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Statistical Characterisation of tropical seagrass bed sediment and adjacent unvegetated sediment in Lae-Lae Island of Makassar (Indonesia)

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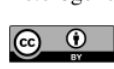
Abstract. The statistical characteristic of sediment is useful in interpretation of the past or future processes acting on the sediments. This paper reports the statistical characteristic of small island sediment taken from seagrass bed and adjacent unvegetated area. Surface sediment samples were collected from four sites using a sediment corer (PVC pipe with a diameter of 6 cm and a length of 15 cm) and dry sieved in the laboratory to determine grain size distribution. The grain size measurement in mm were converted into the phi (ϕ) unit before calculating the statistical parameters of the sediment including mean grain size, sorting, skewness, and kurtosis using a GRADISTAT (a grain size distribution and statistics package for the analysis of unconsolidated sediments). The results show that both seagrass bed sediments and adjacent unvegetated sediments in the study site are characterized by medium to coarse-grained sand fractions, mostly poorly sorted, symmetrical to very coarse skewed, and have platykurtic, mesokurtic, and leptokurtic kurtosis. These findings highlight the practical use of grain size analysis to classify sedimentary environments and elucidate transport dynamics in the Lae-Lae Island.

1. Introduction

Lae-lae Island is one of the coral reef islands in the Spermonde Archipelago, South Sulawesi, Indonesia. Coral reef islands are generally composed of carbonate sediments consisting of various coral fragments, mollusk shells, fish bones, and hard parts of reef-forming organisms and those related to reefs. These sediments are largely supplied by adjacent reefs [1], and a small portion of the remainder is supplied from the mainland.

Erosion, entrainment, transportation, or deposition of reef island sediment is controlled by chemical, physical, and biological characteristics of the sediment particles themselves and also by driving mechanisms acting on the sediments [2]. Sediment characteristics may be changed and be sorted according to size, shape, mineralogy, and density during the erosion, transport, and deposition processes [3]. One important physical characteristics of sediment that can tell us important information about source, transport history, and depositional situation of sediment is particle size [4]. Moreover, sediment particle grain size distribution is also one of the important parameters in developing sediment transport models including the incipient of sediment motion, sediment transport rate, and sediment deposition rate.

Difficulties in characterizing and quantifying various types of sediments make the influence of heterogeneous sediment characteristic on coastal processes is commonly underestimated [5]. So,



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application of a grain size statistical analyses may be an effective way to identify discrete similarities and/or differences between mixed sediment populations.

Moreover, the statistical characteristic of sediment is useful in interpreting the past or future processes acting on the deposits. Detailed studies on the sediment's statistical aspects in Lae-Lae Island, Spermonde Archipelago, Indonesia are still rare. Thus, studies on the statistical characteristic of reef islands sediment are required to improve our understanding of island sedimentology and, in particular, help us classify sedimentary environments and explain sediment transport in Lae-Lae Island.

2. Material and methods

2.1. Study site description

Lae-lae Island is one of the coral reef islands in the Spermonde Archipelago, South Sulawesi, Indonesia. The island is close (about 1,2 km) from the mainland of Makassar, a city inhabited by more than a million people (Figure 1). The tidal regime at the island is a mixed tide, predominantly semi-diurnal, with a tidal range of 1.16 m. Reef flat of the island is covered by carbonate sediments, which mainly consisting of skeletal components eroded from the coral reef by wave action. There are also a few amounts of terrigenous sediments deposited on the island originated from fluvial discharge and erosion products from the Jene Berang River (to the south) derived from volcanic drainage. The Jene Berang contains land-based sediments and pollution from Makassar [6]. Seagrass of *Enhalus acoroides* is well developed at the island reef flat [7].



