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Macroepiphyte biodiversity on *Kappaphycus alvarezii* surface and its interaction with environment in cultivation centers on Lombok Island, Indonesia

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Abstract. *Ghazali M, Widoretno W, Arumingtyas EL, Retnaningdyah C. 2022. Macroepiphyte biodiversity on* Kappaphycus alvarezii *surface and its interaction with environment in cultivation centers on Lombok Island, Indonesia. Biodiversitas 23: 6284-6292.* The aims of this paper are to investigate the influence of environmental factors on the diversity of macroepiphytes in *Kappaphycus alvarezii*. Macroepiphyte sampling was carried out at four cultivation centers: Seriwe Bay, Ekas Bay, Gerupuk Bay, and Siwak of Lombok Island, West Nusa Tenggara, Indonesia. Several stations were placed at each location, and at each station were used one to three cultivation units with five replications. Environmental data measurements were carried out at the time of sampling. Some parameters were measured: pH, temperature, salinity, current velocity, brightness, DO, BOD, nitrate, phosphate, and TSS. Data analysis was performed using several diversity indices. In addition, a biplot analysis was performed using PCA to analyze the correlation between environmental factors and environmental factors to macroepiphytes. The results showed that the most dominant species was *Polysiphonia spaerocharpa*, and the second was *Ceramium* sp1. The highest richness and abundance were found in Ekas Bay. The highest species dominance was in Siwak. The highest diversity index was in Ekas Bay. The correlation between environmental factors showed that hemeroby harmed depth, phosphate, and DO and positively affected BOD and the thallus surface structure. The principal correlation analysis showed that the abundance of macroepiphyte was influenced by BOD, the roughness of host thallus, and the hemeroby index.

Keywords: Abundance, environment, hemeroby, macroepiphytes

INTRODUCTION

Macroepiphyte (epiphyte macroalga) is a common pest phenomenon in tropical and temperate regions. Some plants that are commonly used as hosts include *Halodule* sp. (Papini et al. 2011), *Pocidonia oceania* (Berlinghof et al. 2022), *Sargassum fusiforme* (Xu et al. 2022) and *Kappahycus alvarezii* (Ghazali et al. 2021). Most of the macroepiphyte are opportunistic red algae (Rhodophyta), which take advantage of attaching rhizoids to the leaves/thallus of the host. The presence of macroepiphyte negatively influences the host's growth and development (Tsiresy et al. 2016). Rantetondok and Latama (2017) found a decreasing growth rate of the host due to an epiphytic attack. The presence of epiphytes not only interferes with growth but also causes a decrease in metabolite quality.

Seasonal changes strongly influence the richness and abundance of macroepiphyte. Jamshidzehi et al. (2017) and Nayaka et al. (2017) found the highest diversity value of macroepiphyte in winter and autumn. The different values of the diversity of macroepiphyte in the different seasons causing by the exchange of environmental parameters. In the rainy season, there is an increase in DO, nitrate, and a decrease in phosphate concentration in Papapgayo (Saravia-Arguedas et al. 2021). Changes in the quality of the aquatic environment are further exacerbated by changes in land use in coastal areas. One example is the conversion of mangrove land, causing an increase in sedimentation and turbidity of the water. Mangroves' existence impacts reducing sedimentation and seawater turbidity (Lovelock et al. 2015).

Changes in environmental factors influence the physiology and anatomy adaptation of macroalgae. The surface of the host thallus produces mucus which serves as a protective barrier for the thallus. Nayaka et al. (2017) stated that algae produce and accumulate various metabolites to protect from stress and heat. Under stress conditions, the thallus will secrete mucus in more significant numbers containing compounds that protect it from disease (Vaghela et al. 2022). However, another effect of releasing this mucus is stimulating pathogens (Erbabley and Kelabora 2018) and facilitating the attachment of macroepiphyte spores. The host mucus consists of various polysaccharides and proteins (Hayashi et al. 2011). In addition, epiphytes also produce mucus containing simple sugars, which act as an adhesive (Ouriques et al. 2012). Spore adhesion consists of two processes: (i). Initial and primary attachment and (ii). The secondary process results in permanent attachment. The spore will stimulate growth under optimal environmental parameters (Ordoñez et al. 2017).

In some species, the attachment is followed by rhizoids that penetrate the host thallus's cortical cells (Nakajima et al. 2015; San and Soe-Htun 2018). Macroepiphytes in the thallus will interfere with nutrient uptake, light absorption, and photosynthesis. *Neoshiponia savatieri* competes with the host in absorbing nutrients (N, P, CO2, and other mineral elements). Shaded conditions, high O2 concentrations in light, anoxic conditions in the dark, and competition for nutrients will cause severe decay in the host thallus infected by macroepiphytes, especially *N. savatieri* (Pang et al. 2011). In addition, macroepiphyte infection penetrating the interior of the host thallus has the potential to cause the transfer of nutrients from the host to the macroepiphyte (Papini et al. 2011).

