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# The influence of different substrate types on the diversity of macrofouling organisms at the submerged coastal ecosystem of Karimunjawa Islands, Indonesia

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**Abstract.** *Putro SP, Haqi MDA, Muhammad F, Hariyati R, Helmi M. 2024. The influence of different substrate types on the diversity of macrofouling organisms at the submerged coastal ecosystem of Karimunjawa Islands, Indonesia. Biodiversitas 25: 3394-3400.* Colonizing fouling organisms exhibit taxonomic diversity and distribution in response to environmental variability of the submerged marine ecosystem. This study compares macrofouling organisms found on various substrate types at Menjangan Besar Island, Karimunjawa, Central Java, Indonesia which were varied from coarse to smooth surfaces in the water column. The consisted of High-Density Polyethylene (HDPE) cage framework (3 stations) and lower part of a wooden ship hull are the smooth ones (3 stations), and concrete block at the Menjangan Besar Island dock is the coarse ones (3 stations). Sampling of macrofouling organisms was collected from the substrate within 0.25 $m^2$ area at each station with the purposive random sampling method. Identification of macrofouling organisms was done under Canon MZ25 stereomicroscope. We identified 15 species from 7 classes from Menjangan Besar Island. The most dominant species on concrete blocks was *Septifer* sp. (96 ind.$m^{-2}$), on the ship's hull was *Littoraria* sp. (416 ind.$m^{-2}$), and on the cage framework was *Crassostrea angulata* Thunberg 1793 (240 ind.$m^{-2}$). The diversity index (H') of fouling organisms ranged from 0.69 to 1.82, while the evenness index (e) ranged from 0.25 to 0.67, and the dominance index (C) ranged from 0.24 to 0.51. Differences in index values are likely due to factors related to food source distribution and substrate types. Salinity, temperature, and turbidity were the physical-chemical water parameters significantly affecting fouling organism distribution (BIO-ENV, Primer 6.1.5; Corr. value (r)=0.722). Anthropogenic activities such as aquaculture, fishing and tourism in the area are suspected to influence hydrodynamic changes, subsequently affecting the fouling organism attachment and colonization processes, especially organic matter generated from marine culture activities.

**Keywords:** Biomonitoring, biosecurity, dominant species, Karimunjawa Islands, substrate attachment

## INTRODUCTION

Coastal ecosystems have different environmental conditions from other ecosystems, as organisms have to adapt in different ways (Lin et al. 2017; Liang and Li 2020; Bekci 2021). The structural adaptation of fouling organisms allows them to temporarily submerge in seawater, including ship hulls, anchors, dock foundations, concrete blocks and cultivation facilities like nets and floating cage frames to survive in dynamic coastal environmental conditions (Shilova et al. 2020). The distribution and colonization of fouling organisms depend on ecological quality, hydrodynamics, substrate and dissolved organic matter content as a food source for fouling organisms (Sarkar et al. 2022). There are two groups of these organisms in the water ecosystem: microfouling and macrofouling. Microfouling is the accumulation of unicellular organisms, such as bacteria, algae and fungi, leading to biofilm formation. They help form biofilm, a layer of organic particles in water that become food for more prominent groups, i.e. macrofouling organisms (Cacabelos et al. 2020; Qian et al. 2022). There are organisms exhibit more complex colony attachment and development classes, including clams, barnacles, seaweeds, and lichens (Golinia et al. 2019). Sessile organisms form fouling communities that settle on calcareous shells or specific organs. They have two main groups: primary producers, such as algae, and suspension feeders, which mainly filter feed on plankton and organic matter in the water. Balanomorph are important in the growth of marine communities (Lin et al. 2017). Motile organisms tend to be small in size and light in mass. This Motile organisms inhabit and forage within the fouling community and exhibit various feeding habits, including carnivory, herbivory, and detritus feeding (Lin et al. 2017).

