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State of sediment transport and seagrass distribution under the combined action of velocity and current direction

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Abstract. *Umar W, Hasim H, Moka WJC. 2024. State of sediment transport and seagrass distribution under the combined action of velocity and current direction. Biodiversitas 25: 4515-4524.* This research delves into the intricate dynamics of sediment transport and seagrass distribution on the West Coast of Bone Bay, Indonesia, specifically focusing on the profound influence of ocean currents. Our data, meticulously collected from Karang-Karangan, Siwa, and Sembilan Island, reveal a compelling narrative. We employed quantitative methods, including measuring ocean current speeds using Marotte current meters, which recorded velocities ranging from 0.1 to 0.5 m/s. Sediment samples were analyzed for grain size, with median sizes ranging from 233 µm (fine sand) to 626 µm (coarse sand). Sedimentation rates, a key indicator, were measured using sediment traps, recorded between 10 and 50 mg/cm²/day. Seagrass cover was assessed through line transect sampling, revealing cover percentages from 28 to 45% across the study sites. The results, a testament to the power of scientific inquiry, indicate that Sembilan Island had the highest sedimentation rates and seagrass coverage, which correlates with its unique hydrodynamic conditions, particularly the southward-directed currents. These findings underscore the critical relationship between ocean currents, sediment transport, and seagrass ecosystems, which are essential for the proposed designation of Bone Bay as a marine protected area. This research underscores the importance of combining quantitative data with a thorough understanding of environmental interactions to effectively manage and conserve coastal ecosystems. Further studies are recommended to explore the detailed mechanisms of these interactions, paving the way for a deeper understanding of our natural world.

Keywords: Bone Bay, current, seagrass, sedimentation

INTRODUCTION

Coastal and marine areas, as highlighted by Lu et al. (2015), are currently the hub of global socioeconomic activities. The research of Day et al. (2015) further accentuates this, revealing that coastal nations are reaping increased foreign exchange and revenues from marine products and coastal recreation opportunities. These ecosystems are crucial for the world economy, making their preservation a necessity (Laffoley et al. 2019). However, the stark reality is that these areas are highly vulnerable to future damage due to the escalating impacts of climate change and anthropogenic influences (Grases et al. 2020).

Historically, coastal ecosystems have been shaped by hydrodynamic factors such as ocean currents and sedimentation (Alcérreca-Huerta et al. 2022; Castillo et al. 2023). It has even been suggested that sediment transport is pivotal in formulating the modeling of coastal area evolution (Zuo et al. 2018). In addition, water turbulence is due to the interaction of coastal currents and waves, which contributes to sedimentation and ecological balance (Zuo et al. 2014). Therefore, the study of marine hydrodynamics is not just of interest but of paramount importance (Keyzer et al. 2020). It was further explained that the combination of the ecological functions of coastal areas is closely related to hydrodynamic factors such as waves and storms (Molina et al. 2020; Qu et al. 2022). For example, Fonseca et al. (2019) reported that water flow in coastal ecosystems would carry nutrients, contribute to the stability and chemistry of sediments, and provide hydrodynamic forces that change the configuration of marine plants.

One of the marine products that shows significant potential for coastal areas is the seagrass ecosystem. Globally, seagrass beds are a balancer for marine ecosystems (Montero-Hidalgo et al. 2023), support biodiversity, and protect habitats. Apart from its ecological function, seagrass beds are used to assess heavy metal contamination spatially (Zhang et al. 2021). In addition, extensive research on seagrasses proves their benefits and close relationship with hydrodynamic factors such as sedimentation, which is the process of particles settling out of the water column onto the seafloor, contributing to the formation and maintenance of seagrass beds (Oprandi et al. 2020; Zhu et al. 2022).

Barcelona et al. (2021) reported that seagrass canopies reduce flow velocity, increase sediment deposition, and trap particles. This sediment-trapping function is crucial for maintaining the integrity of the coastline. Despite their strategic function, seagrass beds are often overlooked in coastal management considerations (Nordlund et al. 2018). This is evidenced by the significant transformation of coastal areas, resulting in a decline in the quality and quantity of seagrass beds worldwide, a trend that should be of concern (James et al. 2023). Correspondingly, Griffiths et al. (2020) reported that the critical potential of seagrass ecosystems has yet to be exploited as an alternative solution for coastline protection. However, Astudillo-Gutierrez et al. (2024) firmly stated that the layout and size of seagrass vegetation significantly reduce the speed of breaking waves in coastal areas. Various research has been developed based on the critical role of seagrass beds, especially regarding the interaction of vegetation and coastal hydrodynamics (Maza et al. 2015).

Researchers have conducted previous studies (Lei and Nepf 2019) on the relationship of water flow to seagrass ecosystems, with varying results. As a result, information on the relationship between currents and seagrass meadows still needs to be clarified (Fonseca et al. 2019), and their relationship to sediment transport requires more comprehensive research. Reidenbach and Thomas (2018) stated that the role of the physical interaction of seagrass meadows with the hydrodynamic parameters of currents and waves must be considered. Therefore, seagrass ecosystems and hydrodynamic aspects are important for coastal areas, and evaluating the influence of physical aspects such as current speed is extremely important. This research due to its significance, aims to analyze the relationship between ocean currents, sedimentation, and seagrass distribution on the West Coast of Bone Bay waters.