One of the hosts that have significant economic value is *K. alvarezii*. This macroalga is one type widely cultivated in cultivation centers on Lombok Island. Several macroepiphytes were found attached to *K. alvarezii*, namely *Polysiphonia* sp., *Ceramium* sp., *Monosiphonia* sp., *Padina* sp., *Hypnea* sp., *Laurencia* sp., etc. (Papini et al. 2011). The study of Vairappan et al. (2014) showed that carrageenan from *K. alvarezii* infected with epiphytes had lower quality and quantity than healthy thallus. This study aimed to investigate the influence of environmental factors on the abundance of epiphytes at *K. alvarezii* at the Lombok cultivation center.

MATERIALS AND METHODS

Study area

A sampling of macroepiphytes was carried out at four *K. alvarezii* cultivation centers on Lombok Island, West Nusa Tenggara, Indonesia, at; Ekas Bay (-8.864751, 116.434248), Seriwe Bay (-8.892566, 116511153), Gerupuk Bay (-8.918344, 116.358717), and Siwak (-8.920718, 116.339835) (Figure 1). Each center consisted of different stations depending on the area and number of cultivation units. In detail, the number of stations in each cultivation center is as follows: five stations in Seriwe Bay, three stations at Ekas bay, five stations at Gerupuk bay, and one station at Siwak. The sampling at each station was carried out on 1-3 cultivation units with five replications.

Procedures

Macroepiphyte sampling

The research was conducted in Lombok cultivation centers, West Nusa Tenggara. Macroepiphyte sampling was carried out by taking *K. alvarezii* once in the dry season. The four selected locations have different environmental conditions, such as land use, aquaculture activities, and location (bays or are directly adjacent to the Indian Ocean). Data collection using observation with the quadrant method, using a plot size of 1 x 1 cm^2 (Vairappan et al. 2014). The minimum area of the sample plots is determined based on the sampling area of 10% of the total cultivation plots. The density and dominance of macro-epiphytes data were recorded from each sampling point.

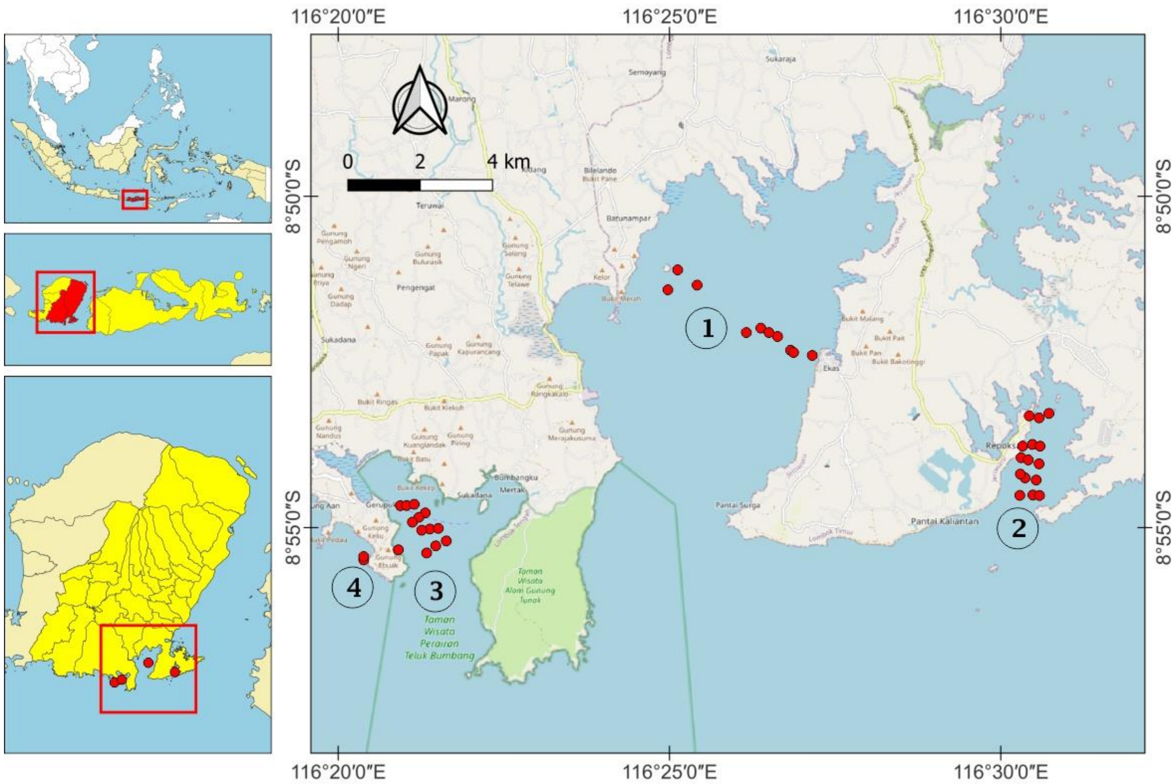

Figure 1. Distribution of macroepiphyte sampling at four *Kappahycus alvarezii* cultivation centers on Lombok Island, West Nusa Tenggara, Indonesia. 1. Ekas Bay, 2. Seriwe Bay, 3. Gerupuk Bay, 4. Siwak, red spot; the sampling site

Identification of macroepiphytes

The collected macroepiphyte were identified based on their morphological and anatomical characteristics. Morphological characters, including holdfast, thallus shape, branching, cell arrangement, and spores, were obtained from photos under a stereo microscope, while anatomical characters were obtained from preparations observed under a microscope. Species were identified based on morphological characters referring to the identification book (Chapman and Chapman 1973), as well as other supporting journals.

