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Assessing the resilience of coral reefs against macroalgae invasion in the Sempu Island Nature Reserve, Malang District, Indonesia

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Abstract. *Isdianto A, Yorarizka PD, Aliviyanti D, Sari SHJ, Yanuar AT, Asadi MA, Setyanto A, Bintoro G, Lelono TD, Atikawati D, Fathah AL, Putri BM, Supriyadi, Luthfi OM. 2024. Assessing the resilience of coral reefs against macroalgae invasion in the Sempu Island Nature Reserve, Malang District, Indonesia. Biodiversitas 25: 2877-2887.* The living coral cover in the Sempu Strait is known to be stuck in the range of 37% due to average data from 2009-2016. Several coral diseases have been documented in this region, which can result in the transformation of coral reefs into algae-dominated communities. This study examines the dynamic interplay between coral reefs and macroalgae within the marine ecosystems of the Sempu Island Nature Reserve, Malang District, Indonesia. Conducted across five research stations, our analysis utilized the Underwater Photo Transect (UPT) method, combined with image analysis tools CPCe and Image-J, and statistical analysis through SPSS. The findings indicate a persistent competition between corals and macroalgae, exacerbated by sedimentation from port activities and river discharges, and significant nutrient loads from human settlements. The average living coral coverage varied significantly, with a range from 12% to 53% across the study period, while macroalgae coverage showed an increase, especially in turf algae. The correlation analysis revealed a 'quite strong' relationship (r=0.783 between coral and macroalgae coverage, suggesting that increases in coral cover could potentially facilitate macroalgae proliferation under current environmental conditions. Notably, the study highlighted the critical role of water quality parameters such as temperature, pH, and salinity, which were within optimal ranges yet facilitated competitive interactions. This research underscores the complexity of coral-macroalgae relationships and the pressing need for integrated management strategies focusing on water quality and habitat preservation to ensure the resilience of these critical marine ecosystems.

Keywords: Competition, CPCe, Image-J, Pearson, underwater photo transect

INTRODUCTION

The marine ecosystems in Indonesia are crucial components of the world's natural heritage, representing the world's highest marine biodiversity (Unsworth et al. 2018. Anzani et al. 2019). Coral reefs are one of the most vulnerable parts to various threats in the marine ecosystem (Gumbira et al. 2017; Mujahidah et al. 2023). Coral reefs are distributed in Indonesian waters, with some found around Sempu Island and on the outskirts of the western and eastern mainland cliffs. Sempu Island is a natural reserve located in Sendang Biru, Tambak Rejo Village, Malang District, East Java, Indonesia with high natural resource potential (Luthfi 2016). However, the conditions are among the most vulnerable areas and are continuing to decline due to fairly various human activities. Coral reefs in the Sempu Island Nature Reserve, Malang District, Indonesia experience several disturbances, ranging from sedimentation due to port reclamation to the impact of the El-Nino event in 2009-2010 (Isdianto et al. 2024a), which caused an anomaly in the sea surface temperature in the Indian Ocean (Kim et al. 2011), triggering bleaching in the coral waters of the Sempu Strait (Carballo et al. 2013). These various events have caused the coverage of living coral in the Sempu Strait waters to remain stuck at around 37% (average data from 2009 to 2016). However, a study in 2017 found that the percentage of living coral coverage in the Sempu Strait is in good condition, ranging from 12% to 53% (Luthfi et al. 2019b). The low coral coverage in the Sempu Strait waters is primarily due to sedimentation and nutrients that pose a threat to increase coral health and diseases prevalence in the Sempu Island Nature Reserve, Malang District, Indonesia (Isdianto et al. 2024b), then leading to an algae phase shift (Luthfi et al. 2015).

Macroalgae are further categorized based on their pigmentation, morphology, anatomy, and biochemical composition into three main groups: Chlorophytes, Rhodophytes, and Phaeophytes (Ismail et al. 2020). Turf algae, which is often found competing with coral, is a collection of small dense multi-specific filaments that have a size of <10 nm or are mostly dominated by filamentous algae (Brown and Carpenter 2015). Turf algae has a low biomass content per area but is able to dominate coral reef areas in large proportions even on healthy coral reefs (Diaz-Pulido and McCook 2008). A study in 2014 showed that in the waters of the Sempu Strait, algae were found at the Teluk Semut station by 0.64% and at the Watu Meja station by 3.04% (Luthfi et al. 2018). Based on research in 2017, at the Teluk Semut station, macroalgae with a type of turf algae accounted for 18%, and at the Watu Meja station, macroalgae with a type of turf algae accounted for 2% (Luthfi et al. 2019b). According to a 2018 study by Luthfi et al. (2019a), there was a rise in the coverage of rock substrate (RC) to 52% in the Sempu Strait waters. This increase was attributed to sedimentation by sand and competition from algae measuring less than 3 cm, which grew on previously living corals. Rapid growth of macroalgae can cover and smothering coral reefs, blocking the sunlight that corals need for photosynthesis and growth.

