and the response of the trophic groups to organic enrichment are discussed. For samples of Site II, macrobenthos will be selected only for polychaetes to describe the composition of trophic groups.

2.3 Relative Contribution of Trophic Groups

The relative contribution of each trophic group over time is shown as area-blocks charts. The

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proportions of abundance and biomass of the trophic groups are related to the relative organic carbon content in sediments. Differences in number of individuals for deposit feeders (SDF and SSDF) and SF between site and time were assessed using a two-way analysis of variance (ANOVA). The data was tested using Komogorov-Smirnov's test for normal distribution and Levene's test for homogeneity of variances. Further test using Tukey's HSD post hoc for multiple comparisons was done if the results revealed significant differences between sampling times ($p<0.05$). Pearson correlation coefficient was used to assess the relationship SF and SDF. Preliminary analyses were carried out to avoid violation of the statistical assumptions of normality, linearity, and homoscedasticity (Palant, 2005).

3. Results and Discussion

3.1 The Abundance of Macrobenthic Assemblages: Emphasizing Polychaetes Abundance

The macrobenthic assemblages were dominated by polychaetes (28 families) at both control and fish farm sites (Figure 1). The proportion of Polychaeta at the control and fish farm pontoon sites was 76.4% and 80.5%, respectively. Other major taxa in the assemblages were Crustacea, Echinodermata, Mollusca, and Sipuncula. The second most abundant group of animals was the Crustacea, which was relatively more abundant at control sites by 3.3% compared to the fish farm sites. Seven families of bivalve molluscs were recorded during sampling period. Other phyla were relatively rare and varied little between fish farm and control sites.

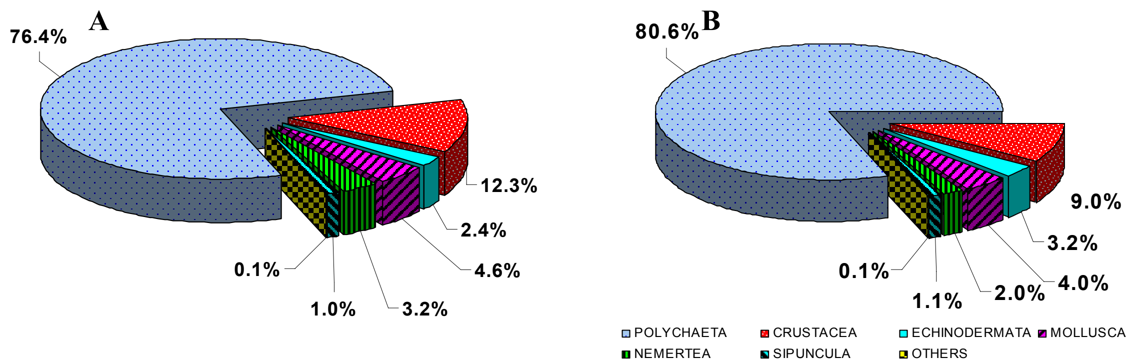

Figure 1. The total proportion of major macrobenthic taxa at control sites (A) and fish farm pontoon sites (B) during the sampling period at Site I

From 8 families of Polychaeta found in the total of sampling sites of Site II, Capitellids dominated at all sites, exhibiting more than 50% of all polychaetes abundance (Figure 2). This result may be due to Capitellid's feeding type as sub-surface deposit feeders, who usually inhabiting muddy sediments. This type of sediments provides more particulate organic matter as a food source of the animals, compared to sandy sediments (Devaney & Eldredge, 1987).

