ORGANIC ENRICHMENT OF SEDIMENTS: A CASE STUDY AT MARICULTURE SITE, PEGAMETAN BAY BALI, INDONESIA

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ABSTRACT

Mariculture industry has been developed progressively in Indonesia, where its impact on the surrounding aquatic environment is inevitable. The particulate wastes produced such as excess food and feces will be discharged from a marine farm and dispersed into the surrounding areas. This process could lead to organic enrichment of the receiving seabed sediment and gradually degrade water quality and disturb local benthic community as well as the aquatic ecosystem of the area. This study focused on determining the level of organic enrichment of sediment underneath four currently-active farms in Pegametan Bay, North Bali, Indonesia. The results showed that high accumulation of organic matters was evident in all sampling farms indicated by a significantly high particulate organic matter (POM) between 75.20 ± 2.57 and $92.97 \pm 0.59\%$, and low redox values between -217.41 ± 2.74 and -343.57 ± 1.48 mV. A visual-based assessment also determined that the sediment had a silt and muddy texture with deep grey to black colorization with noticeable strong H_2S odor. In this case, further investigations and monitoring efforts are needed in the near future to ensure the best management programs for sustainable farming and ecosystem both fish farmers and environmental regulators such as local government.

KEYWORDS: mariculture; organic enrichment; Pegametan Bay; sediment assessment

INTRODUCTION

Mariculture contributes significantly to supply the growing demand for seafood products, considering the relatively stagnant production from wild fish capture and high demand for seafood products. However, increased fish production from mariculture has raised concern over its socio-economic impacts and more importantly environmentally-related issues (Paez-Osuna *et al.*, 1999; Costanzo *et al.*, 2004; Samocha *et al.*, 2004). Fish culture depends on the optimum condition of water quality usually found in unpolluted and preferable-selected sites. On the other hand, fish culture generates significant amounts of effluents such as feces, uneaten feed, and by-products such as disinfectant, medications, and antibiotics which could degrade the said environment (Caroll *et al.*, 2003).

When entering the water column, solids, and dissolve wastes generated from mariculture undergo a series of physical and chemical changes. Solid wastes may accumulate on the seafloor and directly affect the sediment texture, mineral consistency, and benthic community (Buschmann *et al.*, 2009; Soto & Norambuena, 2004). Organic-rich and soluble inorganic materials, such as nitrogen, phosphorus, and carbon, would have direct impacts on the growth of planktonic and benthic algae. When condition permits, it could lead to algal blooms that can create a systemic effect on other tropic webs (Black, 2001; Buschmann *et al.*, 2009).

In Indonesia, assessments on mariculture practices and their potential impacts to the surrounding environment are generally available in the literature. For example, the effects of mariculture sites were discussed by several authors such as Hanafi *et al.* (2006), Sutarmat *et al.* (2014), Septory *et al.* (2016) ranging from water quality degradation, farming zonation, and integrated multi trophic aquaculture (IMTA). In Pegametan Bay which was selected as the study site, mariculture impacts in was discussed by

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Slamet *et al.* (2008) through estimation of effluents released by hatcheries operating on the coastline and Tammi *et al.* (2015) who analyze the trophic state of the waters using TRIX index. However, non of these studies had investigated the accumulation of solid wastes and its effects on the sediments characteristics yet.

This study aimed to determine sediment characteristics receiving continuous solids wastes from fish farms in Pegametan Bay by measuring its amount of organic enrichment and observing its benthic' biological characteristics. This information is needed to fill the knowledge gaps regarding the continuing degradation of Pegametan Bay area as mariculture zones and to devise a better management plan for a sustainable mariculture activity in the area.

MATERIALS AND METHODS

Study Sites

This study was conducted in Pegametan Bay, Buleleng District, Bali Province, Indonesia from January to February 2017 (Figure 1). Four fish farms were selected as the sampling locations considering that they were the most productive mariculture operation out of 30 farms operated in the area (Figure 1). The first two farms (farm-1 and 2) have rectangular net cages used to culture grouper and the other two were circular net cages used to culture barramundi (farm-3 and 4).

