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The relationship between nitrate and phosphate nutrients in substrates with seagrass density: Implications for marine ecosystem sustainability

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ABSTRACT

Introduction: Water conditions that greatly affect the density of seagrass species are the substrate fraction and nutrient content of the base substrate where the seagrass grows. This is important because seagrass utilizes dissolved nutrients in the waters and nutrients on the substrate for the production process. This study aims to determine the relationship between nitrate and phosphate nutrients on the substrate with seagrass density in Pajenekang Island, Liukang Tuppabiring District, Pangkep Regency, South Sulawesi. **Methods**: Data sampling of seagrass was carried out at north and west station using the line transect method where the data taken included seagrass frequency, cover, and density. Meanwhile, data collection of nitrate and phosphate nutrients on the substrate used a random sampling method and analysis with macro nutrien determination Morgan-Wolf extract. **Findings**: The results of study indicated that the seagrass density values in Pajenekang Island have various values, with the average seagrass density at the west station are 275 stands/m^2 and 356 stands/m^2 at the north station. The nutrient content on substrate in Pajenekang Island is low range when compared the result of other studies. Nitrate (0.36 ppm) and phosphate (0.49 ppm) at west station was significantly lower ($P<0.05$) compared to nitrate (0.49 ppm) and phosphate (0.64 ppm) at north station. The results of the Pearson correlation analysis among nitrate content and seagrass density on Pajenekang Island showed a negative relation with moderate correlation (-0.496). Meanwhile, Pearson correlation analysis of phosphate content showed a negative relation by showing no relation (-0.166). This can be explained that there are other factors that effect on seagrass density in research location. **Conclusion**: It can be concluded that the seagrass density at Pajenekang Island varies. The average seagrass density at the western station is 275 individuals/m^2, while at the northern station, it is 356 individuals/m^2. **Novelty/Originality of this article**: The novelty of this research lies in analyzing the relationship between nitrate and phosphate nutrient content in the substrate and seagrass density on Pajenekang Island, which has not been widely studied in this region.

KEYWORDS: seagrass density; nitrate; phosphate; substrate; Pajenekang Island.

1. Introduction

Seagrass is a type of higher plant (Anthophyta) that lives and grows submerged in shallow marine environments, up to a depth of 40 meters. Seagrass has characteristics such as rhizomes, vascular tissue, roots, and reproduces both generatively (through seeds) and vegetatively. The rhizomes are jointed stems that grow submerged and spread out in substrates like sand, mud, and coral fragments (Sjafrie et al., 2018).

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In Indonesian waters, there are 15 species of seagrass, which belong to 2 families and 7 genera. The common seagrass species found are 12 in total, including *Enhalus acoroides*, *Thalassia hemprichii*, *Cymodocea rotundata*, *Cymodocea serrulata*, *Halodule pinifolia*, *Halodule uninervis*, *Halophila decipiens*, *Halophila ovalis*, *Halophila minor*, *Halophila spinulosa*, *Syringodium isoetifolium*, *Thalassodendron ciliatum*, *Halophila sulawesii*, *Halophila becarii*, and *Ruppia maritima* (Sjafrie et al., 2018).

The conditions of the water that most influence the density of seagrass species are the substrate fraction and the nutrient or nutrient content of the substrate in which the seagrass grows. This is important because seagrasses utilize dissolved nutrients in the water and nutrients present in the substrate that are essential for their production processes (Riniatsih, 2016). Nutrient concentrations in the substrate vary significantly. The nutrients that are commonly studied in research concerning the effects of nutrients in water are nitrate and phosphate content. Nitrate and phosphate are macronutrients needed in large quantities by organisms, including seagrass. These nutrients are absorbed by seagrasses through their leaves and root systems, which have well-developed functions (Handayani et al., 2016).

The levels of nitrate and phosphate in the water are strongly influenced by inorganic and organic material sources, either from outside the water (allochthonous) or from within the water itself (autochthonous). Nitrate and phosphate nutrients play an essential role in the growth and metabolism of plants and are indicators used to determine the quality and fertility of a water body (Nabilla et al., 2019). Pajenekang Island has a diversity of seagrass species with varying coverage and density conditions, which are influenced by both natural and anthropogenic factors.

Natural influences may include climate change, changes in current patterns that bring sediment deposits, and sources of nitrate and phosphate from decomposition by decomposer organisms. Meanwhile, anthropogenic influences include development on the island, fishing boat activities, visitor activities, and land-based sources of nitrate and phosphate, which are suspected to have a significant impact on the presence and diversity of seagrasses in the waters. Based on this, the aim of this study is to understand the relationship between nitrate and phosphate nutrients in the substrate and seagrass density in Pajenekang Island, Pangkep Regency. The objective of this research is to determine the relationship between nitrate and phosphate nutrients in the substrate and seagrass density on Pajenekang Island, Liukang Tuppabiring District, Pangkep Regency, South Sulawesi. The usefulness of this research is to serve as a reference and source of information regarding the relationship between nitrate and phosphate nutrients in the substrate and seagrass density on Pajenekang Island, Liukang Tuppabiring District, Pangkep Regency, South Sulawesi.

1.1 Seagrass bed ecosystem

Seagrass meadows are widely distributed throughout temperate tropical and subtropical waters (Hossain et al., 2015). In the world, seagrasses are geographically centered in two regions, namely in the Indo-West Pacific and the Caribbean and there are about 55 types of seagrasses, seagrass meadows in Indonesia are estimated to be 12 types of seagrasses and have an area of about 30,000 km^2 which is quite widespread such as in the waters of Java, Sumatra, Bali, Kalimantan, Sulawesi, Maluku and Irian Jaya (Dahuri, 2001). Seagrass ecosystems are ecosystems that have relatively high primary productivity in waters close to the coast so that they have biodiversity, the existence of this ecosystem is very important to maintain the survival of marine biota because it has an ecological function as a nursery ground, as a feeding ground, spawning ground and shelter for various types of marine biota from the threat of natural predators for small biota (McHenry et al., 2023).