MATERIALS AND METHODS

Study area

This study used quantitative descriptive methods during April 2024. Data was collected in 3 locations on the West Coast of Bone Bay, South Sulawesi Province, Indonesia, each included in 3 districts or cities. Among them are (i) Karang-Karangan Waters, Palopo City; (ii) Siwa Waters, Wajo District; and (iii) Sembilan Island, Sinjai District (Figure 1). The coordinates for each station across all locations are comprehensively presented, offering precise spatial reference for the study (Table 1).

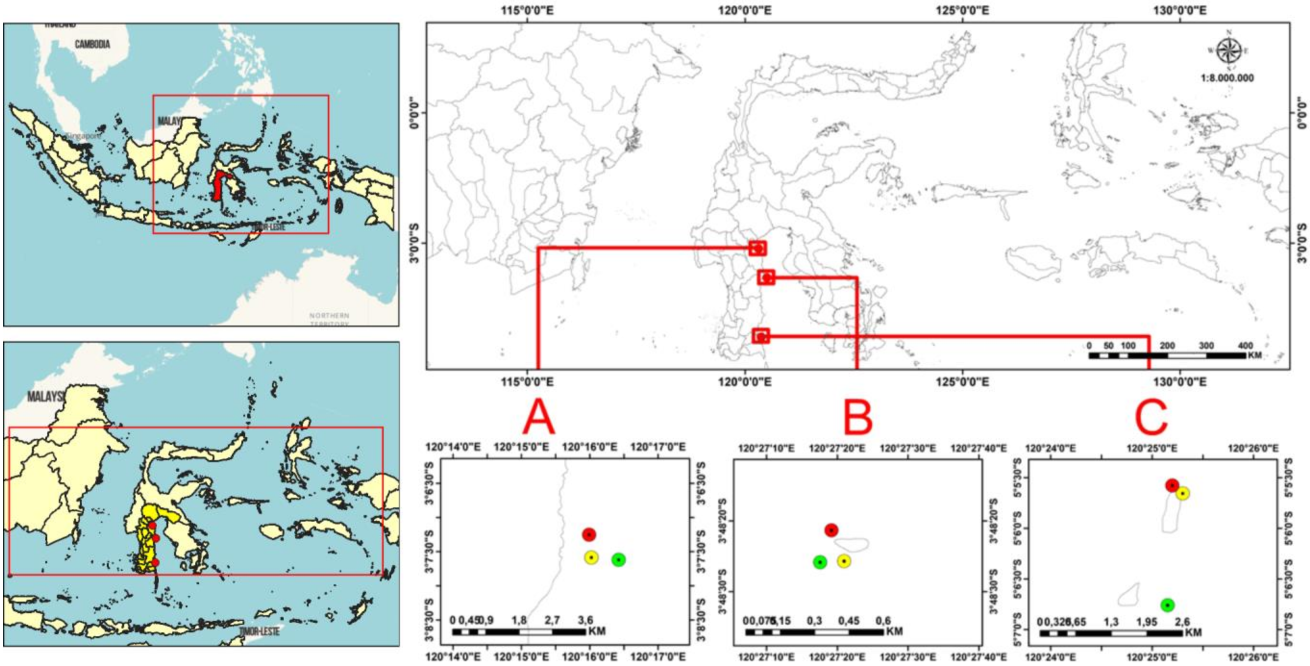

Figure 1. Research location map on the West Coast of Bone Bay, South Sulawesi Province, Indonesia. A. Karang-Karangan; B. Siwa; C. Sembilan Island. Each bullet color represents the station: Red for Station 1; Yellow for Station 2, and Green for Station 3

Table 1. The coordinates data collection sites

	Location	Station	Coordinates	
			Longitude (E)	Latitude (N)
A	Karang-Karangan Waters, Palopo City	1	120° 15' 5"	3° 7' 15,1"
		2	120° 16' 1"	3° 7' 35,1"
		3	120° 16' 2"	3° 7' 37,1"
B	Siwa Waters, Wajo District	1	120° 27' 1"	3° 48' 21,0"
		2	120° 27' 2"	3° 48' 25,0"
		3	120° 27' 1"	3° 48' 25,0"
C	Sembilan Island, Sinjai District	1	120° 25' 11,9"	5° 5' 34,6"
		2	120° 25' 18,1"	5° 5' 39,2"
		3	120° 25' 9,3"	5° 6' 45,5"

Procedures

Measurement of sea currents and tides

Water current measurements were carried out for 24 hours at each location using a Marotte current meter. This measurement is carried out by leaving the measuring device in the water to record data on the direction and speed of the current. The data obtained were analyzed using the Ocean Data View V.5.2.0 program with the following equation:

$$V = \frac{S}{t}$$

Where: V: Current speed (m/s); S: Distance or number of wheel rotations on the tool (m); t: Time (s)

Furthermore, the tide data is 39 hours of secondary data obtained from the BMKG South Sulawesi website.