Sedimentation has detrimental effects on coral by burying coral polyps, causing them to retract and cease tentacular actions, ultimately leading to the death of polyps along the colony edge (Gelais et al. 2016). Additionally, sedimentation can increase the number of competitors, such as algae, and alter the community structure, leading to the proliferation of algae in coral reefs (Anton et al. 2020). The decline in the conditions of coral reef coverage in the waters of the Sempu Strait has been documented in 2017 and 2018. The 2018 study revealed that the coral reef conditions were categorized as poor due to various threats, including the presence of macroalgae (Luthfi et al. 2019a). Furthermore, the aim of this study is to assess the coral reef ecosystem for potential competition between coral and macroalgae, where macroalgae as competitors, in Sempu Strait. The increasing dominance of macroalgae could lead to significant ecological shifts in the coral reef ecosystem by leading to a decline in coral diversity and abundance.

MATERIALS AND METHODS

Study area

The research was conducted in December 2022, February 2023, and April 2023 in the waters of the Strait Sempu, Malang District, Indonesia. Several types of algae that generally compete with coral are known to grow rapidly, such as turf algae which has the fastest growth when in favorable conditions, such his nutrients-rich waters. Therefore, three observation periods are sufficient to illustrate changes in the area of competition between macroalgae and coral in Sempu Strait. The study was carried out at five research stations selected through purposive sampling, as outlined in the book Guidelines for Monitoring Coral Reef Health developed by Giyanto in 2014. These stations include Watu Meja, Waru-waru, Banyu Tawar, Jetty, and Rumah Apung (Figure 1) which each station has unique characteristics.

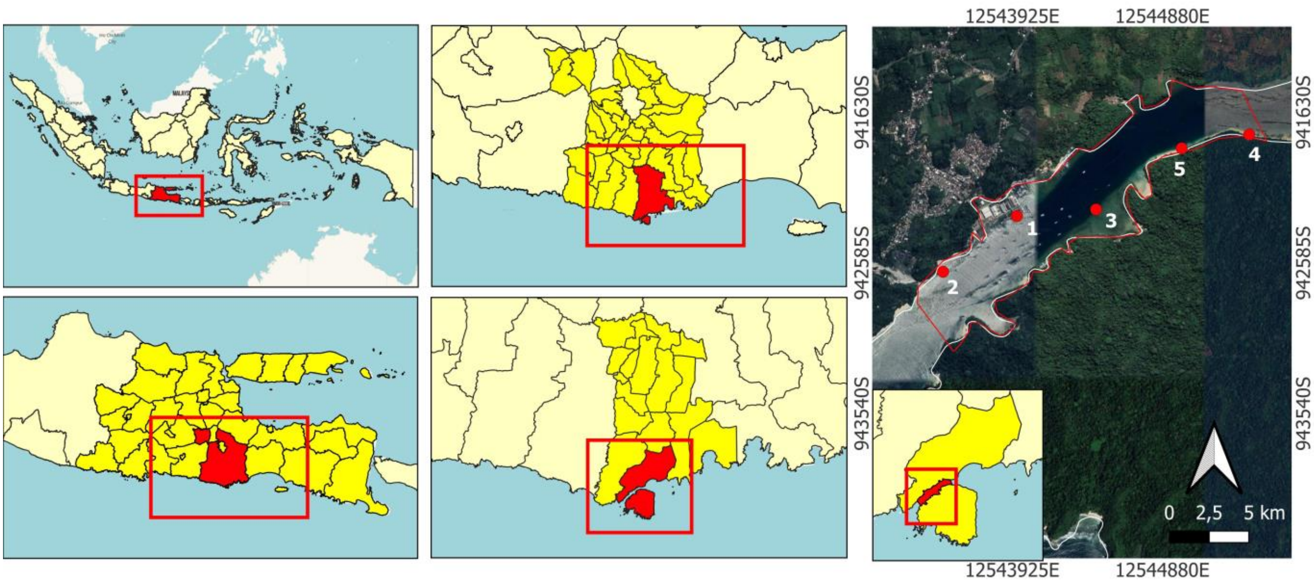


Figure 1. Research stations for coral reefs and macroalgae in the Sempu Island Nature Reserve, Tambarejo, Sumbermanjing, Malang District, East Java, Indonesia. 1. Jetty Port; 2. Rumah Apung; 3. Banyu Tawar; 4. Watu Meja; 5. Waru-waru

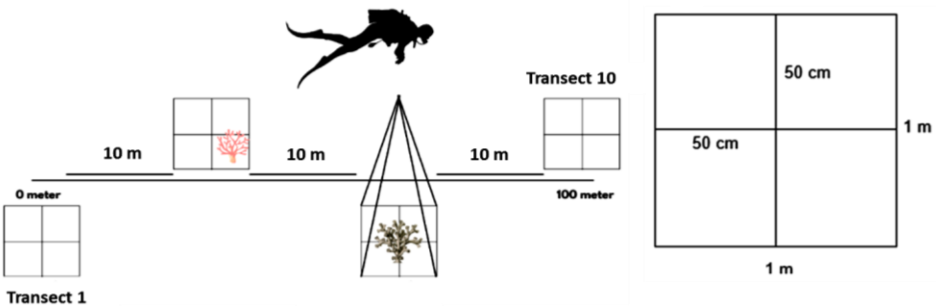
Watu Meja, the first station, is located in open water, the eastmost part of the Sempu Island Nature Reserve, Malang District, Indonesia, bordering directly with the Indian Ocean, resulting in strong currents and high waves. Waru-waru, the second station, is situated in the area of Sempu Island, attracting tourists who engage in activities such as fishing, canoeing, and diving, which negatively impact coral growth due to the presence of broken corals. Banyu Tawar, the third station, is highly sedimented due to the flow of rivers from Sempu Island. Jetty Port the fourth station, is located north of Sempu Island, protected from open sea waves, but still faces challenges such as port debris and other ship activities that affect coral growth. The fifth station, Rumah Apung, is near settlements, leading to household waste that impacts coral growth (Table 1).