Seagrass ecosystems also have physical and economic functions. Physically, seagrasses act as wave and current absorbers so as to prevent coastal abrasion, sediment traps, stabilize substrates and nutrient recyclers. The economic function of seagrass meadows can be used as a basis for meeting food needs, household and industrial needs (Tomascik et al., 1997). These various functions make seagrass meadows very important to continue to maintain the stability of the ecosystem.

Seagrass ecosystems function as energy suppliers, both in the benthic and pelagic zones. Detritus of old seagrass leaves will be decomposed by a group of benthic bodies (such as sea cucumbers, clams, crabs, and bacteria), so that the process produces organic matter both suspended and dissolved in the form of nutrients. The nutrients will later be utilized by seagrass plants, the nutrients are not only beneficial for seagrasses but will also be utilized by phytoplankton, zooplankton and juvenile fish/shrimp (Dahuri, 2003). Seagrass is a plant that is fully adapted to live in the marine environment. Seagrass ecosystems play an important role in coastal areas because they are important habitats for various types of marine animals such as fish, molluscs, crustaceans and echinoderms. Seagrasses thrive mainly in open tidal areas and coastal waters with mud, sand, gravel, and dead coral fractures up to 4 meters deep. Seagrass beds are formed on the seabed where there is still enough sunlight for their growth (Dahuri, 2003).

1.2 Water nutrients

Nutrients are important nutrients in supporting the process of growth and development of potential marine ecosystem resources, nutrient dynamics are one of the indicators determining growth in seagrass ecosystems and other ecosystems, the availability of nutrients is a limiting factor for the growth, abundance and morphology of seagrass in waters (Nabilla et al., 2019). Nutrient availability in seagrass meadow waters can be a limiting factor for seagrass growth, nutrient absorption in seagrasses is carried out through two body tissues, namely through roots and leaves, in the water column nutrient absorption is carried out by leaves while in sediments it is carried out by roots. The uptake of nutrients from the water column by the leaves can be considered less important than the uptake of nutrients by the roots from the sediment, the transport of nutrients from the roots will then be distributed to the leaves (Erftemeijer et al., 1993).

The nutrient content of the substrate depends on the exact form and amount, and determines whether or not marine life is viable. As is known, nutrient content this is because seagrass functions as a nutrient trap and seagrass litter can be utilized (decomposed) by decomposing microorganisms to become a source of organic matter (Tampubolon et al, 2020). If nutrient needs are not met properly, then growth will experience disturbances such as differences in the distribution and density of seagrass itself.

Nutrient concentrations in the substrate vary widely, nutrients that are often studied in research on the influence of nutrients in waters are nitrate and phosphate content. Nitrate and phosphate are macro nutrients that are required in large quantities by an organism. The main source of nitrate and phosphate can come from the process of decomposition, weathering, decomposition of plants, residual dead organisms and supplies from land (erosion, waste, agricultural fertilizers) which are decomposed by bacteria into nutrients (Handayani et al., 2016). Nitrate and phosphate levels in waters are strongly influenced by sources of organic matter originating from outside or land (allochthonous) or from within the waters themselves (autocthonous). The content of nitrate and phosphate nutrients is a nutrient that plays an important role in plant growth and metabolism and is an indicator to determine the quality and fertility of a water body (Nabilla et al, 2019).

Nutrients nitrate and phosphate are essential elements for seagrass growth. Nitrate has a function in the formation of chlorophyll, protoplasm, proteins and nucleic acids that play an important role in growth and development, while phosphate is useful for seagrasses to prepare compounds in energy transfer, genetic information systems, and phosphoproteins (Fahmi et al., 2010). According to Handayani et al. (2016) nutrients for seagrass growth are obtained more from sediment pore water. The content of nutrients (phosphate, ammonium, nitrate and nitrite) in the pore water (sediment pore water) in seagrass meadow waters is higher than the levels in the water column due to the activity of aerobic bacteria around seagrass roots that can dissolve them in the complex form of these nutrients into the sediment (Zulkifli, 2003). Sediment nutrients are in three forms, namely dissolved in sediment pore water, adsorbed on the sediment surface, and contained in the lattice structure of sediment grains. The availability of nutrients in seagrass meadow waters can act as a limiting factor for their growth so that the efficiency of nutrient cycling in the system will be very important to maintain the primary productivity of seagrass meadows (Patriquin, 1992).

1.2.1. Nitrate

The role of nitrate contained in the sediment in seagrass areas is as an important element for the growth and survival of organisms in it. This is in accordance with the statement of Jones & Lee (2005), that nitrate is a parameter that is very influential on the life of marine biota very influential on the life of marine biota. Nitrate content is quite high in sediment pore water due to the speed of use by denitrifying bacteria and anaerobic bacteria. Nitrate (NO_3-) as a nitrogen derivative, comes from a long oxidation process. For nitrate, it comes from the oxidation of N-ammonia (NH_3). This NH_3 compound is the most common compound found in waste water. To form nitrate (NO_3^-), this NH_3 compound is oxidized biologically in the presence of oxygen. The oxidation process for nitrate formation is assisted by nitrifying bacteria, namely Nitrosomonas and Nitrobacter (Farges et al., 2012).

Nitrate is the main form of nitrogen in natural waters and is the main nutrient useful for plant and algae growth. Nitrate is highly soluble in water and is stable. It results from the complete oxidation of nitrogen compounds in water. Nitrification is the oxidation of ammonia to nitrite and nitrate by organisms. This process is important in the nitrogen cycle. The function of nitrogen is to build and repair body tissues and provide energy. Plants and animals need nitrogen for protein synthesis.

1.2.2 Phosphate & substrate

Phosphorus in waters and sediments is in the form of dissolved phosphate compounds and particulate phosphate. Dissolved phosphate consists of organic phosphate (sugar phosphate, nucleoprotein, phosphoprotein) and inorganic phosphate (orthophosphate and polyphosphate) (McKelvie, 1999). The presence of phosphate in the water will break down into ionic compounds in the form of H_2PO_4-, HPO_4^{2-}, and PO_4^{3-}, which will then be absorbed by phytoplankton and enter the food chain.

