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Marine fish farming in Bidong Island, Malaysia and its implications on benthic community structure and functional diversity

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Abstract. A study was carried out to determine the impact of fish farming activity on benthic community in the coastal water of Bidong Island, Malaysia, where fish farming activity has been conducted since relatively recently. Sediment samples were collected in one station inside the fish farm area, as well as another two stations outside the area. The study found out that the fish farming activity did not affect water properties and sediment composition of the area. In contrast, this activity showed an impact on benthic community structure, in particular the abundance and biomass, where station B (inside the fish farm) recorded the lowest values compared to station A and station C. The assessment based on the functional traits of the benthic community also showed that station B was affected by the fish farming activity. The study suggests that the fish farm in Bidong Island showed an evidence of negative impacts that would be detrimental to benthic community and ecosystem function. However, the extent to how severe the impacts were is unknown, and a more comprehensive and longer study has to be carried out to determine this.
Key Words: aquaculture, benthic macrofauna, ecosystem function, habitats.

Introduction. Benthic infauna is one of the most used organisms in assessing marine ecosystem (Borja et al 2003; Borja et al 2014; Daief et al 2014; Dauer et al 2000). Apart from their diversity, other characteristics that make this group as a favourable choice of indicator are limited mobility (meaning they may represent the condition of study area better than other mobile organisms) (Gray 1979) and long life spans of up to several years (Nilsson & Rossenberg 1997). Another factor that makes the benthic infauna suitable indicator organisms is their sensitive response to various environmental stressors due to their physiological tolerances, feeding mechanisms and trophic interactions (Pearson & Rosenberg 1978). Although benthic infauna exhibits many advantages in environmental assessment, the use of these organisms can also be problematic. For instance, the methods used in the analysis (sampling, processing and identification) need a great deal of logistic effort and can be very expensive (Nilsson & Rosenberg 1997).

Many benthic communities support a rich diversity and provide ecosystem goods and services (Costanza et al 1997). A vast variety of commercially important fish and invertebrates (e.g. shrimps, crabs, and lobsters) rely on benthic organisms (infauna and epifauna) as foods source, at least in part of their life. In addition, the benthic habitats are also important for these commercially harvested organisms as their habitat and for sheltering. Bottom communities act as the essential source of organic and inorganic matters that reach the ocean through precipitation, river runoff, or produced in the overlying water. Through various physical and biological processes, the materials reaching the benthic area are broken down and returned to the water column (and eventually atmosphere) (Renaud et al 2008).

The predictable response of benthos to organic enrichment from aquaculture activities is demonstrated in the Pearson & Rosenberg (1978) paradigm which suggests that food availability is the main factor that determines the structure of benthic communities.

Changes in organic matter content may have significant influence on the benthic communities due to their limited mobility which make them heavily rely on the food source within their habitat (Villnas et al 2011). However, this organic matter can be problematic when the increasing rate of organic enrichment may change sediment properties and increase the decomposition rate (Gray et al 2002; Hyland et al 2005). Therefore, the increase of organic matter reduces sensitive and long-lived benthic species while temporarily creates a favourable condition for more tolerant (i.e. opportunistic) species before the whole communities are severely affected (Pearson & Rosenberg 1978). This condition might consequently affect benthic ecosystem function and services (Lohrer et al 2004; Solan et al 2004) since process by benthic communities (bioturbation) continuously reworks the sediments, thus increase the oxygen penetration, nutrient cycling and organic matter mineralisation (Pearson 2001).

The study on the impacts of aquaculture on benthic communities in this region is still scarce. Therefore, the present study aims to determine how habitat changes following aquaculture would affect benthic community structure and to what extent the changes would influence the biological characteristics of the organisms. The use of both structural and functional approaches in the assessment would facilitate for a better recommendation or justification for the future permission for fish farming activity, or even the suitability of on-going activity.

