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Mangrove Vegetation and Sediment Type Influences on Macrobenthic Infauna in Overwashed Mangrove Ecosystems: A Case Study from Pari Islands, Jakarta, Indonesia

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ABSTRACT

Mangrove vegetations and sediment types influence the community structure of macrobenthic infauna in mangrove ecosystems. Those effects are mostly studied in riverine and fringing mangrove ecosystems, with no attention on overwashed ones. The present study analysed effects of mangrove vegetations (i.e. total area, coverage, and density) and sediment types (i.e. gravel, sand, silt, and clay) on macrobenthic infauna (i.e. total abundance, richness, and taxa composition) in the overwashed mangrove ecosystem of Pari Islands, Jakarta, Indonesia. Mangrove area was calculated based on Geographical Information System and remote sensing satellite data, while coverage and density were quantified using a quadratic plot of 10x10 m. Sediment and macrobenthic infauna samples were collected using a hand corer with covering an area of about 0.02 m^2. Effects of mangrove vegetations and sediment types on total abundance and richness were analysed using Generalised Linear Mixed Model, while those on taxa composition were analysed using Redundancy Analysis. Results showed that mangrove vegetations did not provide significant effects on macrobenthic infauna. In contrast, both clay and gravel significantly influenced total abundance and taxa composition but not richness. Therefore, sediment types were more influential than mangrove vegetations in structuring macrobenthic fauna in the overwashed mangrove ecosystems.

Key words: mangrove vegetation, sediment type, macrobenthic infauna, overwashed mangrove ecosystems, Pari Islands, Indonesia

INTRODUCTION

It has been acknowledged that mangrove ecosystems provide ecological services to the coastal area. They are not only involved in carbon dynamics but also provide suitable habitats for a wide variety of marine organisms (Brander *et al*., 2012; Lee *et al*., 2014). Many fishes, shrimps and crabs in any development stages from larvae to mature live in the water column. In the sediment, many invertebrates are found abundantly in many behavior types (e.g. epifauna and infauna) as well as body sizes (e.g. meiobenthos and macrobenthos) (Nagelkerken *et al*., 2008).

In the sediment of mangrove ecosystems, macrobenthic infauna mainly act as deposit feeders. They are directly involved in biogeochemical processes, especially in carbon dynamics (Kristensen *et al*., 2008; Lee, 2008). Therefore, the community structure of macrobenthic infauna is often used as one of the bioindicators for mangrove management (Ellison, 2008; Haryadi *et al*., 2014).

The community structure of macrobenthic infauna is composed of various species and often dominated by Polychaeta (Netto & Gallucci, 2003; Samidurai *et al*., 2012; Melo *et al*., 2013). However, it can differ among locations depending upon the characteristic of macrohabitats (e.g. mangrove vegetations) and microhabitats (e.g. sediment types). Some influential parameters of mangrove vegetations are total area, coverage, and density (Chen *et al*., 2015; Checon *et al*., 2017), while those of sediment types are the proportion of grain sizes, such as gravel, sand, silt, and clay (Melo *et al*., 2013; Thilagavathi *et al*., 2013).

Effects of mangrove vegetations and sediment types on macrobenthic infauna are studied more in the riverine (Nordhaus *et al*., 2009; Kon *et al*., 2011; Basyuni *et al*., 2018) and fringing mangrove ecosystems (Checon *et al*., 2017), with no report on the overwashed ones.Riverine, fringing, and overwashed mangrove ecosystems are often different in the species composition of vegetations and the type of sediments due to the difference in environmental drivers. Overwashed mangrove

