The abundance of Scleractinia corals in relation to water quality in the maricultural area of Menjangan Island, Karimunjawa National Park

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Abstract. Coral reefs ecologically provide nurseries for many species of commercially important fish, and protection of coastal areas from storm waves. Unfortunately, coral reefs worldwide have been degraded in the last few decades, along with human population growth and marine resource utilization. As the main biotic component of coral reef, hard corals (order Scleractinia) are susceptible to environmental disturbances, both natural and anthropogenic induced disturbances. In particular, excessive nutrient concentration could affect hard coral physiologically and ecologically. This study aimned to understand further relationship between nitrate and phosphate and hard coral abundance in the mariculture area. Menjangan Besar island (Site 1-3) was selected as a study site to represent the mariculture area, with Geleang island (Site 4) as a reference site. Coral coverage in Site 1-3 was lower than non-mariculture yet did not indicate damage to coral reefs. No significant difference in coral coverage of Scleractinia at all sites was found ($F_{(1,20)}$=74.51, $p>0.05$). However, the genus composition in Site 1 was significantly different compared to other sites. Phosphate concentration in the non-mariculture area (Site 4) is the highest among all sites, while nitrate is the second highest. Site 2 ($\bar{X}$=0.40, SD=0.03) has significant difference in nitrate concentration ($F_{(1,20)}$=121.19), $p<0.05$) compared to Site 1 ($\bar{X}$=1.46, SD=0.81) and Site 4 ($\bar{X}$=1.28, SD=0.47). Significant difference in phosphate concentration ($F_{(1,20)}$=27.73), $p<0.05$) was found between Site 1 ($\bar{X}$=0.06, SD=0.01) and Site 3 ($\bar{X}$=0.35, SD=0.20). Nutrient concentration in the water ecosystem of the study sites was found to affect the genus composition in Sites 2 and 3. However, they did not correlate significantly to coral abundance (nitrate: R^2=0.0002, phosphate: R^2=0.11), that may relate to seasonal variation in ocean hydrodynamics and nutrient sources caused by anthropogenic activities. Further studies may be required for a more comprehensive review with bigger sample size and physical variables that affect the nutrient distribution.

Key Words: correlation, nutrient, nitrate, phosphate, coral reef, hard coral, Scleractinia.

Introduction. Indonesia is geographically included in the coral triangle area (Spalding et al 2001). The wide distribution of coral reefs in Indonesia is also accompanied by a wealth of biological resources that contain various benefits for humans and the environment. Some benefits include coastal protection and a food source for marine life in the surrounding environment. Humans also benefit from coral reef ecosystems as a fishery resource (Suharsono 2014; Hadi et al 2018). Coral cover (order Scleractinia) is one of the main determinants of coral reef health. Hence, the condition of coral reefs is essential to consider in the ecological assessment of coral reefs (Giyanto et al 2017). Calcareus-producing marine organisms (hermatypic), especially coral reefs, have a significant role in forming coral reef ecosystems. The accumulation of calcareus matter produced in the long term with various environmental influences forms a calcarues coral as the physical foundation of the current coral reef ecosystem (Purohit & Ranjan 2007; Hadi et al 2018).

Coral reefs inhabiting marine ecosystems are considered significant for biodiversity, providing a habitat to 35000–60000 species of plants and animals (El-Naggar 2020; Morrissey et al 2018). Ecologically, they provide nurseries for many species of commercially important fish and protection of coastal areas from storm waves. Unfortunately, coral reef degradation has increased dramatically during the last three decades due to enhanced anthropogenic disturbances and their interaction with natural stressors. Hence, coral reefs are vulnerable to changes in environmental conditions (Zooxanthellae and Coral Bleaching 2018). The increasing rate of population growth and the need for marine and coastal resources are among the main factors causing environmental disturbances and can encourage the emergence of various threats to coral reef ecosystems (Giyanto et al 2017; Hadi et al 2018). Disruption of the aquatic environment can potentially increase the mortality rate of coral reefs and reduce the percentage of live coral cover. This increase can lead to the degradation of coral reef ecosystems (Bruno & Selig 2007; Mona et al 2019). For the last few decades, the world's coral reefs – especially Indonesia – have been undergoing degradation. The world's coral reefs covered an area of 284300 km^2 in 2001 and 249710 km^2 in 2011 – a decrease of about 12% (Spalding et al 2001; Burke et al 2011). Indonesia, as part of the Indo-Pacific region, in 2001, was recorded to have a coral reef area of 51020 km^2, while in 2018, it was recorded at 25000 km^2 – a decrease of almost 51% (Spalding et al 2001; Hadi et al 2018). Direct human activities in coastal areas and the high seas can potentially disrupt the existence of coral reef ecosystems, including pollution and the use of coastal land. In addition, destructive and excessive capture fisheries activities are one of the main factors driving coral reef degradation, especially in Indonesia (Bruno & Selig 2007; Riegl et al 2009). Mariculture activities are an alternative to reduce the rate of destructive fishing and potentially restore the availability of fishery resources in natural habitats (Froehlich et al 2017). However, mariculture activities can produce organic waste from feed residues and digestion of cultivated biota, potentially increasing the concentration of nutrients in the surroundings. The toxicity of aquatic nutrients is relatively low. However, an increase in excess concentration can affect the physiological processes of some organisms and can lead to ecosystem disturbances to a decrease in biodiversity (Romano & Zeng 2007; Parker 2012; Minister of the Environment 2004).