Sampling Methods

There were four sampling stations for each farm distributed as follows: Station-1, located directly underneath the operating net cages. It was assumed that this area was first area to receive waste from the active-operating cages; Station-2: located between two active-operating cages. It was predicted that substrates in this area were still potentially affected by the released waste; Station-3: located about 50 m from the active-operating cages and in the path of the dominant current direction from the farm to detect the waste coverage area; Station-4 (reference site): located ≥ 100 m or more serving as a reference site to compare the sediment type with the other stations. In each station, at least three cages taken and used as replications. In total, there were 24 sampling points used in the study.

Sediment corer made from 20 cm long polyvinyl chloride tubes with 3-inch internal diameter was chosen as the instrument to collect sediment samples. The sediment corer was manually pressed down to the undisturbed substrate until reaching the maximum depth and then carefully lifted. When lifting the corer, the lid was placed on the opening to hold the collected substrate. The samples were kept in clipped plastic bags, labeled and transported to the Laboratory of Water Chemistry of the Institute for Mariculture Research and Fisheries Extension (IMRAFE) for further analysis.
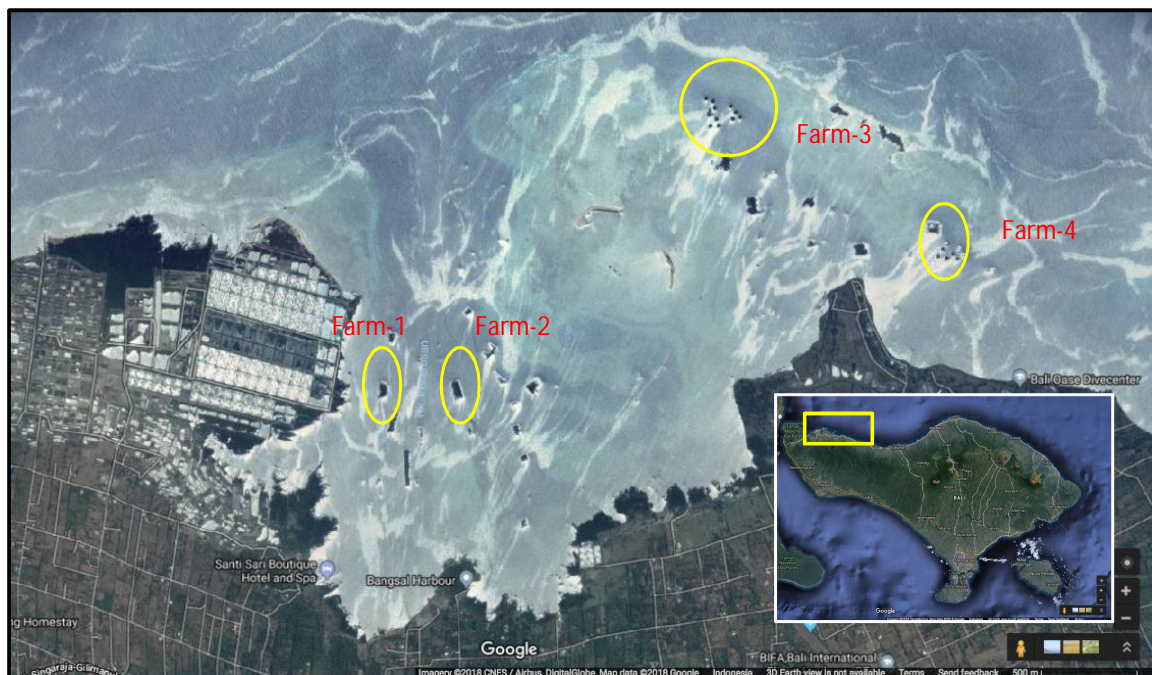

Image sources: Google earth (2018)

Figure 1.   General view of selected sampling cage in Pegametan Bay, Bali.