Fouling organisms started to grow when the substrate was submerged in seawater. Organic Carbon Residue (OCR) is quickly absorbed by wet substrate and forms a film in minutes. Subsequently, after few hours, under the influence of electrostatic force and van der Waals force, bacteria and microorganisms adhere to the conditioned film to form a biofilm. Water, Brownian motion, sedimentation and convection help bacteria and microorganisms stick to the film. Bacteria and microorganisms stick to the surface using substances made of polysaccharides, proteins, and nucleic acids. The early biofilm helps other complex organisms to attach later on. About seven days later, some protists, algae spores and marine larvae attached to the biofilm, providing food for larger biological fouling communities. About a month later, more complex communities formed on the surface of the substrate in the sea (Tian et al. 2021). Fouling occurs when dissolved and particulate matter in feed water deposits on the membrane surface, increasing the overall membrane resistance. The amount of biological matter and particles in the water also affects biofouling (Maddah and Chogle 2017). The harbour facilities create a good environment for new species to settle by providing new, easily accessible materials in sheltered areas. They are an important place for Non-Indigenous Species (NIS) to start. Many species, such as sponges, hydroids, tube worms, barnacles, bryozoans, mussels, ascidians, and algae, have been extensively reported to be introduced to harbors or marinas. They usually settle on hard surfaces (Diem et al. 2023).

Hydrodynamics can be caused by two factors, i.e. natural and artificial factors. Natural factors such as waves, currents, wind direction, coastal plant conditions and tectonic and volcanic activities, while artificial factors such as human intervention activities (fisheries, industry, ports, tourism, agriculture/forestry, mining and settlements) (Hawk and Johnson 2022). Biofilms initiate succession and attachment of fouling organisms. Biofilms are the primary source of nutrients and food and the formation of substrate layers that support colonizing more complex fouling organisms (Cacabelos et al. 2020). In addition to hydrodynamics, the structural complexity of fouling organisms is also influenced by anthropogenic activities, such as aquaculture, tourism, offshore mining and many more (Moya-Urbano et al. 2023).

This study aims to conduct a comparative analysis of fouling organisms present on diverse substrate types of attachment along the Karimunjawa marine ecosystem. The investigation is based on the observation of areas that could be used by fouling organisms, particularly macrofouling species, to attach, colonise and disperse. The study also looks at why these places have fouling organisms. This includes looking at the environment and human activities. There is little existing research on macrofouling organisms in tropical regions. This research aims to provide insights into the interplay between macrofouling organisms and water quality parameters.

## MATERIALS AND METHODS

### Study area

The research was conducted in the coastal area of Menjangan Besar Island in Karimunjawa, Indonesia. Menjangan Besar Island is one of the islands located in the Karimunjawa archipelago. This island is widely used as a place for cultivators to carry out cultivation activities, both for monoculture and polyculture cages. This activity allows fouling organisms to attach to cultivation facilities and infrastructure, because the nutrient content of fish feed can be used as a food source for fouling organisms. Menjangan Besar Island is also included in the Karimunjawa National Park area, so many tourist activities occur around Menjangan Besar Island. This research was conducted on 16th-17th June 2023, and sampled about 2000 macrofouling organisms at three stations with two replications at each location (Figure 1).