Phosphorus elements in nature are found in the form of phosphate ions in both organic and inorganic forms. The presence of this element in the soil layer is unstable because it is in the form of minerals that are very reactive to water flowing on its surface (Pescod, 1978). This element will be easily lost by the process of erosion, weathering and dilution due to water runoff. During the process, phosphate minerals will break down into phosphate ions which are necessary nutrients and play an important role in the growth and metabolic processes of marine organisms in addition to other elements (Tian et al., 2021).

The existence and condition of seagrass is very dependent on the environmental conditions in its habitat, one of the environmental factors that can affect the existence and condition of seagrass is the substrate. The substrate is a place to grow for seagrasses where the roots and rhizomes stick so that they can survive the scouring of waves and waves (Rappe, 2010). In addition, the substrate contains organic and inorganic minerals, the pores of the substrate contain water (interstitial water) which contains nutrients. The substrate has an important role for the growth and survival of seagrasses as a living medium and as a supplier of nutrients (Yunitha et al., 2014).

In the tropics, the concentration of nutrients in the substrate is higher than the concentration of soluble nutrients in the water (Erftemeijer et al., 1993). The amount of nutrient content in the substrate does not mean that it will always be in the same concentration in the characteristics of the bottom substrate and water depth. If there is a difference, this can affect the difference in density and distribution conditions for each type of seagrass that grows in the water. It is known that the substrate contains several nutrients including nutrients that affect the growth and development of seagrasses (Handayani et al., 2016). Seagrasses can be found on a variety of substrates, such as muddy, sandy, clay substrates and substrates with coral fractures and in rock crevices, so seagrasses can still be found in coral and mangrove ecosystems (Kusumaningtyas, 2023). Based on size, substrates are grouped into gravel (>2 mm), sand (0.05-2 mm), silt (0.002- 0.05 mm) and clay (<0.002 mm). The substrate on which seagrasses live is mud, sand, dead coral (rubble), a mixture of the two types of substrate or a mixture of the three (Kiswara, 2004).

1.3 Environmental parameters

1.3.1 Temperature, salinity, pH

In general, organisms like to live in places where the temperature is between 0^{o}-40^{o}C because at temperatures above 40^{o}C most proteins will decompose and break down. The factors that affect temperature are the length of irradiation, the position of the sun against the earth, and the weather. Salinity is the dissolved salt content in water. The unit of salinity is per mile (‰), which is the total weight (gr) of solid material such as NaCl contained in 1000 grams of seawater (Wibisono, 2005). Salinity is one of the environmental parameters that affect physical and chemical processes and will directly affect the life of organisms, among others, affecting the rate of growth, the amount of food consumed, the value of food conversion, and survival (Nontji, 2002).

The degree of acidity (pH) is a measure of the magnitude of the concentration of hydrogen ions that indicate whether seawater is acidic or basic in its reactions, the normal limit on pH is at nilal 7. Changes in pH values can affect the quality of waters which in turn have an impact on the life of biota in it seawater pH generally ranges from 7.6-8.3 pH values are usually influenced by the rate of photosynthesis, industrial discharges and household waste. The pH range in natural waters is strongly influenced by the concentration of carbon dioxide which is an acidic substance.

Phytoplankton and other aquatic vegetation absorb carbon dioxide from the water during the photosynthesis process so that the pH tends to increase during the day and decrease at night but the decrease in pH by carbon dioxide is not more than 4-5 (Lai et al., 2024). The pH value is influenced by several factors including biological activity such as photosynthesis, respiration of organisms, temperature and the presence of ions or mineral content of waters. Waters with pH 5.5-6.5 include unproductive waters, waters with pH 6.5-7.5 include productive waters and waters with pH 7.5-8.5 have very high productivity.

1.3.2 Current velocity and Brightness

Upwelling itself is a process where the mass of water is pushed up from a depth of about 100 to 200 meters and can occur along the west coast of some continents. In general, what is meant by ocean currents is the horizontal movement of sea water masses on a large scale. Currents in the sea are influenced by many factors that affect the onset of currents such as seasonal winds. In Indonesia, such as the existence of two seasons, namely the west season and the east season where the cycle of changes in each season is characterized by changes in air pressure so as to cause different wind direction (Wibisono, 2005).

Water brightness is a measure of the clarity of a body of water, the higher the brightness of the water the deeper the light penetrates into the water. Water brightness determines the thickness of the productive layer, reduced water brightness will reduce the ability of photosynthesis of aquatic plants, but it can also affect the physiological activities of aquatic biota (Risandi et al., 2023). By knowing the brightness of a body of water we can find out to what extent there is still the possibility of assimilation processes in water, which layers are not turbid and the most turbid. Waters that have a low brightness value at normal weather times can provide a clue or indication of the number of particles suspended in the waters, in this case the materials that enter into a body of water, especially in the form of suspension can reduce the brightness of the water. The brightness value is expressed in meters, this value is strongly influenced by weather conditions, measurement time, suspended solids and turbidity (Hamuna, 2018).

2. Methods

This research was conducted from January 2021 to October 2021, which included literature studies, site surveys, research proposal preparation, field data collection, sample analysis, data processing, and the preparation of research reports. Field data collection was carried out in the waters of Pajenekang Island, Pangkajene and Kepulauan District, South Sulawesi. Sediment sample processing for particle size analysis was done at the Oceanography and Physical Geomorphology Laboratory of the Department of Marine Science, Faculty of Marine Science and Fisheries, Hasanuddin University. Meanwhile, the analysis of nitrate and phosphate content in the sediment was conducted at the Chemistry and Soil Fertility Laboratory, Department of Soil Science, Faculty of Agriculture, Hasanuddin University. The data analysis in this study included the calculation of current velocity, turbidity, seagrass density, seagrass cover percentage, substrate, and the determination of nutrient content in the sediment.