Measured Variables and Data Analysis

The sediment sample characteristics were determined using two main methods: organic nutrient assessment and visual observation.

Organic nutrient assessment

Based on their organic contents, sediments are classified as cohesive (mainly organic) material and non-cohesive (mainly mineral) material (Chanson, 1999). Sediment enrichments generated by aquaculture waste are mainly organic, yet the following variable parameters were assessed: 1). Particulate organic matter (POM) and minerals. The contents of POM and mineral in the samples were determined using loss on ignition methods by Dean (1974) and Hieri *et al.* (2001); 2). Redox potential values, were analized using RedOx meter, which was inserted in the top of the corer. pH and electrode potentials were recorded at 0.5-1 cm depth; 3). The water depth was measured using an echo depth sounder instrument.

The environmental parameters were analyzed using univariate statistics. Two-way analysis of variance (ANOVA) was used to test the significance of the differences among farms and stations. Tukey's HSD test was then employed when a difference between means was detected. The level of significance was $P < 0.05$.

Visual observation

Visual and direct scoring methods were used to determine the basic physical condition of the collected sediments, i.e. particle size, color, odor, and organism incidence as proposed by Kusnierz *et al.* (2013). The sediment was evaluated directly after collection by at least three individuals using scoring sheets for several substrate parameters as follows: 1) predominant color (SD= sandy white, G= grey or DG= dark grey/black); 2) H_2S odour (N/A= no, W= weak, M= moderate or S= strong); 3) macro organism presence (N/A= absent, LF= less found (< 5 ind.), MF= moderate found (5-10 ind.), A= abundance (> 10 ind.)); 4) macro benthic organism (N/A= absent (0%), S= sparse (<10%), M= moderate (10%-40%), H= heavy (40%-75%), VH= very heavy (> 75%) from 1 m^3 quadrant areas); and 5) sizes of substrate particles (Sd= coarse sand dominant (> 2 mm) or Si= silt dominant (< 2 mm)).

RESULTS AND DISCUSSION

Organic Nutrient Assessment

This study had detected an incidence of organic enrichment on the seafloor under and near to the operated-cages of the four farms in Pegametan Bay.

The data showed that the POM values of the sediments were considerably high (between 75.0 ± 2.7 and 92.97 ± 0.59%), while minerals were low in values (from 4.1 ± 0.37 to 18.91 ± 1.53%). ANOVA displayed no significant differences between POM and minerals values founded in those four selected farms (Figure 2). Redox potential values indicated significantly different between farm 2 (-297.5 ± 2.0 mV) and other farms (-217.41 ± 2.74 mV; -347.91 ± 1.02 mV; and -343.57 ± 2,58 mV for farms-1, 3, and 4, respectively). These general figures signified that the sediment in Pegametan Bay had substantially high organic nutrient content, and the organic material was widely dispersed throughout the Pegametan Bay areas.

Organic enrichment process may widely vary based on several factors, such as flushing ability of the local recipient water column, assimilation capacity with other matter in water environment, specific area characteristics (topography, bottom depth, and currents patterns), and fish farm management practices (feeding rates and stocking densities) (Ackefors & Enell, 1994; Axler *et al.*, 1996; Caroll *et al.*, 2003; Kelly *et al.*, 1996; Wu *et al.*, 1995).

Pegametan Bay has been designated and used for mariculture activities since late 80's. The lengthy production periods added with relatively high stocking density may be the main reasons for the high organic accumulation level in the sediment of this bay. In terms of productions, farm-3 and 4 were identified as barramundi farms which have shifted to an intensive farming system operating with in higher stocking density stock, greater feeding rate, and frequency, when compared to the relatively lower input of farm-1 and 2 that which were producing grouper. Magill *et al.* (2006) documented that intensive culture for barramundi may accumulate produce by-product waste that settles on the seafloor of the receiving area with a sedimentation rate started ranging from 0.10 to 6.27 cm/s in the seafloor of receiving areas. While for grow-out grouper culture in Pegametan Bay, Sutarmat *et al.* (2014) calculated that between 69% and 85% of N and P, which accounted for 363 kg of total nitrogen and 76 kg of total phosphor/ton of fish/day, were released to the surrounding environment from each productive farm.

