Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 –6131
Vol. 28(4): 1655– 1669 (2024)
www.ejabf.journals.ekb.eg

Scleractinian Coral Communities of the Gili-Noko Island, Bawean, Indonesia

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ARTICLE INFO

Article History:
Received: April 11, 2024
Accepted: Aug. 5, 2024
Online: Aug. 18, 2024

Keywords:
Acropora submassive,
Bawean,
Coral cover,
CPCe analysis,
Scleractinia corals

ABSTRACT

Indonesia is recognized as being among the epicenters of the biodiversity of coral reefs. However, only less than a quarter of Indonesia's coral reefs are in good condition. In the Java Sea, despite many threats, reef-building corals are still thriving on some islands, including the Gili-Noko Island, Bawean. In this study, distribution, coral cover, and ecological indices of Scleractinia corals on Gili-Noko Island were examined. Scuba diving and underwater photo transect (UPT) method were performed. The images were analyzed using coral point count with excel (CPCe). Ecological indices used in this study were Shannon-Wiener diversity index, Eveness index, and Simspon dominance index. At each station, 50 quadrant transects (58x44 cm) were set along a 50-m line transect, totaling 200 quadrants of 4 stations. Life coral covers were almost uniform, ranging from 50.87 to 56.86%, with an average of 52.67%. Overall, there were 20 genera (9 families) of Scleractinia corals, with moderate diversity values (1.51), moderate evenness (0.60), and low dominance levels (0.28). The genera *Acropora*, *Montipora*, and *Favia* were observed at all stations, with *Acropora* dominating the Scleractinia communities with an average of 56.1%. The major coral lifeforms were *Acropora* submassive (ACS), *Acropora* tabulate (ACT), coral massive (CM), and coral branching (CB), with percentages of 17.94, 11.57, 8.54, and 7.54%, respectively. Based on life coral covers, the coral reefs of the Gili-Noko island, Bawean, are in good condition with significant diversity. Therefore, management actions should be implemented to protect those ecosystems's treasure troves.

INTRODUCTION

Coral reefs are some of the Earth's most diverse and productive ecosystems, where at least 25% of all marine species live in coral reef environments **(Hoegh-Guldberg *et al.*, 2019, Vanwonterghem & Webster 2020)**. In Indonesia, there are an estimated 50,000km^2 of coral reefs **(Hopley *et al.*, 2011; Lam *et al.*, 2019)**, representing 51% of the region's coral reefs and 18% of the world's total coral reefs **(Johan *et al.*, 2016)**.The country also has the highest coral biodiversity on Earth, with about 83 genera and 569 species of Scleractinia corals, representing roughly 76% of genera and 69% of species of Scleractiniain the world **(Hadi *et al.*,2020)**. *Scleractinia coralsare* the key habitat-forming group on tropical reefs. This group secretes calcium carbonate ($CaCO_3$), which forms the hard skeletons of the group's population. Over time, these skeletons accumulate and form the complex and massive structures of coral reefs **(Muir &Pichon, 2019)**.

Coral reefs provide a range of benefits, including habitat for fish, shoreline protection in addition to goods and services **(Lam *et al.*, 2019)**. However, these reef ecosystems are threatened by anthropogenic stressors, including coastal development, marine pollution, and destructive fishing practices **(Johan *et al.*, 2016)**. Thermal stress and ocean acidification, as effects of climate change, lead to an increase in coral bleaching events and coral disease outbreaks **(Wear, 2016; Howells *et al.*, 2020;)**. In Indonesia, it appears that coral reef condition was on a declining trend between 2015 and 2016, mainly due to bleaching events. However, there were 533 recorded restoration activities across the country between 1990 and 2020 **(Razak *et al.*, 2022)**. In eastern Indonesia, a field survey in 2020 showed that the establishment of 13 new MPAs resulted in an increase in coral cover from 42 to 45% across all MPAs **(Ceccarelli *et al.*, 2022)**.

Coral reefs flourish in the group islands of the Java Sea, including the Karimun Jawa Islands, Seribu Islands, Kangean Islands, and Bawean Islands **(Hadi *et al*., 2020)**.These groups of islands are among the marine tourism destinations in Indonesia, which affects the reefs in the areas. Moreover, fishing, declining water quality, and climate change are also impacting the coral reef ecosystem **(Kennedy *et al.*, 2020)**.

There are 19 small islands surrounding the Bawean Islands, which have 23 genera of Scleractinia corals **(Dewi *et al.*, 2018)**. On Pakiman’s Patch Reef, the Bawean Islands, there are an estimated 19 genera of hard coral **(Luthfi & Anugrah, 2017)**. Furthermore, the main hotspot of coral reefs on the Bawean Islands is located on the Gili-Noko Island. It is gaining attention for its pristine coral reefs and marine biodiversity, making it a potential hotspot for coral reef tourism **(Noor & Romadhon, 2020)**. Examinations of coral health, coral colony size structure, and coral community structure are necessary to assess the reef's condition and status of the area.