Materials and Methods

Sample collection. The study was conducted in Bidong Island, which is located approximately 35 km off the coast of Terengganu, in Peninsula Malaysia. Sampling was carried out in September 2013 at three stations. Station B was located inside the fish cage, while station A and station C were located outside the cage area, towards the offshore and near the coast of Bidong Island respectively (Figure 1). With the aid of SCUBA diving, four 1L hand corers were used to collect the samples with four replications at each station, making up altogether 36 core samples (benthos samples) in each sampling occasion. Samples were transferred to labelled plastic bags and were added with 10% buffered formaldehyde solution diluted in seawater. Another 1L hand corer sample, with three replications was collected for sediment grain size at each station. The physico-chemical parameters (salinity, pH, temperature and dissolved oxygen) were concurrently measured at each station using YSI hydrometer.

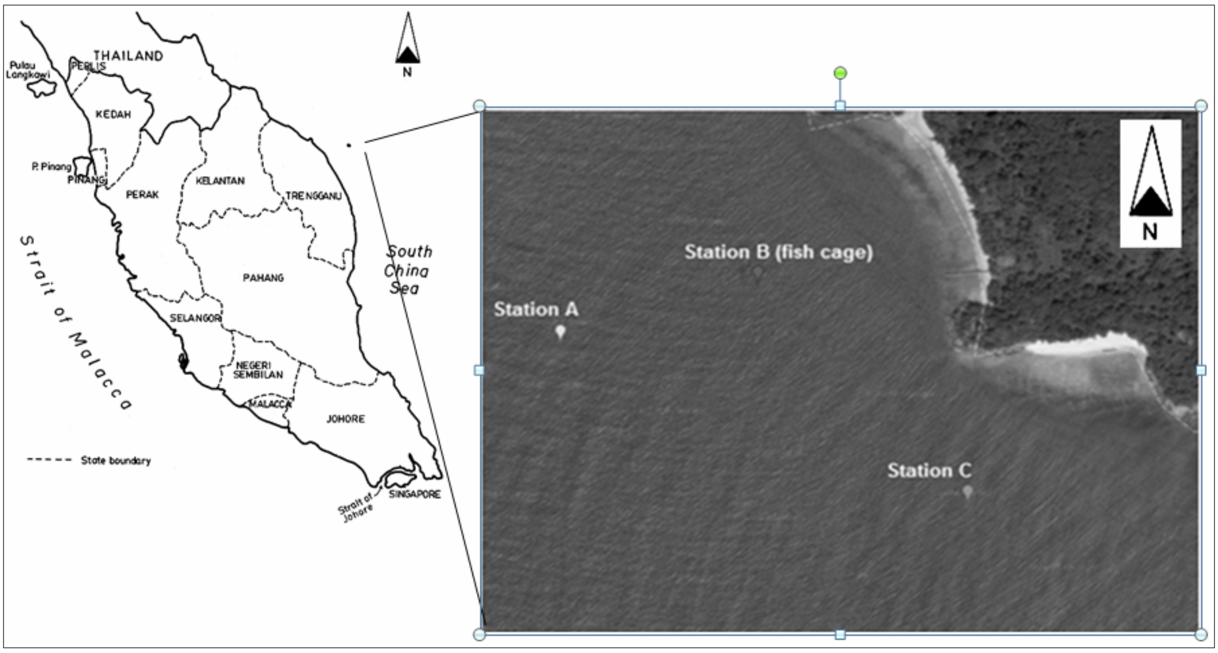

Figure 1. Map of study area with the locations of all stations (FAO 2014; Google Maps 2014).

Sample processing. Macrofaunal samples were kept in laboratory for 4 days to allow the organisms to be properly fixed. After that the samples were washed several times with fresh water over a 500 µm screen to remove the formaldehyde solution. All specimens were then removed into labelled glass vials containing 70% ethanol for identification. All specimens were individually counted and identified to the lowest possible taxonomic level. For biomass measurements, each taxon in every sample was blotted on absorbent paper before being weighed (wet weight) to the nearest 0.0001 g. The measured wet weight was converted to ash free dry weights (AFDW) using standard conversion factors (Ricciardi & Bourget 1998). Meanwhile, for grain size measurement, coarser (> 500 µm) sediment particles were sieved using wet and dry sieving methods, while the finer (< 500 µm) particles were measured using laser-sizing method. All sample processing techniques were following DTLR (2002) and Eleftheriou & McIntyre (2005) with some modifications.