The relationship between nutrient content in the substrate and water quality with seagrass density at the research site was analyzed using Pearson Correlation analysis to determine the presence or absence of a relationship between variables. Pearson Correlation analysis was used as an assessment tool to understand the effect of the relationship between substrate nutrients and seagrass density. The decision criteria for the Pearson correlation analysis results are as follows in decision-making based on correlation analysis, the significance value plays a crucial role (Siregar, 2014). If the significance value is less than 0.05, it indicates the presence of a correlation between the variables. Conversely, if the significance value exceeds 0.05, it suggests there is no significant correlation. The Pearson correlation coefficient helps determine the nature and strength of the relationship between two variables. A negative (-) correlation means that as one variable (x) increases, the other variable (y) decreases. On the other hand, a positive (+) correlation indicates that as x increases, y also increases. The Pearson correlation coefficient measures the strength and direction of the relationship between two variables. A value between 0.00 and 0.20 indicates no or very weak correlation. A value from 0.21 to 0.40 reflects a weak correlation, while 0.41 to 0.60 suggests a moderate correlation. Values between 0.61 and 0.80 indicate a strong correlation, and values from 0.81 to 1.00 represent a very strong or perfect correlation.These guidelines help interpret the strength and direction of relationships between variables, aiding in data-driven decision-making processes.

3. Results and Discussion

Pajenekang Island is located in Mattiro Deceng Village, Liukang Tuppabiring District, Pangkep Regency, South Sulawesi Province, geographically situated between 45°8'07.3" S and 119°19'39.3" E. Pajenekang Island has a land area of 29.50 hectares with a population of approximately 1,130 people, consisting of 252 households (Central Statistics Agency, 2019). Most of the island's residents work as fishermen, while others provide transportation services between Makassar and Pajenekang Island.

Pajenekang Island can be accessed by boat in about 45-60 minutes. The large population and the island's geographic location, surrounded by the ocean, result in relatively high anthropogenic pressure on the waters around Pajenekang Island. One visible direct impact is the waste generated by the island's residents, which is disposed of directly into the sea due to the lack of proper waste disposal and management facilities. This situation can affect the marine life and ecosystem in the surrounding waters. The presence of seagrass is influenced by both physical and chemical water conditions (Hemminga & Duarte, 2000). The results of environmental parameter measurements such as salinity, temperature, current velocity, pH, and turbidity at the research stations are presented in Table 1.

Table 1. Average data of environmental parameter measurements in the waters

Station	Repetition	Salinity (‰)	Temperature	Flow speed (m/s)	Ph Land	Brightness (%)
West	Early	35	31	0.007	7.6	100
	Middle	35	31	0.006	7.5	100
	End	35	31	0.005	7.5	100
	Average	35	31	0.006	7.6	100
North	Early	34	30	0.023	7.6	100
	Middle	35	30	0.019	7.6	100
	End	36	30	0.021	7.6	100
	Average	35	30	0.021	7.6	100

3.1 Substrate

The collection and analysis of substrate texture data from the waters of Pajenekang Island were conducted with the aim of identifying the type of sediment. It was serves as the habitat for the seagrass ecosystem and its influence on the presence of organic matter at the research site. Based on the sediment sample measurements, the percentage of different particle sizes was obtained according to the Wentworth Scale classification (Figure 1).