Coral reef and macroalgae data collection

Data collection of coral reefs and macroalgae at each station was conducted using the Underwater Photo Transect (UPT) method, as outlined in the Coremap-CTI Coral Reef Health Monitoring Guide developed by Giyanto in 2014 (Figure 2.A). The method involved using quadrant transects measuring 100×100 cm, which were further divided into four smaller squares of 50×50 cm (Figure 2.B). These quadrants were positioned at each station, located at depths of 2-6 meters parallel to the coastline and spaced 100 meters apart. Photographs were taken vertically with an underwater camera placed directly above each quadrant. Subsequently, the images were analyzed using CPCe (Coral Point Count with Excel extensions) 4.1 software (Figure 3) to determine the percentage of coral reef coverage, and Image-J 1.53r Java 8 was used to assess both coral and macroalgae coverage (Ludwick et al. 2019).

Table 1. Description of locations

Station	Coordinates	Description
Jetty Port	8°26'1.86"S, 112°41'3.22"E	This location is a busiest station which has lots of fisheries activities including a fishing boat docking facility, ship transit, and also offloading area.
Rumah Apung	8°26'13.99"S, 112°40'48.14"E	Located at the western end of the Sempu Strait and directly adjacent to the Indian Ocean.
Banyu Tawar	8°26'1.35"S, 112°41'19.65"E	This location has run off of small river
Watu Meja	8°25'46.12"S, 112°41'51.24"E	This site located in the east and is directly facing the open sea and far from the influence of anthropogenic activity.
Waru-waru	8°25'48.99"S, 112°41'37.03"E	This location is commonly used as tourist attraction



A B

Figure 2. Data collection. A. Underwater Photo Transect (UPT) method; B. Quadrant transect

Figure 3. Data processing using CPCe (Coral Point Count with Excel extensions) 4.1

Macroalgae identification and competition data processing

The macroalgae data is visually identified and compared using the official Algaebase website. This identification is conducted to determine the genus of macroscopic algae present, which may compete with coral reefs. Competition data between coral reef cover and macroalgae cover was processed using Image-J 1.53r Java 8 software (Figure 4) to quantify the extent of the competition. Subsequently, the data was analyzed using SPSS to ascertain the relationship between the two variables using correlation analysis (Table 2). Correlation analysis is a statistical method used to estimate the strength of the relationship between two variables.

Data collection of water quality parameters

The data collection for temperature, salinity, dissolved oxygen (DO), and pH parameters was gathered from AAQ 1183-IF recordings at depths of 0-5 meters. The data processing using AAQ 1813-IF involves downloading data from the probe using the AAQ Rinko ver. 1.05 program, compiling the data, and then calculating the average for each parameter at each study station. Current speed data is obtained from secondary data on the Copernicus website and then averaged to determine the current speed at each station. Nitrate and phosphate parameter data were measured using seawater samples and analyzed in the laboratory using a spectroscopic photometer. Sedimentation parameters are determined with the aid of a sediment trap placed next to the quadrant transect, which is expected to represent the sedimentation rate at each research station.

Table 2. Correlation coefficient (r)

Correlations coefficient (r)	Level
0.80-1.00	Strong
0.60-0.799	Strong enough
0.40-0.599	Medium
0.20-0.399	Slightly weak
0.00-0.199	Weak

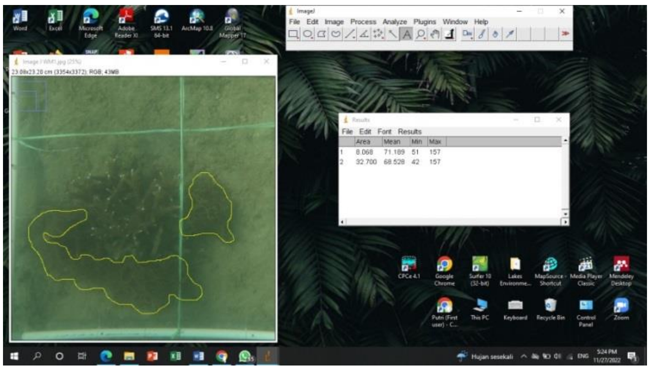


Figure 4. Data processing using Image-J 1.53r Java 8

Sedimentation parameters were carried out by installing sediment traps at each research station and calculating the sedimentation rate using (Formula 2) (Barus et al. 2018).

$$LS = \frac{BS}{n.\pi.r^2}$$

Where:
LS : sedimentation rate (mg/cm^2/day)
BS : dry weight of sediment (mg)
Π : constant (3.14)
r : radius of the sediment trap circle
n : number of days

The water clarity parameter was measured using a secchi disk with three repetitions at each research station and calculated using (Formula 3).

$$K = \frac{d1 + d2}{2}$$

Where:
K : water clarity
d1 : depth of Secchi disk when not visible
d2 : depth of the Secchi disk when it starts to appear again

RESULTS AND DISCUSSION

Water quality parameters

The water quality parameters studied include temperature, water clarity, pH, salinity, DO, nitrate, phosphate, sedimentation rate and current speed. Measurement of water quality parameters was carried out in December 2022, February 2023 and April 2023 at each research station, to determine water conditions that influence the growth of macroalgae and coral (Table 3).