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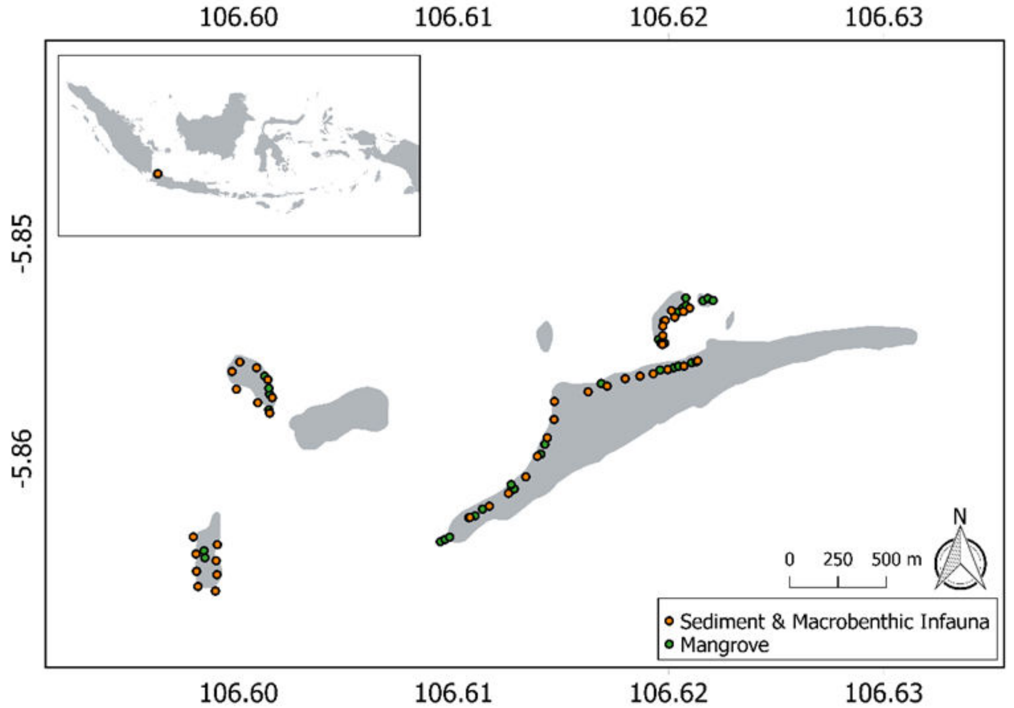

Figure 1. Sampling sites of mangrove vegetations, sediment, and macrobenthic infauna in the study location

ecosystems are a mostly small area, composed of fewer mangrove species due to no zonation, coarser sediments, and low organic detritus due to the strong effect of tidal activities (Lugo & Snedaker, 1974; Sukardjo, 2006; Rodriguez *et al*., 2009). As a result, the contribution of mangrove vegetations on the productivity of below-ground of overwashed mangrove ecosystems is often low (Nurrahman & Nurdjaman 2018). Thus, influential factors on macrobenthic infauna in the overwashed mangrove ecosystems may differ from those in the riverine and fringing ones. Mangrove vegetations may also be less influential than other factors in affecting macrobenthic infauna.

Pari Islands are one of the small islands in Jakarta, Indonesia. These islands consist of five smaller islands: Pari Island, Burung Island, Kongsi Island, Tikus Island, and Tengah Island. Overwashed mangrove ecosystems are found entire these islands with different vegetation species (Sukardjo, 2006). Macrobenthic infauna in the mangrove ecosystem of these islands are also not studied yet. Hence, these islands are one of the appropriate locations for studying effects of mangrove vegetations and sediment types on macrobenthic infauna in the overwashed mangrove ecosystems.

This study aimed to analyse: (1) effects of mangrove vegetations (i.e. total area, coverage, and density) and sediment types (i.e. the proportion of gravel, sand, silt, and clay) on the community structure of macrobenthic infauna (i.e. abundance, species richness, and species composition) in the mangrove ecosystem of Pari Islands, and (2) whether mangrove vegetations or sediment types which are more influential in affecting the community structure of macrobenthic infauna.

MATERIALS AND METHOD

Study area

Pari Islands are reef islands with a lagoon, located in the Java Sea, Indonesia (5°54'26.64" S, 106°35'11.04" E). These islands are composed of five small islands: Pari Island, Tengah Island, Kongsi Island, Burung Island, and Tikus Island, with the total area of about 83.04 ha. Pari and Tengah Island are occupied with the total population of 930 people, while others are not inhabited. Pari Islands are surrounded by three major coastal ecosystems, i.e. mangrove (Sukardjo, 2006), seagrass (Husodo *et al*., 2017), and coral reef (Anggoro *et al*., 2015). The type of mangrove ecosystems in the Pari Islands is overwashed mainly composed of three mangrove species, i.e. *Rhizophora stylosa*, *Avicennia marina*, and *Heritiera littoralis*(Sukardjo, 2006). However, there is a massive reclamation in the Tengah Island causing substantial losses of mangrove area.