Nutrients are one of the limiting factors for marine ecosystems, so their availability determines corals' distribution, growth, and abundance (Mampuk et al 2013). The naturally limited amount is a source of nutrition for coral animals. Reef corals have a soluble nutrient regulation mechanism (Sabdono et al 2019; Saptarini et al 2016). Zooxanthellae in corals were also found to reduce nutrients and translocate photosynthetic products to meet the nutritional needs of their parents. Therefore, excessive water nutrient concentrations have no definite impact on coral conditions (D'Angelo & Wiedenmann 2013). The waters north of Menjangan Besar Island, Karimunjawa National Park, are the scope of research related to the relationship between water nutrient concentrations and the diversity of coral reefs (order Scleractinia) in mariculture areas (Kennedy et al 2020). This study aimed to examine the relationship between the abundance of Scleractinia and the concentration of nutrients (nitrate-phosphate) in the waters (Soltan 2016; Yusuf et al 2012).

The surrounding environment's carrying capacity to the mariculture activity rate is often considered for sustainability. There are two types of environmental carrying capacity for mariculture activities (Gopakumar 2016), namely physical and ecological carrying capacity. Physical carrying capacity pays attention to the entire body of water and the total area suitable for mariculture activities. In contrast, ecological carrying capacity pays attention to ecological processes, ecosystem services, and species diversity in an ecosystem. Therefore, mariculture activities can have a positive impact by reducing pressure on the availability of aquatic biological resources or exacerbating exploitation by damaging the ecosystem due to the waste produced. (Diana 2009; Ross et al 2013). A limited area with a high population level and accumulation of organic waste results in water contamination due to organic enrichment. The main problem lies in cultivation practices that are too oriented to production carrying capacity, so they ignore environmental aspects (Putro 2016).

Naturally, aquatic nutrients come from the waste products of herbivorous and carnivorous organisms, which contain nitrite (NO_2^-), nitrate (NO_3^-), phosphate (PO_4^{3-}). All three are forms of nitrogen and orthophosphate compounds are generally contained in water (Bristow et al 2017). Corals require oligotrophic water conditions to thrive. Nutrient enrichment has been a significant cause of coral reef degradation in recent decades. Water conditions with increased nutrients make coral reefs more susceptible to bleaching. Regional-scale enrichment of aquatic nutrients is often associated with significant coral reef cover and diversity reductions. An increase in dissolved inorganic nitrogen concentration was also associated with decreasing the coral bleaching temperature threshold. This assumption is based on the finding of an inversely shifting ratio of coral cover to algae (Wiedenmann et al 2013). Karimunjawa National Park (KNP) includes 22 of the 27 islands in the Karimunjawa Archipelago. Geographically, the area is 83 km northwest of Jepara Regency, Central Java Province. The Karimunjawa National Park Center is the institution that oversees TNKJ under the Ministry of Environment and Forestry. The KNP area is divided based on zoning, which refers to the Decree of the Directorate General of Forest Protection and Nature Conservation No. SK 28/IV-SET/2012 concerning the zoning of Karimunjawa National Park. Five of the nine zones that have been designated are marine zones, ranging from protection to utilization.

Material and Method

Description of the study sites. The research was conducted during the east monsoon with sunny weather conditions at each station. The underwater currents are quite strong in the waters of Geleang Island and light currents in the waters of Menjangan Besar Island. Stations 1-3, according to KNP zoning, are in the Maritime Cultivation Zone to represent waters suspected of experiencing nutrient fluctuations. Station 4 in the waters of Geleang Island is in the Maritime Protection Zone and represents an area without anthropogenic activity with the initial assumption of not experiencing nutrient fluctuations. This research has been conducted for one year and one month. Field data collection was carried out during September to October 2020, at Menjangan Besar and Geleang Islands, Karimunjawa National Park, Jepara Regency. Primary data collection locations in the form of coral reef cover and water samples for nutrient concentration analysis were divided into four stations in both water areas. The research was conducted quantitatively with descriptive and correlational survey methods. The research location was determined intentionally (purposive sampling) by considering the reasons known from the area (Singarimbun & Effendi 2008). The existence of mariculture activities in the form of floating net cages (KJA) in the waters of Menjangan Besar following the Zoning of the Karimunjawa National Park (Sulisyati et al 2019; Zhang et al 2016; BTNKJ 2004). The locations are spread across four research stations. Station 1 is about 10 meters north of the Multilevel Round KJA (KJABB) installation and monoculture KJA installations. Station 2 is between Station 1 (100 meters southeast) and Station 3 (100 meters southwest), adjacent to the traditional marine cage installation. Station 4, as a reference, is in the waters east of Geleang Island, which is 7.5 km west of Station 3, as shown in Figure 1.

