Omni-Akuatika, 18 (2): 117 - 124, 2022
ISSN: 1858-3873 print / 2476-9347 online

Research Article

journal homepage: http://ojs.omniakuatika.net

The Suitable Sites for Seagrass Transplantation in Lae-Lae Island and Sandbar According to Sediment Characteristics

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Received 25 February 2022; Accepted 20 October 2022; Available online 22 November 2022

ABSTRACT

The success of a seagrass transplantation effort depends on identifying locations with optimal sediment characteristics for seagrass growth and survival. This study analyzed sediment characteristics of seagrass bed sediment and adjacent unvegetated sediment on Lae-Lae Island and Lae-Lae sandbar (Makassar, South Sulawesi) to determine the suitable sites for seagrass transplantation. Seagrass bed sediments and adjacent unvegetated sediments were collected from four locations to measure sediment particle size, redox potential, organic matter, water content, nitrate, and phosphate concentrations. Analysis of similarities (ANOSIM) was performed using PAST (Paleontological Statistics) software to determine a suitable site for seagrass planting (transplantation). The results show that surface sediments in the Lae-Lae Island are composed of medium sand and coarse sand with grain sizes varying from 0.290 to 0.768 mm, whereas in the Lae-Lae sandbar, the sediment is composed of medium sands (0.371 – 0.460 mm). Redox potential (Eh) varied from -34.1 to -65.7mV, water contents were 1.3 to 1.8%, organic contents were 19.85 to 38.53%, nitrate content varied from 0.60 to 3.47, and phosphate content varied from 7.42 to 14.19 ppm. The percentage of mud (clay and silt) and organic matter were slightly higher in seagrass bed sediments compared to unvegetated area sediments. No differences in nutrient contents (nitrate and phosphate) between seagrass sediments and unvegetated were observed in this study. ANOSIM results show no difference in the sediment characteristics between a seagrass bed and unvegetated sand at the north and south sides of Lae-Lae Island and Lae-Lae sandbar, which means that these three sites are suitable for seagrass transplantation.

Keywords: *sediment, seagrass, transplantation, site selection, ANOSIM, Lae-Lae*

ABSTRAK

Keberhasilan suatu upaya transplantasi lamun bergantung pada kemampuan untuk mengidentifikasi lokasi yang memiliki karakteristik sedimen yang optimal untuk pertumbuhan dan kelangsungan hidup lamun. Dalam studi ini, karakteristik sedimen dasar pada daerah lamun dan daerah tanpa vegetasi lamun di Pulau Lae-Lae dan Gosong Pasir Lae-Lae (Kota Makassar) dianalisis untuk menentukan lokasi yang cocok untuk transplantasi (penanaman) lamun. Sedimen dasar pada daerah lamun dan daerah tanpa lamun (tidak bervegetasi) diambil dari empat lokasi untuk menentukan ukuran partikel, potensi redoks, bahan organik, kandungan air, konsentrasi nitrat dan fosfat sedimen. Untuk menentukan lokasi yang cocok untuk transplantasi lamun, dilakukan analisis ANOSIM (*analysis of similarities*) menggunakan perangkat lunak PAST (*Paleontological Statistics*). Hasil penelitian menunjukkan bahwa sedimen dasar di Pulau Lae-Lae terdiri dari pasir sedang dan pasir kasar dengan ukuran butir bervariasi dari 0,290 sampai 0,768 mm, sedangkan di Gosong pasir Lae-Lae sedimennya terdiri dari pasir sedang (0,371 – 0,460 mm). Potensi redoks (Eh) bervariasi dari -34,1 hingga -65,7 mV, kandungan air sedimen bervariasi dari 1,3 hingga 1,8%, kandungan organik sedimen sebesar 19,85 hingga 38,53%, konsentrasi nitrat sedimen bervariasi dari 0,60 hingga 3,47 ppm, dan kandungan fosfat sedimen bervariasi dari 7,42 hingga 14,19 ppm. Persentase lumpur (lempung dan lanau) dan bahan organik sedikit lebih tinggi pada sedimen dasar lamun dibandingkan dengan sedimen tanpa vegetasi lamun. Tidak ditemukan perbedaan kandungan unsur hara (nitrat dan fosfat) antara sedimen lamun dan sedimen tanpa lamun pada penelitian ini. Hasil analisis ANOSIM menunjukkan bahwa tidak ada perbedaan karakteristik sedimen antara daerah lamun dan daerah tanpa lamun di sisi utara dan selatan Pulau Lae-Lae dan Gosong pasir Lae-Lae, yang berarti bahwa ketiga lokasi tersebut cocok untuk transplantasi lamun.