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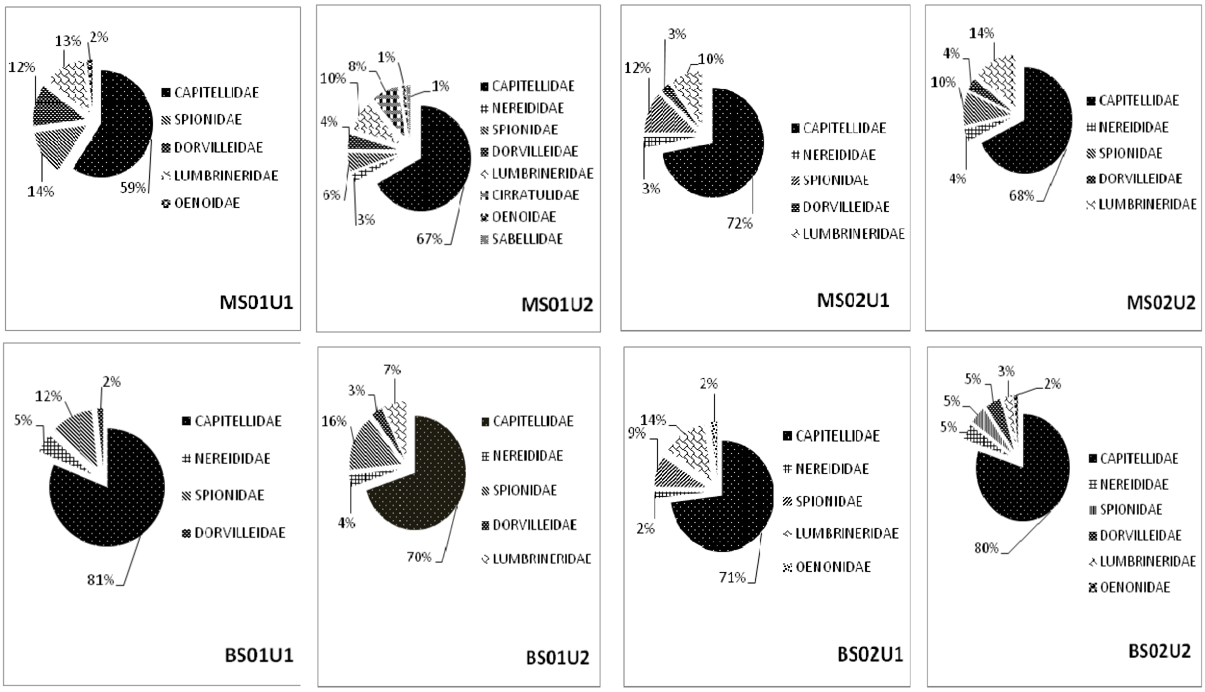

Figure 2. Serial diagram of composition of families of polychaetes for each sampling sites and times

Notes: MS01U1= Mangrove areas, Station 1, first sampling time; MS01U2= Mangrove areas, Station 1, second sampling time; MS02U1= Mangrove areas, Station 2, first sampling time; MS02U2= Mangrove areas, Station 2, second sampling time; BS01U1= Fish farm areas, Station 1, first sampling time; BS01U2= Fish farm areas, Station 1, second sampling time; BS02U1 = Fish farm areas, Station 2, first sampling time; BS02U2= Fish farm areas, Station 2, second sampling time.

3.2 Sediment Properties

The average proportion of silt, clay, fine sand, and coarse sand varied between control and farm sites and sampling time, as shown in Figure 3. Over 5 times of sampling period, the average proportion of sediment structure was dominated by silt (17-24%) and fine sands (20-25%), both control and farm sites.

The proportions of sediment organic matter were spatially variable, especially between sites, ranging from 2.6 to 12.6 mg/g for the control sites and from 0.14 to 24.8 mg/g for the farm sites. This spatial variability may be influenced by great spatial variability in current velocities in this region. It has been reported that, in a Mediterranean oligotrophic-farm area where the mean current was 10-1 cm/s and the depth was 25 m, the influence of carbon and nitrogen from fish farm waste could be detected in both the particulate and the sediments in a wide area around the fish cages (Sara *et al.,* 2004; Fernandes *et al.*, 2004).