Coral's cover and health indices determination can be performed using coral point count with excel extensions (CPCe) **(Pelasula *et al.*, 2021)**. It is an analysis program developed to perform calculations of coral coverage efficiently. The program consists of measurements of each substrate type and each species, including the calculation of relative abundance and the Shannon-Weaver diversity index **(Kohler & Gill, 2006)**. In this study, transect photographs of coral reefs in the Gili-Noko Island, Bawean, were identified and analyzed using the CPCE program to access the coral reef cover and the structure of coral colonies.

MATERIALS AND METHODS

1. Study area

Bawean is located approximately 80 miles north of the coast of Java. The island is under the administration of Gresik Regency, East Java. It has an area of 197km^2 (15km in diameter), the highest altitude of about 655m, and a population of more than 80,000 people. There are several very small satellite islands with the highest altitude of less than 10m, and the biggest one is the Gili-Noko Island, which has approximately 700 households inhabitants **(Dewi *et al.*, 2018)**.

All research sites were in the waters of the Gili-Noko Island. The Gili-Noko Island has a tremendous biodiversity of reef-building corals and coral reef fish **(Dewi *et al.*, 2018)**. It also has white-sand beaches along its coastline. Therefore, this island is the main marine tourism hotspot in the Bawean Islands and could be potentially developed as an ecotourism region **(Noor & Romadhon, 2020)**.The map of the study area is presented in Fig.(1).

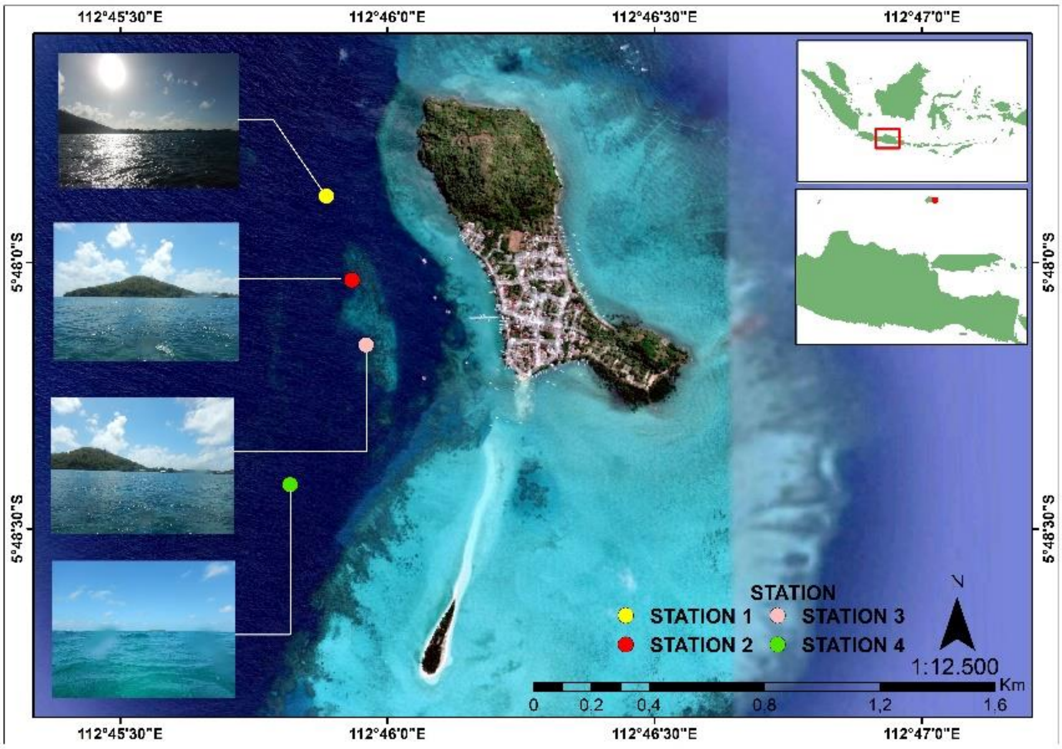

Fig. 1. The map of the research area in Gili-Noko Island

2. Data collection

A survey using the manta-tow technique was performed to select suitable and accessible research stations. The data collection was performed in August 2021 using scuba diving on a reef flat at a depth of 3–5m (Stations 1, 2, and 4) and a reef slope at a depth of 5–8m (Station 3). The coordinates of the study area are presented in Table (1).

Table 1. The coordinates of the research area on Gili-Noko Island

Station	Latitude	Longitude	Description
1	-5.797933	112.764760	Reef flat (3–5m)
2	-5.800560	112.765555	Reef flat (3–5m)
3	-5.802580	112.765997	Reef slope (3–8m)
4	-5.811339	112.763771	Reef flat (3–5m)

The data were collected using the underwater photo transect (UPT) method according to **Giyanto *et al.* (2017)**. In brief, at each station, a 50-meter line transect was established. At every 1m of the line, 58x44cm quadrant transects were alternately placed from right to left, totaling 50 transect quadrants (Fig.2). In addition to coral reef data, some water quality indicators (pH, salinity, water clarity, temperature, and dissolved oxygen) were measured *in situ* using water quality sensors (AAQ 1183s-IF) to access the water quality of research stations.