Kata kunci: sedimen, lamun, transplantasi, pemilihan lokasi, *ANOSIM, Lae-Lae*

http://dx.doi.org/10.20884/1.oa.2022.18.2.956

1. Introduction

The Spermonde archipelago of South Sulawesi (Indonesia) consists of more than one hundred small islands with important marine ecosystems such as seagrass and coral reefs (Nurdin et al., 2014). Lae-Lae Island is one the small island in the Spermonde archipelago. The island is located very close to the city of Makassar (South Sulawesi). Administratively, the island belongs to Makassar. One of the important marine ecosystems in Lae-Lae Island water is seagrass. Surface sediment characteristics on the Lae-Lae Island have been studied by Lanuru (2011), and the bioavailability of Pb and Cu in Sediments of vegetated seagrass on the Lae-Lae sandbar (Lae Lae Caddi Island) has been studied by Werorilangi et al. (2016).

Seagrass is an angiosperm plant that can adapt to seawater, forming a mono or mixture species called seagrass beds/meadows (Duarte et al., 2013). The ecological roles of seagrasses have been reported in many works of literature. For example, seagrasses can influence the hydrodynamic environment by reducing current velocity, dissipating wave energy, and stabilizing the sediment (Ondiviela et al., 2014). Seagrasses also play an important role in water quality improvement and carbon and nutrient cycling and provide habitat for various life forms in coastal waters. In addition, seagrasses also serve as nurseries, shelters, and feeding areas for many species, including numbers of commercially important fish and shellfish (Hemminga and Duarte, 2000).

The main problems affecting seagrass beds in Indonesia, including Lae-Lae Island today, are seagrass damage due to trampling in a seagrass assemblage, local boat mooring/landing activities, boat propeller scarring of seagrass, reclamation activities, eutrophication, pollution by domestic waste disposal, and destructive fishing, (Tomascik et al., 1997; Nadiarti et al., 2012). Loss of seagrass is indicated by loss of marine life, mainly caused by habitat destruction. In some areas, the loss of seagrass communities was only recorded by local fishermen because, unlike mangroves and coral reefs, seagrass communities were not apparent (Dahuri et al. 2001).

Given the significant role of seagrass ecosystems and damage to seagrass beds, efforts to protect and restore seagrass beds need to be carried out. One of the restoration efforts that can be done is transplanting seagrass plants into suitable habitats (Xiao et al., 2020; Pereda-Briones et al., 2018; Vichkovitten et al., 2016; Park et al., 2013; van Katwijk et al., 2009). Transplanted seagrasses will develop quickly because rhizomes that spread under the substrate will give rise to new stands so that seagrass cover in previously bared areas will develop into a seagrass bed.

Among others, sediment is an important factor that has a major influence on the growth and spread of seagrasses and therefore influences the success of seagrass transplants (Zabarte-Maeztu et al., 2020; Nishijima et al., 2015; Statton et al., 2013). Sediments can affect the spread of seagrass seeds through seabed roughness, germination of seagrass seeds embedded in sediments, seagrass seedlings through erosion, sediment deposition, seagrass growth through the availability of nutrients and sulfide toxicity of seagrass (Zhang et al., 2015; Newell and Koch, 2004). Based on the description above, the success of a transplant attempt depends on the ability to identify locations with optimal sedimentary characteristics for seagrass growth and survival.

2. Materials and Methods

This research was carried out on the Lae-Lae Island and Lae-Lae sandbar (Makassar City). The exact location of Lae-Lae Island is at the latitude of 5° 8'14.50" S and longitude of 119°23'30.85" E, while the coordinate of the Lae-Lae sandbar is 5° 7'17.21" S and 119°23'51.16" E. Three sites were selected on the Lae-Lae Island (North, South, and West sides of the island), and one site was selected on the Lae-Lae sandbar for sediment sampling (Figure 1). Only one site was selected on the Lae-Lae sandbar due to the limited distribution of seagrass beds. i.e., only present at the northeast part of the sandbar. Eight sediment samples were taken at each site: 4 samples in the *Enhalus acoroides* seagrass beds and 4 samples in the unvegetated sand approximately 1 meter from the seagrass beds.