Data retrieval. The Underwater Photo Transect (UPT) method was used in coral reef surveys based on the Coral Reef Health Monitoring Guide (Giyanto et al 2015), where two divers held a rolling meter and held an iron frame and took photos of the substrate. Photographs were taken on a 2×25 meter transect/station along the coral reef cover at 10 meters. The location of the second transect was randomly spaced. The interval of photo taking is one meter starting from the 0th meter so that 2×25 meter substrate photos are obtained in one station. Photo analysis was carried out using the Coral Point Count with Excel Extension (CPCe) version 4.1 application with a random point sample counting technique of 50 points, referring to Kohler and Gill (2006) in the Underwater Photo Transect Method for Assessment of Coral Reef Conditions (Giyanto 2013).

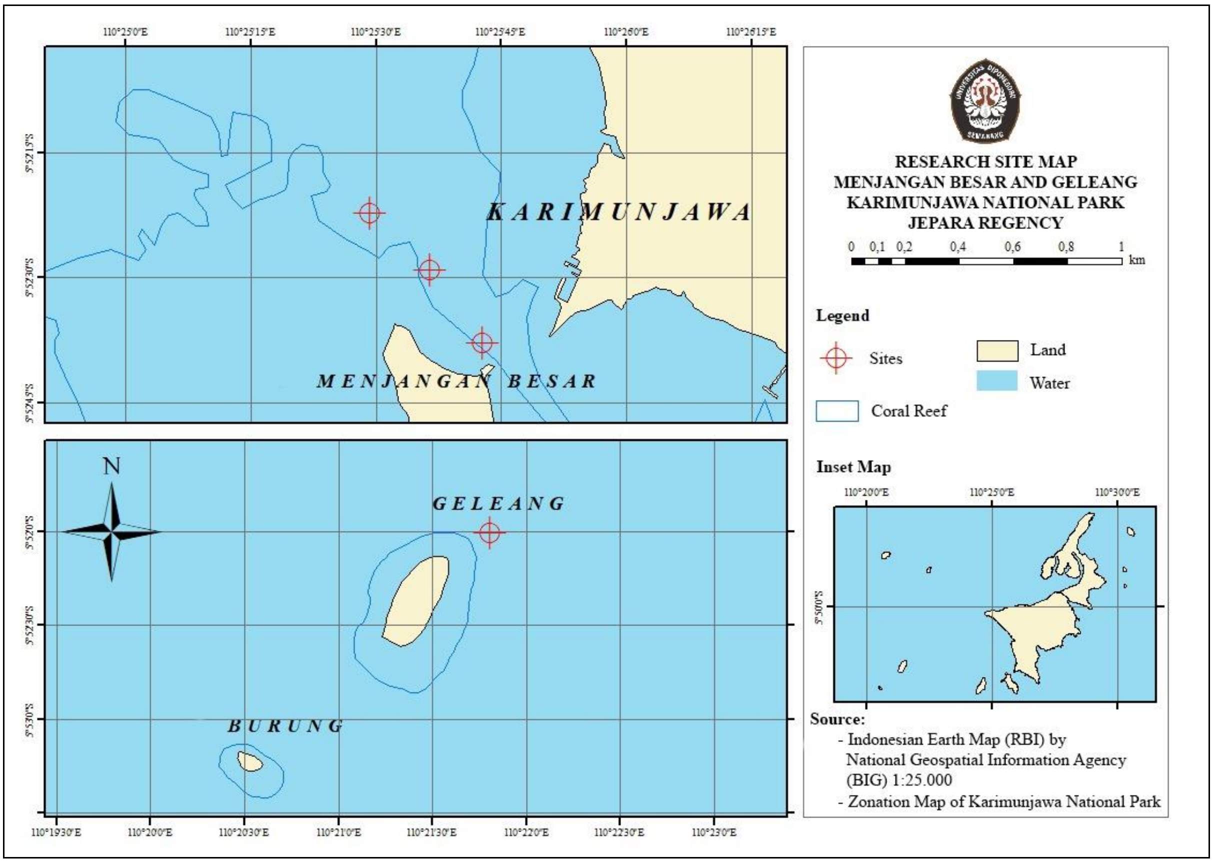

Figure 1. Map of sampling locations (map generated using ArcGis V.10.8).

Coral reefs, as the main object in this study, were categorized by genus according to the identification books (Colin & Arneson 1995; Kelley 2009).