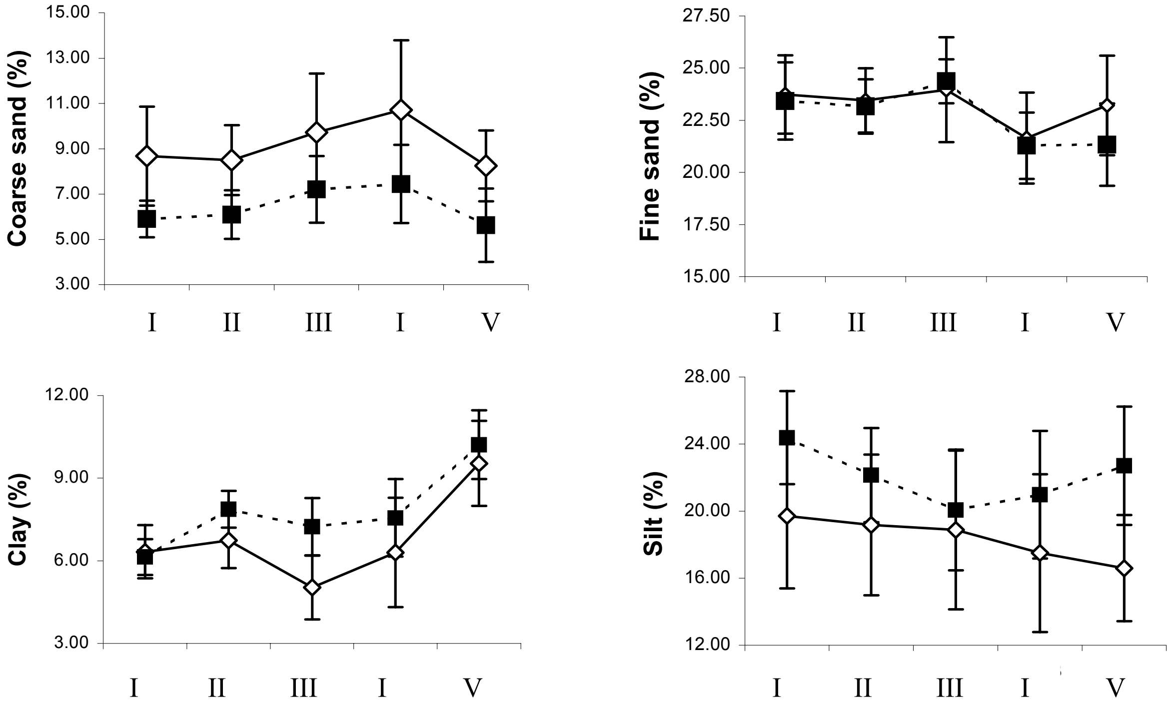

Figure 3. Sediment grain size at control and farm sites over the study period (error bars are 95% CI)

Note: Continued lines represent control sites and dashed lines represent farm sites.

Meanwhile, the sediment structure of Site II, both fishpond and mangrove areas, was dominated by silt (Table 1). The proportion of silt at fishpond areas was slightly higher than those at mangrove areas, from 85.43 to 88.38 at mangrove areas and from 90.08 to 91.21 at fishpond areas. However, the proportion of total organic carbon at mangrove areas was higher (18.18-18.19%) compared to those at fishpond areas (12.88-16.11%).

Table 1. The sediment structure and total organic carbon at fishpond and mangrove areas at Site II

Sediment properties	Fishpond Area		Mangrove Area	
	Sampling I	Sampling II	Sampling I	Sampling II
Silt (weight%)	91.21	90.08	88.38	85.43
Clay (weight%)	2.26	2.92	7	8.31
Total Organic Carbon (weight%)	12.88	16.11	18.18	18.19

3.3 The Structure of Trophic Groups at Control and Farm Sites

Surface deposit feeders (SDF) followed by carnivores dominated in abundance at both control and farm sites over the study period at Site I (Figure 4). The proportion of SDF abundance increased from 42% to 59% in a full year study period at control sites, and at farm pontoon sites from 37% to 64%. However, the proportion of sub-surface deposit feeders (SSDF) abundance was relatively low both control and farm sites ranging between 5 and 6% at control sites and 5 and 12% at farm sites.

On the contrary, the proportion of sub-surface deposit feeders (SSDF) at Site II exhibited highest at both fishpond and mangrove areas, as shown in Figure 5.