The temperature values at the five study locations are not much different, with an overall average value of 29.648°C. The optimal temperature for coral growth ranges between 28-32°C, while the optimal temperature range for macroalgae growth ranges from 21-32.4°C (Hamzah et al. 2020). Temperature influences the growth rates of both corals and turf algae. Corals generally thrive in warmer waters, excessive heat can lead to coral bleaching, a phenomenon where corals expel the symbiotic algae living in their tissues, causing them to turn white and potentially die. On the other hand, turf algae tend to thrive in warmer temperatures, and their growth can outcompete corals, especially following coral bleaching events (Hughes et al. 2018).

The average pH conditions of coral and macroalgae in study locations are ideal for their growth which range from 8.05-8.33 with an average of 8.22. The optimum pH of coral range is between 7-9. Meanwhile the optimum pH conditions for macroalgae growth range from 6.8-8.2. Macroalgae growth rate is inhibited by low pH, and excessive acidity can be deadly, resulting in a complete absence of macroalgae reproduction (Hamzah et al. 2020). Ocean acidification, resulting from low pH levels in water, not only increases the competitive advantage of macroalgae over corals but also presents significant consequences for the ability of reefs to recover and adapt (Harvey et al. 2021). Corals are particularly sensitive to the direct effects of ocean acidification and can be outcompeted by macroalgae under acidified conditions (Fu et al. 2022). Under thermal stress, the competition between corals and macroalgae becomes more intense, with macroalgae causing detrimental effects on corals that are similar to the impacts of ocean warming.

Generally, corals are more sensitive to change in salinity compared to turf algae. Salinity is important to identify, the impact of river runoff and rain on coral reefs, because this is one of the main causes of coral death, especially corals that are close to river systems (Berkelmans and Jones 2015). The optimum salinity for coral ranges from 33-34 ppt. Meanwhile the optimum value for macroalgae growth range between 15-38% (Hamzah et al. 2020). Studies have shown that moderate increases in salinity can benefit turf algae growth, potentially leading to competition with corals. However, extreme salinity levels can stress both corals and algae, affecting their growth and health (Hughes et al. 2017).

Dissolved oxygen plays a significant role in coral cover, calcification, and overall reef health (Mcclanahan et al. 2021). The value of dissolved oxygen at five stations was above 5 mg/L, with an average of 6.354 mg/L. This is considered optimal for coral growth. Reduced dissolved oxygen concentrations can lead to increased microbial metabolism, decreased availability of oxygen, and impact competitive dynamics between corals and macroalgae (Haas et al. 2014). Turf algae can potentially lead to hypoxia in coral tissues due to their interactions with corals (Liao et al. 2019) by increasing microbial oxygen demand from their exudates. Turf algae have been observed to limit the establishment of canopy algae and the expansion of corals, potentially leading to shifts in competitive balances favoring turf algae over corals (Brien and Scheibling 2018).

Water clarity is affected by sedimentation and roughness thus interfering with the photosynthesis process by corals. Based on the category of sedimentation by Pastorok and Bilyard (1985), the sedimentation rate in the Sempu Island Nature Reserve, Malang District, Indonesia is categorized as severe-catastrophic by a value of 73.73 mg/cm^2/day. High sedimentation rate enhances water turbidity, which can reduce incident light and potentially decrease coral bleaching during thermal-stress events (Asmawi et al. 2020). This relationship suggests that sedimentation, by inducing turbidity in the water column, may indirectly impact the growth of macroalgae by disrupting photosynthesis in corals, leading to coral death and subsequent overgrowth by algae (Sully and Woesik 2020).

Another water-physical characteristic, such as current, is important for macroalgae and coral as well, because it influences the nutrient and oxygen fusion in the water. Generally, a moderate to strong current is ideal for coral. Corals in areas with moderate to strong currents tend to show faster growth rates, higher resilience to environmental stressors, have been shown to prevent bleaching and minimize associated mortality (Roche et al. 2018). An optimal current rate for the growth of macroalgae is 0.2-0.4 m/second (Handayani et al. 2023), this is related to the ability of macroalgae to maintain their thallus during strong waves. The current speed in the Sempu Island Nature Reserve, Malang District, Indonesia ranges from 0.38-0.50 m/s, categorized as moderate speed according to Ramlah et al. (2015), where this value is optimal for coral and macroalgae.