Water quality parameters. Measurement of physicochemical parameters is needed to determine the water quality at the research site. Therefore, physical parameters such as brightness and temperature as well as chemical parameters such as pH and dissolved oxygen (DO) were measured in situ, whilst nitrates and phosphates were analised ex-situ. Water samples were taken at each station using a 600 mL polyethylene bottle. Water samples were analyzed to determine the concentration of nitrate and phosphate in the laboratory of the Equipment Testing Center of the Public Works Service (BP2 DPU) of Central Java Province. The nitrate and phosphate tests were performed using ultraviolet spectrophotometry for the nitrate test and ascorbic acid spectrophotometry for the phosphate test, respectively (Baird et al 2017).

Data analysis. Coral reef cover composition data, including abundance percentage and other ecological indices, were obtained from substrate photo analysis using the CPCE 4.1 application. Based on these data, the calculation of the percentage of live coral cover is automatically carried out by the application using the following formula (Kohler & Gill 2006):

$$pi = \frac{ni}{N} \times 100\% \qquad \text{(i)}$$

where:
pi: i-th closing percentage (%)
ni: Number of i-th type cover (species abundance)
N: Total cover

The cover of the coral reef was assessed based on their composition and percentage. The categorization of coral reef cover refered to the Decree of the Minister of the Environment Number 4 of 2001, as summarized in Table 1.

Table 1

Standard criteria for coral reef damage

Percentage of living coral cover area (%)	*Categories*
0 – 24.9	Bad
25 – 49.9	Moderate
50 – 74.9	Good
75 – 100	Very well

The diversity index is a calculation to describe how many different species there are in a community. The results of photo analysis in the form of coral reef cover percentage were calculated for the diversity index using the formula according to Shannon-Wiener in Campbell et al (2011). In addition, the evenness index is needed to compare the diversity value of a community with the number of biotas found (Krebs 2014).

Statistical analysis was preceded by transforming the Scleractinia abundance data with the $\log_{(x+1)}$ function and the nitrate-phosphate data with the square root (√) to homogenize the data form and avoid the absence or excess values of biotic and abiotic variables. All statistical analyses were carried out using the RStudio version 4.0.5 (R Core Team 2019). The normality test using the Shapiro-Wilk method is needed beforehand to determine the level of evenness of all data. After being tested normal, all data were tested by One-Way ANOVA to determine the significance of the difference in the mean data on the abundance of Scleractinia as well as nitrate and phosphate in all research stations. Furthermore, regression tests were carried out to determine the relationship between the abundance of Scleractinia and nitrate-phosphate quantitatively (Krebs 2014). The Non-metric Multi-dimensional Scaling (NMDS) for the configuration of the two variables were done to assess the distance between the variables. NMDS is one of the most widely applicable ordination techniques in ecological data, both biotic and abiotic, as it is considered a robust multivariate ordination method (Putro 2010).

Results and Discussion

Percentage of coral cover and ecological index. A visual presentation of the condition of coral reefs at each research station is presented in Figure 2.

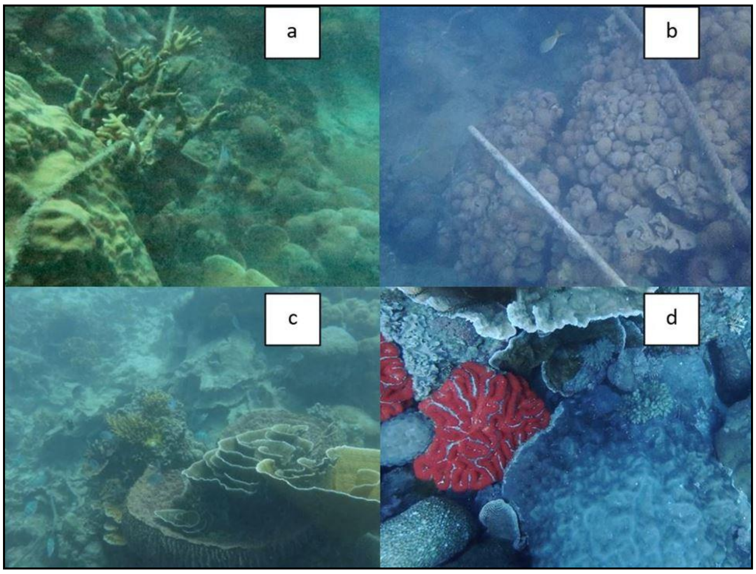

Figure 2. Visual performance of coral cover at the studied sites representing mariculture sites: (a) Station 1 , (b) Station 2, (c) Station 3, and reference site (d) Station 4.