Seagrass observation

Seagrass observations included percent cover and species density at three stations with three replications. Sampling used line transects 100 m long, placed perpendicular to the coastline. The starting point (0 m) was determined by measuring the seaward distance from the first point where the seagrass was found. Quadrat transects measuring 1 × 1 m were used to observe seagrass cover at 10 m intervals along the line transects. The estimated percentage of seagrass covers is based on photos taken using the standard seagrass watch method (McKenzie 2003). The type and cover percentage are determined, assuming each seagrass stand is counted as one for each type. The percentage of seagrass cover is determined by comparing the total area covered by all types of seagrasses with the following equation:

$$C = \sum \frac{Mi\ x\ fi}{f}$$

Where: C: Percentage of seagrass cover; Mi: Percentage of the midpoint of the class presence of seagrass i; fi: Number of sub-plots in the presence of seagrass; f: Frequency of all types of cover

Furthermore, the density of seagrass species is determined by calculating the number of individuals (stands) per area using the following equation:

Di = (∑Ni)/A

Where: Di: Density of type (ind/m^2); ni: Total of stands C-i species; A: The area of an observational plot

Collection of sediment data

Sediment sampling is intended to measure sediment transport's rate and accumulation and analyze sediment grains size at the research location. For sediment transport, sediment carried by physical oceanographic influences is trapped using sediment traps in five directions (north, south, west, east, and surface). This sediment trap has a pipe diameter of 7 cm and a length of 25 cm. The tool is placed for 24 hours at a depth of 3-5 meters with the help of weights to reach the bottom so that results can be obtained regarding the rate, direction, and speed of sediment accumulation. The calculation of sediment transport uses the Engelund and Hansen (1967) method, namely the bed load, as follows:

$$q_s = 0.05\ \gamma_s\ V^2 \left[\frac{d_{50}}{g\left(\frac{\gamma_s}{\gamma}-1\right)}\right]^{1/2} \left[\frac{\tau o}{(\gamma_s - \gamma) d_{50}}\right]^{3/2}$$

$$\tau o = \gamma\ D\ S$$

Where: To: Shear stress (kg/m^2); γ: Specific gravity of water (kg/m^3); γs: Sediment specific gravity (kg/m^3); D: Water depth; S: Tilt; V: Flow rate (m/s); g: Speed of gravity (m/s^2); d50: Diameter of sediment particles that 50% pass through the sieve (m); qs: Bed sediment load (kg/s/m)

The sedimentation rate is calculated with the formula as follows (Jawahir et al. 2020):

Ls = m/L/ t

L = 〚πr〛 ^2

Where: Ls: Sedimentation rate (mg/cm^3/day); m: Weight of trapped sediment (g); t: The period the sediment trap was installed (day); L: Sediment trap area (m^2); r: sediment trap radius (m)

Next, samples were taken using a grab sampler to measure sediment grain size. The sediment samples obtained were then dried at 105°C for several days until the water content disappeared. Sediment particle size was separated using a sieve net, then sorted based on the Wentworth Scale. To calculate the percent (%) weight of sediment grains, use the formula:

%Weight = (Sieved Weight)/(Initial Weight)×100%

RESULTS AND DISCUSSION

Physical oceanography on sediment transport ability

The sea level height at the 3 locations is secondary data obtained from the BMKG South Sulawesi website. The analysis results show that Sembilan Island waters had the highest peak at the 30-hours measurement and the lowest at the 37-hour measurement. Overall, the average sea level height of Karang-Karangan Waters is the weakest among all locations, followed by Siwa Waters. Measurements of sea level height at all locations are shown in Figure 2.

These results explain that the waters of Sembilan Island experience the most enormous tidal variations based on the highest and lowest peaks. In contrast, the waters of Karang-Karangan and Siwa have almost the same tidal peaks except at the beginning (9-11 hours) and the end (34-36 hours). Ocean currents at the 3 study locations are shown in Figure 3.