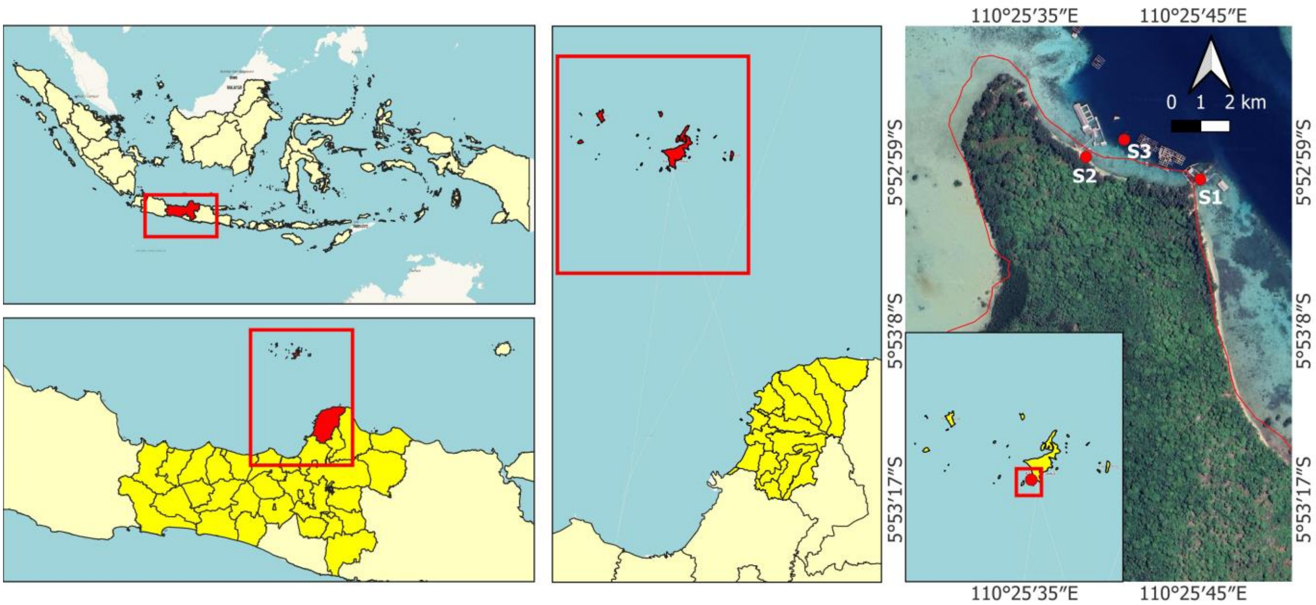


**Figure 1.** Map of sampling locations on Menjangan Besar Island, Karimunjawa, Central Java, Indonesia

**Procedures**

We used purposive random sampling to determine sampling stations. The macrofouling sample is randomly collected using hands or a knife by scraping the surface of the substrate based on predetermined boundaries (the substrat type and the surface area) to ensure that the sample contains specific characteristics or elements while maintaining an element of randomness to reduce bias in the data and increase generalizability (Sofiana et al. 2016). A sample of fouling organisms was collected from the substrate within 0.25 $m^2$ area at each station. The stations are located at three different sampling sites: Location 1 was characterised by a High-Density Polyethylene (HDPE) cage framework; Location 2, with a concrete block at the Menjangan Besar Island dock; and Location 3, the lower part of a wooden ship hull at Teluk Awur.

The identification of fouling organisms was conducted in Ce-MEBSA (Center Marine Ecology Biomonitoring for Sustainable Aquaculture) Laboratory, Universitas Diponegoro, using a Canon MZ25 stereomicroscope. We also measured water quality (physio-chemical parameters), including temperature and turbidity, pH, Dissolved Oxygen (DO) and salinity using a Horiba U-50 WQC at each location.

**Data analysis**

Community structure was analysed using the Shannon-Wiener diversity index (H'), evenness index (e), and Simpson's dominance index (C).

Shannon-Wiener diversity index (Odum 1993) with the formula:

$$H' = \sum_{i=1}^{s}(p_i) \ln p_i$$

Where:
H' : Shannon-Wiener diversity index
S : Number of species
pi : The proportion of ith species in the total sample (ni/N)
ni : Number of individuals of the species
N : Number of individuals of all species

The diversity index (H') used is the diversity index by Odum (1993). diversity index (H') is divided into three levels, namely 0< H' <1.5, which indicates low diversity; 1.5< H'<3.5, which indicates moderate diversity; and H'>3.5, which indicates high diversity.

Evenness Index (Krebs 1985), with formula:

$$e = \frac{H'}{\text{Ln}\, S}$$

Where:
e : Evenness index
H' : Shannon-Wiener diversity index
Ln : Exponential logarithm
S : Number of species

The Evenness index (e) determines the level of evenness of organisms in an area. The evenness index (e) used is the evenness index by Krebs (1985). The level of evenness can be known from 2 existing categories, including 0<e<0.50, which means the evenness index of fouling organisms, is uneven, and 0.50<e<1.00, which means the evenness index of fouling organisms is evenly distributed.

Simpson's Dominance index (Odum 1993) with the formula:

$$C = \sum Pi^2$$

Where:
C : Simpson's Dominance Index
Pi : The proportion of ith species in the total sample (ni/N)

The dominance index (C) is an index in accordance with Odum (1993) used to determine the extent to which a species of organism in an area dominates other species. The Dominance Index (C) can be distinguished by a range of $0 < C < 0.5$, which means there is no dominant species, while 0.5<C<1 means there is a dominant species. The dominance index (*C*) shows the tendency of a specific type of organism to dominate over other kinds of organisms.