The roughness of the host thallus surface

The rough thalli surface of *K. alvarezii* allows easy attachment of epiphyte during low water motion. The more epiphyte can attach and colonize the thallus surface, the more the thallus surface becomes a suitable medium for growth. The surface roughness of the thallus is determined using a level of damage to the surface of the thallus. The higher the level of damage, the higher the score given. Thallus damage between 0 to 25% given a score of 1, 26-40% given a score of 2, 41-60% given a score of 3, 61-80% given a score of 4, and 81-100% given a score of 5.

Water quality

Environmental parameters were measured in each station. The data collected three samples from each station, except in Siwak and one station in Gerupuk Bay (limited cultivation unit), so the total of the data collected is 40 samples. Measurement including pH, temperature, salinity, water current, dept, DO (dissolved oxygen) (on-site), BOD (biological oxygen demand), nitrate (Method 8192), phosphate (Method 8048), and TSS (total suspended solid) (Method 8006).

Assessment of land use and human activity Impact

The land use and human activities data was collected using a survey method to obtain an overview of land use and human activities' impact on the sea waters at seaweed cultivation sites. The results of the land use survey were then scored using the Hemeroby approach (Kim et al. 2002).

Data analysis

Diversity analysis

Species diversity is a characteristic of the community level based on their biological organization. Therefore, species diversity can be used to express the stability of community structure. The diversity indices used for diversity analysis were the important value index (IVI), richness, density, evenness index, dominance index, and Shannon-Wiener diversity index (Odum 1971). The diversity index formula has been used is presented below:

Important value index (IVI) = relative density + relative frequency

Richness index = number of taxa

Density = total of individuals of the species in all the sample plots/total number of sample plots studied (cm^2)

Evenness index

$E = H'/\ln S$

Where:

H': Shannon-Wiener diversity index

S: Simpson diversity index

Dominance index

$C = \Sigma(ni/N)^2$

Where:

ni: important value of species i

N: total of important values

Diversity index

$H' = -\Sigma\ (ni/N) \log (ni/N)$

Where:

ni: important value of species i

N: total of important values

Environmental analysis

Environmental quality analysis was conducted using ANOVA (Robin et al. 2012) with different replication and continued using the least significant difference (LSD). This analysis was conducted to determine differences in environmental quality between locations.

Correlation analysis

Biplot analysis was performed using principal component analysis (PCA) using Past 4.08 software (Retnaningdyah et al. 2019). The output of the analysis is environmental to environmental factors correlation and the correlation of environmental factors to the macroepiphytes (Figure 7). The ordinance diagram consists of plant species and plots depicted as points and environmental factors in the form of arrows. Raw correlation shows the relationship between the measured environmental factors. The minus or negative sign on the correlation value indicates an inverse relationship.

RESULTS AND DISCUSSION

Important value index

As many as 13 macroepiphytes were identified in the cultivation center on the island of Lombok (Figure 2. Each species has a different important value index, ranging from 3.44 to 162.96 (Figure 2. The highest important value index in three cultivation centers, namely Siwak (162.96), Seriwe (133.29), and Gerupuk (108.20), was *Polysiphonia spaerocarpha*. Meanwhile, specifically for the cultivation center of Ekas Bay, the epiphytic species that dominates is *Ceramium* sp1, with a value of 82.83. On the other hand, *Calliblepharis saidana* had the smallest important value index (10.4). Overall, *P. spaerocharpa* was a species that dominated all cultivation centers on the island of Lombok. These results indicate that *P. spaerocharpa* was the species that had the best adaptability. The results also showed that some species were only found in one cultivation location with a limited number of individuals. These species include *Tolypiocladia* sp1, *Hypnea* sp, *C. saidana, Tolypiocladia* sp2, and *Champia parvula*. Another unique result was *C. saidana* and *Tolypiocladia* sp2 only found one individual at one sampling point.