Table 3. Water quality parameters

Parameters	Unit	Stations					Average	Criteria*
		Jetty	Rumah Apung	Banyu Tawar	Watu Meja	Waru-waru		
Temperature	(°C)	29.58	29.71	29.74	29.43	29.78	29.648	28-32 [a]
Water clarity	(m)	2.70	2.19	1.96	2.99	2.38	2.444	>5 [a]
pH	-	8.31	8.05	8.25	8.33	8.16	8.22	7-8.5 [a]
Salinity	(‰)	32.06	32.16	32.11	32.36	32.41	32.22	33 -34 [a]
DO	(mg/L)	6.38	6.36	6.33	6.37	6.33	6.354	>5 mg/L [a]
Nitrates	(mg/L)	0.021	0.027	0.010	0.550	0.347	0.191	0.06 mg/L [a]
Phosphate	(mg/L)	0.011	0.019	0.008	0.303	0.287	0.1256	0.015 mg/L [a]
Sedimentation	(mg/cm^2/day)	89.27	58.13	61.05	74.73	85.49	73.734	1-10 slight moderate [b] 10-50 moderate-severe >50 severe-catastrophic
Current speed	(m/s)	0.38	0.45	0.47	0.50	0.49	0.458	Slow: 0-0.25 m/s [c] Moderate: 0.25-0.50m/s Fast: 0.50- 1 m/s Very fast: >100 m/s

Notes: Source: [a]Indonesian Government (2021), [b]Pastorok and Bilyard (1985), [c]Ramlah et al. (2015). *Standard Based on Indonesian Government (2021) regulation decree of the Indonesian Government No. 22/2021 about the seawater quality standard for marine biota

The ability of turf algae to persist under conditions of elevated nutrients, such as nitrate and phosphate, has been linked to their competitive advantage over other organisms. The tolerance of phosphate levels in water varies between corals and turf algae. Corals are generally sensitive to high phosphate levels, as elevated phosphates can lead to increased algal growth, including turf algae, which can outcompete corals for space and light. This can inhibit coral calcification and result in coral reef degradation (Nakajima et al. 2015; Al-Sawalmih 2016). Turf algae, on the other hand, can tolerate higher phosphate levels and may even benefit from increased nutrient availability. Additionally, nitrogen eutrophication specifically promotes the growth of turf algae in coral reefs, further supporting their capacity to thrive under nutrient-rich conditions (Hamzah et al. 2020; Karcher et al. 2020). Excessive algal growth leads to oxygen depletion in aquatic ecosystems, which is primarily driven by nutrient enrichment (Sidabutar et al. 2021).

Living coral coverage percentage

Temporally collecting live coral cover data is important for monitoring changes in the health of coral reef ecosystems, identifying coral decline or recovery. Meanwhile, recording coral growth forms is important to identify potential threats, one of which is the ability to survive in competition with macroalgae. According to the result (Figure 5), the lowest percentage of coral reef coverage was at Watu Meja Station of 10.28% and the high coral coverage of 18.30% at the Rumah Apung Station, which belonged to the poor category according to the Ministry of Environment No. 4 Year 2001.

According to the coral life form data result (Figure 6), the lowest percentage of live coral cover was obtained at five stations, and the dominant lifeform is Coral Massive (CM) with an average of 4.39%. Massive corals, which have ecomorph forms, play a crucial role in aiding corals to cleanse themselves from accumulated sediments with the assistance of current movements (Wanma et al. 2022), allowing for faster physiological recovery of the reef (Anggara et al. 2022). Massive corals, such as *Porites* spp., may tolerate high turbidity levels because their hemispherical shape and smooth surface reject sediment better than other rougher coral types. Meanwhile, branching corals, such as *Acropora* spp., thrive at the handling of sediment because their rough branch shape helps the coral to easily move particles and prevent accumulation, which can lead to smothering (Jones et al. 2019). The ability of corals to adapt to turbid conditions is further supported by research indicating that South Atlantic corals have developed critical features that make them less susceptible to mass coral bleaching, including a higher tolerance to turbidity and nutrient enrichment, as well as a dominance of massive growth forms among species (Mies et al. 2020).

Coral growth form significantly influences the coral's ability to compete with algal turf. Research by Swierts and Vermeij (2016) demonstrated that the ability of corals to outcompete turf algae depends on the growth form of the coral colony, with encrusting coral form, followed by massive and upright form to engage in more competitive interactions with turf algae compared to coral structures that grow in branching, plating, or solitary forms. Turf algae can rapidly overgrow adjacent corals due to their ability to increase in length and occur in both creeping and upright growth forms. Previous research has also found that encrusting corals suffer the least harm from turf algae and have a higher success rate in competitive interactions with turf algae compared to other coral growth forms (Liao 2018).

Composition of macroalgae type

Data on macroalgae composition are very important in the study of competition with corals, as they can identify macroalgae types that have high growth rates and dominance potential, thereby enabling the assessment of specific impacts on the health and sustainability of coral reef ecosystems. Algae found in the Sempu Island Nature Reserve, Malang District, Indonesia are turf algae, commonly found growing on coral surface and *Halimeda*, which are found in very small quantities. The description of turf algae and *Halimeda* is presented in Table 4. The distribution of turf algae is most commonly found competing with coral which can impact coral growth and health. The turf algae coverages are mapped at each station as shown in Figure 7.