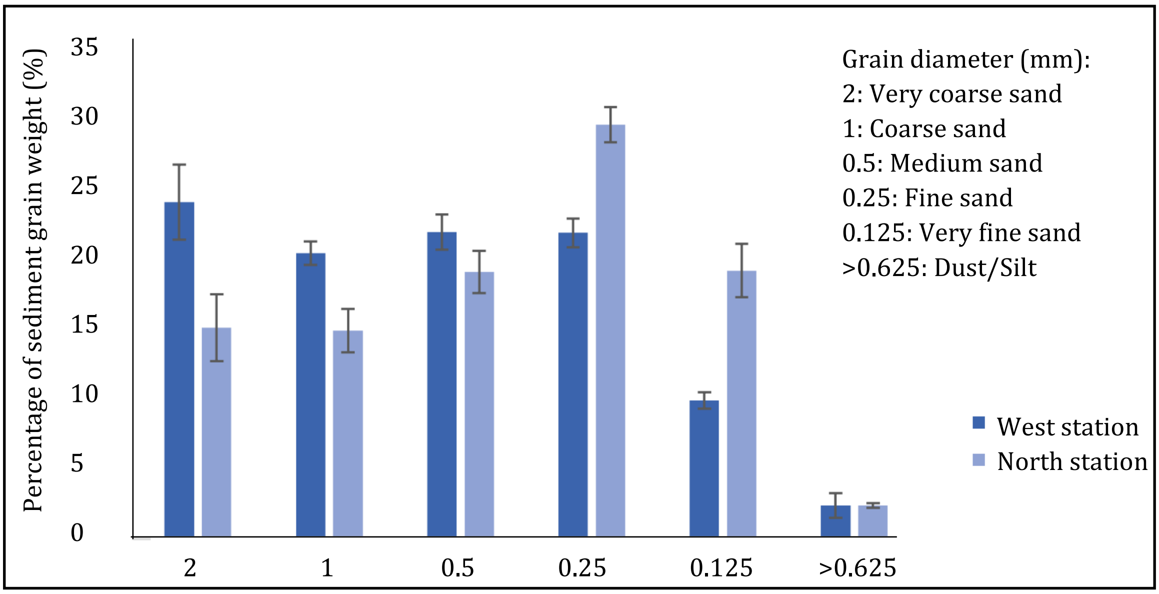


Fig. 1. Distribution of sediment grain types

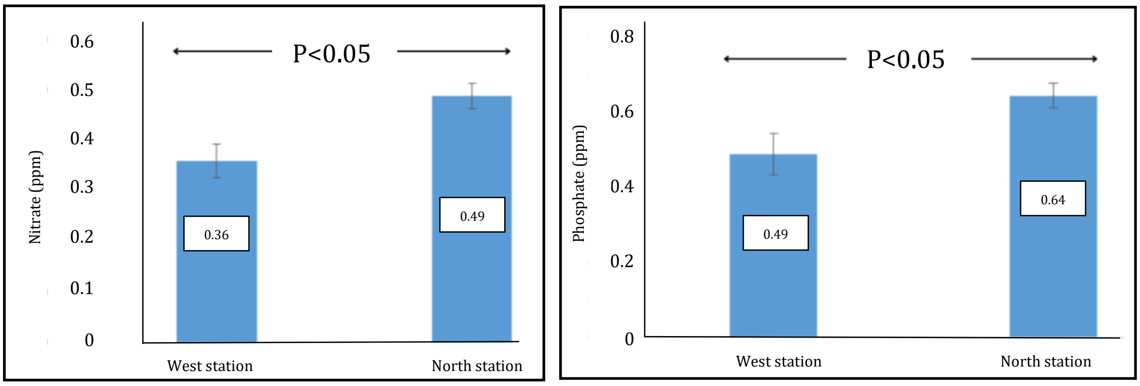
The sediment sample measurements showed varying percentages of sediment particle weights. At the western station, the substrate was dominated by grains with a diameter of 2 mm (very coarse sand), while at the northern station, the substrate was dominated by grains with a diameter of 0.25 mm (fine sand). The analysis of sediment type percentages, performed using Gradistat Software, revealed two types of sediment: coarse sand and medium sand. The sediment types based on the Gradistat Software results are presented in Table 2.

Table 2. Results of sediment type measurements using Gradistat Software in the waters

		Size of sediment grain	
Station	Transect	Median (mm)	Type of sediment
West	1	0.6994	Coarse sand
	2	0.6991	Coarse sand
	3	0.5872	Coarse sand
	4	0.8975	Coarse sand
	5	0.6816	Coarse sand
	6	0.7313	Coarse sand
	7	0.7196	Coarse sand
	8	0.8756	Coarse sand
	9	0.8829	Coarse sand
North	1	0.4907	Medium sand
	2	0.3916	Medium sand
	3	0.4874	Medium sand
	4	0.4883	Medium sand
	5	0.4851	Medium sand
	6	0.6996	Coarse sand
	7	0.5649	Coarse sand
	8	0.4705	Medium sand
	9	0.5183	Coarse sand

3.2 Nutrient content in the substrate of the waters

The measurements show that the nitrate content at the western station (0.36 ppm). It is significantly lower compared to the northern station (0.49 ppm) in the waters of Pajenekang Island, Pangkep (Figure 2a). The measurements also indicate that the phosphate content at the western station (0.49 ppm) is significantly lower compared to the northern station (0.64 ppm) in the waters of Pajenekang Island, Pangkep (Figure 2b).



a) Nitrate b) Phospate

Fig. 2. Content in the substrate at each station: a) Nitrate; b) Phospaate

The frequency of seagrass occurrence shows varied conditions at the research site (Table 3). The abbreviations represent different species of seagrass commonly found in marine ecosystems. Cr stands for Cymodocea rotundata, Hu for Halodule uninervis, Cs for Cymodocea serrulata, and Si for Syringodium isotifolium. Additionally, Ea refers to Enhalus acoroides, Th to Thalassia hemprichii, and Ho to Halophila ovalis. The symbols (+) and (-) indicate the presence and absence of these species, respectively, within a specific study area or sampling site. This classification helps in documenting seagrass distribution and assessing ecosystem health.

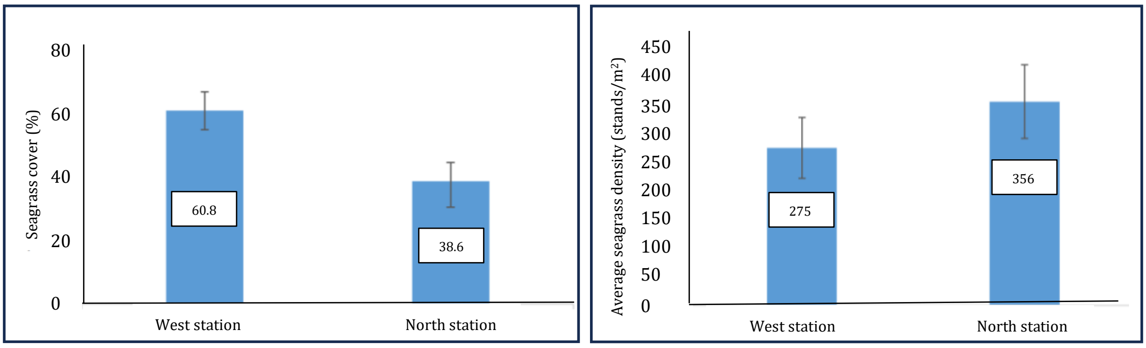
Table 3. Frequency of occurrence at each research station in the waters of Pajenekang Island, Pangkep

Station	Transect	Frequency of seagrass occurance						
		Cr	Cs	Ea	Ho	Hu	Si	Th
West	1	+	-	+	+	-	-	+
	2	-	-	+	-	-	-	+
	3	+	-	+	-	-	-	+
North	1	+	-	-	+	-	-	+
	2	+	-	+	+	-	+	+
	3	+	+	+	+	+	+	+

Notes:
+: There are seagrasses
-: There are no seagrasses
Cr: *Cymodocea rotundata*
Cs: *Cymodocea serrulata*
Ea: *Enhalus acoroides*
Ho: *Halophila ovalis*
Hu: *Halodule uninervis*
Si: *Syringodium isotifolium*
Th: *Thalassia hemprichii*

The highest seagrass occurrence frequency in the waters of Pajenekang Island, Pangkep, was found for *Thalassia hemprichii* with an occurrence frequency of 100%, followed by *Cymodocea rotundata* and *Enhalus acoroides* with an occurrence frequency of 83%. *Halophila ovalis* had an occurrence frequency of 66%, *Syringodium isoetifolium* had 33%, and the lowest occurrence frequencies were recorded for *Halodule uninervis* and *Cymodocea serrulata* with an occurrence frequency of 16%.