The number and types of epiphytic species found in macroalgae cultivation centers on Lombok Island (Gerupuk Bay) are always changing. Mardiana et al. 2018) found 20 species in this cultivation center. Meanwhile, in this study, only five macroepiphytes species were found in Gerupuk Bay. In addition, (Ghazali et al. 2021) found as many as 21 species of macroepiphytes in Seriwe Bay. Meanwhile, in this study, only six species of epiphytic macroalgae were found in Seriwe Bay. The difference in environmental parameters and sampling time causes a difference in the number of macroepiphytic species found. The research conducted on the Island of Lombok in recent years has only carried out an inventory of species and the number of species without analyzing the important value index. The significance value index determines the level of species dominance in the community. This value indicates the role of the species in the community. The greater the IVI value of a species, the greater level of control over the community (Sunil et al. 2016). The dominance of *P. spaerocarpha* in this study indicates that this species is the most adaptable. This alga has rhizoids that can penetrate the host cell (Vairappan 2006), making it more resistant to environmental changes. Islam et al. (2020) stated that the presence of a species is strongly influenced by the ability of the species to survive changes in water conditions, level of clarity, and type of substrate. Meanwhile, Vairappan (2006) explained that the presence of epiphytic species in *K. alvarezii* is strongly influenced by spores in the seeds used; these spores are usually embedded in the thallus of *K. alvarezii* to form lumps (Tsiresy et al. 2016).

Species richness and density

The Ekas Bay cultivation center was the highest richness and abundance of macroepiphytes. The number of macroepiphytes found was twelve species with a density of 91.2 individuals/cm^2. Meanwhile, six species were found at the Seriwe Bay cultivation center, at Gerupuk Bay five, and at Siwak two (Figure 3). The richness and abundance of epiphytic macroalgae species are strongly influenced by the quality of the waters in which they live (Jover et al. 2021). These data indicated that the water conditions of Ekas Bay were very supportive of the growth of epiphytic macroalgae compared to the other seaweed cultivation centers; Ekas Buana has the highest BOD and hemeroby index value, indicating high organic contamination (Table 1). The High organic contaminant causes a decrease in the host's ability to survive a macroepiphyte infection. Macroepiphytes are organisms that live attached and can't move, so their abundance and composition are strongly influenced by the quality of the waters in which they live, such as waves, contamination of organic matter, and nitrogen (Hyndes and Hanson 2009). Substrate type, season, and both interactions influence species richness. Therefore, immobile organisms such as macroepiphytes are often used as bioindicators of fertility and pollution.

Ekas Bay is not only used as a center for seaweed cultivation but also as a center for lobster and grouper cultivation. This cultivation activity is suspected to be one of the sources of pollutant organic matter leftover feed. The increase in organic pollutants harmed *K. alvarezii* as a host but was positive for the abundance and richness of macroepiphyte. The Ekas Buana cultivation is very different from the Siwak. The Siwak is directly adjacent to the Indian Ocean, the bottom of the waters is rocky, and there are no sources of pollutant organic matter. This condition makes the abundance and species richness of macroepiphytes very low. Differences in abundance due to environmental parameters are common (Silaban and Kadmaer 2020). The results of the research by Tsiresy et al. (2016) in the waters of Lamohara and Tampolove revealed the same results, wherein different macroepiphyte abundances were obtained in both locations. Seasonal differences also influence species richness (Adam et al. 2017). Seaweed species richness is lower in the rainy season compared to the dry season (Titlyanov et al. 2019). Therefore, their ability to survive strongly influences the value of species richness and abundance.

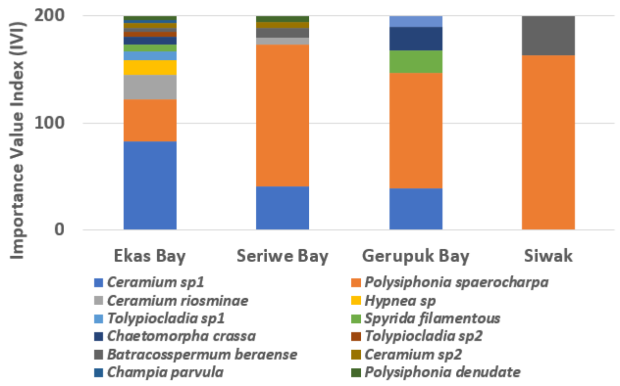

Figure 2. Important value index of macroepiphyte in *Kappahycus alvarezii* (Host) cultivated on Lombok Island

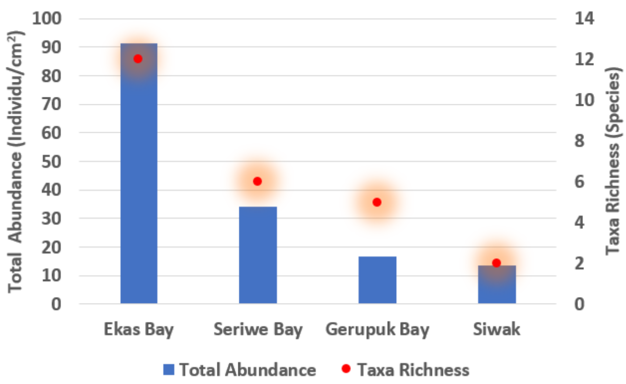

Figure 3. Taxa richness and individual density of macroepiphyte on the surface of *Kappahycus alvarezii* thalli