Figure 1. Map of the study site showing the sampling locations

2.2. Field sampling and laboratory work

A total of 32 sediment cores were collected from four different stations (Figure 1). Three stations were selected on the Lae-Lae Island reef flat and one station on the Lae-Lae sandbar reef flat (Figure 1). At each station, four sediment cores in the *Enhalus acoroides* seagrass beds and four sediment cores in the unvegetated sand approximately 1 meter from seagrass beds were taken using a PVC sediment corer (diameter 6 cm, length 15 cm) for grain size analysis. At the laboratory, sediment samples were dry sieved using standard laboratory test sieves of mesh sizes 2.0 mm, 1.0 mm, 0.500 mm, 0.250 mm, 0.125 mm, and 0.063 mm.

The grain size measurement in mm was converted into the phi (ϕ) unit before calculating the statistical parameters of the sediment, including mean grain size, sorting, skewness, and kurtosis using

[8] formula as listed in Table 1. The sediment statistical parameter calculation was performed using a GRADISTAT software package.

Table 1. Formulae used in the calculation of statistical grain size parameters using the logarithmic Folk and Ward (1957) graphical measures.

Sediment Statistical Parameter	Formulae
Mean (M_z)	$M_z = \frac{(\phi_{16} + \phi_{50} + \phi_{84})}{3}$
Sorting (σ)	$\sigma = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_5}{6.6}$
Skewness (Sk_1)	$Sk_1 = \frac{\phi_{16} + \phi_{84} - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \frac{\phi_5 + \phi_{95} - 2\phi_{50}}{2(\phi_{95} - \phi_5)}$
Kurtosis (K_G)	$K_G = \frac{\phi_{95} - \phi_5}{2.44(\phi_{75} - \phi_{25})}$

3. Results and discussion

Grain size parameters of the seagrass bed sediment and adjacent unvegetated sediment from four sampled stations are presented in Table 2. The average values of grain size parameters for each station presented in Table 3. Seagrass bed sediments and adjacent unvegetated sediments in the study site are characterized by medium to coarse-grained sand fractions. Station A and D were predominantly formed by medium sands both in the seagrass bed and adjacent unvegetated area, whereas Station B and C were formed mostly by coarse sands in the unvegetated area and medium sands in the seagrass bed.

Table 2. Sediment statistical parameters on the study site. M_z , σ , SK_1 and K_G in phi (ϕ) value.

No	Sample code	Mean grain size (M_z)	Sorting (σ)	Skewness (SK_1)	Kurtosis (K_G)
Station A					
1	A-Unvegetated1	1.504	1.467	-0.313	0.994
2	A-Unvegetated2	1.785	1.195	-0.318	1.418
3	A-Unvegetated3	1.549	1.335	-0.373	0.953
4	A-Unvegetated4	1.463	1.348	-0.356	0.94
5	A-Seagrass1	1.36	1.431	-0.365	0.84
6	A-Seagrass2	1.288	1.417	-0.35	0.849
7	A-Seagrass3	1.401	1.416	-0.384	0.889
8	A-Seagrass4	1.482	1.484	-0.316	1.01
Station B					
9	B-Unvegetated1	0.489	1.363	-0.1	0.813
10	B-Unvegetated2	1.184	1.137	-0.523	1.375
11	B-Unvegetated3	1.155	1.086	-0.49	1.33

12	B-Unvegetated4	0.874	1.144	-0.149	1.291
13	B-Seagrass1	1.298	1.327	-0.304	1.263
14	B-Seagrass2	1.343	1.365	-0.307	1.183
15	B-Seagrass3	1.271	1.411	-0.313	0.821
16	B-Seagrass4	1.365	1.365	-0.358	0.916
Station C					
17	C-Unvegetated1	1.236	1.421	-0.297	0.823
18	C-Unvegetated2	0.379	1.332	-0.034	0.861
19	C-Unvegetated3	1.003	1.374	0.033	0.854
20	C-Unvegetated4	0.898	1.177	-0.058	1.269
21	C-Seagrass1	1.031	1.344	0.021	0.88
22	C-Seagrass2	1.299	1.396	-0.309	1.184
23	C-Seagrass3	1.067	1.426	-0.011	0.814
24	C-Seagrass4	0.798	1.228	-0.048	0.869
Station D					
25	D-Unvegetated1	1.428	1.31	-0.304	0.892
26	D-Unvegetated2	1.118	1.384	0.025	0.672
27	D-Unvegetated3	1.313	1.366	-0.288	1.154
28	D-Unvegetated4	1.276	1.386	-0.288	0.861
29	D-Seagrass1	1.368	1.373	-0.309	0.856
30	D-Seagrass2	1.391	1.36	-0.314	0.851
31	D-Seagrass3	1.351	1.434	-0.369	0.83
32	D-Seagrass4	1.387	1.382	-0.328	0.853