The sediments underneath and around farm-2, 3, and 4 were detected to have significantly different POM values. The POM values were also varied between potentially impacted stations (station-1, 2, 3) and reference station (station-4) (Figure 3). All sampling stations in farm-1 have the lowest POM values compared to those of other farms ranged from 78.64
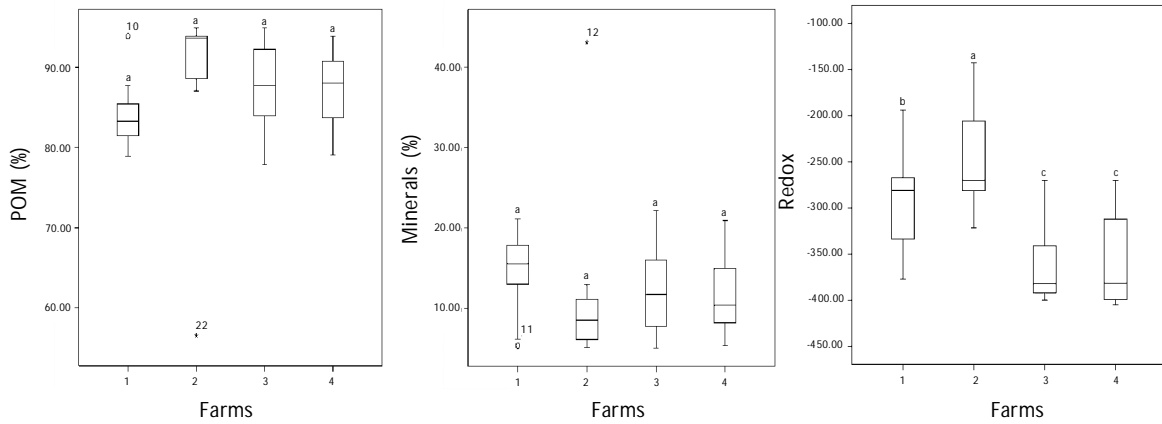
Figure 2. Mean ± SE of POM, minerals, and redox values collected from four sampling farms in Pegametan Bay. Different superscript letters show significant differences between farms (P < 0.05).

± 2.57% in station-4 to 85.61 ± 0.45% in station-1. These numbers are closed to values of POM in station-1, 2, and 3 of other farms (≥ 80%), except in reference stations).

Mineral values displayed an opposite trend compared to POM values. Minerals values were considered fairly low, accounted below 25% (Figure 2 and 4). Stations located just under and close to the cages have lower mineral values (station-1, 2, and 3), which

was confirmed by no significant differences in the statistical analysis among stations, compared to the reference station (station-4). Station-4 as the reference station had the highest mineral level among all stations in four sampling sites (from 15% to 25%).