Benthic community structure. The benthic community structure was assessed by means of abundance (N), species richness (S) and biomass (B) of the community at each station. N and S were simply the mean number of individuals and number of species recorded. B was calculated using standard conversion factors (Ricciardi & Bourget 1998) and expressed as AFDW.

Biological traits analysis. Biological Traits Analysis (BTA) uses specific species traits and variation in the pattern of traits to assess the functioning of ecosystem (Bremner et al 2006). As the traits are directly related to ecosystem structuring mechanisms, they are believed to be able to illustrate the factors that govern the changes in the communities (Statzner et al 1994). Index value was calculated based on five different categories namely: size, mobility, body form, feeding habit and habitat. The individual taxa were then scored using a "fuzzy coding" procedure. Fuzzy coding allows taxa to exhibit trait categories to different degrees (Chevenet et al 1994) to take into account of intraspecific variations in trait expression (Charvet et al 2000). The scoring range from 0 to 3 was adopted; where 0 being no affinity to a trait category while 3 being high affinity. The species by traits matrix and species by station matrix were developed. The resulting values from these two matrixes were then being multiplied in order to create traits by station matrix. Data was further analysed using multivariate analysis.

Statistical analysis. All data did not meet requirement for a parametric test (most likely due to small sample size). Therefore non-parametric tests were performed. Kruskal-Wallis test was applied using the mean values for each of the above indices to verify the significant difference between stations. A post-hoc Mann-Whitney test was applied to further verify which sample was different to which (pair-wise test).

Multivariate analyses were performed using PRIMER (Plymouth Routines in Multivariate Ecological Research) package version 6 (Clarke & Gorley 2006) to measure spatial and temporal differences in macrofaunal assemblages and sediment distribution. A resemblance matrix of the biological data (i.e. the abundance data and the BTA) was constructed using the Bray-Curtis similarity measure, which then was used to construct a non-metric multi-dimensional scaling (MDS) ordination and to perform Analysis of Similarity (ANOSIM). The ordination explains the relative similarity between samples where the closer the samples grouped together indicates the more similar the samples are. The stress value of a MDS ordination indicates a level for goodness-of-fit with a stress value of < 0.1 gives a useful ordination with no prospect of misinterpretation (Clarke & Warwick 2001). ANOSIM measures the significant difference between samples and the level of difference/similarity is indicated by R-value. The value close to 0 indicates the high similarity between samples while the value closer to 1 indicates that the samples are becoming less similar. A similarity percentages program (SIMPER) was performed to determine the species or traits that contributed to the observed dissimilarity. The similarity of samples based on values from environmental data was measured by principle component analysis (PCA), based on Euclidean distance.

Results and Discussion

Environmental parameters. Four water parameters were measured in the sampling namely salinity, pH, temperature and dissolved oxygen. The values of the parameters are presented in Table 1. All parameters showed no significant difference between stations (Kruskal-Wallis test; $p > 0.05$). The similar water characteristics at all stations might be due to the stations was relatively close to each other. This condition was also in accord with the studies by Ibrahim et al (2006) and Lotfi et al (1994) in nearby areas, Karah Island and Redang Island respectively, which found out that water physico-chemical parameters showed little variation between stations.

Table 1

Water physico-chemical parameters values (± standard deviation) at all stations

Station	*Salinity (ppt)*	*pH*	*Temperature (^oC)*	*Dissolve oxygen (DO)*
A	29.58±0.07	8.08±0.18	29.96±0.44	3.80±0.02
B	29.54±0.09	7.90±0.24	29.95±0.42	3.87±0.02
C	29.48±0.09	8.46±0.22	29.87±0.36	3.85±0.02

In terms of particle size, sediment samples at station B and station C were more similar to each other than to the sediments at station A (Figure 2). Generally, stations B and C comprised of high percentage of gravel and coarse sand while lower percentage of gravel was recorded at station A. Station A seemed to have a more balanced sediment composition, particularly the sand particles with percentage between 22.8 to 31.1%. The difference of sediment composition at station A compared to station B and station C is also showed by the separation of samples in the PCA ordination (Figure 3). The ordination shows samples from station A are distributed apart from samples from station B and station C, which are relatively closely together indicating a higher similarity in terms of particle size composition. Both stations B and C were characterised by gravel and coarse sand, while station A was characterised by medium and fine sand.