In geneal, live corals cover at Stations 1-3 (mariculture area) were considerably lower than those at Station 4 (reference site). However, the percentage of cover and the diversity index of all stations did not show disturbed/damaged areas (medium category) according to the quality standard criteria for coral damage. Station 4 has the highest percentage of coral cover compared to other stations. However, the level of diversity and evenness of coral reefs at the station was the lowest. This case indicates the dominance of a particular genus—the composition of the genus in Section 4.1.2. Coral Reef Composition explains that more than half the percentage of live coral cover was dominated by the genus *Porites*, followed by the genus *Acropora* with a percentage of almost one-fifth of the total live coral cover. This condition shows that the percentage of coral cover is not always directly proportional to the level of diversity. Sulisyati et al (2014) noted that the Menjangan Island tourist area has a coral diversity index of 3.75 (high category) but with a percentage of coral cover that is categorized as "medium". Munasik and Siringoringo (2011) explained that similar conditions could be caused by acute environmental disturbances and differences in the ability of each type of coral to adapt. Station 3 has the highest level of diversity and evenness compared to other stations. The high evenness indicates the distribution of species that is not unequal to each other, supported by a low dominance index. Such conditions make it a stable community called Muttaqin et al (2013), so their coral colonies tend to increase their size dimensions instead of adding other colonies. Visualization of the value of the ecological index to the percentage of coral cover is presented in Figure 3.

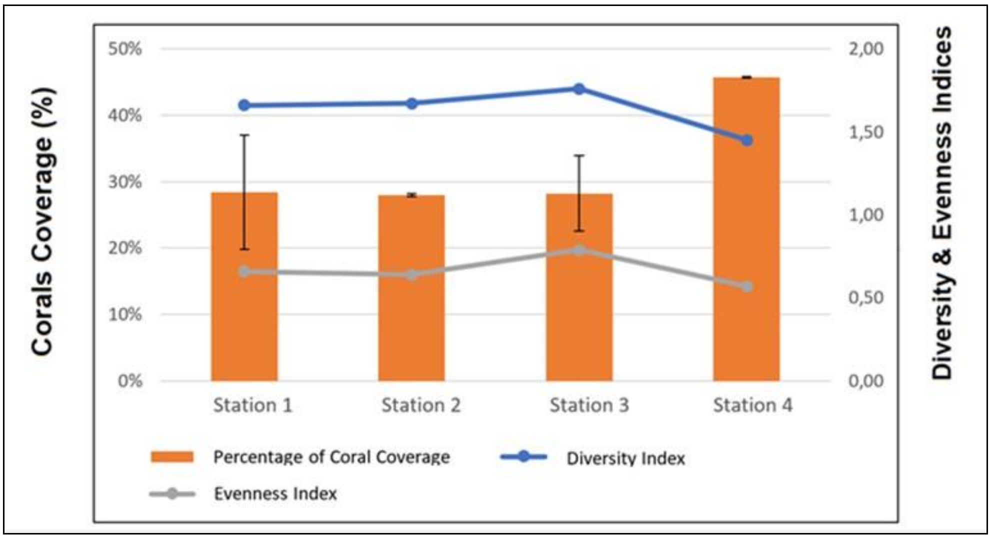

Figure 3. Comparison of the average proportion of live coral cover with ecological indices.

Coral reef composition. The coral reefs found were all from 11 families and 27 genera. They are commonly found in the Karimunjawa National Park area, according to Karimunjawa National Park Office (BTNKJ 2017). Most of the genus found came from the family Faviidae. However, five families each recorded only one genus. A more detailed composition is presented in Table 2.

Table 2

Cover composition of Scleractinia

Family	*Genus*	*Coral Type Cover (%)*			
		Station 1	*Station 2*	*Station 3*	*Station 4*
Faviidae	*Cyphastrea*	-	1.86	1.84	-
	Diploastrea	-	5.01	-	0.10
	Echinopora	-	0.14	-	-
	Favia	0.28	0.29	1.42	1.22
	Favites	5.49	0.14	-	0.20
	Goniastrea	0.14	6.30	14.73	7.93

	Leptastrea	1.13	-	-	-
	Montastrea	-	0.14	-	-
Fungiidae	*Ctenactis*	-	-	0.28	-
	Fungia	0.14	0.43	0.57	1.32
	Heliofungia	-	0.43	-	-
	Herpolitha	-	-	-	0.31
Acroporidae	*Acropora*	1.69	7.16	7.51	17.80
	Astreopora	4.93	13.04	7.51	2.44
	Montipora	3.24	4.87	2.83	2.24
Poritidae	*Alveopora*	0.14	-	-	0,20
	Goniopora	38.17	5.01	5.81	1.63
	Porites	37.04	45.56	28.05	55.14
Agariciidae	*Leptoseris*	0.56	-	-	-
	Pachyseris	1.83	6.02	28.75	8.34
Pocilloporidae	*Pocillopora*	0.14	0.86	-	-
	Seriatopora	0.70	1.29	-	-
Caryophylliidae	*Euphyllia*	-	-	-	0.10
Dendrophylliidae	*Heteropsammia*	-	-	-	0.10
Merulinidae	*Hydnophora*	2.96	0.57	0.71	-
Mussidae	*Symphillia*	1.27	0.14	-	0.92
Siderastreidae	*Psammocora*	0.14	0.72	-	-