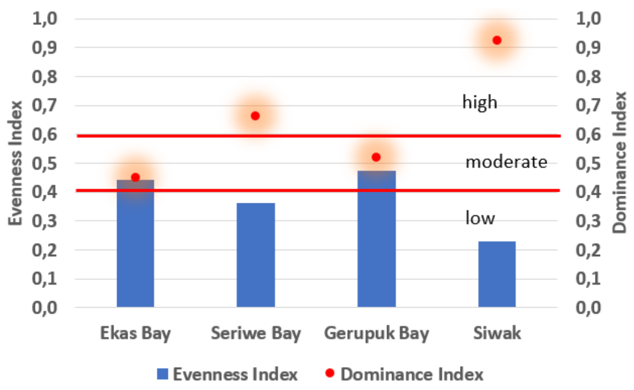

Figure 4. Evenness index and dominance of macroepiphytes on the thallus surface of *Kappahycus alvarezii*

Evenness and dominance index

The evenness index values contradict dominance index values (Zhang et al. 2019). At Seriwe Bay, the evenness index was low (0.23), and the dominance index was high (0.92) (Figure 4). A community with a dominance index value close to one indicates that one species controls the community. The number of species found was only two species with different densities. Meanwhile, the evenness and dominance index of Ekas Bay and Gerupuk Bays is in the medium category. The index values (evenness and dominance index) at both locations are between 0.4 and 0.6. This value indicates that there were no dominant species in the cultivation center.

The evenness index is a value that shows the level of evenness in the number of individuals in each species in a particular community. Evenness index values ranged from 0-1. The higher the evenness index obtained, the more uniform the number of individuals of each species obtained in one community (Ogi et al. 2021**)**. The evenness index value is largely determined by species abundance (Mason and Mouillot in Levin 2013). The evenness index shows the level of distribution of individuals of each species, the balance of the number of individuals of each species, and then the value of the evenness index will be high (>7). The distribution of individuals within a species is not significantly different if the evenness index value is close to 1. Pathak and Lavudya (2021) found a difference in the evenness index (E) due to the influence of the season. The highest evenness index (0.71) on Veraval Beach occurs in January, and the lowest (0,54) is in September. Meanwhile, in Sikka Beach, the highest evenness index occurred in November and December, and the lowest was in September. Differences in species distribution levels are caused by differences in the ability of individuals to survive, including the ability to stick to the substrate (Papini et al. 2011). Substrate stability, hardness, and surface texture strongly support macroalgae growth, including epiphytic macroalgae. A stable substrate impacts the low index's dominance (Widyartini et al. 2021), including the thallus surface of *K. alvarezii* as substrate. The more stable the substrate where the macroepiphytes grow, the fewer macroepiphytes will dominate. Kepel et al. (2019) got an evenness index value at several stations ranging from 0.81 to 0.9. These results indicate that the seaweed community is at a stable station. This result differed from the results of the research conducted, where the level of evenness was low. In the research of Kepel et al. (2019), the water current ranged from 0.9 to 9.5 cm/s. While in this study, the water current ranged from 7.16 to 13.9 cm/s. Water current significantly affects the presence and abundance of macroepiphytes in the thallus of *K. alvarezii*. The only species with rhizoid-type holdfast can survive on strong water currents. The other factor that contributed to the evenness index was the stability of the thallus surface of the host as a substrate for macroepiphytic**.** The surface of the host thallus tends to be unstable. This instability was caused by changes in the surface due to changes in environmental factors (Figure 6). Environmental changes are factors that trigger changes in the species that dominate (Jones and Magurran 2018). Marlia et al. (2016) observed changes in macrophyte community structure in *K. alvarezii* thallus.

Diversity index

The health level of a community was assessed based on the diversity index value. The value of the Shannon-Wiener diversity index in seaweed cultivation centers ranged from 0.23 to 1.58 (Figure 5). Siwak was a cultivation center that had the smallest diversity index value. This value was due to the limited number of species found. Meanwhile, the highest diversity index value was obtained from Ekas Bay. This value indicates that the environmental parameters of Ekas Buana Bay were more supportive of macrophytes than Siwak's. Based on the diversity index value, Ekas Bay and Gerupuk bay were two locations with a moderate diversity of macrophytes. Meanwhile, Seriwe Bay and Siwak belong to the low diversity of macrophytes.

The diversity index was used to determine the community. Diversity contains two essential things, namely wealth and abundance. Richness refers to the number of species, while abundance refers to the number of individuals of each species. An environment with a diversity index value of less than 1 is an environment of low quality, between 1 and 3 of moderate quality, and an index value of more than 3 of high quality (Retnaningdyah et al. 2019). The higher the diversity index value, the higher the species richness with evenly distributed abundance. Based on the assessment criteria, all seaweed cultivation centers have a low-quality environment. The low diversity index value on community indicates that the environmental parameters do not support the growth and development of the research object. In this case, it is the macroepiphytes species. The difference in value of the diversity index was different at each location. Fitrian et al. (2017) found that four observation stations in the TayandoTam archipelago had a diversity index value of less than 1. This value indicates that the species diversity index is in a low category. Another factor that determines the value of the diversity index is the season. Pathak and Lavudya (2021) found a difference in the value of the diversity index in Sikka waters in the September-February period.