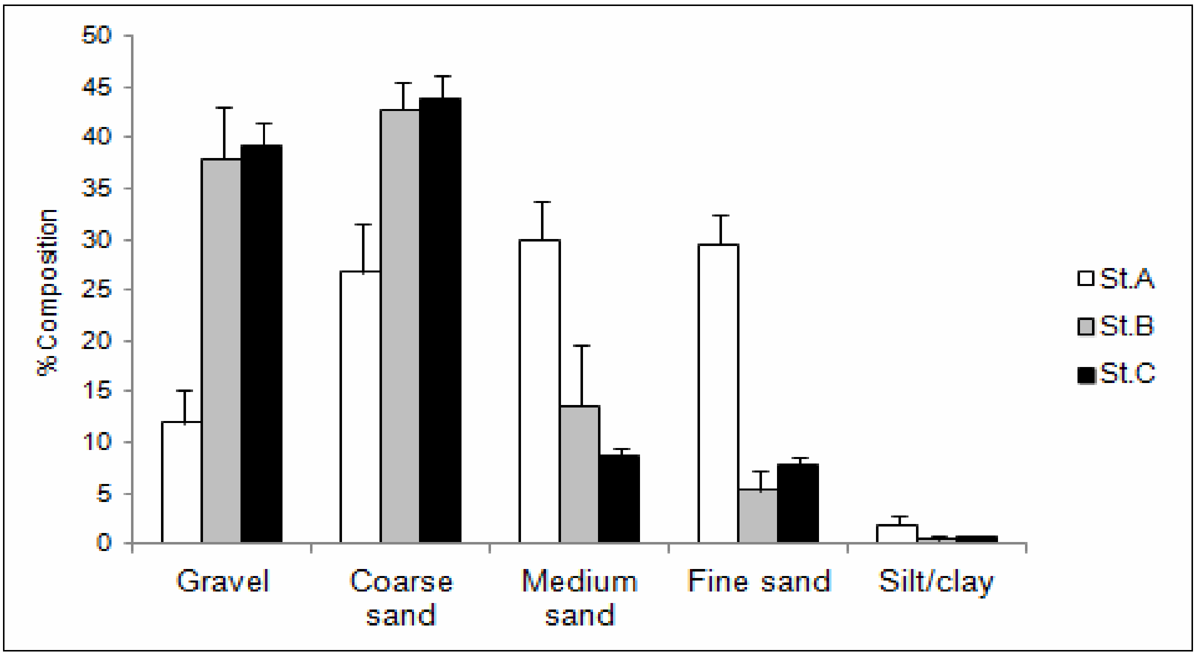

Figure 2. Mean particle size (± confidence intervals) of samples at stations A, B, and C.

Although there are studies that suggested the waste products from fish farm may attribute to the changes in sediment composition (e.g. Buhl-Mortensen et al 2013; Keeley 2013; Mazzola et al 2000), such effects were not evident in the present study. The possible explanation is the sediment composition might have more impacted by the coastal hydrodynamic. The location of stations B and C which were closer to the coast might contributed to the higher percentage of coarser particles, while the station A which is located further from the coast was characterised by the dominance of finer particles. Waves and currents in the coastal water are the major forcing conditions that influence the sediment transport (Soulsby & Damgaard 2005). Therefore it is assumed that stations B and C which are located close to the coastline had similar sediment transport rate, while the rate was different at station A.