Porites can be found in all the stations. At Station 1, the percentage cover of the genus was slightly below *Goniopora*. The genus *Pachyseris* dominated the coral cover at Station 3 with a percentage slightly above *Porites*. According to Munasik and Siringoringo (2011), the abundance of *Porites* coral is caused by its resistance to various environmental conditions. The family Acroporidae was found to be the second dominant at Stations 2 and 4. Rudi (2012) stated that Acropora corals are generally not resistant to environmental changes but have relatively fast growth and rapid cover recovery. Further mentioned by Ricardo et al (2021), partial damage to early-stage recruits only had a small impact when the damage was inflicted in the first few days of treatment using *Acropora millepora*. Documentation of several genera found in the field is presented in Figure 4.

Station 4, in terms of diversity, has the lowest value compared to other stations. However, three genera were not found at other stations: *Euphyllia, Heteropsammia*, and *Herpolitha*. At Station 1, *Leptastrea* and *Leptoseris* are not found in other stations. At Station 2, there are also unique genera such as *Montastrea* and *Heliofungia*; at Station 3, there is only *Ctenactis* as a unique genus. Fungiidae coral groups such as *Ctenactis*, *Herpolitha*, and *Heteropsammia* indicate previous ecosystem damage. Their distribution patterns may be phylogenetically closely related to their ecological differentiation along environmental gradients in coastal reef areas (Hoeksema 2012). When viewed specifically, the *Fungiidae* family is mainly found in waters facing the open sea, following its presence at Station 4 to the east of Geleang Island.

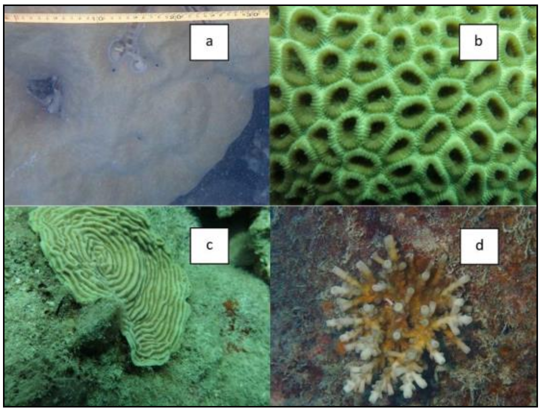

Figure 4. Coral genus: *Porites* (a), *Favia* (b), *Pachyseris* (c), and *Acropora* (d).

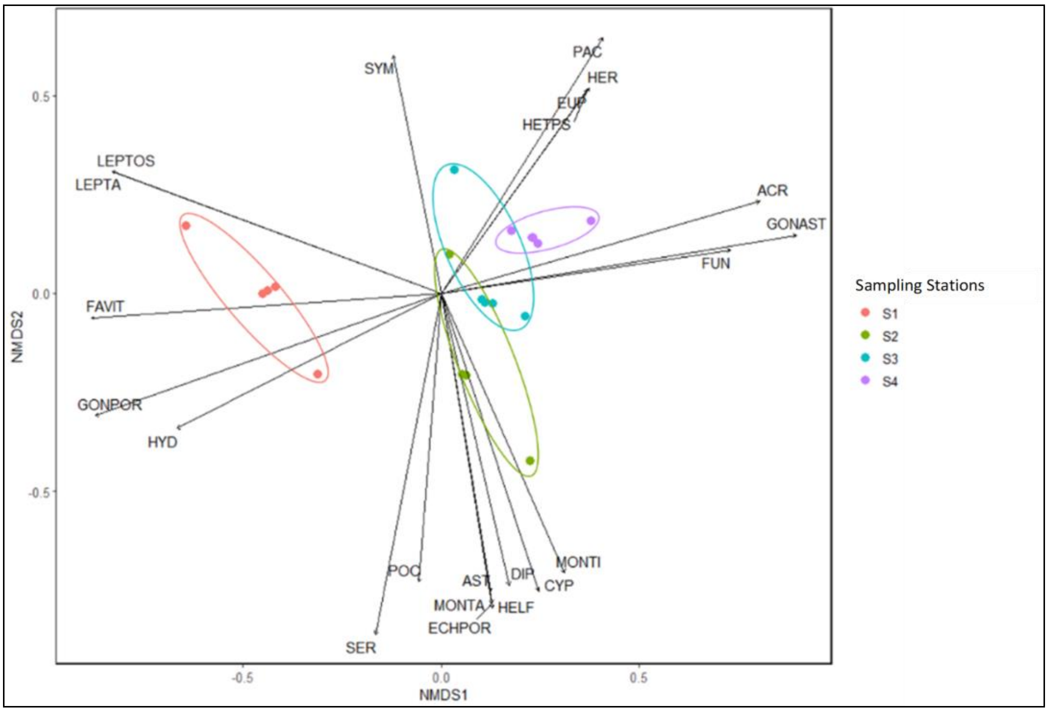

Figure 5. Genus significance in the coordination of coral abundance and nutrient concentrations at each station.