Sea surface temperatures around Pari Islands fluctuates semi-annually between 28.39°C (October-November) and 32.58°C (July) depending upon the sun position, water current, and rainfall (Nababan, 2016). The velocity of the surface water current around Pari Islands is about 0.0138-0.4082 m/s, and its directions are determined by local winds during tidal activities. The south-westerly current occurs during the high tide, while the northeasterly current occurs during the low tide (Aunillah *et al*., 2014; Putri *et al*., 2017). The type of tidal activities around Pari Islands is diurnal, with the low tidal range about 0.5 m (Putri *et al*., 2017).

Data collection

Observation design

Macrobenthic infauna, mangrove vegetations, and sediment types in the Pari Islands were studied in five stations: Pari Island (St. 1 and St. 2), Kongsi Island (St. 3), Burung Island (St. 4), and mangrove cluster (St. 5). Data of sediment types and macrobenthic infauna were collected in March 2013, while those of mangrove vegetations were collected in February 2018. We assumed that the condition of mangrove vegetations in 2018 did not differ substantially from that in 2013. It is because there was no extreme events or mangrove destructions in those stations during that period.

Macrobenthic fauna data

Macrobenthic infauna data collected were total abundance, species richness, and species composition. Macrobenthic fauna were sampled at eight sites at each of stations (Figure 1) during the low tide when the water depth was about 10 cm. Sediment samples were collected to a depth of about 15 cm using a hand corer with covering an area of about 0.02 m^2. In the field, those samples were sieved through a 0.5 mm mesh size then fixed using 10% formaldehyde-seawater solution. In the laboratory, those samples were washed using freshwater to remove salt that might attach to the fauna. Macrobenthic infauna were sorted under a binocular stereoscopic microscope with the magnification of 6.5 times into five taxa group: Polychaeta, Mollusca, Crustacea, Echinodermata, and minor phyla. Macrobenthic infauna were identified until the lowest taxon possible based on external morphologies and preserved in the 96% ethanol.

Mangrove vegetations

Mangrove vegetation data collected were total area, coverage, and density. Total area was estimated using Geographical Information Systemand remote sensing satellite data acquisitioned on 13 May 2017. Digital interpretation with unsupervised classification method was used to process the map. The classification employed four spectrum bands of satellite imagery: blue, green, red, and near-infrared. Near-infrared spectrum can discriminate mangrove and non-mangrove vegetations because those vegetations have different reflectance levelson internal leaf structures (Kuenzer *et al*., 2011; Kamal *et al*., 2015).This process produced a digital map of mangrove distribution thus its total area could be calculated.

Density and coverage data were collected from 36 sites (Figure 1) based on three quadratic plots of 10x10 m at each site. Density was quantified by individually counting the number of vegetations at each plot, while coverage was determined using a hemispherical photography technique following (Dharmawan & Pramudji, 2017). At each plot, forest canopy was semi-circularly photographed around 4-9 times. Each photo was converted into an 8-bit-color mode, properly counted the number of coverage pixels (CP) and the number of total pixels (TP). Coverage was then calculated following the formula:

$$Coverage = \frac{CP}{TP} x100\%$$

Sediment types

Sediment data collected were the relative proportion of grain sizes (i.e. gravel, sand, silt, and clay). About 100 g of sediment samples was collected at the same sites of macrobenthic fauna (Figure 1). At the laboratory, those samples were dried in the oven at 70°C for around 5-7 days until the constant weight was obtained. The dried samples were sieved through a series of mesh sizes (i.e. 8, 4, 2, 1, 0.5, 0.25, 0.125, and 0.063 mm), then the retained samples at each mesh size were weighed. Sediment types were determined based on the Udden/ Wentworth grade scale following these criteria: gravel (4 -8 mm), sand (0.125-2 mm), silt (0.063-0.125 mm), and clay (<0.063 mm) (Bale & Kenny, 2005). The relative proportion of those sediment types was then calculated.