The analysis of environmental factors and their correlation with the growth process of fouling organisms was carried out with the PRIMER v6.1.5 application. BIO-ENV (Primer v6.1.5) is a feature of the PRIMER application that serves to calculate the Spearman correlation coefficient between the distances in the response matrix and the environmental distance matrix, which means, this value determine the matrix correlation between macrofouling abundance and environmental parameters (used by the Spearman correlation test). Water quality data were transformed using square root transformation. The data were then normalised using Euclidean distance and the weighted Spearman correlation value. We also looked at the water quality and fouling organisms with Spearman's correlation. The abundance of fouling organism data was transformed by log10 (V+1) and then tested for similarity using the Bray-Curtis similarity matrix. The transformation results in the first normalisation were analyzed using Euclidean Distance and Spearman Stepwise correlation methods to identify which environmental parameters factor influence the most the colonization of macrofouling organisms (He et al. 2022).

## RESULTS AND DISCUSSION

Our results show that the diversity of macrofouling organisms from Consisted of High-Density Polyethylene (HDPE) cage framework was 1056, concrete block at the Menjangan Besar Island dock was 176, and lower part of a wooden ship hull was 768 (Table 1). The highest diversity was in Station 1, which is consisted of High-Density Polyethylene (HDPE) cage framework with value H':1.82 and the lowest diversity was in Station 2, which is concrete block at the Menjangan Besar Island dock with value H': 0.69. The difference of the value caused by the difference condition of each locations, based on the tested environmental parameters, then the value affected to the result. Each station have different occasion, which means the organisme that obtained was different too. The parameters of the aquatic environment influence the colonization capacity of biofouling organisms, while the population density is influenced by their growth rate (Shilova et al.

2020). Biological indices are needed to measure diversity, evenness and dominance. Biological indices can help analyze the distribution and dominance of organisms in each station (Shilova et al. 2020; Sarkar et al. 2022).

The community structure of fouling organisms found in all stations included seven classes and 15 species, including four species from the Bivalve class, namely, *Crassostrea* sp., *Pteria* sp., *Pecten* sp., *Septifer* sp., and four species from the Gastropods class, namely, *Cellana* sp., *Littoraria* sp., *Tectus* sp., and *Nerita* sp., and three species from the Anthozoa class, namely *Mopsella* sp., *Euafricana* sp., and *Astrangia* sp., and one species from the Ophiuroidea class, namely, *Ophiactis* sp., and one species from Polychaeta class, namely, *Neodexiospira* sp., and one species from the Ulvophyceae class, namely, *Halimeda* sp., and the last was one species from the Gymnolaemata class, *Cryptosula* sp. Species found in all stations indicate their ability to adapt to various substrates. In contrast, species found in one or two stations can adjust to specific substrates.

The dominant species at Station 1 was *Crassostrea angulata* Thunberg from bivalve class as much as 240 ind.m$^{-2}$ (Figure 2.A). The *C. angulata* became the dominant species at Station 1 because this species typically inhabits the intertidal zones, the areas of the coastline that are alternately submerged at high tide and exposed at low tide. Some species in the bivalves class are suspension feeders, which allow them to feed on plankton and filter particles from the water (Sievers et al. 2019). This form of Bivalvia class macro biofouling is solid to binds to the substrate and is not easily detached when waves and currents are under strain. However, Bivalvia can attach to just a few substrates. This is because the Bivalvia class has an attachment organ (Nybakken 1988)Station 1 was a cage framework, which also widely use in the open sea and offers this species extremely favorable environmental conditions and nutrient sources for colonization.

The dominant species at Station 2 was *Septifer* sp., as much as 96 ind.m$^{-2}$ (Figure 2.B). *Septifer* sp. can be a dominant species at Station 2 because these mussels are commonly linked with coastal areas such as salt marshes, mudflats and mangrove swamps. In such environments, these mussels perform a critical ecological function by purifying water and serving as a habitat and food source for numerous other organisms (Sievers et al. 2019; Moya-Urbano et al. 2023). Station 2 was a concrete block dock, so the anthropogenic activity affected the hydrodynamic around the areas, which made this species highly distributed. They also can be found attached to rigid substrates like rocks, wooden pilings, or other shells.

The most dominant species at Station 3 was *Littoraria* sp., as much as 416 ind.m$^{-2}$ (Figure 2.C). *Littoraria* sp. can be a dominant species at stations 3 because the species can find many food sources at related locations. This species is also called hard fouler because its hard shell can protect against predators and environmental threats. *Littoraria* sp., which is included in the gastropod class, has slow movement but can pass through various substrates, making this species able to find food quickly. The food of *Littoraria* sp. is generally detritus, organic matter, and water-soluble organic particles (Azevedo et al. 2020; Hawk and Johnson 2022).