Surface sediment samples were taken using a sediment corer on April 14, 2019. The sediment corer was pushed into the sediment to take a sediment sample of approximately 10 cm in length. Sediment samples were then put into a sample bag, labeled, and taken to the laboratory. In the laboratory, sediment redox potential is measured by placing a redox electrode in the middle of the sediment sample and recording the redox value in millivolts (mV). Organic sediment content was measured using the loss by ignition method following the method used by Fairhurst and Graham (2003). Sediment water content is determined by drying 1-2 grams of sediment samples in an oven at 105 ^{o}C for 24 hours. The percentage of water content is

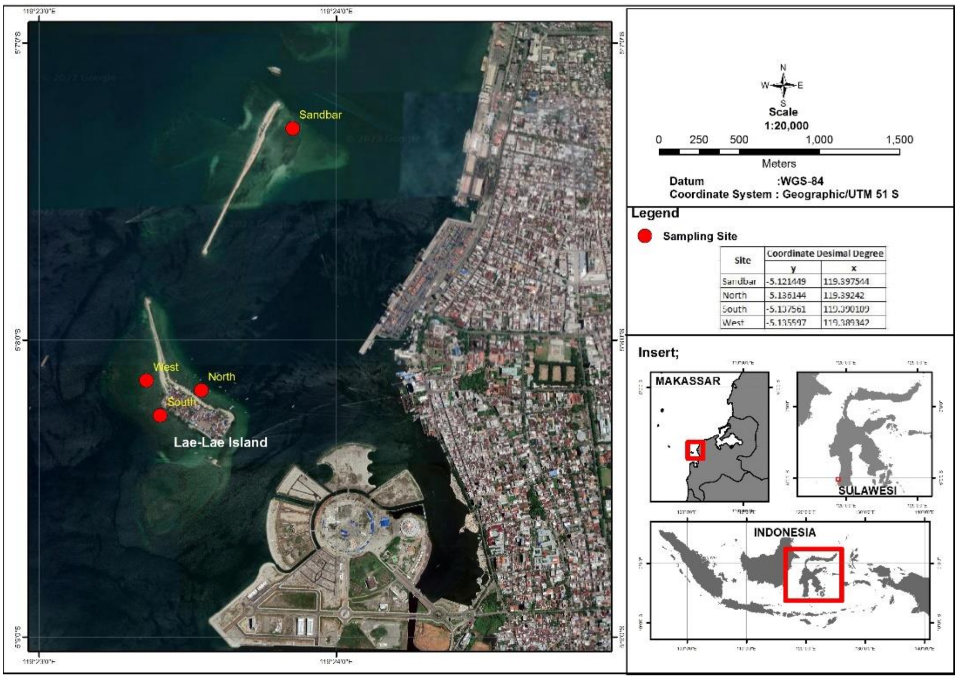

Figure 1. Location of the sediment sampling sites

calculated from the difference between the sediment's wet and dry weight. Nitrate and Phosphate sediment contents were determined using Spectrometry methods.

Determination of sediment grain size using the dry sieve method by dry sieving sediment samples 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 percentage retained on each sieve (percentage by weight) is determined by dividing each weight retained by the initial weight of the sediment sample. The percentage-by-weight data were then used to determine each sediment sample's mean grain size and grain size distribution. The sediment type of each sample was determined based on the mean grain size according to the Wentworth scale (Table 1).

To find the suitable site for seagrass transplantation, an Analysis of similarities (ANOSIM) was carried out on sediment characteristic data using a PAST (Paleontological Statistics) software introduced by Hammer et al. (2001). We used PAST software in this study because the software is comprehensive but simple to execute a range of standard numerical analyses and operations used in paleontology and ecology. In addition, the software can be run on standard Windows computers and is available free of charge. The station where sediment in the seagrass beds is remarkably similar to sediment without seagrass (unvegetated sand) is a potential site for seagrass transplantation.

Table 1. Wentworth scale for classifying sediments based on grain size.