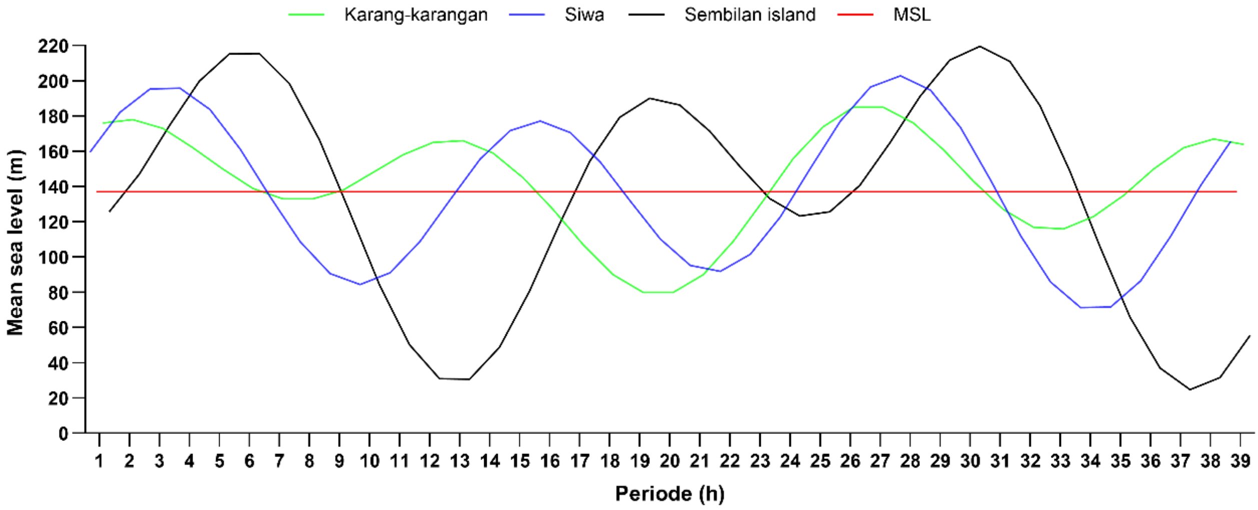

Figure 2. Tides in Karang-karangan, Siwa, dan Sembilan Island, West Coast of Bone Bay, South Sulawesi Province, Indonesia

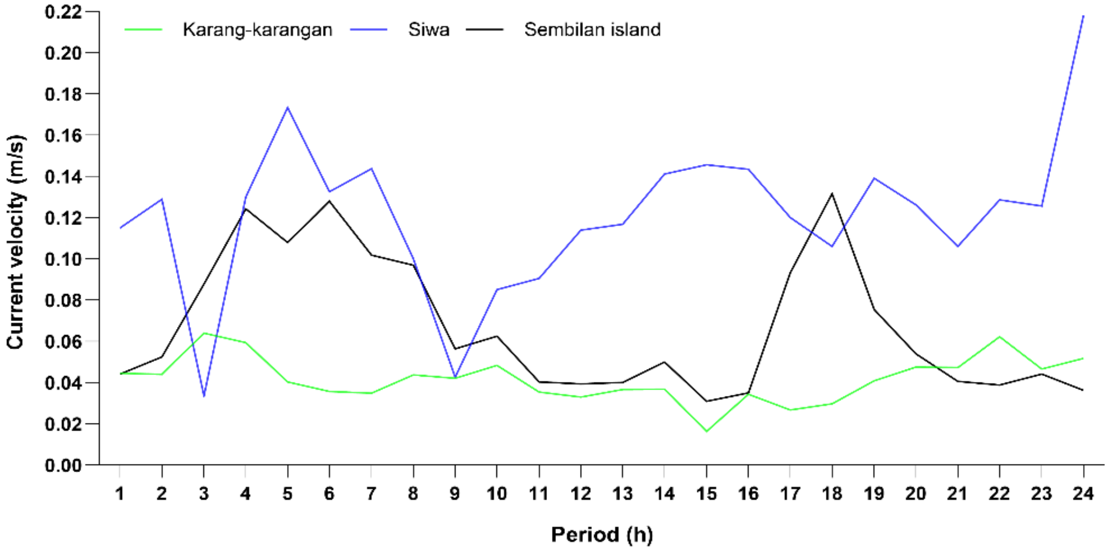

Figure 3. Current speed in Karang-karangan, Siwa, dan Sembilan Island, West Coast of Bone Bay, South Sulawesi Province, Indonesia

Ocean currents are meticulously measured 24 hours, starting at 11.00 CIT (Central Indonesian Time) and ending at 10.00 CIT the next day. The data reveals a surprising result: the Siwa Waters boast the highest current speed compared to all data collection locations. The peak current speeds were precisely recorded at 15.00 CIT and 10.00 CIT, corresponding to 5-hour and 24-hour measurements. In contrast, the Karang-Karangan Waters exhibit the lowest current speed, followed by Sembilan Island Waters. Notably, the highest current speed on Sembilan Island was observed at 03.00 CIT, a result of an 18-hour measurement, while the highest speed in Karang-Karangan was at 13.00 CIT, or a 3-hour measurement.

Our current data processing results, as depicted in Figure 4, reveal a significant pattern. Most currents in our research locations are oriented towards the east and north, with only a small portion flowing westward, particularly in Siwa Waters. This directional flow, opposite to the wind direction, is a key aspect of our findings. Furthermore, the research by Zhang et al. (2020) elucidates that the speed of currents is influenced by surface wind, particularly when the wind vector and surface current vector align in the same direction (opposite).

Further explained, in some cases, the influence of ocean currents is very significant and plays a role in modifying ocean wave deviations. Ecologically, current patterns in marine waters influence the sustainability of coastal areas: coastline changes, larvae movement, pollutant mobilization, and sediment transport (Ouillon 2018; Bashevkin et al. 2020; Zhou et al. 2022; Wang et al. 2023). In oceanology, currents are one of the most critical marine environmental responses alongside temperature, salinity, waves, and plankton (Wang et al. 2016; Wu et al. 2020). Bore et al. (2019) assume, in an accurate mathematical model, that knowledge of current velocity as a function of depth significantly influences the welfare of marine organisms.