Data analysis

Relationships between each of univariate data of macrobenthic infauna (i.e. total abundance and species richness), mangrove vegetations (i.e. total area, coverage, and density), and sediment types (i.e. the relative proportion of gravel, sand, silt, and clay) were analysed using Generalised Linear Mixed Model (GLMM) (Bolker *et al*., 2009). In these analyses, the station was treated as a random factor.

Relationships between multivariate data of macrobenthic infauna (i.e. species composition), mangrove vegetations, and sediment types were analysed using Redundancy Analysis (RDA) with 999 permutations (Borcard *et al*., 2018). Prior to analyse, macrobenthic fauna data were transformed using the Hellinger distance to meet multivariate normality assumption (Legendre & Gallagher, 2001). Mangrove and sediment data were standardised using z score technique to put data onto the same scale. Thus, the effect of mangrove vegetations and sediment types on the species composition of macrobenthic fauna was comparable (Legendre & Legendre, 1998).

All statistical analyses were performed using R software (R Core Development Team, 2016) with following packages: vegan for RDA analysis (Oksanen *et al*., 2016) and glmm for GLMM analyses (Knudson, 2015).

RESULTS

The community structure of macrobenthic fauna

Overall, 434 individuals of macrobenthic infauna belonging to 44 morphologically distinct taxa were collected in this study. Polychaeta was the most dominant group regarding abundance (359 individual or 83% of total individuals) and richness (28 taxa or 64% of total taxa). Juveniles of Capitellidae (Polychaeta) was the most abundant (106 individuals or 24% of total individuals). This taxon was also the most frequent about 70% of total sites, followed by *Mediomastus* sp. about 57.5% of total sites and *Prionospio* sp. about 47.5% of total sites. Others (41 taxa) were only found in less than 30% of total sites.

Mangrove vegetations and sediment types

In total, mangrove area in the Pari Islands was about 16.9 ha (19.98% of total area of Pari Islands) and showed

Table 1. Ranges and means of mangrove vegetations and sediment types in the study location

	Range	Mean ± Standard Deviation
Mangrove vegetations		
Area (ha)	0.27 – 2.69	1.36±0.81
Coverage (%)	74.44 – 86.59	81.03±4.25
Density (tree/100 m^2)	18 – 32	25.4±5.49
Sediment types		
Gravel (%)	0 – 3.44	0.85±1.09
Sand (%)	62.88 – 94.98	83.37±9.18
Silt (%)	2.87 – 25.6	8.95±5.31
Clay (%)	1.91 – 17.33	6.84±4.60

Table 2. Pearson correlation coefficients among mangrove vegetations and sediment types. The superscript of "ns" means non-significant correlation (p>0.05), while the asterisk symbol (*) means significant correlation (p<0.05)

	Area	Coverage	Density	Gravel	Sand	Silt
Area						
Coverage	-0.08^{ns}					
Density	0.48*	-0.85*				
Gravel	-0.71*	0.26^{ns}	-0.39*			
Sand	0.09^{ns}	-0.14^{ns}	-0.05^{ns}	-0.55*		
Silt	0.24^{ns}	-0.18^{ns}	0.40*	0.10^{ns}	-0.85*	
Clay	-0.29^{ns}	0.42*	-0.26^{ns}	0.75*	-0.89*	0.51*

Table 3. Coefficients associated between macrobenthic fauna, mangrove vegetations, and sediment types in the mangrove ecosystem of Pari Islands. NA means not available. The superscript of "ns" means non-significant correlation (p>0.05), while the asterisk symbol (*) means significant correlation (p<0.05)

	Macrobenthic Fauna		
	Abundance	Richness	Taxa Composition
Mangrove vegetations			
Area	0.053^{ns}	0.26^{ns}	NA ^{ns}
Coverage	0.077^{ns}	-0.02^{ns}	NA ^{ns}
Density	0.013^{ns}	-0.04^{ns}	NA ^{ns}
Sediment types			
Gravel	0.457*	0.11^{ns}	NA *
Sand	-0.043^{ns}	0.04^{ns}	NA ^{ns}
Silt	-0.006^{ns}	0.04^{ns}	NA ^{ns}
Clay	-0.153*	0.05^{ns}	NA ^{ns}

variations within islands (Figure 2). Coverage was high about 80% with the density approximately 25 vegetations/100 m^2 (Table 1).