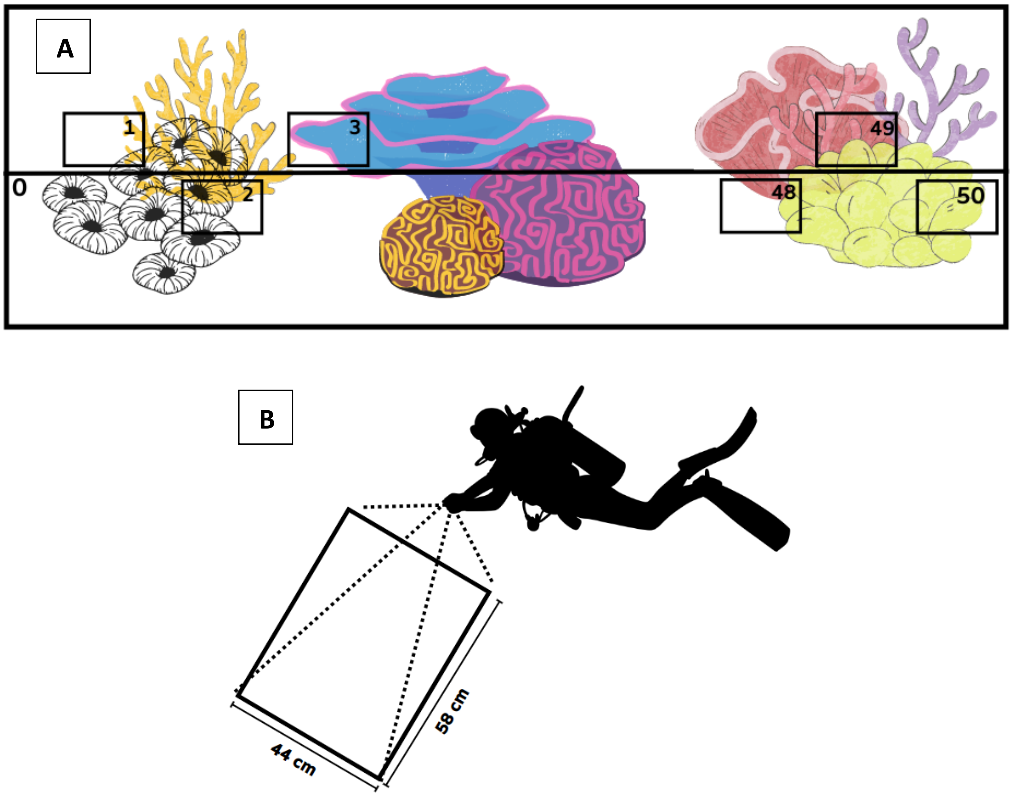

Fig. 2. UPT method illustration: (A) Placement of the transect quadrant (Frame); (B) Pictures taken with a distance of ±60cm. Zero (0) is a starting point, 1, 2, 3 are the first, second, and third transect quadrant (frame), respectively. Fifty (50) is the last transect quadrant on the line transect. Note: The images are created by the authors

3. Data processing

Random point count methodology was applied to determine the coral and substrate coverage using a standalone visual basic program, coral point count with wxcel extensions (CPCe 4.1)**(Kohler & Gill, 2006)**. Using this program, 30 spatially random points in each transect quadrant image were selected for data identification and determination. The data were used to determine benthic composition, life-form composition, and genus identifications which were performed according to the method of **Kelley (2012)**, **Veron and Stafford-Smith (2000)** and **Suharsono (2004)**.

4. Data analysis

4.1 The percent of Scleractinia corals cover

The proportion of reef surface covered by live Scleractinia corals was used to measure the coral health. Percent *Scleractinia* corals is a measurement standard that applies to all locations and is widely used by scientists worldwide **(Emslie, 2021)**. The percentage of coral coverage is calculated using the following formula **(Giyanto, 2014)**:

$$Percentage\ of\ Coral\ Cover = \frac{Total\ point\ of\ category}{Total\ of\ random\ point}\ x\ 100\%$$

4.2 Ecological index

The Shannon-Wiener diversity index (H') was automatically computed by the CPCe software based on the number of genus present in each frame. However, other indices are not available in the program. Therefore, the Pielou's evenness index (E) and the Simpson dominance index (C) were simulated using model as per **Zar (2010)**, as follows:

$$E = \frac{H'}{\ln S}$$

Where:

E : Pielou's evenness index

H' : The Shannon Diversity index

S : The total number of unique species

$$\boldsymbol{C} = \sum_{\boldsymbol{i}=1}^{\boldsymbol{n}} (\boldsymbol{Pi})^2$$

Where:

C : SimpsonDominance index

Pi : Ratio of the number of members of a species to the total number of members of all species.

n : Number of individuals of a species on the transect line

RESULTS

1. Water quality parameters

Based on Table (2), the temperature, salinity, DO, and pH of each research station were not significantly different, with values of around 28.5°C, 31.5ppt, 8.62mg/L, and 8.4 for temperature, salinity, and pH, respectively. Meanwhile, the water clarity in the research stations was 100%, as the light could penetrate to the bottom of the sea.