Classification	Grain size (mm)
very coarse sand	1.0 – 2.0
coarse sand	0.5 – 1.0
medium sand	0.25 – 0.5
fine sand	0.125 – 0.25
very fine sand	0.0625 – 0.125
silt	0.002 – 0.0625
clay	0.0005 – 0.002

ANOSIM statistical test is a program used to statistically analyze whether there is a difference between test parameters or simply to test whether there are real differences between the test factors being compared (Clarke 1993). The difference is reflected from the Global R-value based on the following equation:

$$R = \frac{aver.rb - aver.rw}{\frac{M}{2}}$$

$$M = \frac{n(n-1)}{2}$$

Where *aver.rb* is the average of rank similarities arising from all pairs of replicates between different sites, *aver. rw* is the average of rank similarity of pairs among replicates within sites, and n is the number of samples under consideration. The Global R-value describes the level of difference between groups, ranging from 0 (indistinguishable) to 1 (all data similarity in groups < data similarity between groups). In addition, the level of difference is also seen based on the value of the statistical significance of the level. There is a real difference if the significance level is <5% ($p < 0.05$), and it is very significant if the significance level is <1% or $p < 0.01$ (Amin, 2016).

3. Results and Discussion

The result of seagrass bed sediment and unvegetated sediment characteristics measurement is presented in Table 2. The results of grain size analysis show that the surface sediments in the Lae-Lae Island are composed of medium sand and coarse sand with grain sizes varying from 0.290 to 0.768 mm, whereas in the Lae-Lae Sandbar, the sediment is composed of medium sand (Table 2). The particle size distribution of sediment at each sampling station is presented in Figure 2.

As seen in Figure 2, the percentage of mud (clay and silt) or sediments with grain size smaller than 0.063 mm was slightly higher in seagrass bed sediments than in the unvegetated area. Likewise, with very fine sand (grain diameter of 0.063 - 0.125 mm), the percentage was slightly higher in seagrass bed sediments compared to unvegetated sediments. The high content of mud and very fine sand in seagrass sediments compared to unvegetated sediments is probably caused by the ability of seagrass to slow down currents and reduce wave energy so that the waters become calmer and fine sediments can settle.

The results of this study in line with the results reported by Bos et al. (2007), who found silt fraction (grain diameter < 63 µm) increased, and a sand fraction (63-500 µm) decreased in seagrass beds sediment in the intertidal of eastern Dutch Wadden Sea (Netherlands). Furthermore, Bos et al. (2007) explained that the increase in fine sediment (silt) in seagrass beds resulted from the presence of seagrass.

Another researcher, McKenzie (2007), also found differences in the fine sediment composition due to the presence of seagrass, where the composition of fine sediments was greater found in the southern Queensland coast of Australia dominated by seagrass *Zostera capricorni* compared to the northern part of Queensland coast.

Table 2. Grain size, sediment type, redox potential (Eh), water content, organic matter content, nitrate concentration, phosphate concentration of seagrass bed sediments (L) and unvegetated sediments (P).