Table 3. Average values of statistical parameters of seagrass bed sediments and adjacent unvegetated sediments.

	Station A		Station B		Station C		Station D	
	Unvegetated	Seagrass	Unvegetated	Seagrass	Unvegetated	Seagrass	Unvegetated	Seagrass
15 Mean grain size (Mz)	1.58	1.38	0.93	1.32	0.88	1.05	1.28	1.37
Sorting (σ)	1.34	1.44	1.18	1.37	1.33	1.35	1.36	1.39
Skewness (Sk1)	-0.34	-0.35	-0.32	-0.32	-0.09	-0.09	-0.21	-0.33
Kurtosis (KG)	1.08	0.90	1.20	1.05	0.95	0.94	0.89	0.85
Mean grain size classification	7 Medium sand	17 Medium sand	7 Coarse sand	17 Medium sand	Coarse sand	Medium sand	7 Medium sand	7 Medium sand
Sorting classification	Poorly sorted	Poorly sorted	Moderately well sorted	Poorly sorted	Moderately well sorted	Poorly sorted	Poorly sorted	Poorly sorted
Skewness classification	Very coarse skewed	Very coarse skewed	Very coarse skewed	Very coarse skewed	Symmetrical	Symmetrical	Coarse skewed	Very coarse skewed
Kurtosis classification	Mesokurtic	Mesokurtic	Leptokurtic	Mesokurtic	Mesokurtic	Mesokurtic	Platykurtic	Platykurtic

It is shown from grain size analysis that at Station B, seagrass bed sediment was slightly finer (average $Mz = 1.32 \phi$) than unvegetated area sediment (average $Mz = 0.93 \phi$). Also, seagrass sediment at Station C was slightly finer (average $Mz = 1.05 \phi$) than unvegetated sediment. It should be noted that the finer the sediment, the higher the phi (ϕ) value. The slightly finer sediments found in the seagrass bed indicate that seagrass beds can trap fine-grained sediment. The leaves, together with epiphytic growth on the leaves of the seagrass, can actively trap finer-grained sediments by adhering waterborne particles to the leaves [9]. Also, [10] revealed that seagrass leaves act as a baffle dampening wave and current energy and allowing fine particles to settle from the water column.

Seagrass sediment and unvegetated sediments in Station A and D were poorly sorted, whereas unvegetated sediment sediments in Station B and C were moderately well sorted. Similar to Station A and D, seagrass sediments in Station C and B were poorly sorted. In this study, seagrass sediments were generally poorly sorted than those in an adjacent unvegetated area. This finding consistent with the study of [9] who reported that sediments in the seagrass zone of Seychelles were more poorly sorted than those in an adjacent seagrass free area. The sorting, sometimes referred to as standard deviation, indicates the range of forces that have produced the sediment. Poor sorting means that limited selection of grains has taken place during transport or deposition, for example, in seagrass beds in this study. On the other hand, good sorting is produced by the selective action of waves or currents that transports and deposits only a limited range of grain sizes [11].

Sediment collected at the seagrass bed and adjacent unvegetated area were very coarse skewed in all stations except at Station C where sediments were symmetrical, and in the unvegetated area at Station D where sediment was coarse skewed. The skewness of a sediment distribution is a useful indicator of the history of the sediment sample. Beach sand like sand collected at the seagrass bed and unvegetated area in this study usually exhibit negative skew - a preponderance of coarse grains, since the fines have been removed by wave or current actions [11]. Moreover, the skewness values reflect the influence of coastal processes in the grain size distribution and the mixing of terrigenous and biogenic sediment on the study site. The symmetrical curves of sediments observe at Station C indicating that marine sediment at the station has been likely mixed with fluvially-sourced material.