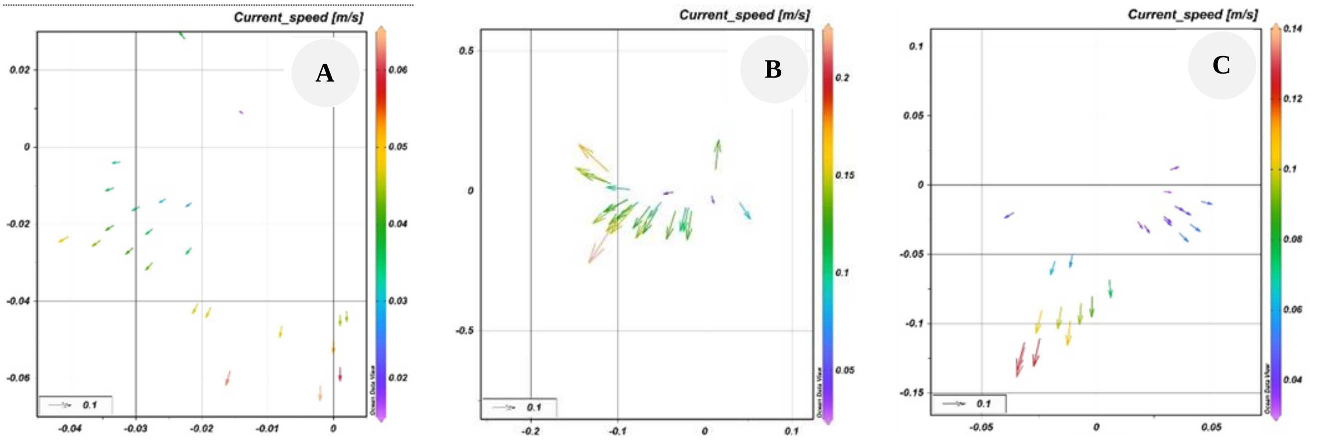

Figure 4. Current direction in A. Karang-Karangan; B. Siwa; C. Sembilan Island of the West Coast of Bone Bay, South Sulawesi Province, Indonesia

Table 2. Substrate type in Karang-Karangan, Siwa, dan Sembilan Island of the West Coast of Bone Bay, South Sulawesi Province, Indonesia

Wentworth (1922)		Location	Point	Grain diameter (µm)	Type
Grain diameter (µm)	Category				
2000	Very coarse sand	Karang-Karangan	1	441	Medium sand
1000			2	596	Coarse sands
500	Coarse sand		3	363	Medium sand
250	Medium Sand		4	452	Medium sand
125	Fine sand		5	429	Medium sand
63	Very fine sand		6	365	Medium sand
31	Coarse silt		7	457	Medium sand
15.6	Medium silt		8	370	Medium sand
7.8	Fine silt	Siwa	1	285	Medium sand
3.9	Very fine silt		2	233	Fine sand
<0.06	Clay		3	485	Medium sand
			4	305	Medium sand
			5	626	Coarse sand
			6	446	Medium sand
			7	534	Coarse sand
			8	365	Medium sand
		Sembilan Island	1	296	Medium sand
			2	399	Medium sand
			3	456	Medium sand
			4	455	Medium sand
			5	350	Medium sand
			6	285	Medium sand
			7	456	Medium sand
			8	458	Medium sand

Sediment sampling was carried out at 8 points at each location to assess substrate type (Table 2), sedimentation rate (Figure 5), and sediment transport (Figure 6). The results of measuring substrate types at 3 locations showed that the medium sand type was dominant. Karang-Karangan waters are classified as coarse sand only at the second sampling point, while Siwa waters are coarse sand at the 5th and 7th sampling points and fine sand at the 2nd sampling point. In contrast, Sembilan Island Waters have a medium-sand substrate at all sampling points. Assessment of sedimentation rates based on location (Figure 5.A) shows that Sembilan Island has the highest sedimentation rate, followed by Siwa and Karang-Karangan Waters. On the other hand, the sedimentation rate based on direction (Figure 5.B) shows that the sedimentation rate tends to be higher in the south and west directions of Sembilan Island Waters. In contrast, the Siwa Waters have more sedimentation in the east direction, and Karang-Karangan is dominant in the north direction.