No	Sample code	Sediment type	Grain size (mm)	Eh (mV)	Water content (%)	Organic matter (%)	NO_3 (ppm)	PO_4 (ppm)
1	North P1	Medium sand	0.352	-65.7	1.56	37.14	2.06	12.05
2	North P2	Medium sand	0.290	-59.8	1.60	21.31	1.70	12.93
3	North P3	Medium sand	0.341	-59.6	1.47	38.44	1.32	10.14
4	North P4	Medium sand	0.362	-58.7	1.61	37.49	2.22	12.31
5	North L1	Medium sand	0.389	-57.6	1.33	23.68	2.85	8.69
6	North L2	Medium sand	0.409	-53.3	1.30	25.77	1.85	8.97
7	North L3	Medium sand	0.378	-49.7	1.58	21.51	2.26	10.56
8	North L4	Medium sand	0.358	-51.6	1.54	38.53	3.47	10.99
9	West P1	Coarse sand	0,712	-49.5	1.56	21.18	2.61	9.60
10	West P2	Medium sand	0.440	-51.2	1.47	31.92	3.14	9.09
11	West P3	Medium sand	0.449	-53.6	1.80	19.98	3.27	14.19
12	West P4	Coarse sand	0.545	-49.1	1.33	29.64	2.97	9.16
13	West L1	Medium sand	0.406	-52.9	1.47	36.16	2.20	11.89
14	West L2	Medium sand	0.394	-54.5	1.55	29.74	2.22	13.17
15	West L3	Medium sand	0.414	-55.4	1.47	27.74	1.48	11.91
16	West L4	Medium sand	0.388	-45.8	1.61	31.05	1.45	12.73
17	South P1	Medium sand	0.424	-49.5	1.42	31.15	1.57	12.40
18	South P2	Coarse sand	0.768	-53.4	1.50	31.14	1.31	11.88
19	South P3	Medium sand	0.499	-59.7	1.53	25.20	1.98	11.93
20	South P4	Coarse sand	0.536	-53.9	1.48	19.85	1.38	11.25
21	South L1	Medium sand	0.489	-46.5	1.62	25.36	2.30	8.99
22	South L2	Medium sand	0,406	-58.4	1.31	29.29	0.60	7.42
23	South L3	Medium sand	0.477	-50.7	1.34	26.88	2.34	7.53
24	South L4	Coarse sand	0.575	-42.5	1.45	28.89	0.83	9.10
25	Sandbar P1	Medium sand	0.371	-37.5	1.45	30.63	1.64	8.45
26	Sandbar P2	Medium sand	0.460	-41.9	1.44	26.91	3.25	10.53
27	Sandbar P3	Medium sand	0.402	-35.5	1.56	29.87	0.93	11.09
28	Sandbar P4	Medium sand	0.412	-42.2	1.41	28.03	1.69	10.40
29	Sandbar L1	Medium sand	0.387	-35.3	1.44	35.14	2.00	9.64
30	Sandbar L2	Medium sand	0.381	-36.6	1.33	35.97	2.97	8.36
31	Sandbar L3	Medium sand	0.392	-38.6	1.55	29.39	2.05	9.45
32	Sandbar L4	Medium sand	0.382	-34.1	1.52	23.39	1.36	10.70

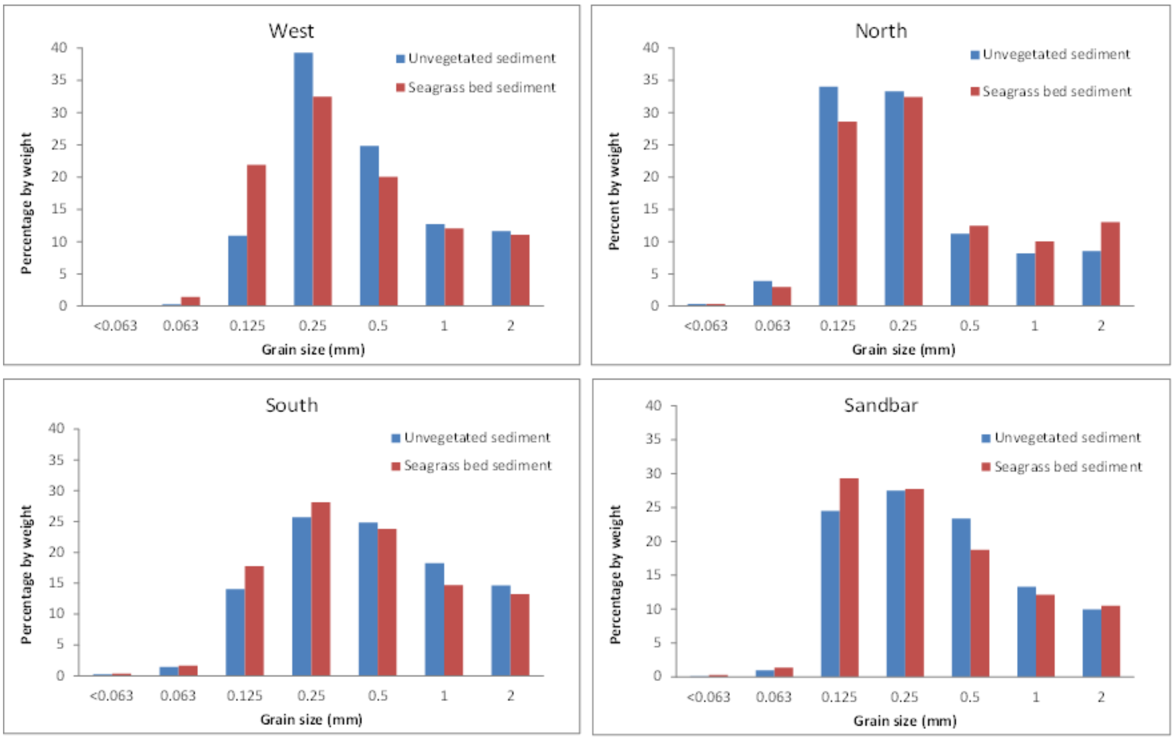

Figure 2. Grain size distribution of seagrass bed and unvegetated surface sediment at each station