The fact that station-1, 2, and 3 have high POM values and lower mineral values than station-4 indicate that the organic enrichment to sediment started from the center area directly underneath of culture
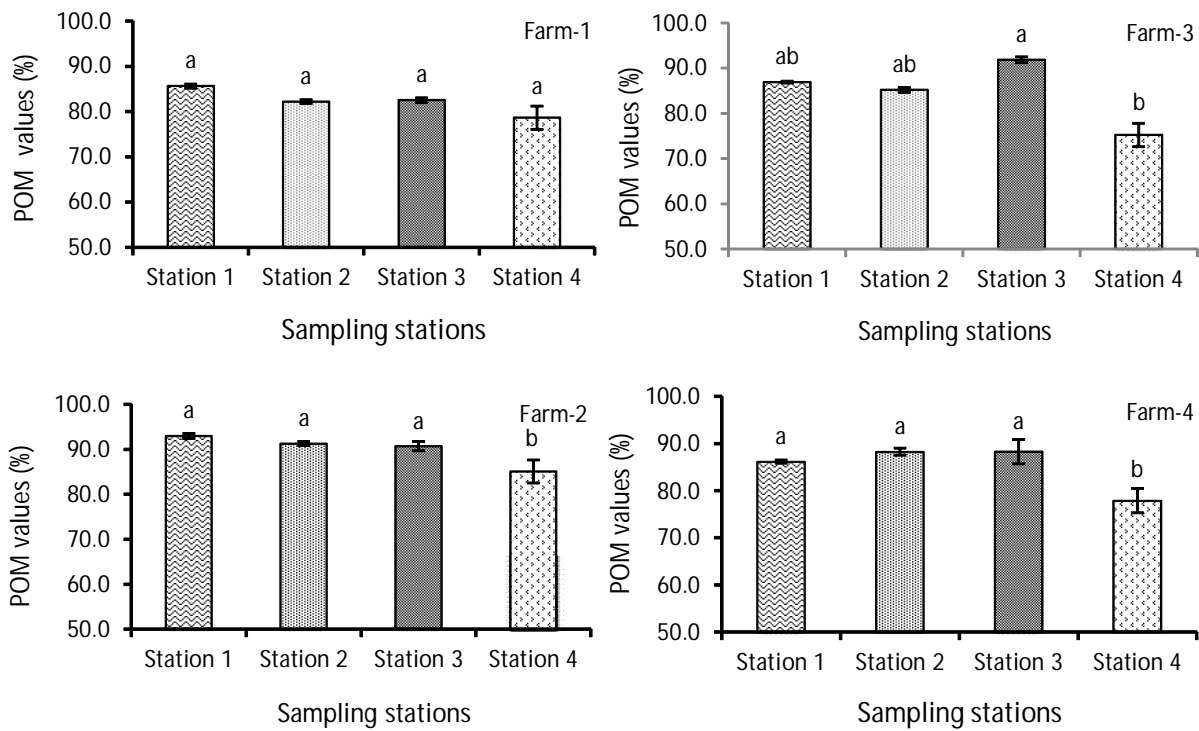

Figure 3. Mean ± SE particulate organic matter (POM) values collected from selected stations of the four farms. Different letters above each bar show significant differences between sampling stations (P < 0.05).
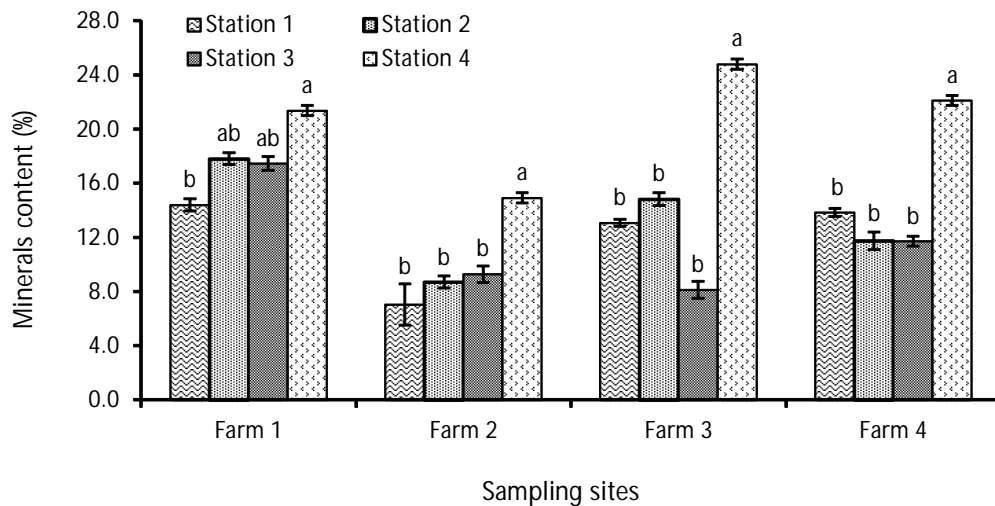
Figure 4. Mean ± SE minerals values collected from selected stations of four sampling farms. Different letters above each bar show significant differences between sampling stations in each farm (P< 0.05).