Table 2. Water Quality of research stations (Gili-Noko island waters)

Stations	Water quality parameters				
	Temperature (^{O}C)	Salinity (ppt)	DO (mg/l)	pH	Water clarity (%)
Station 1	28.5	31.5	8.60	8.4	100
Station 2	28.5	31.5	8.58	8.4	100
Station 3	29	32	8.65	8.4	100
Station 4	28.5	31	8.62	8.4	100

2. Benthic composition

On average, hard coral (HC) represented slightly more than 50% of all benthic features with the highest value at Station 4 (56.86%). Dead coral with algae (DCA) had second highest benthic coverage with the average of 13.05%. Other significant benthic forms were rock (RK) and sand (S) which on average shared 11.19 and 9.09%, respectively. On the other hand, soft corals (SC) were much higher at Station 3 (9.52%) than other stations. Silk (S), freshly algae (FS), and sponges (SP) constituted only less than 1% of benthic coverages (Fig. 3).

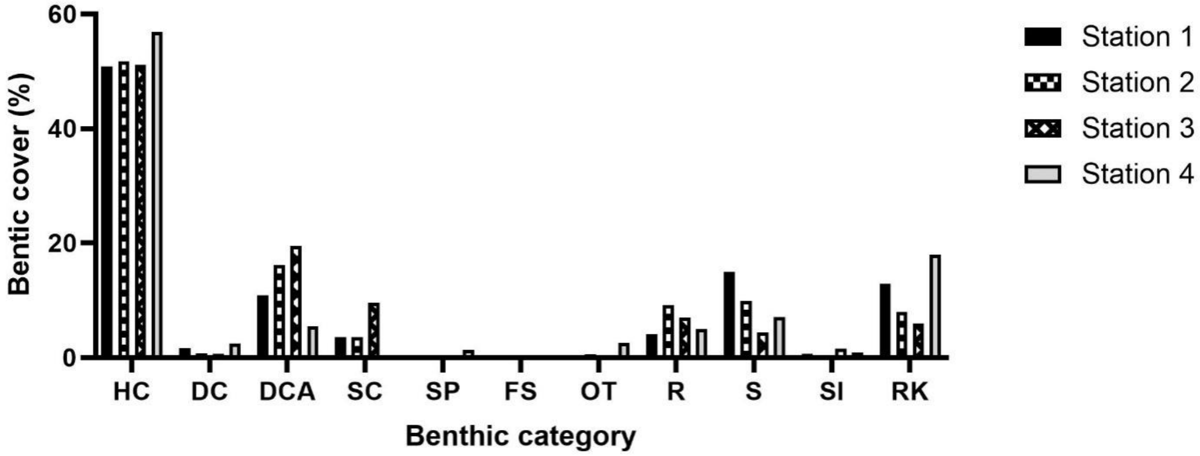

Fig. 3. Benthic Category Percentage Cover of coral reef environment in Gili-Noko Island. HC = hard coral, DC = dead coral, DCA = dead coral with algae, SC = soft corals, SP = Sponges, FS = Freshly algae, OT = others, R = Rubble, S = Sand, SI = Silt, RK = Rock

3. Lifeform composition

In the Gili-Noko waters, the lifeforms of *Acropora* were digitate, submassive, and tabulate; *Montipora* was an encrusting lifeform, and *Porites* had a massive lifeform. *Acropora* submassive (ACS) was the most common lifeform at stations 1 (23.06%), 2 (21.50%), and 3 (24.48%), while coralbranching (CB) had the highest percentage at station 4 (21.60%) (Fig. 4). Overall, *Acropora* submassive (ACS), *Acropora* tabulate (ACT), coral massive (CM), andcoral branching (CB) were the dominant types of lifeforms in the Gili-Noko waters and accounted for 17.94, 11.57, 8.54, and 7.54%, respectively. Meanwhile, *Acropora* branching (ACB) and coral encrusting (CE) only shared 2.86 and 1.86%, respectively. Furthermore, five other lifeforms shared a total of 2.35% with each other (Fig. 5).

4. Genera distribution

There were 20 genera of *Scleractinia* coral observed in the research areas, namely: *Acropora*, *Porites*, *Montipora*, *Favites*, *Echinopora*, *Favia*, *Goniastrea*, *Lobophyllia*, *Sandalolitha*, *Fungia*, *Merulina*, *Pocillophora*, *Seriatopora*, *Stylophora*, *Galaxea*, *Astreopora*, *Pavona*, *Coeloseris*, *Astreopora*, and *Platygyra*. Station 4 had the highest number of genera (16 genera), while there were only 9 genera at Station 1. *Scleractinia*corals of the genera *Acropora* and *Montipora* from the family Acroporidae, *Echinopora* and *Favia* from the Faviidae family, and *Stylophora* and *Porites* from the families Pocilloporidae and Poritidae, respectively, were observed at all research stations (Table 3).