Sediment organic content varies from 19.85 to 38.53% on Lae-Lae Island and 23.39 - 35.97% on the Lae-Lae sandbar (Table 2). A comparison of the organic content of seagrass bed sediments and unvegetated sediment at each station is presented in Figure 3.

The organic contents of seagrass bed sediment were slightly higher than unvegetated sediments at all stations. Higher seagrass bed sediment organic content observed in the study could be due to the enrichment of organic matter originating from the macroscopic fraction of seagrass, acid-insoluble, and amorphous organic fraction (Miyajima et al., 1998), which these increase the organic content of the seagrass bed sediments. In addition, higher organic content in the seagrass sediments could also be due to entrapping effect and sediment stabilization by seagrass vegetation which increased the accumulation of organic particles in seagrass sediments (Almasi et al., 1987).

The nitrate content of the seagrass bed sediment varied from 0.60 to 3.47 ppm on Lae-Lae Island. In addition, it ranged from 1.36 to 2.97 ppm in the Lae-Lae sandbar, while the nitrate content of the unvegetated sediment varied from 1.31 to 3.27 ppm in the Lae-Lae Island and varied from 0.93 to 3.25 ppm in the Lae-Lae sandbar (Table 2).

The sediment phosphate content was more varied on Lae-Lae Island (7.42 - 14.19 ppm) than the sediment phosphate content in the Lae-Lae sandbar (8.36 - 11.09 ppm). No consistent patterns in the sediment nitrate and phosphate content were observed at the study site. For example, at the North of Lae-Lae Island and Lae-Lae sandbar, the nitrate contents were higher in seagrass sediments, but at the other two sites, the nitrate contents were lower in unvegetated sediments.

No differences in nutrient content (nitrate and phosphate) between seagrass sediments and unvegetated were observed in this study. This is probably due to the small structure of seagrass *E. acoroides* at the study site. The same phenomenon was also reported by Mellors et al. (2002). They found no significant differences in the nutrient content of sediments present in a seagrass bed and unvegetated sand in the intertidal tropics of Australia's Great Barrier Reef World Heritage Area. At Mellors et al. (2002) study site, seagrass beds are mostly temporary and consist of seagrass vegetation with small structures and low biomass. As a result, the sediment trapped in these meadows is largely insignificant.

Site selection for seagrass transplantation should consider the suitability of environmental conditions in meeting the requirements for healthy seagrass growth and spread. Sediment characteristics and substrate stability are important aspects to be considered in site selection since sediment has a considerable influence on the growth and spread of