cage and gradually distributed to the surrounding areas. Mente *et al.* (2006) classified that there were four profile zones may be created from intensive cage culture: (1) an azoic zone, which located under the cages; (2) a highly-enriched zone, located 0-8 m from the edge of cage; (3) a slightly enriched transitional zone, located between 8 m and 25 m from the cages; and (4) a normal zone beyond that.

Even though organic matters depositions tend to be higher in depth between 10-20 m and lower in the deeper elevation of substrate, scatter plot data of the depth and POM values suggest that there is no distinct correlation between water depth and deposition values of organic materials rate (Figure 5). Pegametan Bay is located in the sheltered coastal waters with relatively shallow waters (9 to 25 m depth) and considerably low currents. In this case, solid wastes generated from aquaculture platforms tend to settle at the base of the net cage due to lower chance for water mixing and a higher rate for sedimentation.

Redox potential values were significantly low (-152 to -401 mV) from all sampling stations in all selected farms (Figure 6). This suggests that the oxygen level in the sediment was below 1 mg O_2L^{-1} meaning that oxygen consumption rate was high and phosphorous ion released, or it was performing anoxic process. A lower degree of redox potential tends to occur when finer sediment with high organic matter content, accumulate more than coarse sediment (Viaroli *et al.*, 2004). In farm-1 and 2, all stations have no statistical difference, though the values in station-4 are slightly higher than the remaining stations. Farm-

3 and 4 displayed a significant statistical difference between reference and potentially impacted stations. Overall, the area under the cage (station-1) has the lowest values of redox potential compared with three other stations, where as stations-4 in each farm has the highest values of potential redox. The values of sediment redox potential may also depict the correlation between organic content and benthic assemblage fauna structure (Porrello *et al.*, 2005).

Visual Observation

Visual assessment of sediment characteristics and benthic community validates that the farms' solid wastes have influenced the sediment characteristic underneath and surrounding the farms (Table 1). Scoring results show that the substrate in Pegametan Bay was dominated by sandy silt with predominant colors from grey to black indicating that this area receives continuous organic enrichment. Substrates from station-1, 2, and 3 from all farm areas have noticeable H_2S odor ranging from weak to moderate level suggesting an ongoing oxidation process. Macroorganisms were absent in all sampling stations excluding station-4 of farm-1 and 2. Station-4 of farm-1 and 2 have the lowest level of organic enrichment in which microorganism were present such as crustacean larvae, sea star larvae, and juvenile of crabs.