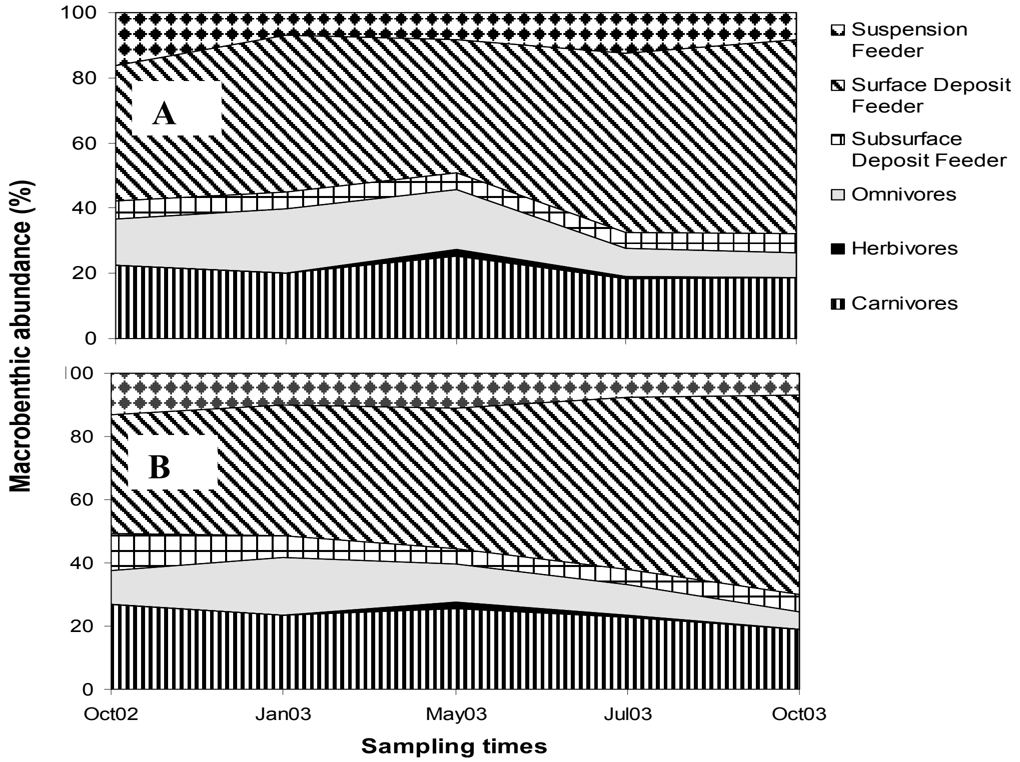

Figure 4. The proportion of trophic groups of the fauna at control (A) and fish farm (B) sites over the sampling period

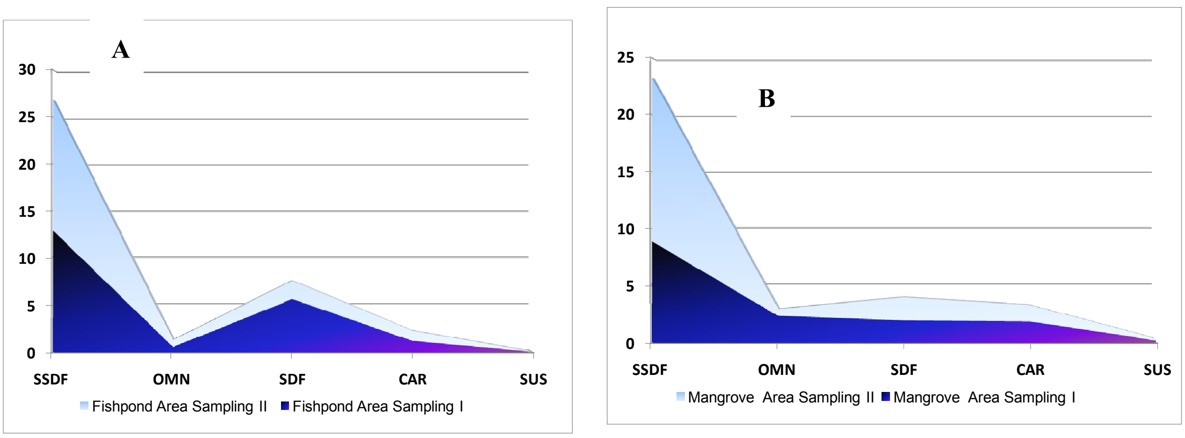

Figure 5. The proportion of trophic groups of polychaetes at fish farm (A) and mangrove (B) sites over the sampling period

The domination of SSDF is also consistent over time and areas, indicating the severe disturbance caused by high organic matter in the sediments at both areas. This is mainly due to high concentration of total organic matter and domination of silt in the sediments, as shown in Table 1.