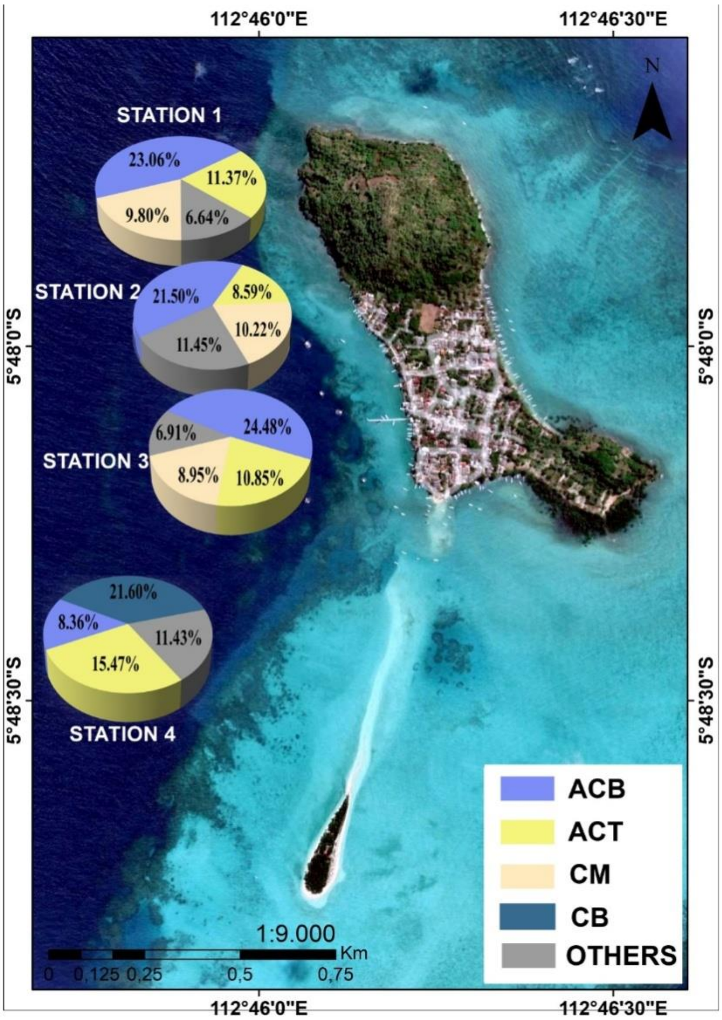

Fig. 4. Lifeform distribution map of hard coral in Gili-Noko waters

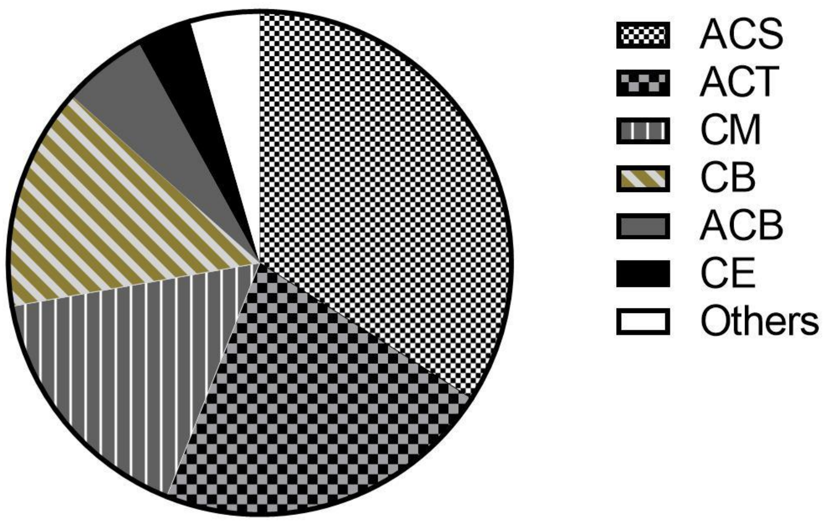

Fig.5. Lifeforms composition of *Scleractinian* coral in Gili-Noko waters

Note: *Acropora* submassive (ACS), *Acropora* tabulate (ACT), coral massive (CM), coral branching (CB), *Acropora* branching (ACB), coral encrusting (CE), and other lifeforms (others)

Table 3. The distribution of *Scleractinia* coral of Gili-Noko waters

No	Genus	Stations			
		Station 1	**Station 2**	**Station 3**	**Station 4**
Acroporidae					
1.	*Acropora*	+	+	+	+
2.	*Montipora*	+	+	+	+
3.	*Astreopora*	-	+	+	+
Agariciidae					
4.	*Pavona*	-	+	+	+
5.	*Coeloseris*	-	-	+	+
Faviidae					
6.	*Echinopora*	+	+	+	+
7.	*Favia*	+	+	+	+
8.	*Favites*	+	-	-	+
9.	*Goniastrea*	-	+	+	+
10.	*Platygyra*	+	-	-	-
Fungiidae					
11.	*Fungia*	+	-	+	-
12.	*Sandalolitha*	-	-	+	-
Merulinidae					
13.	*Merulina*	-	+	-	-
Mussidae					
14.	*Lobophyllia*	-	-	+	+
15.	*Symphyllia*	-	-	-	+
Oculinidae					
16.	*Galaxea*	-	+	+	+
Pocilloporidae					
17.	*Pocillopora*	+	-	+	+
18.	*Seriatopora*	-	-	-	+
19.	*Stylophora*	+	+	+	+
Poritidae					
20.	*Porites*	+	+	+	+
Total Genus		10	11	15	16