CONCLUSION

This study has identified and provide the evidences that the seabed underneath and surrounding four of the most productive farms in Pegametan Bay had undergone organic enrichments. The organic matter
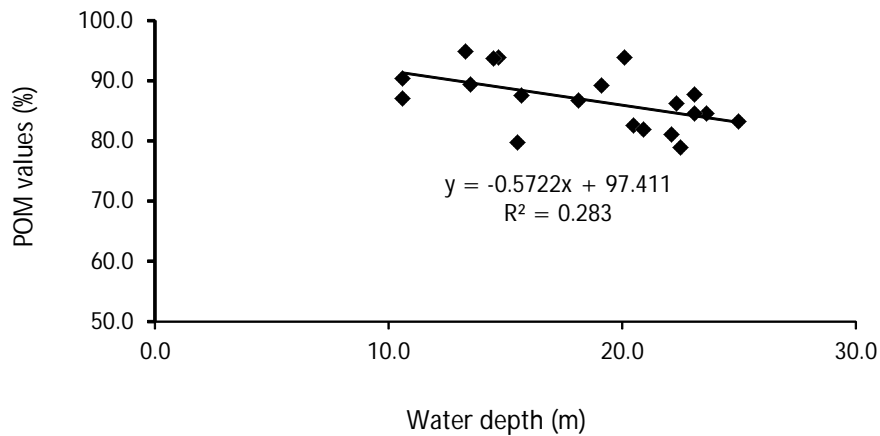
Figure 5. Plots of particulate organic matter (POM) values in relation with deposition of sedimentation substrate in Pegametan Bay (n= 24 stations).
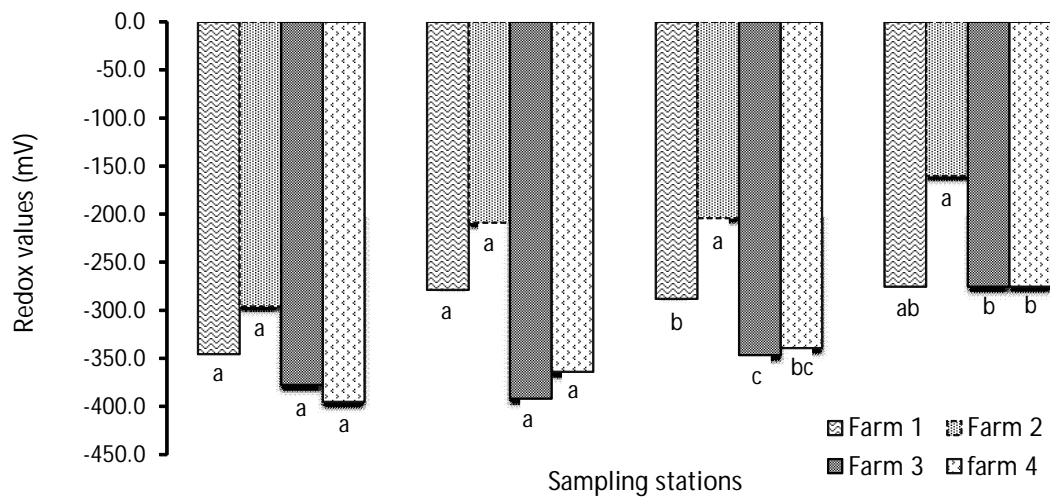

Figure 6. Mean ± SE redox potential values collected from selected stations of four sampling farms. Different letters under each bar show significant differences between sampling stations in each farm (P<0.05).

accumulations in the seafloor sediments were indicated by the high content of POM, low value of mineral, and redox potential as well as alteration of several physical sediment characteristics. The accumulation of organic matter in the sediment was detected in all sampling stations starting from the center area underneath the fish cages to 200 m outward. Future studies regarding the extent of the organic enrichment impacts to benthic communities are needed in order to fully understand the site-specific responses of the organism to the prolonged organic enrichment.

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Table 1.   Scoring result of sediment characteristics from sampling stations underneath four farms in Pengametan Bay

Farms code	Stations	Grain size	Predominant color	H$_2$S odor	Macroorganism	Macrobenthic plant
Farm-1	1	Silt	Grey	Moderate	N/A	N/A
	2	Silt	Grey	Moderate	N/A	N/A
	3	Silt	Grey	Moderate	N/A	N/A
	4	Coarse sand	Grey	N/A	< 5 ind.	N/A
Farm-2	1	Silt	Dark grey	Moderate	N/A	N/A
	2	Silt	Dark grey	Strong	N/A	N/A
	3	Coarse sand	Grey	Medium	N/A	N/A
	4	Coarse sand	Grey	N/A	< 5 ind.	N/A
Farm-3	1	Silt	Dark grey	Strong	N/A	N/A
	2	Siilt	Dark grey	Strong	N/A	N/A
	3	Silt	Dark grey	Strong	N/A	N/A
	4	Silt	Grey	Medium	N/A	N/A
Farm-4	1	Silt	Dark grey	Strong	N/A	N/A
	2	Silt	Dark grey	Strong	N/A	N/A
	3	Silt	Grey	Strong	N/A	N/A
	4	Silt	Grey	Strong	N/A	N/A

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