Table 1. The environmental parameters of the Lombok Island, West Nusa Tenggara, Indonesia seaweed cultivation center and the environmental quality standards refer to the decree of the minister of the environment number 51 of 2004 (Retnaningdyah et al. 2019)

Parameter	Ekas Bay	Seriwe Bay	Gerupuk Bay	Siwak	Standard
Hemeroby	2.50 ± 0.71 ^{b}	2.00 ± 0.85 ^{a}	1.38 ± 0.77 ^{a}	1.00 ± 0.00 ^{a}	-
Dept (m)	2.48 ± 0.53 ^{a}	8.27 ± 5.15 ^{b}	14.21 ± 5.37 ^{b}	1.50 ± 0.00 ^{a}	-
Water Current (cm/s)	13.90 ± 5.09 ^{b}	7.16 ± 3.63 ^{a}	11.68 ± 3.53 ^{a}	13.40 ± 1.27 ^{b}	-
TSS (mg/L)	0.062 ± 0.01 ^{a}	0.080 ± 0.03 ^{a}	0.081 ± 0.02 ^{b}	0.042 ± 0.01 ^{a}	20
Salinity %o	29.80 ± 1.69 ^{a}	29.40 ± 1.30 ^{a}	31.38 ± 1.19 ^{ab}	33.00 ± 0.00 ^{b}	33-34
pH	7.97 ± 0.10 ^{b}	7.80 ± 0.08 ^{a}	7.99 ± 0.07 ^{b}	7.92 ± 0.01 ^{ab}	7-8.5
Temp (^{o}C)	28.57 ± 0.80 ^{ab}	29.45 ± 0.55 ^{abc}	28.17 ± 0.88 ^{a}	29.70 ± 0.57 ^{c}	28-32
DO (mg/L)	4.02 ± 0.73 ^{a}	5.43 ± 0.61 ^{b}	7.76 ± 0.79 ^{c}	8.70 ± 0.14 ^{c}	>5
BOD (mg/L)	2.44 ± 1.38 ^{c}	0.91 ± 0.47 ^{b}	0.53 ± 0.42 ^{a}	0.70 ± 0.28 ^{a}	20
NO3-N (mg/L)	0.01 ± 0.00 ^{a}	0.01 ± 0.00 ^{a}	0.02 ± 0.01 ^{b}	0.01 ± 0.01 ^{ab}	0.008
PO4-P (mg/L)	0.16 ± 0.18 ^{a}	0.16 ± 0.07 ^{a}	0.28 ± 0.12 ^{a}	0.26 ± 0.10 ^{a}	0.015
The roughness of host thallus surface	2.28 ± 0.42 ^{a}	2.48 ± 0.69 ^{a}	1.95 ± 0.60 ^{a}	2.60 ± 0.00 ^{a}	-

Note. Different notation on parameter values indicate significance between location

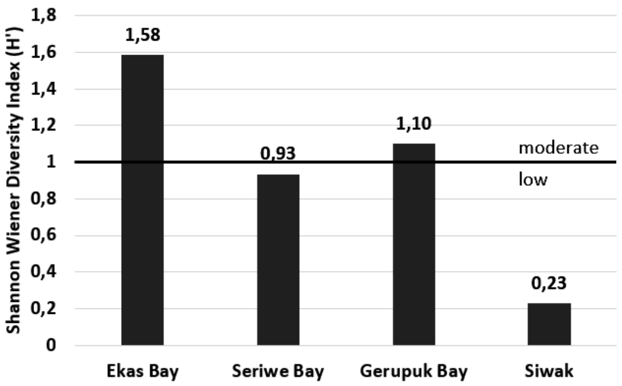

Figure 5. Macrophyte diversity index value on the thallus surface of *Kappahycus alvarezii*

Environmental parameters

The environmental parameter data showed that the ten observed parameters differed significantly (Table 1). Various factors, including the position of the waters, depth and human activities, caused this difference. In addition, differences in environmental factors can also be caused by the influence of other environmental factors. For example, TSS has a relationship with the movement of seawater. Seawater's movement brings suspended substances in the water column to spread in various directions, which impacts the turbidity of seawater (Ismail and Prayitno 2020). However, in general, the parameter values are still in the range of environmental quality standards for marine plants based on the Decree of the Minister of the environment number 51 of 2004. On the other hand, the standard value of DO in Ekas Bay was below the standard. This value was lower than the results of research conducted in 2015. The DO value in Ekas Buana Bay's surface waters, East Lombok, ranges from 5.2-6.8 mg/L (Marpaung et al. 2015). The decrease in DO value may be caused by the increased fish and lobster cultivation and land conversion from coastal areas to corn fields.