Most macrobenthic species are relatively unselective in their food requirements and rely on spatial partitioning of the habitat (Dernie *et al*., 2003); however, species may still be functionally grouped based on their feeding patterns. Fauchald and Jumars (1979) categorized polychaete families based on their motility and feeding patterns into several major feeding guilds and grouped polychaete families as surface deposit feeders (19 families), carnivores (19 families), subsurface deposit feeders (13 families), herbivores (10 families), filter feeders (8 families), and a few families as omnivores. Nevertheless, assessing trophic groups of macrobenthic assemblages can be complicated, because overlapping in food selection can occur, especially suspension feeders (Roth, 1998). They can also switch feeding patterns during their life span depending on environmental factors (Snelgrove & Butman, 1994). In this study, the classification of all taxa (mostly at the family level) of the assemblages into the main trophic groups is based on a general trend of most members of a family categorized by the literature (Jones & Morgan, 2002; Pardo & Dauer, 2003; Rouse & Pleijel, 2001).

A two-way ANOVA showed that the abundance of deposit feeders was significantly higher at the farm sites than at the control sites ($F(1, 158) = 6.817$, $p = 0.01$); however the effect size was small (partial eta squared = 0.044). The difference between times was also significant, with a large effect size (partial eta squared = 0.208). ($F(4, 158) = 9.767$, $p< 0.001$), showing that only 4.4 % of the variance can be contributed to "site" while 20.8% can be contributed to "time". Post hoc comparisons, using the Tukey HSD test, indicated that the mean abundance of deposit feeders in the last sampling time ($\overline{X}$ = 39.94, SD= 22.32) was significantly different from the first sampling time ($\overline{X}$ = 19.25, SD= 11.022). However, no significant difference between sites ($F(1, 158) = 1.527$, $p>0.05$) and times ($F(4, 158) = 0.716$, $p>0.05$) were observed for the abundance of suspension feeders.

The result showed that deposit feeders dominated both control and farm sites over time at Site I, while subsurface deposit feeders. Despite a significant higher abundance of deposit feeders at the farm sites than at the control sites, the result showed that the abundance of SDF increased at both sites over the study period. Because the high presence of this trophic group is an indication of a disturbed environment, there appears not to be any sign of a major recovery of the infauna after a twelve-month period of fallowing. It is likely that food abundance and variety regulate the organization of deposit-feeding assemblages. The various particle types found in the sediments at the sampling sites were considered potential food particles for deposit feeding organisms. These particles are organic-mineral aggregates, organic-encrusted mineral grains (bacterial films and diatoms), fecal pellets and fragments, living diatoms (pinnate, centric, and pleurosigmoid-like), angiosperm plant fragments, meiofauna (nematodes, copepods, ostracods, turbellarians, naupli), chitinous molts and fragments, protozoans (ciliates, foraminiferas, amoebas), and pollen or spores. Similar results have been reported by Pardo and Dauer (2003) showing that deposit feeders obtain their nutritional requirements from the organic fraction of ingested sediments, which constitutes a wide variety and large number of food particles including mineral grains, detritus, diatoms, protozoans and metazoans. Thus, the higher abundance of deposit feeders at the farm sites in this study may indicate a wider variety of food particles or organic matter at these sites.

Although the proportions of SF decreased and SDF increased at both control and farm sites throughout the sampling period, the presence of SDF does not seem to influence the presence of SF. A weak negative correlation between density of deposit feeders and suspension feeders has also been reported, suggesting that the species utilizing different trophic groups can co-occur in large numbers and that distributions of suspension and deposit feeders are not mutually exclusive (Snelgrove & Butman, 1994). It has been reported that suspension feeders trap particles that are transported horizontally close to the bottom, and thus collect particles before they settle on the bottom (Loo & Rosenberg, 1996), whereas deposit feeders rely on particles that have settled on to the bottom (Snelgrove & Butman, 1994). Deposit feeders utilize organic materials deposited on the sediment surface (Hansen & Josefson, 2004), while suspension feeders catch suspended particles from near-bottom water. Thus, the difference in feeding patterns and subsequently difference in food resources may be the main explanation for the co-occurrence of the two trophic groups.