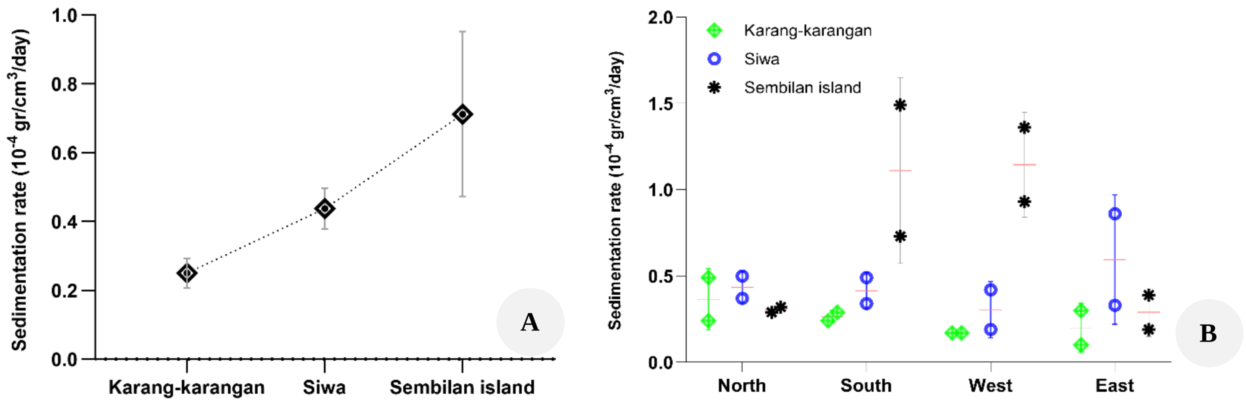

Figure 5. Comparison of sedimentation rate in the West Coast of Bone Bay, South Sulawesi Province, Indonesia. A. Sedimentation rate across locations; B. Sedimentation rate by direction

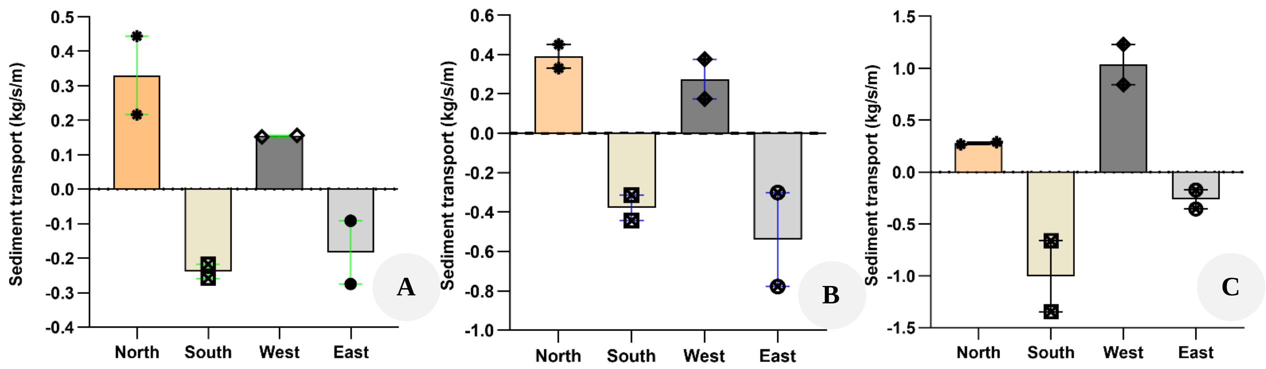

Figure 6. Sediment transportin the West Coast of Bone Bay, South Sulawesi Province, Indonesia. A. Karang-Karangan; B. Siwa; C. Sembilan Island

There are currently very few studies on sedimentation in Sembilan Island, Siwa, and Karang-Karangan Waters. The management and preservation of coastal environments stand to gain significantly from a deeper understanding of these factors. The oceanic dynamics of Bone Bay exert a direct influence on these three coastal localities. The profusion of rivers in this area plays a pivotal role in the sedimentation process. As per the spatial data monitoring, the research region is home to approximately 28 river flows that discharge into the sea. The sedimentation rate in these waters is accelerated by these rivers' inevitable introduction of sediment particles into the ocean.

In particular, Uspar et al. (2020) research only discovered information about the Sembilan Island region, which was categorized as having excessive sedimentation. According to Rani et al. (2018), Sembilan Island has a greater sedimentation level than the other South Sulawesi locations they measured. Historical evidence shows that Bone Bay has high sedimentation (Sarmili 2015). According to the paper, Bone Bay's sediment transport flows north and south, with fine sediment types predominating. However, the eastern portion of the bay is seeing an increase in coarse material. According to Jourdon et al. (2020), this change in sediment type is believed to be a major factor in the sedimentation process, especially in Bone Bay and Eastern Indonesia, which should be further explored to better understand its role in the sedimentation dynamics.

The results of sediment transport data analysis at the three research locations are shown in Figure 6. In line with the results of sedimentation rate measurements, sediment transport from Karang-Karangan Waters is dominant towards the north, Siwa Waters towards the east, and Sembilan Island Waters towards the south and west. The lowest sediment transport in Karang-Karangan and Siwa Waters is found in the west direction, while on Sembilan Island, it occurs in the north and east directions. If linked to the results of current data analysis, sediment transport may be influenced by the direction and speed of the current. For example, Sembilan Island's Ocean currents tend to the south (Figure 4.C) and are assumed to contribute to the high sedimentation rate on the south side (Figure 6.C). However, unexpectedly, in the Karang-Karangan and Siwa Waters, a contradiction was found between the direction of the current and sediment transport. The direction of the Karang-Karangan Water flow is more to the west side, while sediment transport is more to the north. This is the same as the Siwa Waters, where the current direction tends to the south and west, but sediment transport is more significant in the east. These results prove that currents do not affect sedimentation in some cases, such as the erosion of bed material, which is transported through shear stress at the bottom of seagrass beds (Forsberg et al. 2018).