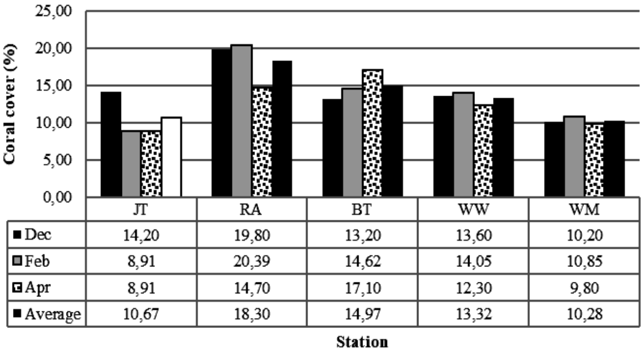


Figure 5. Percentage of live coral cover in the Sempu Island Nature Reserve, Malang District, Indonesia

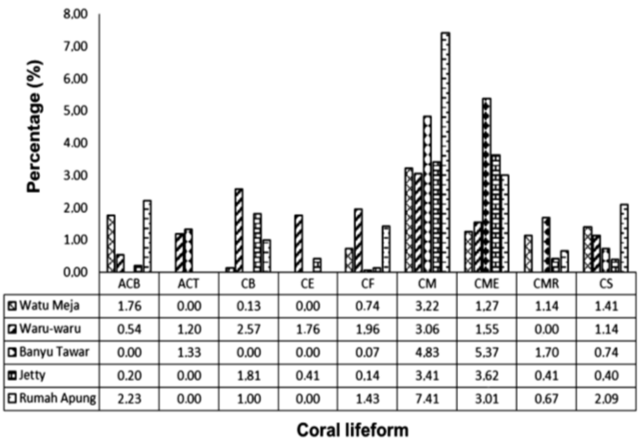
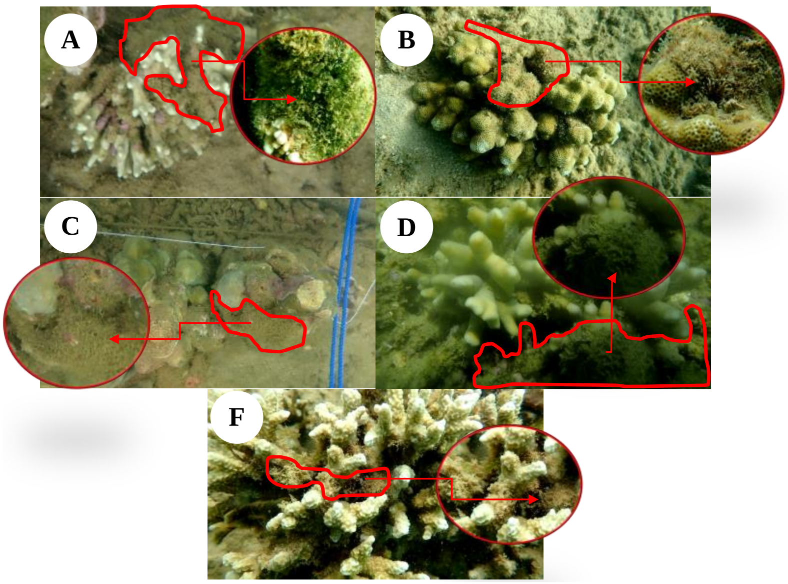


Figure 6. Percentage of live coral cover by lifeform in the Sempu Island Nature Reserve, Malang District, Indonesia

Table 4. General description of algae found in Sempu Strait, Malang District, Indonesia

Algae found	Description
	Turf algae found competing with various coral lifeform (A) Jetty, (B) Banyu Tawar, (C) Rumah Apung, (D) Watu Meja, (E) Waru-waru. The turf algae observed grow to only a few centimeters and cover surfaces such as unhealthy coral, dead coral, and rocks. They usually found in green color and shaped like soft filaments.
	Genus *Halimeda* was also found at the Jetty Port station with an area of 6,04 cm^2 in April 2023. Halimeda belongs to the classification of green macroalgae or Chlorophyta. These macroalgae can live in shallow waters on hard substrate or dead coral reefs. However, the *Halimeda* genus macroscopic algae were only found sticking to the rocks of one of the quadrant transect at Jetty's research station. Macroalgae of the *Halimeda* genus have peach-shaped and green-colored features.

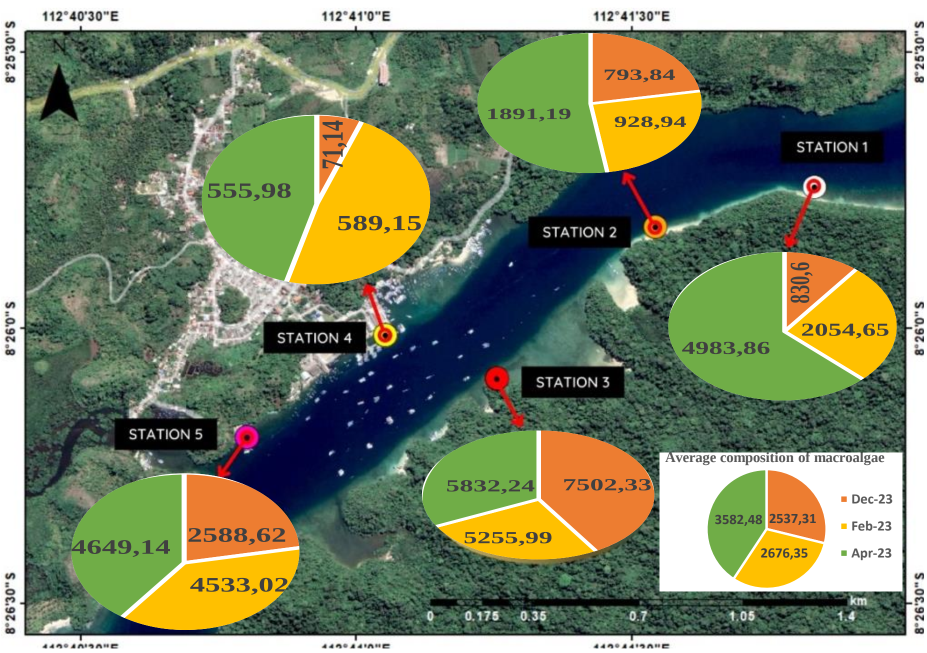


Figure 7. Distribution of macroalgae that compete with coral each month in the Sempu Island Nature Reserve, Malang District, Indonesia