Correlation of the environment to the environmental parameter and environmental to macroepiphytes

Some environmental parameter values are primarily the result of the impact of exchanging other parameters; even the interaction is of very significant value (Figure 6). Human activities in coastal areas and the waters around the cultivation sites significantly increase BOD and decrease DO and PO4-P. Land conversion from bushland to corn fields and water use for fish and lobster culture increase the water's organic matter. Saunders et al. (2017) state that land use significantly affects aquatic environmental parameters. The increase in organic matter affects the microbial activity that utilizes DO, resulting in an increase in BOD and a decrease in DO. Microbes are not only in the water, but some are also attached to the surface of the thallus *K. alvarezii*. The presence of microbes causes damage to the cuticle layer (Ward et al. 2020). Another factor that plays a role is the increase in total suspended solids in the *K. alvarezii* cultivation area, which impacts the covering of the thallus surface by water dust (Yulianti and Kasim 2018). This condition makes the talus's surface rough. The rougher the thallus surface, the easier the epiphytic spores to attach (Chao et al. 2016). The number of spores attached greatly determines the abundance of macroepiphytes that grow on the surface of the host thallus. The more spores attached, the higher the survival rate.

The environmental influences of BOD, hemeroby and the roughness of the host thallus (*K. alvarezii*) correlated to the abundance increase of macroepiphytes. Meanwhile, it negatively correlates with DO, PO4-P, and depth. These results indicate that the higher the BOD and hemeroby, the lower the DO, and the closer the cultivation area to the organic contaminant source, the higher the epiphytic macroalgae. Based on environmental parameters, Ekas bay's water quality strongly supported the growth of epiphytic macroalgae. This cultivation center has the characteristics of low DO, relatively shallow BOD, and high human activity. Meanwhile, Siwak and Gerupuk Bay have environmental parameters supporting *K. alvarezii* cultivation activities but not macroepiphyte. One of the epiphytic species used as a model is *Ceramium* sp1. This species was very easy to find in the Ekas Bay and Seriwe

Bay seaweed cultivation centers compared to other cultivation centers.

Naturally, the increase in BOD and decrease in DO are closely related to organic matter contamination in the water (Lee et al. 2013). BOD often indicates organic matter contamination (Koda et al. 2017; Retnaningdyah et al. 2019). Organic matter pollution can come from human activities on land and around the waters (Wen et al. 2017). Changes in activities that occur on land in the southern part of Lombok are the conversion of land functions from forests to corn fields and increased human activity. The higher human activities in coastal areas impact the increasing environmental pressure (Retnaningdyah et al. 2019).

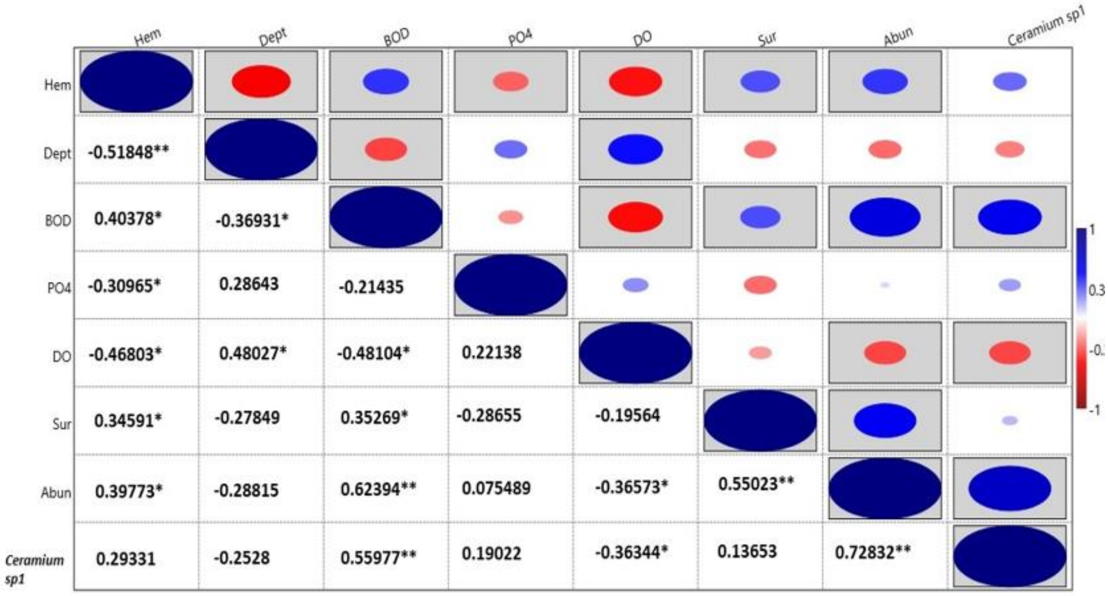

Figure 6. Environmental to environmental correlation and environmental to macroepiphyte, blue spots (positive correlation), red spots (negative correlation), and grey boxes (significant correlation)