Note: (+) Found(-) Not found

The percent of *Scleractinia* coral's cover for reef in the Gili-Noko waters had the highest value from the family Acroporidae. The genus *Acropora* shared the highest value in Stations 1, 2, and 3 (71.20, 67.15, and 62.08%, respectively), while in Station 4, the genus *Montipora* shared 34.74%; in contrast, *Acropora* only shared 24.08%. *Porites* accounted for 13.32, 20, 24.87, and 8.13% at stations 1, 2, 3, and 4, respectively(Fig. 6).On average,*Acropora* shared 56.13% of *Scleractinia* coral in the Gili-Noko waters, followed by *Porites* and *Montipora* (16.48 and 9.36%, respectively). *Echinopora, Favia*, and *Favites* constituted only 2.10, 1.54, and 1.11%, respectively. There were 12 genera that only had less than 0.5% coral cover, which in total shared 3.36% of all *Scleractinia* coral's cover (Fig. 7).

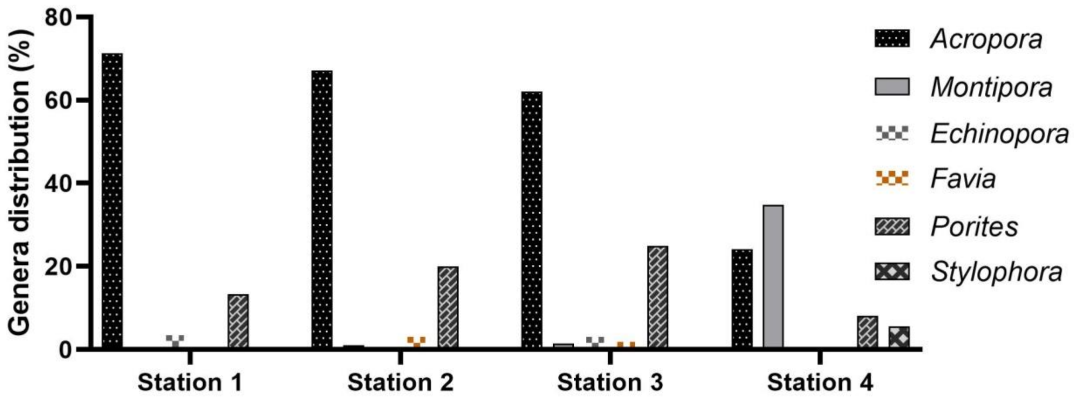

Fig. 6. The genera distribution of *Scleractinia* corals in Gili-Noko waters. This figure shows the Scleractinian genera that were present at all stations

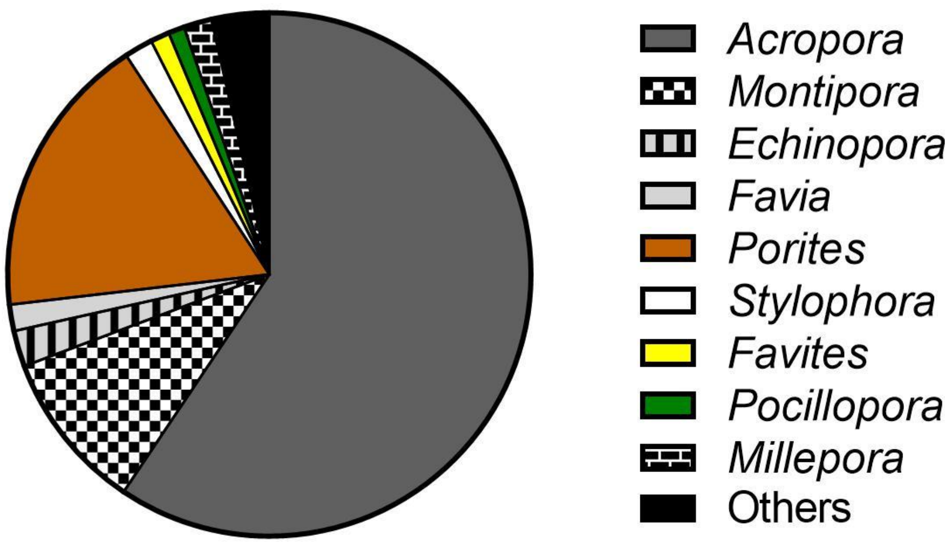

Fig. 7. The average percentage of Scleractinian genera in Gili-Noko waters

5. Diversity, evenness and dominance of *Scleractinia* corals

The Shannon-Wiener diversity index of *Scleractinia* corals in the Gili-Noko waters ranged between 1.33 and 1.61. The Pielou's evenness index(E) ranged between 0.49 and 0.67, while the Simpson dominance index (C) was on average 0.28± 0.03. The ecological index of *Scleractinia* coral of the Gili-Noko waters is presented in Table (4).