3.4 Trophic Structure Related to Environmental Variables

Changes in the proportion of trophic groups and the abundance of dominant taxa were observed over the study period at Site I. However, the relative composition of the trophic groups were similar, in which surface deposit feeders (SDF) dominated the assemblages at all sites/zones, followed by carnivores (CAR), suspension feeders (SF), and sub-surface deposit feeders (SSDF). This was expressed by the domination of Spionidae (SDF), which was the most dominant taxon at all sites/zones. Although the proportion of organic carbon was higher and current velocities slower at farm sites than at control sites, there were no significant differences between sites, as well as between zones for the two variables. However, sediment composition was significantly different between sites, especially for coarse sand, clay and silt, suggesting that sediments at farm pontoon sites had less coarse sand, but more silt and clay compared to control sites. Given that the proportions of SF decreased and SDF increased at both control and farm sites throughout the sampling period, attempts were made to assess the relationship between two trophic groups using Pearson correlation coefficient. The result showed that there was no significant correlation between the two trophic groups ($r = 0.05$, $n = 626$, $p>0.05$), suggesting that the presence of suspension feeders is unlikely to be influenced by surface deposit feeders in the sediments. Correlations between the other trophic groups also revealed similar results, in which none of the correlation between any of two trophic groups (within SF, SDF, SSDF, OMN, and CAR) was significant.

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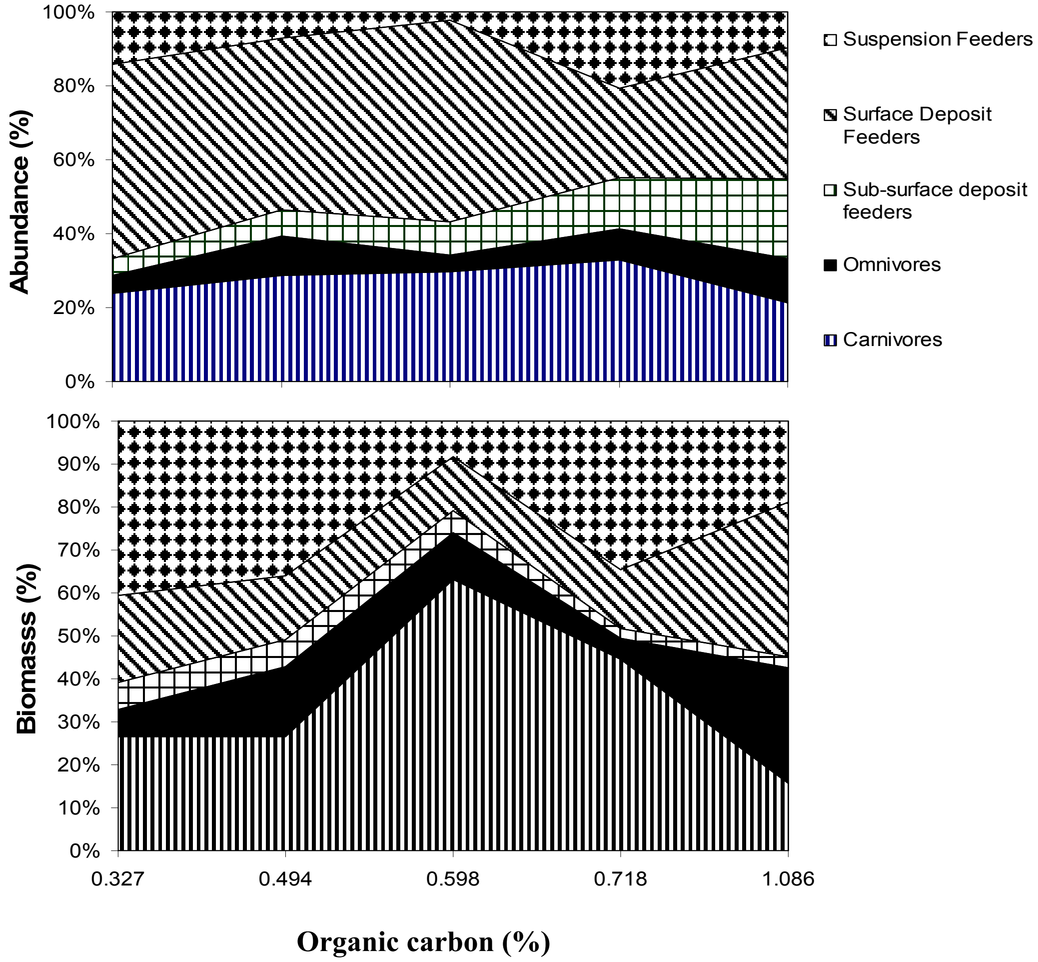