Sediment types in the mangrove ecosystem of Pari Islands were dominantly composed of sand, followed by silt, clay, and gravel. Each island showed high variations in the composition of sediment types (Table 1).

There were significant correlations between mangrove vegetations and sediment types (p<0.05). Positive correlations were found between clay and coverage, as well as between silt and density. In contrast, negative correlations were detected between gravel and both area and density (Table 2).

Significant correlations also occurred within mangrove vegetations and within sediment types (p<0.05). Density positively correlated with area but negatively correlated with coverage. Clay positively correlated with both gravel and silt, while sand negatively correlated with any other sediment types (Table 2).

Relationships between macrobenthic infauna,mangrove vegetations, and sediment types

Mangrove vegetations and sediment types influenced the community structure of macrobenthic infauna in different ways. Mangrove vegetations (i.e. area, coverage, and density) did not provide significant effects on the abundance and richness of macrobenthic infauna (p>0.05). In contrast, sediment types (i.e. gravel and clay) significantly affected the abundance of macrobenthic infauna (p<0.05) but not the richness (p<0.05). More specifically, the abundance of macrobenthic infauna increased with the proportion of gravel but decreased with the proportion of clay (Table 3).

In these analyses, station as a random factor provided non-significant effects on the abundance and richness of macrobenthic fauna (p>0.05). Hence, the effect of stations can be ignored in this study.

Figure 2. Mangrove area around Pari Islands

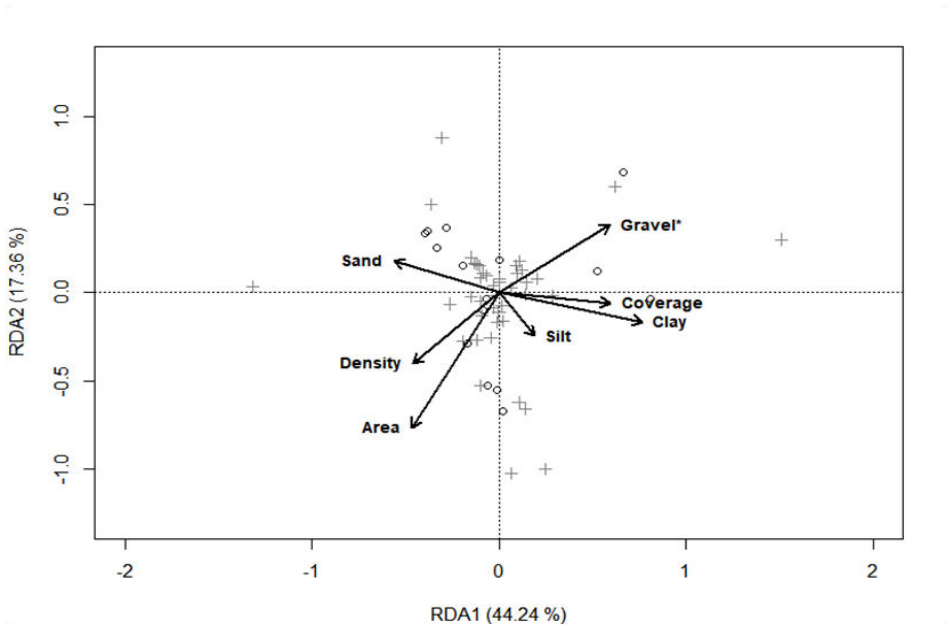

Figure 3. RDA triplot of environmental variables (vector), sites (o), and species (+). Asterisk symbol (*) in the environmental variable showed significant relationship with species composition (p perm<0.05)