Seagrass cover indicates how much area is covered by seagrass, usually expressed as a percentage. The average seagrass cover shows varied conditions at each research station (Figure 3a). Based on the seagrass cover (Figure 3a), the highest average seagrass cover was found at the western station with 60.8%, while the lowest average seagrass cover was at the northern station with 30.8%. The average seagrass density at the research site shows different conditions at each station (Figure 3b).



a) Seagrass cover b) Average seagrass density

Fig. 3. Reach research station in the waters of Pajenekang Island, Pangkep

The average seagrass density at the western station is 275 shoots/m^2, while at the northern station, the average seagrass density is 356 shoots/m^2 (Figure 4). Additionally, the research site also shows varying densities of seagrass species. The measurements of seagrass species density ranged from 6 to 158 shoots/m^2, with the highest density found for *Cymodocea rotundata* at the northern station and the lowest density found for *Halophila ovalis* at the western station.

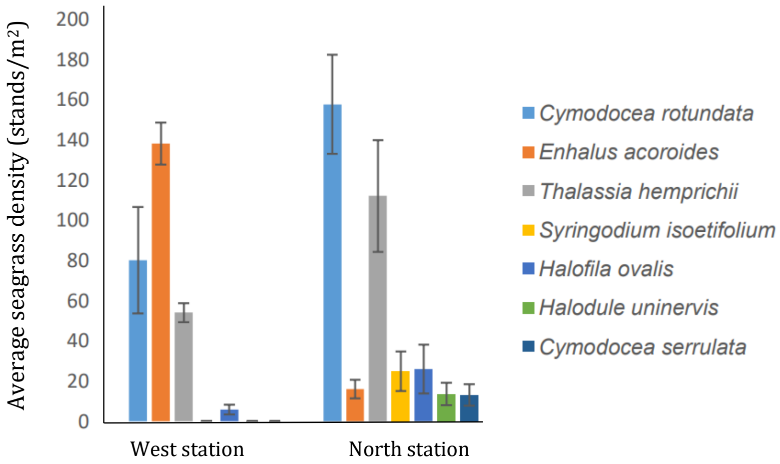


Fig 4. Seagrass density at each research station in the waters of Pajenekang Island, Pangkep Regency

3.2.1 Oceanographic parameters

The presence and growth of seagrass are greatly influenced by oceanographic conditions, both physical and chemical. The results of oceanographic parameter measurements such as salinity, temperature, current velocity, pH, and turbidity in the waters around Pajenekang Island, Pangkep, show varied results. Salinity is one of the factors that can influence seagrass growth, as it affects the physiological processes of seagrasses related to osmotic pressure in their environment. If the osmotic balance of the water is disturbed by either high or low salinity, it can affect seagrass growth and lead to a decrease in seagrass density (Handayani et al., 2016).

The salinity measured during the study had an average value of 35 ‰ at both stations, which is within the optimal range for seagrass growth. This is in accordance with the statement by Dahuri et al. (2001) that seagrass species have different tolerance levels to salinity within the range of 10–40 ‰, with the optimum tolerance for seawater salinity for seagrass growth being 35 ‰. According to Tuapattinaya (2014), seawater salinity is influenced by various factors such as water circulation patterns, evaporation, and rainfall.

3.2.2 Temperature and current velocity

Temperature is an important factor in regulating metabolism and the distribution of organisms (Nontji, 2002). Temperature data were collected during the daytime when the tide was low, which likely influenced the average values obtained, namely 31°C at the western station and 30°C at the northern station, both of which are still within the optimal range for seagrass growth. Erftemeijer (1993) explains that seagrass can live within a temperature range of 26.5–32.5°C and can even tolerate temperatures up to 38°C during the daytime when the tide is low. Temperature can influence photosynthesis and reproduction, thus enhancing seagrass growth.

The current velocity measurements showed higher values at the northern station compared to the western station. This is likely due to the fact that the northern station is relatively more exposed, while the western station is more sheltered by a breakwater structure. Additionally, the dominant seagrass species at the northern station have narrower leaf blades compared to those at the western station, which is dominated by species with broader leaves. Dense and wide seagrass leaves slow down currents and waves, creating calmer waters (Sjafrie et al., 2018). Overall, the current velocity at the study site is very slow. Current speeds in the range of 0-0.25 m/s are classified as very slow.

3.2.3 Sediment pH and turbidity

The sediment pH obtained from the measurements (7.6) is still within normal conditions and has not exceeded the standard threshold for seagrass growth. This is in line with the Decree of the Minister of Environment No. 51 of 2004, which sets the pH standard for seagrass growth between 7 and 8.5. The obtained pH value is likely influenced by weather conditions, as the observations were made during clear, dry weather, which helped maintain a normal pH level in the water. Sediment pH can affect the transport and availability of nutrients needed by plants. pH determines how easily nutrients can be absorbed by plants. Generally, nutrients are more readily absorbed by plants at near-neutral pH, as most nutrients dissolve easily in water at this pH level (Murdiyanto, 2004).

The turbidity measurements at both stations were 100%, indicating that light can still penetrate to the bottom of the water at both observation sites. Based on these data, it can be concluded that the observation locations around Pajenekang Island are shallow and clear waters. Shallow water conditions can influence seagrass growth, as sunlight intensity is a key factor supporting seagrass growth and productivity (Syawal et al., 2019).