Currents significantly impact erosion and sediment transport in waterways (Zuo et al. 2017). However, there are other variations, and small details must be clarified. For example, sediment transport in the inner layer changes with the strength of waves, while the outer layer currents influence it as part of the contribution of weather and seasons. These nuances underscore the need for mathematical model experiments to accurately assess the role of currents (Dufois et al. 2014). Identifying this new knowledge gap is a call to action, urging us to delve deeper into our understanding. The combination of currents and tidal factors leads to a characteristic scale of turbulence and sand ripples on the seabed, a crucial hydrodynamic process that regulates sediment transport. This report was confirmed by Lu et al. (2015), who explained that sediment transport is influenced by currents and sheer stress at the bottom of semithe water, leading to the formation of ripples and turbulence. In his research, assessing the influence of the interaction of currents and sea waves on the initial movement of sediment suggests the need for further comprehensive research, as many micro-aspects are not yet clearly understood. It is further estimated that tidal currents influence sediment erosion in the water (Li et al. 2020).

Seagrass condition on the West Coast of Bone Bay

Seagrass data was collected at each of the three stations per location. The results showed that the waters of Sembilan Island at station 3 had the highest percent cover, reaching 45%. In contrast, Siwa waters have the highest percentage of cover at station 2, namely 43%, while Karang-Karangan Waters have the highest percentage at station 1, reaching 39%. The lowest results were found in the Siwa Waters, with a percent cover of 28% at station 3. Data on the percent cover of seagrass is shown in Figure 7. During the research, six types of seagrasses were found at three locations (Figure 8). Sembilan Island has the most types of seagrasses found, namely six, while the fewest types are found in Karang-Karangan Waters, with two types, and Siwa Waters, with five types of seagrasses.

These results are most likely related to sediment transport and ocean current data. In general, seagrass can be affected by the type of substrate at a location; in this case, the kind of substrate found was medium-sand substrate (Table 2). Tahir et al. (2023) report that seagrass meadows are often found on soft substrates, and our research supports this. We found that the rate of carbon absorption by seagrass was not optimal on rigid substrates. This finding is further supported by Potouroglou et al. (2017), who mentioned the role of seagrasses in sediment stabilization and surface elevation. Seagrasses reduce physical stress on the sediment-water interface, creating a stable hydrodynamic state and contributing to sediment retention and modification. These various functions have earned seagrass beds the nickname "ecosystem engineers" because of their ability to modify the environment (Zabarte-Maeztu et al. 2021). Our next step was to evaluate the density of seagrass species (Figure 8) in connection with current data.

The highest seagrass species density was found in the waters of Sembilan Island for the *Cymodocea rotundata* (Ascherson & Schweinfurth, 1870) at station 3. Still, on Sembilan Island, the density of the *Thalassia hemprichii* (Ehrenberg, 1834). was also relatively high at station 1 compared to other locations. Karang-Karangan Waters also have the highest density of *Thalassia hemprichii* compared to different types of seagrasses at that location. On the other hand, Siwa Waters shows that *Cymodocea rotundata* is the type with the highest density, followed by *Thalassia hemprichii*. *Cymodocea serrulata* (R. Brown, 1810) and *Halodule pinifolia* (Miki-Hartog) had the lowest density, while *Cymodocea rotundata* and *Thalassia hemprichii* were the highest.

Regarding current data in Karang-Karangan Waters, these findings show results that follow data on the cover and frequency of seagrass species. Ocean currents in Karang-Karangan tend to be westward (Figure 4.A), and seagrass data shows the same results with high percent cover and species density at station 1 (Figure 6.A), which is in the western part of the sampling location. Likewise, the direction of the water currents on Sembilan Island, which tends to the south (Figure 4.C), is very likely to contribute to the high percent cover and density of seagrass species at station 3, namely the southern part (Figure 6.C). It is suspected that the direction of the current and the type of substrate have an influence, as explained by Fitrian et al. (2017), who found that there is a relationship between the type of bottom substrate and the distribution and the type of seagrass. This result is supported by the findings of Paul and Gillis (2015), who state that the current direction contributes to seagrass vegetation and surrounding water turbulence. Recent research results by Montero-Hidalgo et al. (2023) revealed that seagrass beds are influenced by pressure originating from the speed of ocean currents. Laia et al. (2023) added that sea currents are an important parameter in the existence of seagrass meadows.