According to the result (Table 5), the lowest composition of macroalgae area in December 2022 was at Jetty station at 71.14 cm^2 and the highest was at Banyu Tawar at 7502.33 cm^2. The lowest composition of macroalgae area in February 2023 was at the Jetty station at 589.15 cm^2 and the highest at the Banyu Tawar station at 5255.99 cm^2. The lowest composition of macroalgae area in April 2023 was at the Jetty station at 555.98 cm^2 and the highest at the Banyu Tawar station at 5832.24 cm^2.

Based on previous research conducted in the waters at Teluk Semut station at the Sempu Island Nature Reserve, Malang District, Indonesia, macroalgae were found with algae turf species of 18% and at the Watu Meja station, there were macro-algaes with turf algae around of 2%. Moreover, turf algae are highlighted as one of the most abundant algal competitors that corals face, playing a crucial role in initiating algal phase shifts on coral reefs (Roach et al. 2020). Turf algae are fast-growing, opportunistic algae that can quickly colonize available substrate on coral reefs. As they grow, they can outcompete corals for space, leading to reduced coral growth and survival. Additionally, turf algae can shade corals, reducing the amount of light available for photosynthesis, which is essential for coral health and growth (Connell et al. 2014; Roach et al. 2020). Turf algae have been identified as one of the most abundant algal competitors that corals face, playing a crucial role in initiating algal phase shifts on coral reefs (Wild et al. 2014). The presence of turf algae can lead to coral tissue damage, overgrowth, and a decrease in pigmentation, particularly in contact areas with the algae. Furthermore, the removal of algal turfs and fleshy macroalgae has been shown to enhance coral growth (Jorissen et al. 2016).

Based on research in 2017, *Halimeda* macroalgae were found at 50% and *Padina* sp. at 48% at the port site of Sendang Biru (Bhoke 2017). *Halimeda*, a tropical macroalga, is known for its ability to colonize various substrates like soft bottoms by firmly attaching itself through holdfasts (Mateo-Ramirez et al. 2022). This attachment mechanism allows *Halimeda* to thrive in environments around living or dead corals and rocks, making it challenging for the current to displace it. However, *Halimeda*'s ability to withstand various conditions is evident in its adaptability to rocky substrates and survival even in dry environments (Aprilia et al. 2023). The growth of *Halimeda* macroalgae is influenced by changes in pH, nutrients, water movement, precipitation, temperature, salinity, sunlight intensity, substrate type and depth (Peach et al. 2016).

Coral reef-macroalgae competition

The rapid growth of several types of macroalgae can be a major threat to coral. Understanding the dynamics of macroalgae-coral competition can identify factors that influence the growth and distribution of macroalgae and corals, as well as their impacts on biodiversity and ecosystem function. Graphic descriptive analysis is presented to determine the representation of the area of competition between macroalgae and coral cover. Competition between coral reefs and macroalgae found in the Sempu Strait mostly dominated by turf algae type and presented in the form of an average area of competition (Figure 8).

The competition between macroalgae and coral reefs found in the Sempu Island Nature Reserve, Malang District, Indonesia is mostly macroalgae with the type of turf algae found attached to coral reefs. Overall, the area of coral cover is higher than macroalgae. The highest average macroalgae cover was at Banyu Tawar station (6,196.86 cm^2) and the lowest at Jetty Port station (405.4 cm^2). The competition data was then analyzed using correlation analysis to find out how big the relationship between coral reefs and macroalgae.

Banyu Tawar station has a high level of competition compared to other stations. Parameters of temperature, pH, water clarity, salinity, nitrates and phosphate at Banyu Tawar station belong to the optimal category for macroalgae growth. The high sedimentation at Banyu Tawar station is due to the presence of dissolved particles carried by river streams coming from inside Sempu Island. Sedimentation can lead to the death of some coral colonies due to coral polyps being covered with sediments, which can hinder their feeding and growth processes (Tuttle and Donahue 2022). Additionally, sedimentation can increase the number of competitors for corals, such as macroalgae, which thrive faster in stronger currents due to the diffusion of nutrients, outpacing coral growth (Rogers and Ramos-Scharrón 2022).