In term of multivariate data, RDA biplot explained 61.59% of total variation of macrobenthic infauna, mangrove vegetations, and sediment types in the mangrove ecosystem of Pari Islands (Figure 3). Gravel was the only environmental factor that significantly affected the taxa composition of macrobenthic fauna (p perm<0.05) (Table 1) through significant changes in the abundance of six species. An increase in the proportion of gravel significantly increased the abundance of Capitellidae, Capitellidae juveniles, *Chone* sp., Terebellidae, and *Leptochelia* sp. ($p<0.05$) but significantly declined the abundance of *Mediomastus* sp. ($p<0.05$).

DISCUSSION

Previous studies presented effects of mangrove vegetations and sediment types on macrobenthic infauna in the riverine (Nordhaus *et al*., 2009; Kon *et al*., 2011; Basyuni *et al*., 2018) and fringing mangrove ecosystems (Checon *et al*., 2017). The present study showed those effects on the community structure of macrobenthic fauna in the overwashed mangrove ecosystems, particularly in the Pari Islands, Jakarta, Indonesia. There were two main results: (1) mangrove vegetations (i.e. area, coverage, and density) did not provide significant effects on the community structure of macrobenthic infauna (i.e. abundance, richness, and taxa composition) and (2) sediment types, especially gravel and clay, significantly influenced the abundance and taxa composition of macrobenthic infauna but not the richness.

The present study showed that mangrove vegetations did not provide significant effects on macrobenthic infauna in the overwashed mangrove ecosystems. Compared to riverine and fringing mangrove ecosystems, mangrove area shows significant influences on the abundance of macrobenthic infauna (Chen *et al*., 2015; Checon *et al*., 2017), although those effects are also not significant in the riverine mangrove ecosystems of Brazil (Bernardino *et al*., 2018). Non-significant effects of mangrove vegetations on macrobenthic infauna in the present study can be explained through two possible reasons. Firstly, overwashed mangrove area in the Pari Islands is small despite high coverage. Hence, the total production of mangrove litters is probably insufficient to supply organic detritus for macrobenthic infauna although the litter production in these islands is not studied yet. Secondly, mangrove density in the Pari Islands may be not high enough to reduce the flushing effect of water current and tidal activities. As a result, water current and tidal activities carry organic detritus far away from the mangrove area to the calmer places and did not return them (Lugo & Snedaker, 1974).

In contrast, clay and gravel provided significant effects on the abundance of macrobenthic infauna but in different ways. Clay declined the abundance of macrobenthic infauna, while gravel increased it. Decreases in the abundance of macrobenthic infauna due to the higher clay content are also confirmed previously (Musale & Desai, 2011). Clay has a compact texture that may inhibit the flow of oxygenated surface water into sediments. As a result, an increase in the proportion of clay makes the sediments less oxygenated (Dye, 1983) or even hypoxia (Ferreira *et al*., 2007). Hypoxia negatively influences macrobenthic infauna in many things, including community structure, energy flow, behavior, recovery, and adaptation (Diaz & Rosenberg, 1995). In contrast, gravel has a loose texture providing a lot of interstitial spaces for macrobenthic infauna to colonise. Rapid colonisation of macrobenthic infauna in the coarser sediments has been evaluated through an experimental study in the laboratory (Guerra-García & García-Gómez, 2006) and field (Faraco & Lana, 2006).

Gravel also significantly determined the taxa composition of macrobenthic infauna through two possible mechanisms. The first mechanism is that gravel may regulate the spatial distribution of macrobenthic infauna around mangrove ecosystems. Influences of microhabitat, including sediment types, on the spatial distribution of macrobenthic infauna have been reported in many studies (Hsieh, 1995; Kon *et al*., 2011; Pinto *et al*., 2013). Gravel possibly restrict many macrobenthic infauna to occupy most habitats as shown in the present study that about 90% of macrobenthic infauna only inhabited less than one-third of total sites. At the same time, gravel may also allow doing some replacements by more adaptive taxa. In the present study, the restriction and replacement of taxa seemingly occur in equal numbers. In fact, the present study showed that there was no significant change in the richness of macrobenthic infauna over the gradient in the proportion of gravel. Non-significant effects of gravel on the species richness of macrobenthic infauna are also reported in the other mangrove ecosystems (Melo *et al*., 2013).