Figure 6. Abundance and biomass of macrobenthic fauna as a function of increasing amount of organic carbon

The distribution of abundance and biomass of the trophic groups as a function of organic carbon content in sediments at Site I is shown in Figure 6. At low levels of organic carbon, SDF (mostly sipunculans, terebellids, and sabellids) dominated macrobenthic abundance (52.4%), and SSDF had the lowest proportion (4.8%) while carnivores (mostly eunicids, lumbrinerids, and nemerteans) and SF (mostly bivalve molluscs) were recorded as having the highest (47.0%) and the lowest (14.3%) biomass, respectively. At high levels of organic carbon recorded, however, three detritivore feeding groups (SF, SDF, and SSDF) dominated numerically, contributing about 67% of total abundance. At the same level of organic carbon, the biomass was dominated by nearly equal proportion of SF (31.8%) and omnivores (32%), while SSDF (mostly capitellid polychaetes) showed the lowest proportion of the total biomass. The abundance of SSDF increased gradually as a function of organic carbon content, but decreased markedly in biomass proportion owing to the elimination of some large body taxa and the dominance of small body size-opportunistic taxa, such as echinoids (the largest omnivore group collected). Other large animals recorded over the sampling period were mytilids for suspension feeders and holothuroids for surface deposit feeders. Attempts have been made by several authors to relate organic content and abundance of trophic groups (Rossi, 2003; Davault & Gounin, 1995; Rakoncinski *et al.*, 2000; Venturini & Tommasi, 2004). The proportion of subsurface deposit feeders generally increase along an organic-chemical contamination gradient, whereas carnivores filter feeders, and surface deposit feeders decrease. Organic carbon in the sediment surface correlated with deposit feeding species richness, whereas total and food particulate matter correlated with species diversity. Most results showed that responses of benthic fauna to organic matter (assessed using % organic carbon) are likely to be in accordance with the theory of macrobenthic succession proposed by Pearson and Rosenberg (1978). The main trophic groups seem to respond the classical way to organic enrichment at the farm sites. As the amount of organic material on the sediment surface increases, the larger and deeper burrowing species are gradually eliminated and replaced by greater numbers of small surface deposit feeders. A simple trophic system composed of only non-selective deposit feeders and carnivores can be established in sediments where input levels of organic matter are noticeably high. Weston (1990) observed that trophic diversity was reduced with proximity to a salmon farm as a result of increasing organic matter. He found that suspension feeders constituted 10% of the assemblages at 450 m from the farms, but disappeared at 45-90 m from the farm, whereas sub-surface deposit feeders increased directly under the farm. In this study, however, the reduction of trophic diversity, as has been reported by Weston (1990), did not occur as organic carbon increased. Beside high variability during the sampling time, the low levels of organic carbon recorded may be the main reason of this. It is likely that organic loading from southern bluefin tuna farms at this region is relatively low in comparison to most situations that have been studied elsewhere.

4. Conclusions

Macrobenthic assemblages dominated by all polychaetes, they are Capitellidae, Cirratullidae, Lumbrineridae, Nephtyidae, and Spionidae at Site I (temperate region), owing to their relatively tolerance to organic enrichment, both at the farm sites and at control sites. In particular, spionids and lumbrinerids were found to be the responsible taxa for assessing levels of disturbance at farm sites. At Site II (tropical region), Capitellids tend to increase in number as a response of organic enrichment at the site, thus increase the proportion of SSDF. The trend of macrobenthic abundance and domination at both temperate and tropical region are likely to be similar in response to environmental disturbance, especially organic enrichment caused by fish farming activities. The responses of the main trophic groups to organic matter are in accordance with Pearson and Rosenberg (1978) in that larger and deeper burrowing species are gradually replaced by greater numbers of small suspension- and surface deposit feeders as organic matter increases. However, reduction in trophic groups did not occur, implying only moderate levels of disturbance at the studied sites.

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