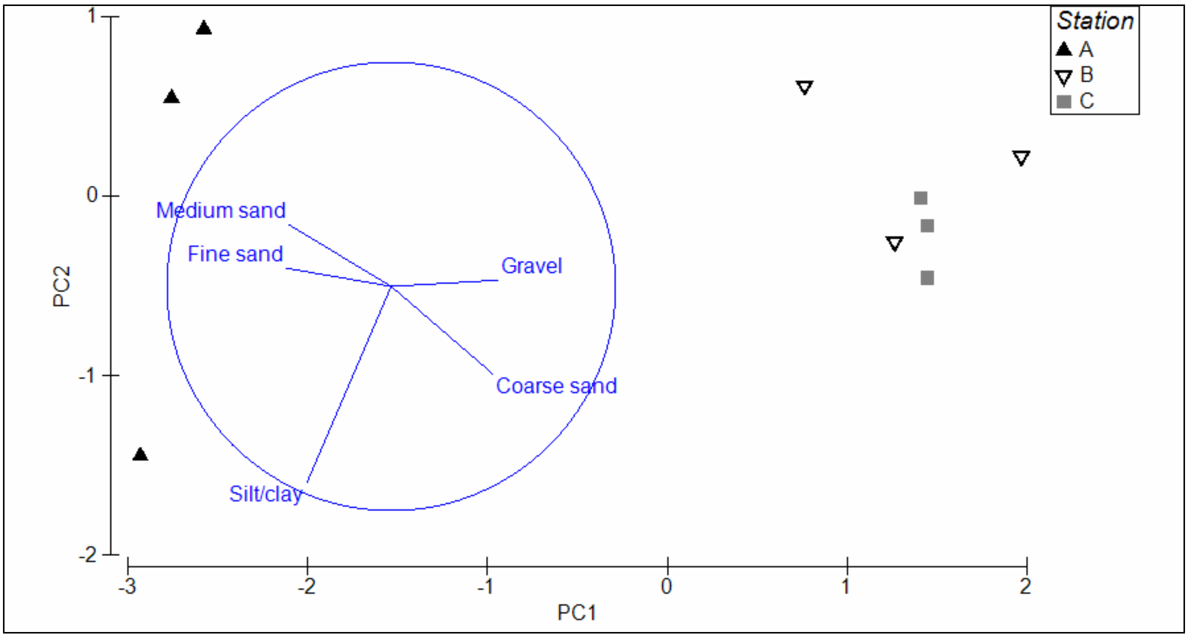

Figure 3. Two dimensional correlation-based PCA ordination of sediment particle size data from the study area.

Macrofaunal community structure. In general, stations outside fish farm area recorded the higher value than station inside fish farm area in terms of abundance, species richness and biomass (Table 2). Station B recorded a significantly lower number of individual compared to other stations (Mann-Whitney test; $p < 0.05$). No significant differences were observed between the abundance at stations A and C (Mann-Whitney test; $p > 0.05$). Meanwhile, biomass measurement also showed a significant difference between stations (Kruskal-Wallis test; $p < 0.05$), and the subsequent post-hoc test showed that the difference was recorded between stations A and B, and stations A and C (Mann-Whitney test; $p < 0.05$). All stations recorded no significant difference in terms of the number of species (Kruskal-Wallis test; $p > 0.05$).

Table 2

Mean value of abundance, species richness and biomass (± standard deviation) at all stations

	Station A	*Station B*	*Station C*
Abundance	43.5±24.9	11.5±8.3	54.6±15.9
Species richness	14.3±3.9	8.0±5.8	12.0±3.9
Biomass (g)	0.47±0.40	0.04±0.04	0.05±0.03

Although the univariate measures showed a significant difference in terms of abundance and biomass, the difference was not evident when data were analysed using multivariate measure. The MDS ordination of abundance data shows that samples from all stations are equally separated from each other, with the exception only for an individual sample from station B which is at a great distance from other samples (Figure 4). Similarly, no clear clustering of samples also recorded for biomass (Figure 5). This indicates that samples are almost equally similar from each other. The similarity between samples shown in MDS is further confirmed by the ANOSIM which recorded no significant difference between the samples at all stations for both abundance (R-value = 0.155, $p > 0.05$) and biomass (R-value = 0.137, $p > 0.05$).