Table 4. Ecological index of *Scleractinia* coral of Gili-Noko waters

Station	**Ecological index**		
	H'	**E**	***C***
Station 1	1.52	0.66	0.29
Station 2	1.61	0.67	0.26
Station 3	1.33	0.49	0.32
Station 4	1.59	0.57	0.25
Average	1.51 ± 0.13	0.60 ± 0.08	0.28 ± 0.03

Note: H' = Diversity index Shannon-Wiener, E = Evenness index dan C = Dominance Index Simpson

DISCUSSION

Regarding the water quality of research areas, the temperature, salinity, and DO values were in suitable environmental ranges for coral habitats. A previous study in the research location also revealed environmental parameter values that are likely in the same range, in which the temperature, salinity, and DO were around 29 29°C, 31ppt, and 8mg/L, respectively **(Noor & Romadhon, 2020)**. Globally, the average tolerance temperature and salinity limit for coral reefs to thrive are 21.7–29.6°C and 28.7–40.4ppt, respectively**(Guan *et al*., 2015)**. Typically, in coral reef environments, DO concentration is 3.4–13.6mg/L, depending on time of day and location. Oxygen is fundamental to many physiological processes in corals, including photosynthesis, respiration, and calcification; therefore, DO is a critical factor that can be limiting in reef-building corals **(Nelson & Altieri, 2019)**. Furthermore, a study reported that the lethal threshold of DO for branching corals is around 4mg/ L **(Hughes *et al*., 2020)**.

The relatively high pH in the research stations may be due to the waters being supersaturated with calcium carbonate, which is needed to form coral structure. The world's sea surface pH has fallen by 0.1 pH unit from 8.2 to 8.1 due to the increasing CO_2 in the atmosphere **(Wu *et al.* 2018)**. Lower pH levels can reduce the availability of carbonate ions available for corals to maintain calcium carbonate structures and, therefore, can decline larval settlement **(Stark & Langdon, 2019)**. This reduction in carbonate availability can lead to a decline in both the abundance and diversity of the Scleractinian corals **(Veron, 2011)**.

Acropora submassive (ACS), which accounted for approximately 18% of the coral's lifeforms in the whole research area, is characterized by upright branches with a wedge-like shape. Submassive and massive lifeforms are commonly found in reef flat zones **(Mardani *et al*., 2021)**. Moreover, those lifeforms are well adapted to reef flats that are frequently exposed to air exposure during low tide **(Brown *et al.*, 2014, Zahidi *et al.*, 2022**). Meanwhile, the second most abundant lifeform, tabulate, has the shape of a flat table and usually flourishes in waters with low sedimentation **(Nusaputro *et al.*, 2019)**.

Acropora, *Favia*, and *Porites* were presented at all research stations on Gili-Noko Island. Gili-Noko waters have ideal and healthy environmental conditions for coral reefs to thrive. Moreover, *Acropora* grows quickly compared to other corals**(Shinzato *et al.*, 2021)**. It thrives in oligotrophic waters and prefers clear, shallow waters with high light availability **(van der Zande *et al*., 2021)**. However, the genus is highly sensitive to environmental changes, such as temperature fluctuations, sedimentation, and water quality **(Mercado-Molina *et al*., 2020, Rada-Osorio *et al.*, 2022)**. Meanwhile, *Porites* corals are more adabtable and can inhabit deeper waters than *Acropora* and *Favia* **(Eagleson *et al.*, 2023)**, showing greater depth adaptability, as was also observed at the research stations where *Porites* spp. were found in the deeper waters. Therefore, the Gili-Noko waters provide niches for different genera of coral to sustain.

Acropora, *Favia*, and *Porites* have widespread distributions in both the Atlantic Ocean and the Indo-Pacific. Meanwhile, *Montipora* corals are common in the Southern Pacific Ocean and Western Indian Ocean, but are absent in the Atlantic Ocean **(Veron & Stafford-Smith, 2000; Kelley, 2012; Raghunathan &Venkataraman, 2015)**. However, in many areas, *Porites* spp. have been documented to harbor many coral diseases, from pink line syndromes (PLS) **(Asadi *et al.*, 2019)** to white syndromes **(Samsuvan *et al.* 2019)**. There were about 20% of *Porites* spp. infected with coral diseases in the Gili-Noko waters, mainly in the form of PLS. The value was quite low in comparison to *Porites* spp. in South Malang waters, in which 47% of them were infected with PLS **(Asadi *et al.*, 2019)**.