Biological indices are quantitative measurements or mathematical formulas used to assess various aspects or parameters of ecology, species evenness and diversity in an ecosystem or the condition of a population or community. Biological indices help researchers evaluate ecological conditions and environmental changes over time (Pawhestri et al. 2015). Biological indices are correlated, which is helpful in determining colonization, distribution and the most dominant species in an area. The dominant species is found at that location because it can provide the nutrition of detritus, organic material, and decaying food remnants. The biological indices used to analyze the community structure of fouling organisms are the Shannon-Wiener diversity index (Odum 1993), Evenness index (Krebs 1985), and Simpson's dominance index (Odum 1993).

**Table 1.** Fouling organisms at each station

| Class | Family | Species | Number of Individuals (ind.m$^{-2}$) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | **S1U1** | **S1U2** | **S2U1** | **S2U2** | **S3U1** | **S3U2** |
| Bivalves | Ostreidae | *Crassostrea* sp. | 80 | 160 | 0 | 0 | 48 | 16 |
| | Pteriidae | *Pteria* sp. | 48 | 64 | 0 | 0 | 0 | 0 |
| | Pectinidae | *Pecten* sp. | 48 | 32 | 0 | 0 | 48 | 16 |
| | Mytilidae | *Septifer* sp. | 0 | 0 | 32 | 64 | 0 | 16 |
| Gastropods | Littorinidae | *Littoraria* sp. | 0 | 0 | 0 | 0 | 240 | 176 |
| | Nacellidae | *Cellana* sp. | 16 | 0 | 0 | 0 | 16 | 32 |
| | Tegulidae | *Tectus* sp. | 0 | 0 | 0 | 0 | 0 | 16 |
| | Neritidae | *Nerita* sp. | 0 | 0 | 0 | 0 | 0 | 16 |
| Anthozoa | Melithaeidae | *Mopsella* sp. | 64 | 80 | 0 | 0 | 0 | 0 |
| | Caryophylliidae | *Euafricana* sp. | 16 | 16 | 0 | 0 | 0 | 0 |
| | Astrangiidae | *Astrangia* sp. | 48 | 16 | 0 | 0 | 0 | 0 |
| Ophiuroidea | Ophiactidae | *Ophiactis* sp. | 0 | 0 | 0 | 0 | 16 | 0 |
| Polychaeta | Serpulidae | *Neodexiospira* sp. | 64 | 80 | 48 | 32 | 64 | 48 |
| Ulvophyceae | Halimedaceae | *Halimeda* sp. | 32 | 32 | 0 | 0 | 0 | 0 |
| Gymnolaemata | Cryptosulidae | *Cryptosula* sp. | 64 | 96 | 0 | 0 | 0 | 0 |
| Total Ind.m$^{-2}$ | | | 480 | 576 | 80 | 96 | 432 | 336 |

Notes: S1: Station 1, consisted of High-Density Polyethylene (HDPE) cage framework; S2: Station 2, concrete block at the Menjangan Besar Island dock; S3: Station 3, the lower part of a wooden ship hull. U1 means first replication and U2 means second replication

Biodiversity signifies the quantity of organisms present within an ecosystem, and the vitality of an ecosystem is evident when it exhibits a robust diversity index. Conversely, when an ecosystem displays a diminished diversity index, it indicates a state of decline or degradation (Augousti et al. 2021). The results of the data analysis of fouling organisms obtained diversity index values (H'), including Station 1 (cage frames) with H': 1.82, Station 2 (concrete blocks) with H': 0.69, and Station 3 (ship hulls) with H': 1.52. The error bar shows the tolerance limit between the data obtained and the original data in the field. The results show the difference in substrate conditions, nutrients, and food sources found at each station. Some organisms probably relate to environmental conditions, seasonal change, and water hydrodynamics (Antoniadou et al. 2013). Station 1, which attached on the HDPE cage framework, has the highest diversity value, suggesting that the station supports many diverse species according to environmental factors (Figure 3).

The results of the data analysis of fouling organisms obtained evenness index (e) values, including Station 1 (cage frames) with e: 0.67, Station 2 (concrete blocks) with e: 0.25 and Station 3 (ship hulls) with e: 0.56. The difference in index values indicates the different species found at each station. Environmental factors, such as temperature and water material content, allegedly cause the distribution and colonization of fouling organisms, especially bivalves and gastropods (Antoniadou et al. 2013; Arifin et al. 2021). Station 1, which consisted of HDPE cage framework showed the highest evenness value, means the organisms are evenly distributed based on the fouling organisms found at the station.