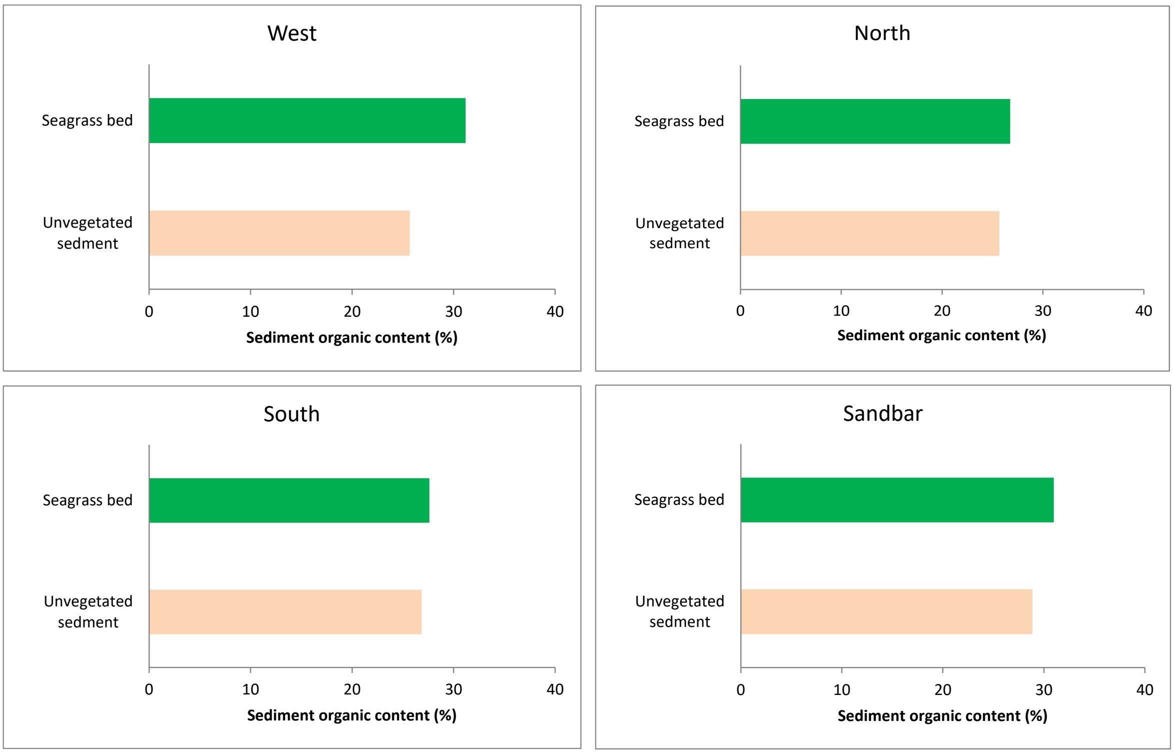

Figure 3. Comparison of the average organic content of seagrass bed sediment and unvegetated sediment at each station.

seagrasses and hence influences the success of seagrass transplantation (Zabarte-Maeztu et al. 2020; Newell and Koch, 2004). Sediment characteristics are also essential in choosing a suitable transplantation method for a particular area (Park and Lee, 2007).

Ambo-Rappe (2022), working on seagrass restoration using *E. acoroides* seeds, recently reported that seagrass restoration success using *E. acoroides* seeds is correlated with substrate and hydrodynamic conditions. She found that *E. acoroides* seed settlement and seedling establishment can readily occur at sites with fine sand substrate and lower wave exposure. Another recent study by Jiang et al. (2022) also reported sediment's importance on seagrass's growth and survival. According to Jiang et al. (2022), seagrass *Thalassia hemprichii* often grows better on coarse sand substrates because coarse beach sand indirectly enhances photosynthesis in *T. hemprichii* by reducing sulfide intrusion with lower amino acid and flavonoid concentrations.

In this study, Analysis of similarities (ANOSIM) was carried out on sediment particle size and other sediment parameters data to determine suitable sites for seagrass transplantation based on the similarities between sediments in seagrass beds and adjacent unvegetated sand. The result of the ANOSIM analysis is presented in Table 3.

ANOSIM results show no difference in the sediment characteristics between seagrass bed and unvegetated sand at the North and South of Lae-Lae Island and sand bar of Lae-Lae, which means that these three sites have a high

Table 3. Result of the ANOSIM analysis for differences in the sediment characteristics between seagrass bed and unvegetated sediment at each station.

Site	Global R value	significance level (p)	Remarks
North	0.1146	0.2603	The characteristics of seagrass sediments and sediments without vegetation are no different
West	0.3125	0.0293	The characteristics of seagrass sediments and sediments without vegetation differ significantly
South	0.4792	0.0598	The characteristics of seagrass sediments and sediments without vegetation are no different
Sandbar	0.1146	0.286	The characteristics of seagrass sediments and sediments without vegetation are no different

potential for successful seagrass transplantation because they have sediment characteristics for a successful establishment of seagrass beds. In contrast, at the West of Lae-Lae Island, a significant difference in sediment characteristics was found between seagrass beds and adjacent unvegetated sand, and hence it could be concluded that this site was not suitable for seagrass transplantation.

4. Conclusion

After performing an Analysis of similarities (ANOSIM) on the seagrass bed and unvegetated sediment characteristics at the study site, we concluded that the North and South of Lae-Lae Island and the Sandbar of Lae-Lae were suitable sites for seagrass transplantation. In contrast, the West of Lae-Lae Island has not been considered a potential site for seagrass transplantation since seagrass bed sediment characteristics in this station was less similar to the adjacent unvegetated sediment.

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