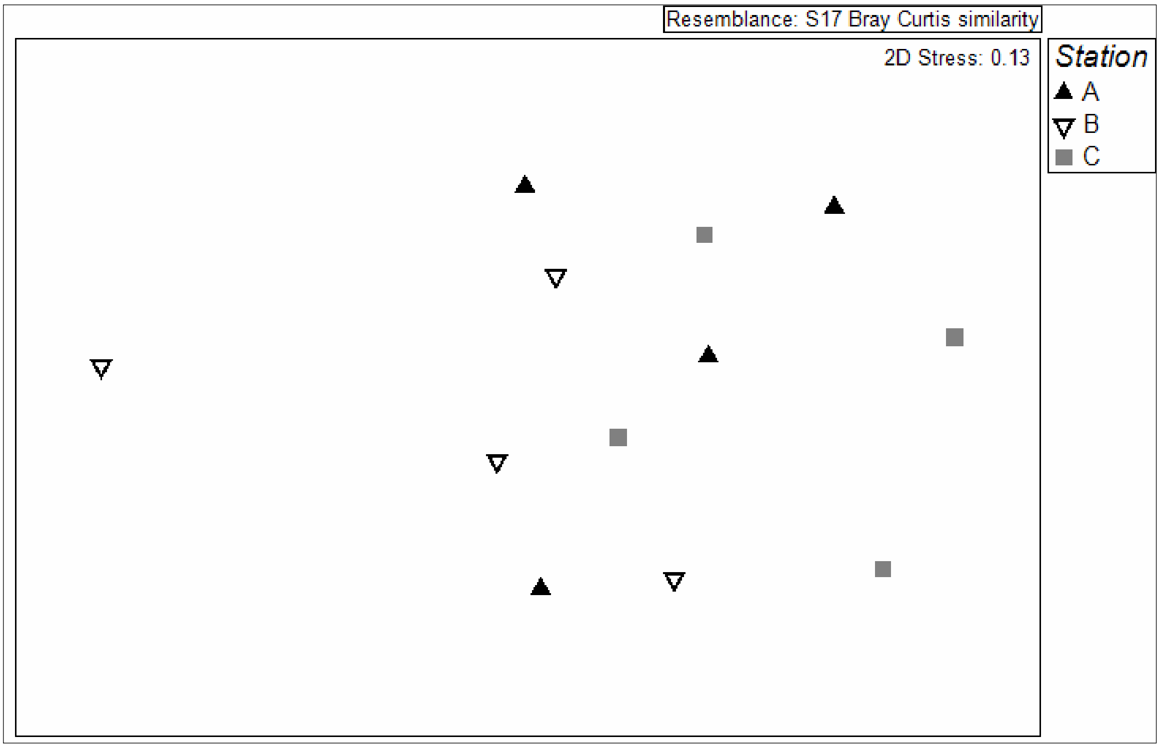

Figure 4. An MDS plot of Bray-Curtis similarity based on square root transformed data of abundance at stations A, B and C.