The results of the data on fouling organisms obtained dominance index (C) values, including Station 1 (cage frames) with C: 0.51, Station 2 (concrete blocks) with C: 0.24, and Station 3 (ship hulls) with C: 0.33. Differences in dominance index values are caused by the different dominant species. Evaluation of functional groups can be used to determine the role of species in the community of fouling organisms and the ecological functions that determine how fouling organisms colonize and compete for food and space. The dominance index is calculated from the quantity and number of organisms found (Tapia-Ugaz et al. 2022).

Research on marine organisms, especially fouling organisms, requires environmental quality test parameters to determine the influence of environmental factors on the distribution and colonization of fouling organisms (Tapia-Ugaz et al. 2022). Marine biofouling results from colonizing marine organisms on all submerged surfaces, including various natural and artificial habitats. This complex process is generally described as a chronological sequence that depends on several factors related to environmental conditions and the physio-chemical properties of the colonized substrate (Portas et al. 2022). Biotic factors are the biological characteristics of various organisms that play a pivotal role in determining the likelihood of settlement on a submerged substratum. Species-specific interactions influence this process and vary significantly across different species and locations.

Furthermore, chemical cues released in response to competition, reproduction, grazing, and predation substantially influence diverse organisms' settlement and surface recruitment (Vinagre et al. 2020). Abiotic factors commonly used to determine environmental influences are physical and chemical parameters. Physical parameters include temperature and salinity, while chemical parameters include pH and dissolved oxygen or DO. The results of measuring environmental factors were analyzed with the BIOENV-PRIMER application to determine the correlation between biotic and abiotic ecological factors.

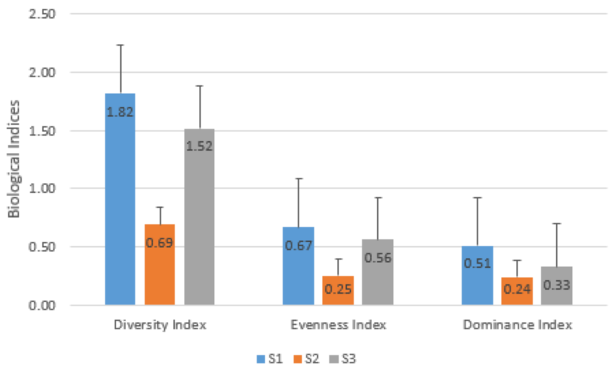


**Figure 3.** Biological indices. S1: Station 1, Consisted of High-Density Polyethylene (HDPE) cage framework; S2: Station 2, Concrete block at the Menjangan Besar Island dock; S3: Station 3, The lower part of a wooden ship hull (Error bars represent +SD)


**Figure 2.** The most dominant species at each station: A. Station 1 was *Crassostrea angulata*; B. Station 2 was *Septifer* sp.; C. Station 3 was *Littoraria* sp.

**Table 2.** The results of measurement of water physio-chemical parameters

| Station | Physical Parameters | | Chemical Parameters | | |
|---|---|---|---|---|---|
| | Temperature (ºC) | Turbidity (NTU) | DO (mg.L$^{-1}$) | pH | Salinity (º/ₒₒ) |
| S1U1 | 25.51 | 0 | 13.61 | 9.10 | 30 |
| S1U2 | 25.50 | 0 | 8.92 | 9.13 | 30 |
| S2U1 | 25.79 | 0 | 8.92 | 9.18 | 30 |
| S2U2 | 25.80 | 0 | 8.90 | 9.20 | 30 |
| S3U1 | 25.32 | 0 | 9.15 | 9.68 | 30 |
| S3U2 | 25.30 | 0 | 8.92 | 9.70 | 30 |
| Min | 25.30 | 0 | 8.90 | 9.10 | 30 |
| Max | 25.80 | 0 | 13.61 | 9.70 | 30 |
| Average | 25.54 | 0 | 9.74 | 9.33 | 30 |

Note: *S1: Station 1, consist of High-Density Polyethylene (HDPE) cage framework; S2: Station 2, concrete block at the Menjangan Besar Island dock; S3: Station 3, The lower part of a wooden ship hull. U1 means first replication and U2 means second replication

**Table 3.** Results of BIO-ENV analysis to determine the correlation between biotic and abiotic parameters

| P value/Corr. value | Variable |
|---|---|
| 0.722 | Temperature, Turbidity, Salinity |
| 0.423 | Turbidity, Salinity |
| 0.213 | Temperature, Turbidity, Salinity, pH |

Based on the data presented, it can be seen that temperature, turbidity and salinity have major effect on the growth and colonization of fouling organisms (Table 3). Fouling organisms are very dependent on environmental conditions, where every change that occurs in the environment has a significant role to the organisms in it (Sarkar et al. 2022). The correlation value obtained is r=0.722 (r>0.5), which indicates that the correlation value shows a strong influence based on the value of the Interpretation criteria for the relationship between two variables.