Analysis of variance results (ANOVA). The results showed no significant difference in abundance between stations with a significance value above the limit (p=0.05), which was 0.053. These results provide further information that the abundance of coral reefs recorded at each station is similar. However, the results of the ordinance of the abundance of the genus from each station are presented in Figure 5, which shows the distance between the different compositions of coral reefs between Station 1 and other stations that are similar to each other. Non-metric Multi-Dimensional Mapping that has been carried out shows many significant genera from each station. This case can be seen in the direction of the significance of the genus and the ordinance of each station close to each other. At Station 1, the genera *Favites*, *Goniopora*, *Hydnophora*, *Leptoseris,* and *Leptastrea* became a significant biotic component. Compared with the percentage cover data in Table 2, *Goniopora* is the most significant and second dominant genus after *Porites*. *Favites* and *Hydnophora* were found at other stations but with an insignificant percentage of their presence at Station 1. The genus *Leptoseris* and *Leptastrea* were detected significantly because their presence was only at Station 1 but with a low value, directly proportional to the cover percentage. Daniel and Santosa (2014) explained that the distribution of corals in the high seas is influenced by oceanographic factors, one of which are currents. Mapping predicted distribution pattern of coral planula by Nurulita et al (2018) in the same season as this study (eastern season) shows a reversing current pattern in the waters of Menjangan Besar and Geleang Islands. However, the current recorded study tends to move towards the islands' west. This current pattern is thought to have formed similar coral reef compositions between the two islands.

All nitrates and phosphates at each station exceeded the specified quality standards. The highest nitrate and phosphate concentrations were recorded at Stations 1 and 3. The average concentration of nitrate and phosphate in the waters of Menjangan Besar Island in 2017 was recorded by Sulardiono et al (2018) as much as 0.625 mg/l and 0.094 mg/l, respectively. The following year, Farantika et al (2020) found a lower concentration of nitrate (0.3525 mg/l) and a slightly higher concentration of phosphate (0.0133 mg/l). Compared to those two years, the concentration of nitrate and phosphate at Stations 1, 2, and 3 increased since 2017. Station 4, as a reference, was recorded as having the highest concentrations of nitrate and phosphate.

The results of the analysis of variance (ANOVA) showed a significant difference in the nutrient data group from each station with a significance value below the limit (p=0.05), which was 0.008 and 0.00046, respectively. All data groups were further tested by post-hoc test using the Tukey HSD method. The test was run to determine the location of the significant differences between stations. The results of the follow-up test showed that the nitrate concentration at Station 4 ($\bar{x}$=1.28; SD=0.470) as a reference was significantly higher ($F_{(1,20)}$=121.19) than Station 2 ($\bar{x}$=0.40; SD=0.027) with a significance value of 0.0208. Apart from Station 4, the nitrate concentration at Station 1 ($\bar{x}$=1.46; SD=0.815) was also significantly higher than at Station 2, with a significance value of 0.0222. The significance of the phosphate concentration at Station 4 ($\bar{x}$=0.19; SD=0.069) was also found to be different ($F_{(1,20)}$=27.73) with Station 2 ($\bar{x}$=0.05; SD=0.015) with a significance value of 0.0329. There is a high significance between Station 3 ($\bar{x}$=0.35, SD=0.20) and Station 1 ($\bar{x}$=0.06, SD=0.01) and 2, worth 0.00198 and 0.00103 consecutive.

Station 4 in the waters of Geleang Island as a reference recorded higher nitrate concentrations than Stations 2 and 3 and phosphate from Stations 1 and 2. The absence of anthropogenic activity at that location indicates that nutrient concentrations are not only controlled by the presence of organic pollutant sources. According to Abigail et al (2015), the distribution of nitrate and phosphate is influenced by physical factors such as tides, waves, and currents. This statement is supported by the season when field data collection was carried out. Research conducted by Handoko et al (2013) and Nurulita et al (2018) in the same seasonal period as this study (east monsoon) found that the direction of the current in the Karimunjawa Islands was dominant to the west. In addition, it was also found that both locations were recorded to have the same range of nitrate concentrations (0.49 mg/l–0.85 mg/l). It indicates a dominant water movement from Menjangan Besar Island to Geleang Island's waters in the east monsoon.

Abundance correlation to nitrate-phosphate concentration in waters. A regression test was conducted to determine the correlation between variables parametrically. As a result, no significant relationship was found between reef coral abundance and nitrate concentration (R2=0.0002; p=0.95), and with phosphate (R2=0.11; p=0.15). Kaczmarsky and Richardson (2011) found a correlation between high concentrations of aquatic nutrients and the prevalence of the coral disease. The regression test plot is presented in Figure 6.