The second mechanism is that gravel may differently change the abundance of some taxa. This study showed that the abundance of five taxa i.e. Capitellidae, Capitellidae juveniles, *Chone* sp., Terebellidae and *Leptochelia* sp. increased significantly with the proportion of gravel, while *Mediomastus* sp. showed an opposite trend. Gravel may support the colonisation of Capitellidae and Capitellidae juveniles as confirmed by previous studies (Faraco & Lana, 2006; Guerra-García & García-Gómez, 2006). Gravel may also provide a substratum for the attachment of sand-tube-building macrobenthic infauna, including *Chone* sp., Terebellidae, and *Leptochelia* sp. It is supported by previous studies (Mendoza, 1982; Seiderer & Newell, 1999). However, coarser sediments often contain low organic matters (Wang *et al*., 2016). Therefore, these are probably unsuitable for burrower and deposit feeder species that eat organic matters from sediments, likely *Mediomastus* sp. (Jumars *et al*., 2015). Most species of *Mediomastus* are often found abundantly in the finer sediments with high proportions of silt or clay (Warren *et al*., 1994) due to their capacity to effectively accumulate organic matters (Sebastian &Chacko, 2006).

Gravel and clay are two limiting and substantial factors for macrobenthic infauna in the overwashed mangrove ecosystems. It is because these sediment types significantly affected the abundance and taxa composition of macrobenthic infauna, although their proportions were lower than those of sand and silt. In the riverine and fringing mangrove ecosystems, gravel and clay are not always a limiting and substantial factor for macrobenthic infauna. A previous study showed that the proportion of gravel in the riverine and fringing mangrove ecosystems is lower than that of other sediment types, but it does not provide significant effects on macrobenthic infauna (Melo *et al*., 2013). In contrast, the proportion of clay in the riverine and fringing mangrove ecosystems is often high, while its effect on macrobenthic infauna is not always significant (Schrijvers *et al*., 1995; Samidurai *et al*., 2012; Melo *et al*., 2013; Dissanayake & Chandrasekara, 2014). Hence, in related to macrobenthic infauna, important sediment types in the overwashed mangrove ecosystems differ from those in the riverine and fringing ones.

According to the significant results of the present study, sediment types, especially gravel and clay, are more influential than mangrove vegetations in structuring macrobenthic infauna. Sediment types may directly influence macrobenthic infauna via enhancing the heterogeneity of microhabitats that allows more species to occupy (Kon *et al*., 2011; Pinto *et al*., 2013). In contrast, effects of mangrove vegetations on macrobenthic infauna may be more indirectly through the modification of sediment composition (Adame *et al*., 2010). In fact, the present study showed that there were significant correlations between gravel and total area as well as between clay and coverage, while both gravel and clay have significant effects on macrobenthic infauna. Hence, relationships between macrobenthic infauna and mangrove vegetations may be more complicated involving both direct and indirect interactions.

Overall, the present study provided new insight into important environmental factors that determine macrobenthic infauna in the overwashed mangrove ecosystems. Hence, it enhances our understanding of ecological interactions between those fauna and marine environment in the mangrove ecosystems. As sediment types (i.e. gravel and clay) showed significant effects on macrobenthic infauna, the present study suggests that controlling sedimentation is one of the appropriate ways for managing overwashed mangrove ecosystems. Future studies should analyse the complex interactions between macrobenthic infauna and the mangrove environments through path analyses, such as structural equation modelling (Grace *et al*., 2010).

CONCLUSION

Mangrove vegetations did not provide significant effects on the community structure of macrobenthic infauna. Meanwhile, gravel and clay increased the abundance and changed the taxa composition of macrobenthic infauna although those sediment types did not significantly influence the richness. Thus, sediment types are more influential than mangrove vegetations in determining the community structure of macrobenthic fauna in the overwashed mangrove ecosystems.

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