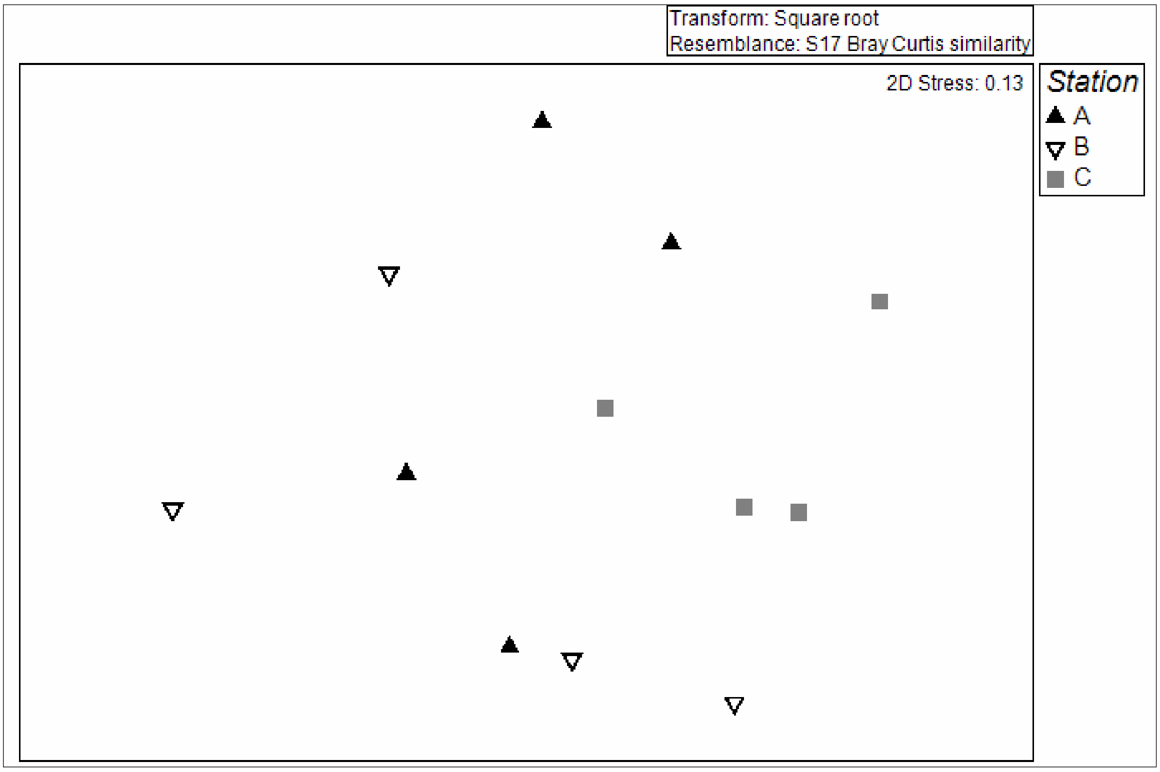

Figure 5. An MDS plot of Bray-Curtis similarity based on square root transformed data of biomass at stations A, B and C.

The finding from this study (based on univariate analysis) was in accord with the other studies (e.g. Brown et al 1987; Pocklington et al 1994; Mazzola et al 2000; Giles 2008) which recorded the negative impacts of aquaculture activities on benthic community structure in coastal areas. The impacts are mainly due to the sedimentation of waste feed pellets and fish faecal matter from the cage. These waste matters are commonly associated with the effect of increase in sediment organic matter, organic carbon, nitrogen, particulate acid-volatile sulfides (AVS), and would subsequently reduce macrofaunal biodiversity (Hargrave 2010). Conversely, the multivariate analysis which showed no significant difference of benthic community structure between stations might suggest the effect of waste matters from the fish cage have been minimised by the hydrodynamic properties of the study area. As shown in the sediment composition (where the fish farm imposed no impact due to wave and current factors), it is equally possible that the impacts on benthic community structure had been weighed down by the wave and current forces. However, the 'non-impacted' characteristic showed by multivariate analysis might also be misleading. This is due to the MDS plot for both abundance and biomass (Figure 4 and Figure 5) were constructed with a stress value of > 0.1; which, according to Clarke & Warwick (2001), such value could possibly give inaccurate misinterpretation.

Biological traits analysis. The species trait-by-sample matrix constructed in Biological Traits Analysis is subjected to multivariate analysis only. The MDS ordination shows that samples from station B recorded a greater dispersion from samples of stations A and C (Figure 6). The difference of station B from two other stations is shown in ANOSIM test (Table 3), where the pair-wise comparison involving station B recorded a greater R-value (means low similarity). In addition, the ANOSIM test also showed that station B was significantly different from stations A and C, while no significant difference was recorded between stations A and C. A further analysis using SIMPER program revealed that the trait that contributed the most to the dissimilarity between stations was the 'Thread-like' body form. The taxa *Magelona mirabilis* and Glyceridae which have a strong affinity to this trait were the most dominant taxa at station A and station C respectively. In contrast, the taxon Hesionidae which was the most dominant at station B has no affinity to this trait.