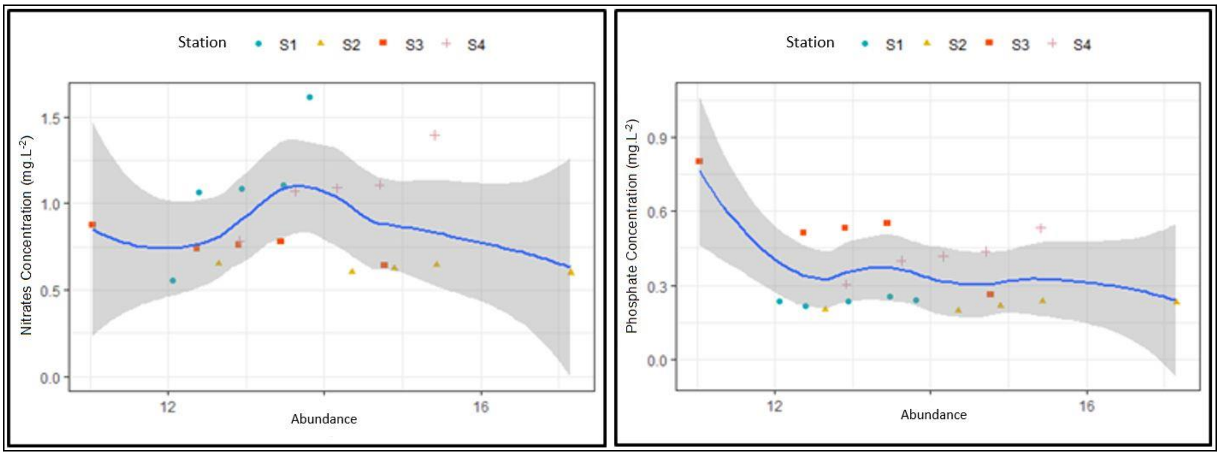

Figure 6. Abundance correlation plot with nitrate (a) and phosphate (b) concentrations.

Non-metric dual dimension mapping (NMDS). Non-metric multi-dimensional scaling (NMDS) was conducted to determine the correlation between genus abundance and water nutrient concentration in a non-parametric manner. The stress plot with a stress value of 0.963. The NMDS results show the significance of nutrients (nitrate and phosphate) on the composition of coral reefs, as presented in Figure 7. Based on the mapping results, it appears that nitrate affected the abundance of live corals at Station 2 and Station 3. Meanwhile, phosphate has a more significant effect on the live coral cover when compared to nitrate concentration, especially at Stations 3 and 4.

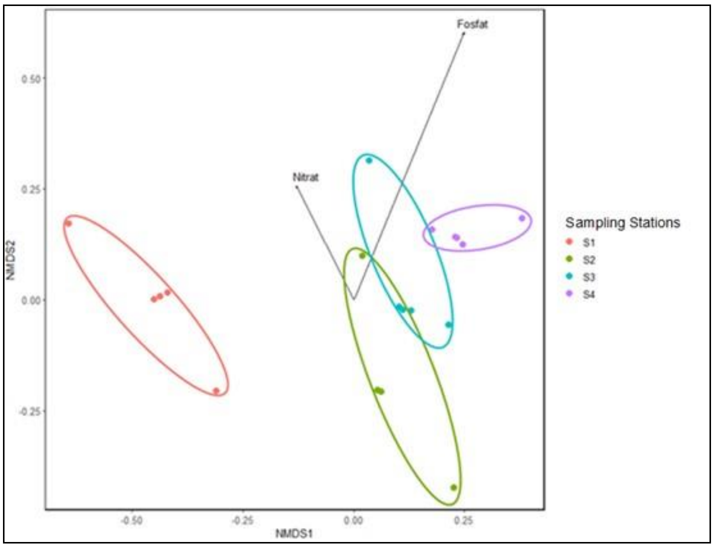

Figure 7. Significance of nutrients in the ordinance of coral abundance and nutrient concentration of each station.

Conclusions. The level of coral abundance at each station was similar, but there were significant differences in species composition between Station 1 and other stations. The concentration of nitrate (0.39-14.6 mg/l) and phosphate (0.05-0.36 mg/l) in the mariculture area of Menjangan Besar Island, Karimunjawa National Park, passed the quality standard. Significant differences with Station 4 as a reference are only found at Station 2. These findings imply that areas without anthropogenic activity may still experience soluble nutrient fluctuations due to the dynamics of seawater. Nutrient concentrations were not closely related to the abundance of reef corals. However, there was a significant effect of nutrients on genus composition at Stations 2, 3, and 4. Further studies are needed to examine the relationship between reef coral abundance and nitrate-phosphate concentrations by increasing the sample size and the repeatability and variables of marine hydrodynamics.

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Conflict of interest. The authors declare that there is no conflict of interest.

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