Overall, reefs in the Gili-Noko waters had high (<50%) coral covers. Even in the Great Barrier Reefs, the world's largest reefs, the overall coral cover was averaging only 29%, which was categorized as stable **(Osborne *et al.*, 2011)**. Annual coral reef monitoring by the Australian Institute of Marine Science reported that 36 out of 127 reefs in GBR had 30–50% hard coral cover, which is already categorized as high **(Emslie *et al.*, 2021)**. Furthermore, on a global scale, hard coral cover was declining from 39% in 1998 to only 19% in 2018 **(Tebbett *et al.*, 2023)**.The decrease of *Scleractinia*, or stony corals, is largely associated with increased benthic algal covers such as crustose coralline algae and algal turfs **(Zaneveld *et al.* 2016; Tebbett *et al.* 2023)**. In the study area, station 4 had the highest *Scleractinia* coverage and was also shown to have the lowest algae coverage (dead coral with algae).

Acropora, *Porites,* and *Montipora* shared the highest coral coverage on the Gili-Noko island. These three hard-coral genera flourish in tropical reefs, and Indonesia is among the biodiversity hotspots of those genera **(Xu *et al.*, 2017; Hadi *et al.*,2023)**. *Montipora* is the second-most species-rich coral genus after *Acropora*, with 85 known species **(van Oppen, 2004)**. The genus *Acropora* itself has 180 known described species **(Veron & Stafford-Smith, 2000; Mercado-Molina *et al*., 2020)**. *Montipora* grows well in shallow waters less than 5 meters, with high light intensity and water clarity **(Suharsono, 2004; Veron, 2011; Sembiring *et al*., 2018)**. Therefore, *Montipora* dominated Station 4, featured as the shallowest station.

Regarding ecological indices, Shannon-Weiner diversity values for coral reefs between 1.31 and 1.61 indicate moderate diversity, which might suggest a healthy ecosystem but potentially face some stressors **(Odum & Barrett, 2005)**, as healthier reefs typically have higher Shannon-Weiner diversity values **(Akmal *et al.*, 2019)**. However, Shannon-Weiner diversity values in the Gili-Noko waters are quite higher compared to those in Calangahan, Lugait, and Misamis Oriental in the Philippines. The diversity index in the area was also calculated using CPCE software, and the average diversity value was around 1.2 **(Tabugo *et al.*, 2016)**.

The evenness value ranges between 0 and 1, with values closer to 1 indicating a more equitable distribution of individuals among species in a community **(Roberts, 2019)**.This study's average evenness index of 0.6 denotes a moderately equitable distribution of individuals within a species within a community **(Zar, 2010; Asadi *et al.*, 2018)**. This implies that the community, nevertheless, maintains a fairly balanced species makeup even in the presence of some degree of dominance by particular species **(Zar, 2010)**.The results demonstrated that the magnitude of the diversity index was not proportional to the number of identified genera **(Abiyasa *et al.*, 2021)**. For instance, the diversity index was greater at Station 2 than Station 3; however, Station 3 had more identified genera. This can be determined by examining the value of the evenness index. In this case, genera at Station 2 were more evenly distributed than those at Station 3.

Although, somehow, genus *Acropora* shared slightly more than 50% of all *Scleractinia* coral in the Gili-Noko waters, the dominance indices of all stations were still categorized as "low." It was due to the presence of many other coral genera that they were likely distributed evenly throughout the whole research station.

Coral reefs in Gili-Noko waters face significant threats from fisheries, ship routes, and tourism, which can have detrimental impacts on *Scleractinia* corals **(Lachs & Oñate-Casado, 2020, Sabdono *et al*., 2024)**. During low tide, in the shallower area of the Gili-Noko waters, many corals are prone to damage from ship transportation that directly hits the Scleractinian coral physically. The impact of tourism on the Scleractinian coral can lead to physical damage from direct contact, pollution, and increased sedimentation, which contribute to coral stress and decline **(Lachs & Oñate-Casado, 2020)**. The Gili-Noko waters were included in the proposed initiative for prospective marine conservation areas of the Bawean Islands and are currently under the status of reservation for marine conservation areas by the Ministry of Marine Affairs and Fisheries. The establishment and implementation of marine protection areas are crucial for the future of reef communities in the Bawean Islands.

CONCLUSION

Overall, the Gili-Noko waters have favorable water parameters for the Scleractinian coral to thrive, in which 52.67% of the reefs are covered by life Scleractinian corals. These factors collectively create an environment where niche coral reefs can thrive, supporting a diverse range of corals, from *Acropora* and *Porites* to *Stylopora*. The dominance and diversity of *Acropora* lifeforms, from *Acropora* submassive to *Acropora* branching, implies that the waters are typically vibrant and support healthy coral reef ecosystems. The ecological values of the Scleractinian coral in the Gili-Noko waters indicate a balanced and potentially stable community, which can be maintained and improved through a combination of conservation efforts and sustainable practices.

ACKNOWLEDGEMENT

This study was part of the “Hibah Professor dan Doktor” research scheme at the University of Brawijaya. The authors would like to thank Luthfil Hakim Salim, Riqki Yoga Aprilianto, Aditya Nata Azhari, Mahendra Ahmad Munif, and Mohamad Faisal for assisting in taking field data. The authors also thank Pak Subhan from POKWASMAS Hijau Daun, Bawean, for facilitating research in Gili-Noko waters, Bawean.

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