The graphic kurtosis is a measure of the part of the sediment already sorted elsewhere in an environment and later transported and modified by another type of environment [12]. The average kurtosis (KG) values for seagrass bed sediments range from 0.85 to 1.05, which falls in the Platykurtic to Mesokurtic, whereas average kurtosis values in the unvegetated sediment range from 0.89 to 1.20 (Platykurtic to Leptokurtic). The variations in kurtosis values observed in this study are probably due to changes in the flow regime of the depositional medium [13]. The dominance of fine sand-size particles of platykurtic-mesokurtic nature and roundness of the particles observed in the seagrass sediment reveal the sands' maturity, and this could be related to the accumulation of fine sand-size particles in a dominant low-energy marine environment [14].

A linear discriminant analysis was performed to discriminate the four sampling stations based on the grain-size distribution parameters, and the result is presented in Figure 2. The discriminant analysis shows that skewness was the variable that better discriminate the sediment between Stations A, B, D, and Station C. Moreover, the group formed by the unvegetated sediment in Station B is separated from the rest of the group (Figure 2). The variables that better discriminate the sediment between Station B unvegetated area and other stations were grain size, sorting, and kurtosis.

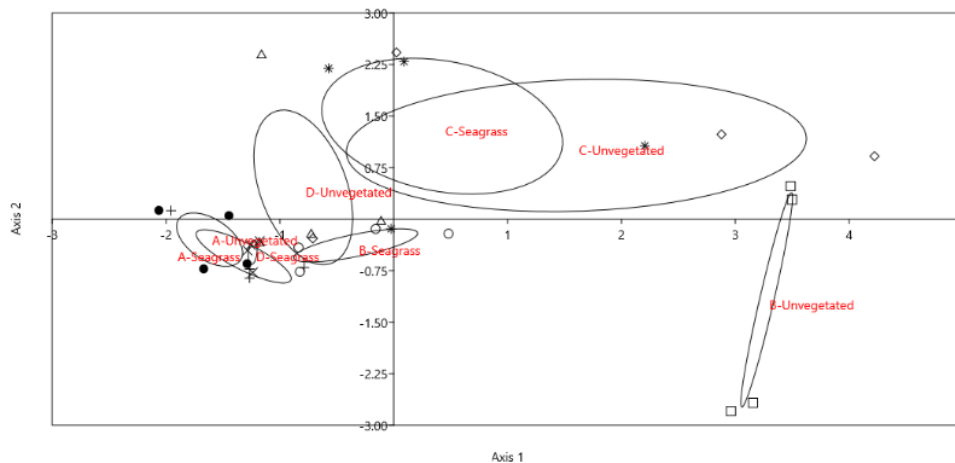


Figure 2. Linear discriminant analysis result using all data set

4. Conclusion

Seagrass bed sediments and adjacent unvegetated sediments in the study site are characterized by medium to coarse-grained sand fractions. Sediments from seagrass bed were slightly finer at Station B and Station C than unvegetated sediments. Seagrass sediment and unvegetated sediments in Station A and D were poorly sorted whereas unvegetated sediment sediments in Station B and C were moderately well sorted. Seagrass sediments were generally poorer sorted than those in an adjacent unvegetated area. Sediment collected at the seagrass bed and adjacent unvegetated area were very coarse skewed in all stations except at Station C where sediments were symmetrical. Sediment at the study site has platykurtic, mesokurtic, and leptokurtic kurtosis. The linear discriminant analysis shows that unvegetated sediment in Station B was different from those sediments in the other stations. The variables that better discriminate the sediment between Station B unvegetated area and other stations are grain size, sorting, and kurtosis.

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