Based on environmental parameters which can be seen in Table 2, the average value of water physio-chemical parameters shows that all parameters all parameters have an impact for the life or presence of biofouling organisms. Environmental parameters, such as salinity, pH, temperature, density, dissolved organic matter, water current rate, sunlight exposure and intensity, dissolved gas concentration, and substrate topology, influence the colonization of fouling organisms (Sarkar et al. 2022). Temperature is a significant factor in the survival of living things. Marine biofouling tends to be more influential in higher temperatures, marking a clear difference between tropical and temperate communities. In tropical regions, seasonal variability is scarce, and water temperature is high and stable, enabling a continuous settlement throughout the year (Almeida and Coolen 2019). The environmental temperature reflects the differences in the composition of fouling organisms in different climate zones. The number of species, formation stage, and attachment rate of fouling organisms are closely related to water temperature (Lin et al. 2017).

Turbidity determines how much light enters the water. Organic and inorganic dissolved particles influence the water turbidity level. Turbidity plays an essential role in the colonization of fouling organisms because of the factors that influence the condition of the water to become turbid. Salinity is an integral part of the description of marine water quality because of its essential role in the distribution of aquatic biota. Salinity affects the flotation process of dissolved matter. The higher the salt content, the higher the salinity level. Therefore, organic and non-organic dissolved particles can be distributed from the seabed to the surface, which then affects the hydrodynamic conditions in the surrounding waters. Some possible causes of high and low salinity are rainfall, seasonality, and anthropogenic activities (Rifahyanti et al. 2022; Sarkar et al. 2022). Anthropogenic activities such as fishing, offshore aquaculture, and tourism are also suspected of influencing fouling organisms' distribution and colonization. Fishing and aquaculture activities are assumed to control the distribution of fouling organisms because aquaculture cages submerged in water for a long time. Residues from aquaculture feeding can add nutrients and food for fouling organisms in the water, so there is a food source that can help colonize fouling organisms on the substrate of related facilities and infrastructure. Concrete blocks of docks, harbors and bridges, can widely become substrates that can be used as attachment media by fouling organisms. This is probably because the materials used, such as wood, concrete blocks or cement, are homogeneous, so some microorganisms can still adapt to these substrates (Hawk and Johnson 2022). Tourism activities such as swimming and fishing may also affect water hydrodynamics, allowing dissolved particles to disperse. Additionally, fouling organisms can search for and settle on substrates, which can be influenced by human activities such as aquaculture, fishing, and tourism that alter water currents. The movement of fouling organisms through water currents becomes very easy when human activities directly or indirectly affect the hydrodynamics.

In conclusion the fouling organisms in all stations consisted of 7 classes and 15 species, with the most discoveries being *Littoraria* sp. (Gastropoda), with a total of 416 ind.m$^{-2}$ at all stations. Then, they were followed by *Neodexiospira* sp. (Polychaeta), with a total of 336 ind.m$^{-2}$ at all stations. The results of the biological index obtained show that the highest Diversity index value is located in the Station 1, Consisted of HDPE cage framework with a value of H'=1.82 (moderate). The highest evenness index value is located in the Station 1, Consisted of HDPE cage framework with a value of e=0.67 (evenly distributed). The highest dominance index value is located in the Station 1, cage framework with a value of C=0.51 (there is a dominating species). The difference in index values indicates the diversity of each species' taxa, nutrients, food sources, substrate types and adaptabilities to the water environment. The physio-chemical parameters of water were analyzed using BIO-ENV, Primer 6.1.5, showed that the most influential environmental factors were temperature, turbidity, and salinity (Corr value (r) = 0.722). Anthropogenic activities such as aquaculture, fishing and tourism in the area are suspected to influence hydrodynamic changes, subsequently affecting the fouling organism attachment and colonization processes.

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