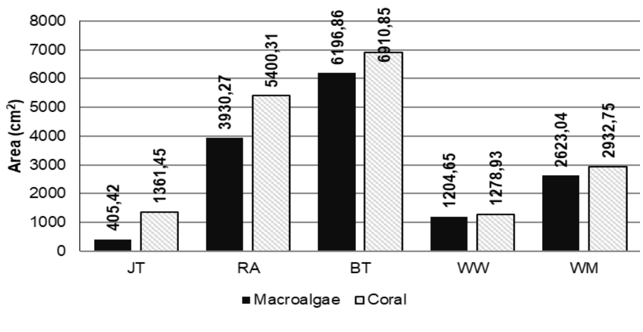


Figure 8. Area of competition between coral reefs and macroalgae in the Sempu Island Nature Reserve, Malang District, Indonesia

Table 5. Changes in the area of macroalgae composition (cm^2)

Month	The research station					Average
	Jetty	Rumah Apung	Banyu Tawar	Watu Meja	Waru-waru	
Des-22	71.14	2588.62	7502.33	830.60	793.84	2357.31
Feb-23	589.15	4553.05	5255.99	2054.65	928.93	2676.35
Apr-23	555.98	4649.14	5832.24	4983.86	1891.19	**3582.63**
Average	405.42	3930.27	6196.86	2623.04	1204.65	

This imbalance in growth rates can eventually lead to the degradation of coral reef coverage and diversity levels, as macroalgae can outcompete corals for space and resources. The Jetty Port station has had extensive competition between the macroalgae with the lowest coral reefs over three periods. The current speed at the Jetty station is 0.38 m/s and the sedimentation rate is 89.27 mg/cm^2/day. The temperature, pH, water clarity, salinity, nitrate and phosphate parameters at the Jetty station belong to the optimal category for macroalgae growth. Several types of herbivores, such as *Trochus* spp. can control the abundance of algae and increase the success of coral recruitment. Sea urchin (*Diadema antillarum* Philippi 1845) also has a positive effect on coral recruitment because it can control the dominant benthos and macroalgae (Nozawa et al. 2020). Increased density of herbivorous invertebrates such as sea urchins (*Diadema*) is associated with reduced macroalgae cover, which can increase the abundance of young corals (Edmunds and Carpenter 2001). In addition, *D. antillarum* is known to consume and control most macroalgae so that it can increase substrate cleaning and crustose coralline algae cover, where crustose coralline algae is an important factor in the coral recruitment process (Williams 2018).

Watu Meja and Waru-waru stations have a relatively balanced area of competition between macroalgae and coral reefs. The parameters of temperature, pH, water clarity and salinity at the Jetty station belong to the optimal category for macroalgae growth, but the values of nitrate and phosphate at these two stations are very high. Nitrate values in these stations are 0.550 and 0.347 mg/L, respectively. Nitrate that are more than 0.2 mg/L, potentially cause eutrophication in the waters and stimulate algae growth and harm coral reefs. Meanwhile, the phosphate content in the Watu Meja and Waru-waru are the highest among other stations with value of 0.303 and 0.287 mg/L respectively, which can support the survival of macroalgae (Runtuboi et al. 2023). Studies have shown that the enrichment of water with nitrogen and phosphorus accelerates eutrophication, promoting the dominance of cyanobacteria and algae (Ma et al. 2014). Both phosphate and nitrate enrichment can lead to the degradation of habitats, favoring fast-growing ephemeral algae over perennial macroalgae and seagrasses, oxygen depletion, changes in plankton community, and further exacerbating the euthrophication process (Picart et al. 2015; Ostman et al. 2016).

Correlation-regression tests on the relationship between coral competition and macroalgae are important to understand the correlation strength between two factors and are useful in predicting the impact of changes in macroalgae abundance on coral abundance in the future, which is important for coral reef conservation strategies. According to Table 6, it was found that the correlation value (r) between the two was 0.783, based on the correlation value (r) obtained, the level of competition relationship between macroalgae and coral reefs is included in the quite strong correlation (0.60-0.799). The correlation value is positive (+), which means that the higher the coral reef cover, the higher the chance of macroalgae growing on coral reefs (competitors).

Table 6. Results of the correlation analysis of the competition between coral reefs and macroalgae

Correlations			
		Macroalgae	**Coral**
Macroalgae	Pearson correlation	1	.763**
	Sig. (2-tailed)		.001
	N	15	15
Coral	Pearson correlation	.783**	
	Sig. (2-tailed)	.001	
	N	15	15

Notes: **Correlation is significant at the 0.01 level (2-tailed)

Macroalgae can be a key indicator in finding out the state of coral reefs in water (Bruno et al. 2014). The interactions between turf algae and corals are complex and involve microbial dynamics as well. The microbiota associated with turf algae play a detrimental role in coral health, contributing to coral disease and impacting coral-algal dynamics on reefs (Casey et al. 2014). Studies have also highlighted the role of herbivores in influencing turf algae dynamics. Damselfishes, for example, have been observed to expand their territories by causing white scars on corals, which are then often covered by turf algae, weakening the competitive ability of corals (Hata et al. 2020). Research conducted by Bintoro et al. (2023) at the same location states that the Acanthuridae species are often found in the Sempu Island Nature Reserve, Malang District, Indonesia and are the most numerous. This type of fish is able to help control algae cover on coral. Furthermore, the availability of open substrate for colonization influences the cover of turf algae on reefs, demonstrating a complex interplay of numerous factors regulating turf algae abundance (Lefcheck et al. 2019).

In conclusion, coral-algae competition is influenced by various factors, including nutrient availability, herbivory, and physical disturbances. Nutrient enrichment can favor the growth of macroalgae, giving them a competitive advantage over corals. Herbivores, such as fish and sea urchins, can control macroalgal growth and promote coral dominance. Physical disturbances, such as storms or human activities, can also affect the outcome of this competition. Understanding these factors is essential for effective coral reef management and conservation, as maintaining a balance between corals and macroalgae is important for the health and resilience of coral reef ecosystems.

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