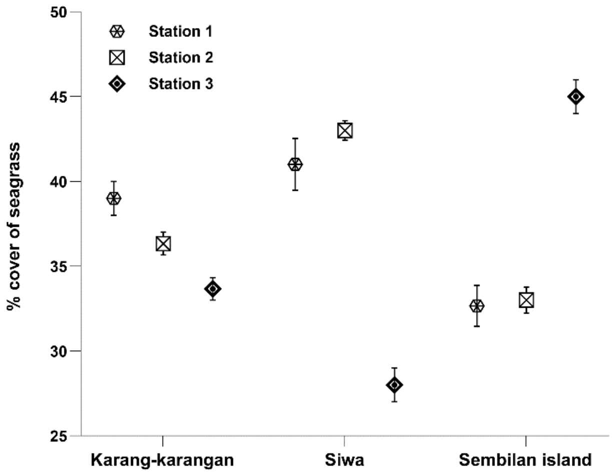

Figure 7. The percentage of seagrass covers Karang-Karangan, Siwa, and Sembilan Island in the West Coast of Bone Bay, South Sulawesi Province, Indonesia

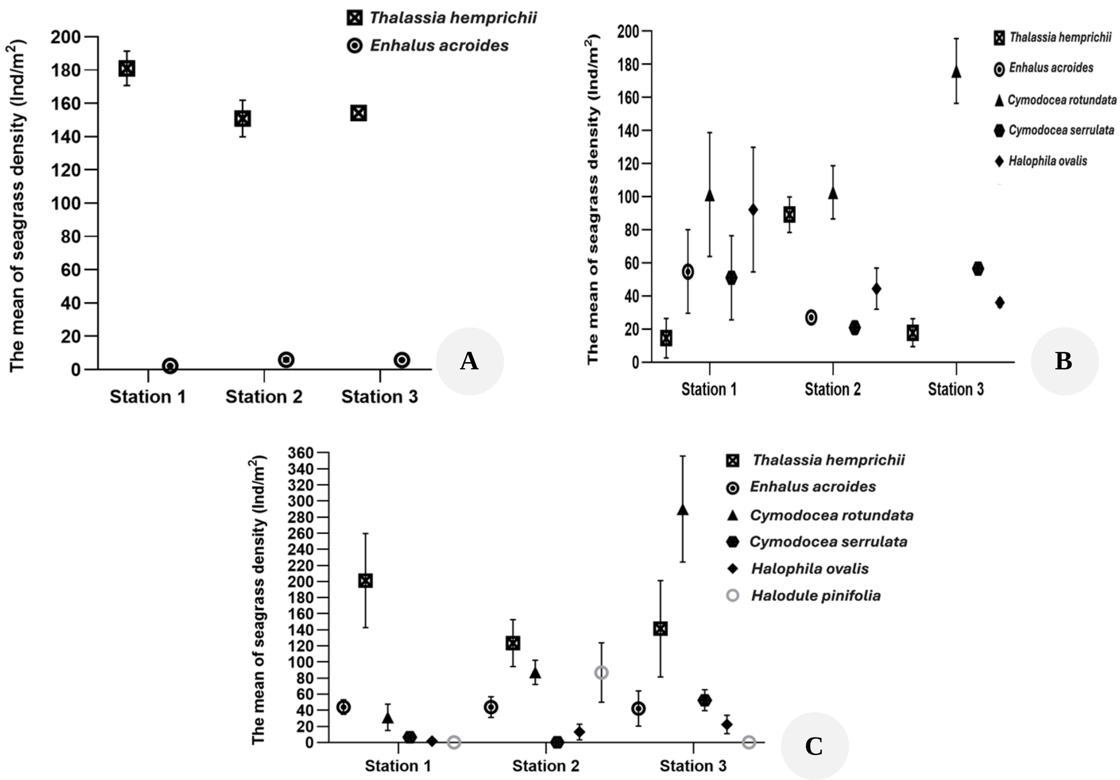

Figure 8. Seagrass density at all locations in the West Coast of Bone Bay, South Sulawesi Province, Indonesia: A. Karang-Karangan; B. Siwa; C. Sembilan Island

However, there are still many aspects that need to be investigated. Areas with high cover and species density do not necessarily correspond to the direction of currents in the waters. However, the current speed parameter is thought to play a role, as shown in Figure 3. When combined with seagrass data, Siwa Waters have a pattern of percent cover and species density that corresponds to the direction and speed of the current at that location. Various studies support this assumption; for example, Maza et al. (2015) reported the effect of current and wave speed on seagrass vegetation. They are supported by Wang et al. (2016), who stated that the speed of currents and waves affects the pull of the canopy or leaves and the curvature of seagrass vegetation. Schaefer and Nepf (2022) added that the combination of currents and waves significantly influences seagrass vegetation.

The findings of this study underscore the significant influence of ocean currents on sediment transport and seagrass distribution in the West Coast of Bone Bay, particularly highlighting the variations observed across Karang-Karangan, Siwa, and Sembilan Island. With its unique hydrodynamic conditions, Sembilan Island exhibited the highest sedimentation rates and seagrass cover, suggesting a strong correlation between current velocity and direction and ecological outcomes. These results emphasize the critical role of physical oceanographic factors in shaping coastal ecosystems, reinforcing the necessity of incorporating these dynamics into coastal management strategies. Given the proposed designation of Bone Bay as a marine protected area, this research provides essential data-driven insights crucial for informed decision-making. The study highlights the need for ongoing monitoring and comprehensive analysis of sediment transport and seagrass ecosystems to effectively conserve these vital marine environments. By understanding and managing the interactions between hydrodynamic forces and ecological health, stakeholders can better safeguard the biodiversity and ecological functions of Bone Bay, contributing to sustainable coastal management and protection efforts.

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