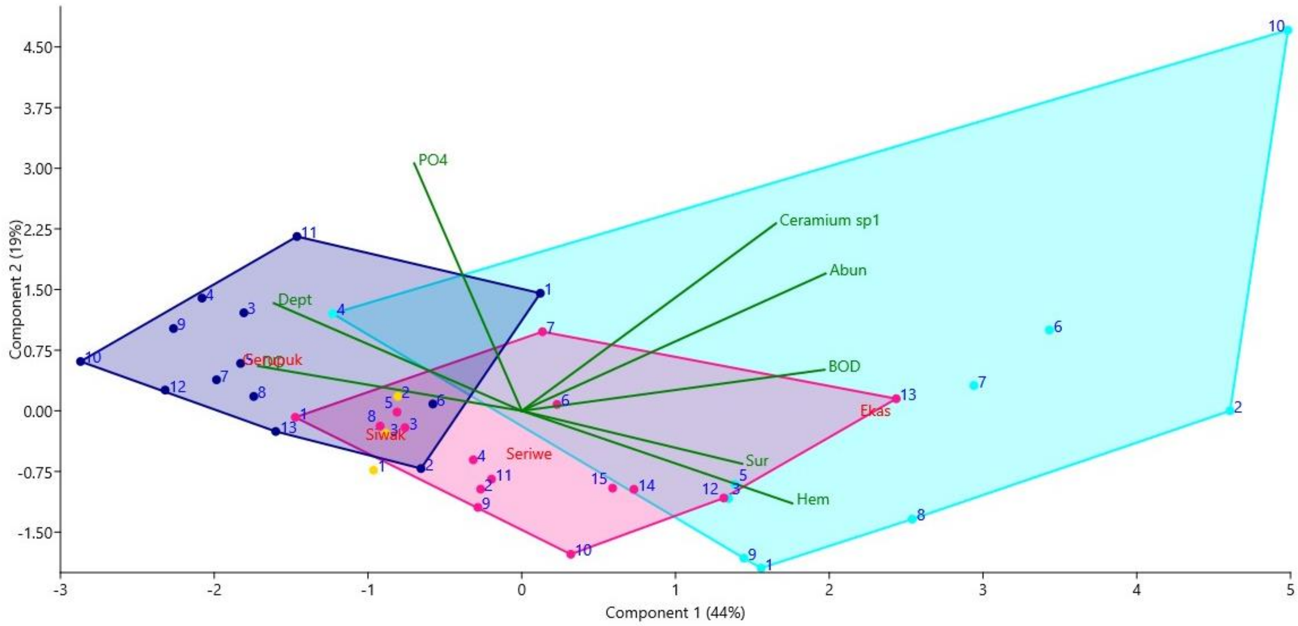

Figure 7. Principal component analysis (PCA) shows the correlation of environmental factors to macroepiphyte species. Spots with a number are species codes, vectors in the same direction show a positive correlation, and the opposite direction shows a negative correlation

These activities impacted the increasing organic compounds carried to the surrounding sea waters (Jiang et al. 2014). Sources of pollution also come from the disposal of organic waste and food scraps from nearby stalls and restaurants. In addition, there are fish and shrimp cultivation activities in several centers of seaweed cultivation. Fish and shrimp farming uses trash fish and pellets as feed. This feed will leave residues that play a role in enriching organic matter in water bodies. Fish farming impacts decreasing water quality (Gao et al. 2022). The increase in organic matter impacts the abundance of microorganisms that can survive in conditions of high contamination (Rodríguez et al. 2018). The higher the abundance of microorganisms that live in the waters, the higher the amount of oxygen needed, increasing BOD and decreasing DO (Spietz et al. 2015). Increasing the abundance of microorganisms requires attachment media. One of the attachment media for microorganisms is the thallus surface. The abundance of microorganisms has an impact on increasing the stress of *K. alvarezii*.

The indication of *K. alvarezii* stress is the appearance of a layer of mucus, thinning the cuticle and the surface of the thallus rougher (Hayashi et al. 2011). Changes in the level of surface roughness of the thallus have a positive impact on the attachment of epiphytic macroalgae spores (Chao et al. 2016). If the spores and microbes stick more and more, then the richness and abundance of epiphytic macroalgae. The occurrence of macroepiphyte is one of the main problems in seaweed cultivation (Vairappan et al. 2014). The higher the abundance of macroepiphytes on the thallus surface of *K. alvarezii*, the greater the chance of crop failure (Ghazali et al. 2021). Therefore, to maintain the sustainability of aquaculture activities, efforts are needed to reduce the pollution of organic matter from land and fish and lobster cultivation activities. Specifically, reducing the effects of contamination of organic matter from fish and lobster cultivation activities can be done by zoning water use. Fish farming utilizes shallow subtidal zones adjacent to the mainland, while seaweed farming utilizes the central area with water depths of more than 10 m.

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