3.2.4 Substrate

Substrate data analysis was conducted to determine the type of substrate that serves as the habitat for the seagrass ecosystem and its influence on the presence of organic material in the study area. The substrate samples collected at the research site, based on the analysis using Gradistat software, were predominantly classified as coarse sand and medium sand. Substrate characteristics greatly influence nutrient availability and the presence of seagrass. The most dominant seagrass species at the research site was *Thalassia hemprichii*, which is suspected to be related to the sandy substrate at the study site. According to Anggraini (2008), *Thalassia hemprichii* is commonly found in association with other species and generally grows in sandy substrate areas.

Based on the nitrate and phosphate content at the study site, the concentrations were within the low range. This is likely due to the fact that the substrate at each station consists of sandy material. According to Tomascik et al. (1997), fine substrates have higher nutrient content compared to coarse substrates. In terms of nutrient absorption, sandy substrates are less effective than finer, muddier substrates.

3.2.5 Nutrient content in the seafloor substrate

Nutrients Nutrients that affect seagrass growth are nitrate and phosphate (Riniatsih, 2016). Nitrate and phosphate are nutrients that are needed and have an influence on the growth and development of living organisms in waters including seagrasses, nutrient content in the form of nitrate and phosphate in the substrate will be absorbed through the root system (Riniatsih, 2016). If these two elements increase excessively, it can affect seagrass survival and morphology (La Nafie et al., 2012).

The results of nitrate analysis on the substrate have concentration values ranging from 0.36 - 0.49 ppm. The nitrate concentration value at the research site is relatively low when compared to the results of Nabilla's research (2019) which reported that the value of nitrate content on Bengkoang Island, Karimunjawa Islands was 0.85-3.10 ppm. The nitrate content of the substrate on Pajenekang Island has a low value when compared to coastal waters in Indonesia. The main things that distinguish it are sources, distribution patterns, geographical location, oceanographic factors and the level of nutrient utilization by primary producers in the food chain. The geographical location of pajenekang island greatly affects the distribution and availability of nitrate, pajenekang island is located in the middle of the sea far from the source of nitrate enrichment. Many sources of nitrate enrichment come from large river estuaries, mangrove forests, agricultural areas, mining areas, industry, settlements and coastal area development.

The results of the t-test analysis related to the amount of nitrate between the two stations showed that there was a significant difference ($p<0.05$), this was thought to be due to differences in sediment particle size. There is a relationship between nutrient content and sediment particle size, in fine sediments the percentage of nutrients is higher than in coarse sediments. Based on this, the western station has a lower nutrient content due to the coarser sediment particle size, while the northern station has a lower nutrient content due to the coarser sediment particle size while the north station has a higher nutrient content due to the finer sediment particle size.

3.2.6 Phosphate

The results of phosphate analysis in the substrate show concentrations ranging from 0.49 to 0.64 ppm. The phosphate concentration at the research site is considered low when compared to the study by Nabilla (2019), which reported phosphate concentrations ranging from 0.24 to 4.07 ppm in Bengkoang Island, Karimunjawa Archipelago.

The phosphate content in the substrate of Pajenekang Island is relatively low compared to coastal waters in Indonesia. The main factors distinguishing this are the source, distribution pattern, geographical location, and oceanographic factors. Phosphate primarily comes from the decomposition of organic material in the sediment, and also from weathering of rocks, industrial, domestic, and agricultural waste (Maurya et al., 2024). The phosphate content in the substrate of Pajenekang Island's waters is slightly higher than the nitrate content. This is due to the rapid decomposition of nitrate, which causes it to convert into nitrogen gas, lowering the nitrate concentration. Decomposition rates are influenced by temperature, and when the water temperature reaches the optimal level, denitrification occurs, causing the decomposition rate to increase (Seitzinger, 1988).

3.3 Seagrass conditions

According to a study conducted by Ilyas et al. (2020), there are five seagrass species distributed around Pajenekang Island. However, during the data collection, seven seagrass species were found in the waters of Pajenekang Island, Pangkep: *Enhalus acoroides*, *Thalassia hemprichii*, *Cymodocea rotundata*, *Cymodocea serrulata*, *Syringodium isoetifolium*, *Halophila ovalis*, and *Halodule uninervis*. The presence of different seagrass species at each station indicates that these species can tolerate the environmental conditions, including both substrate and oceanographic conditions (Angellica et al., 2024).

Observations of the frequency of seagrass occurrence in the waters of Pajenekang Island, Pangkep, revealed 7 seagrass species. *Thalassia hemprichii* was the most dominant species in the study area, with 7 occurrences and a frequency of 100%, while the species with the lowest frequency of occurrence were *Halodule uninervis* and *Cymodocea serrulata*, each with 1 occurrence and a frequency of 16%.

The high frequency of occurrence of *Thalassia hemprichii* at all observation stations indicates that this species can adapt to the habitat characteristics of the waters around Pajenekang Island. This is in line with the statement by den Hartog and Kuo (2006) that *Thalassia* species (with long, ribbon-like leaves that are not too broad) can be found in various habitats. This species is often encountered in shallow or intertidal areas and grows in sandy substrates. Sjafrie et al. (2018) also supported this, stating that *Thalassia hemprichii* is the most commonly found seagrass species in Indonesian waters.

3.4 Seagrass cover

Seagrass bed conditions are categorized in the Ministry of Environment and Forestry Decree No. 200 of 2004. According to the decree, seagrass bed conditions are divided into three categories: healthy, moderately healthy, and poor. A seagrass bed is considered healthy if the seagrass cover is greater than 60%, moderately healthy if it ranges from 30-59.9%, and poor if it is between 0-29.9%. The seagrass cover observed at both stations showed different conditions. The seagrass cover percentage at the western station was classified as healthy, while at the northern station, it was classified as moderately healthy.

The seagrass cover observed was based on leaf area; the broader and longer the seagrass leaves, the greater the coverage of the substrate. This explains why the seagrass cover at the western station was higher, as *Enhalus acoroides*, which has wider leaves compared to other species, dominated the station. On the other hand, the seagrass cover at the northern station was lower, as *Cymodocea rotundata*, with narrower leaves, was the dominant species.