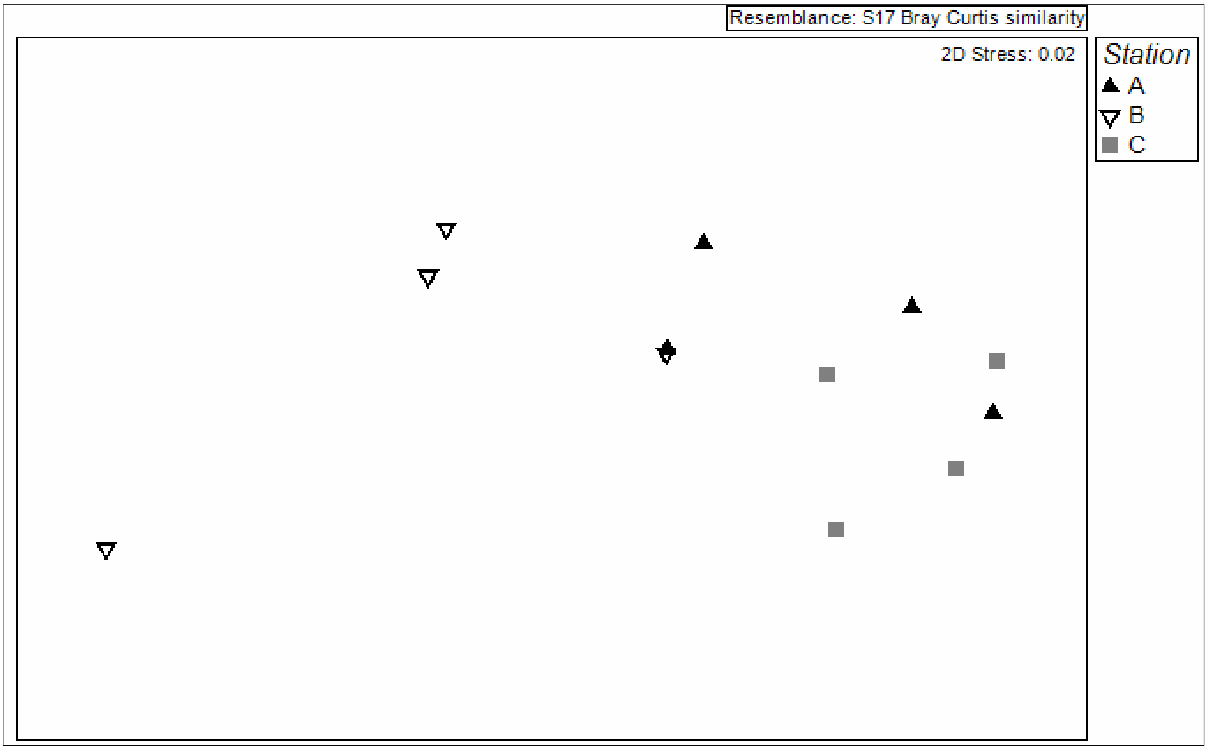

Figure 6. An MDS plot of Bray-Curtis similarity of BTA at all stations in the study area.

Table 3

Summary of R-values derived from ANOSIM test based on value of Biological Traits Analysis

Pair-wise comparison	*R-value*
Station A vs. Station B	0.417*
Station A vs. Station C	0.083
Station B vs. Station C	0.667*

* Denotes significant difference at $p < 0.05$.

It is increasingly accepted that the measurement based on the community structure could not accurately explain the functional status of the communities (Diaz & Cabido 2001). Therefore the use of index such as BTA that accommodates the functional capacity of the ecosystem is of a great complement (Bremner et al 2006; Bolam & Eggleton 2014; Cooper et al 2008; Wan Hussin et al 2012). BTA uses multiple functional traits of benthic community and thus is useful to show the link between organisms and the environment. The present study showed that the fish farming activity had, to some extent, impacted the functions of benthic community, which can be related to the impacts on benthic ecosystem function. This was in contrast to the multivariate measures of abundance and biomass which recorded no impact. However, the limitations of BTA need to be taken into account should the assessment to be done based on functional capacity of the ecosystem. There is a wide range of benthic traits which can be used, but to select a few most important and meaningful traits can be challenging. Similarly, exclusion of certain traits could give inaccurate explanation on describing influence of certain traits on the whole community (Bremner et al 2006).

Conclusions. The study suggests that the fish farm in Bidong Island would be detrimental to benthic community and ecosystem function. However, the discrepancies recorded between different indices indicated there was no definite conclusion as to suggest the extent to how severe the impacts were. For managerial purposes, it is impractical to use all the indices to determine the recovery of an area after disturbance. Therefore the index selection should reflect the purpose of study. In addition a more comprehensive and longer study has to be carried out to understanding this trend.

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