Data collection was conducted during low tide, which could affect seagrass cover. Seagrass cover can be influenced by tidal conditions; during high tide, the seagrass leaves will be upright due to being submerged, thus reducing the cover, while during low tide, the leaves will droop, resulting in greater cover. The seagrass cover at the western station was higher compared to the northern station, which contrasts with the seagrass density, where the northern station had a higher density. This discrepancy is because seagrass cover refers to the area covered by seagrass in the water, while seagrass density refers to the number of individual plants in a given area, so cover does not always correlate linearly with density (Navarro-Mayoral et al., 2023).

3.5 Seagrass density

Seagrass density in the waters of Pajenekang Island, Pangkep, was relatively diverse. The average seagrass density at both stations ranged from 275 to 356 shoots/m^2, while the density of individual species ranged from 6 to 158 shoots/m^2. The seagrass density at the research site was lower compared to a study by Supriadi et al. (2012), which reported seagrass densities ranging from 2 to 343 shoots/m^2 on Barrang Lompo Island in the Spermonde Archipelago. The difference in seagrass density is likely due to the more open water conditions at Barrang Lompo Island, which results in stronger currents, and the higher population density, which may influence nutrient enrichment (nitrate and phosphate) in the area.

The density of seagrass at the northern station was higher compared to the western station due to the greater variety of seagrass species found at the northern station. Additionally, pioneer seagrass species (*Cymodocea rotundata*, *Halodule uninervis*, *Syringodium isoetifolium*, and *Halophila ovalis*) were more abundant at the northern station. According to Zurba (2018), pioneer seagrass species typically have the ability to grow quickly, which can influence their density. The density of *Cymodocea rotundata* was higher compared to other species, which is likely supported by several factors, including oceanographic conditions, substrate type, and nutrient content. This is consistent with Riniatsih (2016), who stated that *Cymodocea rotundata* is commonly found in sandy habitats rich in organic matter.

The densities of *Enhalus acoroides* and *Thalassia hemprichii* were relatively close to the highest density values. *Enhalus acoroides* was more abundant at the western station, while *Thalassia hemprichii* was more dominant at the northern station. According to Ikhsan et al. (2019), *Enhalus acoroides* is highly adaptable to different substrate types, making it widespread, particularly in subtidal areas. In contrast, Anggraini (2008) stated that *Thalassia hemprichii* is often found in association with other species and typically grows in sandy substrate areas.

The densities of *Syringodium isoetifolium*, *Halophila ovalis*, *Halodule uninervis*, and *Cymodocea serrulata* were low, with relatively limited distribution. The lowest density was found in *Halophila ovalis* at the western station, with 6 shoots/m^2. This low density is likely due to the dominance of *Enhalus acoroides*, whose long and broad leaves block sunlight, making it difficult for *Halophila ovalis* to thrive. Additionally, the western station is more sheltered, which results in slower currents. Meanwhile, *Syringodium isoetifolium*, *Halodule uninervis*, and *Cymodocea serrulata* were only found at the northern station in a single transect line.

Seagrass density is influenced by various factors, including temperature, salinity, pH, light intensity, current speed, substrate type, and nutrient content. Environmental conditions also differ between the two stations. The western station had high amounts of inorganic waste due to it being a garbage dumping site and a docking area for fishing boats. In contrast, the northern station was more natural with fewer anthropogenic activities. Disturbances to seagrass ecosystems can be caused by domestic waste disposal and human activities like boat docking. Seagrass density tends to be higher in more natural areas, away from anthropogenic activities.

3.6 Relationship between substrate nutrients and seagrass density

Based on research conducted in the waters of Pajenekang Island, nutrient content (nitrate and phosphate) contributes low to seagrass growth, the average value of nitrate content in the waters of Pajenekang Island ranges from 0.36-0.49 ppm and the average value of phosphate content ranges from 0.49-0.64 ppm. The results of pearson correlation analysis of nitrate content on seagrass density in Pajenekang Island Waters show a negative relationship with a significant value of 0.036 and a pearson correlation number of 0.496 *. This means that nitrate and seagrass density are not correlated based on the significance value because it is below 0.05 and has a medium pearson correlation value because it is close to 0.60.

The results of the Pearson correlation analysis show that phosphate content to seagrass density in the waters of Pajenekang Island has a negative relationship with a significant value of 0.511 and a Pearson correlation number of 0.166*. This shows that phosphate and seagrass density are correlated based on the significance value because it is above 0.05 and has a pearson correlation value that is not related because it is below 0.20. According to Siregar (2014) Pearson correlation value is the value that most determines the existence of a relationship, the significance value determines the strength of the relationship while the r value is the direction of a relationship in Pearson correlation analysis which is expressed by a positive value (the relationship is directly proportional) or negative (the relationship is inversely proportional). The low content of nitrate and phosphate in the waters of Pajenekang Island is thought to have no effect on the value of seagrass density. Temperature, salinity, pH, brightness, current speed and substrate are thought to be factors that influence the value of seagrass density in Pajenekang Island Waters, Pangkep.

4. Conclusions

Based on the results and discussion, it can be concluded that the seagrass density at Pajenekang Island varies. The average seagrass density at the western station is 275 individuals/m^2, while at the northern station, it is 356 individuals/m^2. The nitrate content in the substrate ranges from 0.36 to 0.49 ppm, while the phosphate content ranges from 0.49 to 0.64 ppm. The nutrient content of nitrate and phosphate in the substrate at Pajenekang Island is considered low compared to other coastal waters in Indonesia.

This is believed to be due to the island's geographical location, which affects the distribution and availability of nutrients. Pajenekang Island is located in the middle of the sea, far from nutrient enrichment sources. The Pearson correlation analysis between nitrate content and seagrass density at Pajenekang Island shows a negative relationship with a moderate correlation coefficient. Meanwhile, the Pearson correlation analysis of phosphate content reveals a negative relationship, indicating no significant correlation between phosphate content and seagrass density.

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