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Coral disease prevalence and compromised health in the Sempu Island Nature Reserve, Malang District, Indonesia

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Abstract. *Isdianto A, Fewila AR, Rijal SS, Setyanto A, Fathah AL, Atikawati D, Putri BM, Puspitasari ID, Luthfi OM. 2024. Coral disease prevalence and compromised health in the Sempu Island Nature Reserve, Malang District, Indonesia. Biodiversitas 25: 1404-1412.* Since the Dutch colonialization era, the Malang District's Sempu Strait has been designated a natural reserve. Environmental changes and human activities have contributed to the 14.28% coral cover in the Sempu Strait. This study aims to assess coral health in the Sempu Strait and detect coral diseases or compromised conditions. At five stations, data were gathered utilizing the Underwater Photo Transect method with a 10-meter interval and a 1x1 meter transect implemented across 100 meters. The average coral cover in Sempu Strait is 14.28%, considered inadequate according to categories for determining coral reef status. Fish Bite, Black Band Disease (BBD), Ulcerative White Spots (UWS), Non-Focal Bleaching (NFBL), Trematodiasis, and Pigmentation Response are the six categories of coral reef diseases that have been identified. Sediment damage is the only compromised health condition that has been identified. With an average prevalence of 15.35%, Non-Focal Bleaching (NFBL) is the most prevalent disease; Black Band Disease (BBD) has the lowest prevalence at 0.8%. The insufficient coral coverage in the Strait of Sempu is caused by the surrounding environmental conditions that stress corals to the point where the prevalence of coral-eating diseases is increased.

Keywords: Coral coverage, coral damage, coral reef diseases, nature reserve, sedimentation, underwater photo transect method

INTRODUCTION

Coral reefs provide both ecological and economic functions; the ecological functions of coral reefs include reef formation (calcium carbonate production and bioerosion), food chains (primary and secondary production), and nutrient uptake and release (Brandl et al. 2019). As an economic function, it provides opportunities to people through tourism and commercial fisheries (ICRI 2018). Coral disease is correlated with coral reefs' resilience and ability to recover from chronic and transient stress disturbance (Zakaria et al. 2021). The coral disease causes a physiological disorder to the coral biotope, impairing the vital functions of coral animals, organs, or organ systems, disrupting organ growth and reproductive processes, changing community structures, and decreasing marine animal associations in coral reefs (Beeden et al. 2008). Coral diseases have biotic and abiotic causes, such as climate change and anthropogenic activity induce coral disease by raising sea surface temperatures, which weaken coral immune systems (Thurber et al. 2020). Corals indicated by the disease are characterized by color changes, coral biota's skeleton damage, loss of its net, and sores or bands of missing coral tissue. Biotic factors such as bacteria (Castañeda-Chávez et al. 2018), viruses (Sweet and Bythell 2017), protozoa (ciliates) (Cheng et al. 2021) or fungi (Soler-Hurtado et al. 2016) can damage corals on a large scale. Compromised health is a form of health threat to corals caused by several factors (Sweet et al. 2019) such as sponges, cyanobacteria, red algae, and peach worms compete with corals, while sediments close coral polyps and impede coral metabolism (Luthfi et al. 2014).

Sempu Strait waters of southern Malang, Indonesia have an ecosystem of coral reefs of less than 10 hectares (Luthfi et al. 2014), which was once rich in coral reefs around Sempu Island, but it is currently decreasing due to continuous exploitation by the surrounding community as Sempu Island is an open tourist area, fishing catchment, poorly managed household waste, port activities and also the opening of land for development that directly brings sediment supplied by the river into the sea. Sediment originating from land is a combination of organic and inorganic materials (nutrients, toxins, and pathogens is one of the causes of sediment entering the water has a lot of impact on corals (Rogers and Ramos-Scharrón 2022; Tuttle and Donahue 2022). Anthropogenic activities can leave residues in water, reducing its use value and affecting humans and aquatic organisms (Nguyen and Vo 2022). Coral reefs can recover slowly if anthropogenic or natural stresses are reduced (Luthfi et al. 2020). A "coral-algal phase shift" occurred when aquatic and land-based activities caused coral death and recruitment failure, shifting dominance from hard corals to macroalgae (Fabricius et al. 2023).

Previous research conducted in the Strait of Sempu in 2018 revealed that the coverage of living corals in Sempu Strait ranged between 6.94-42.4% or clustered in damaged conditions. The number of large-scale corals that are very rare in the Sempu Strait is possible because they are taken physically for human needs or damaged due to the role of a bioreoder (organisms that cause bioerosion) with more than 100 species that live on massive corals, and will accelerate coral fragmentations into smaller colonies (Luthfi et al. 2018). The study aims to determine the life forms, coral coverage, and the prevalence of coral disease and compromised health in the Sempu Strait waters. Therefore, the results can be used as a benchmark for data on the destruction of the coral reef ecosystem caused by changes in the water environment.

MATERIALS AND METHODS

Study area

The research was carried out in December 2022, located in the Sempu Strait waters, Malang District, East Java, Indonesia, and was carried out at five stations. The first station is Rumah Apung, located at the end of the western islands. The current and waves at this first station are quite high, but the water conditions are quite clear. The second station, Jetty Port, located in Pondokdadap, Sendang Biru Port, has very dense community activities compared to other stations. The third station, Banyu Tawar, which runs off of a small river, resulted in the lower salinity of the other station. The fourth station is Waru-Waru, a tourist destination. The fifth station is Watu Meja, at the east end of the Sempu Strait and close to the Indian Ocean, so these waters' conditions have strong currents and waves.

Data assessment of coral coverage and coral disturbance using the Underwater Photo Transect method (Figure 2) is done with underwater photography using digital cameras. Data on coral conditions observed from five sites were collected using a quadran transect. The coral coverage percentage is analyzed using CPCE software and refers to the Coral Reef Health Monitoring Guidelines to determine coral cover condition by 0-25% as poor, 26-50% as fair, 51-75% as good, 76-100% as excellent (Giyanto et al. 2017).

Colonies of corals affected by disease/compromised health of other coral reefs are documented using underwater cameras, and parts of the coral affected with disease/disorder are enlarged to facilitate identification inside the quadrant transect (Giyanto et al. 2017). Identifying the types of diseases and compromised health was done descriptively by observing the coral coloration changes, such as white, yellow, pink, black, and others (Peixoto et al. 2017).

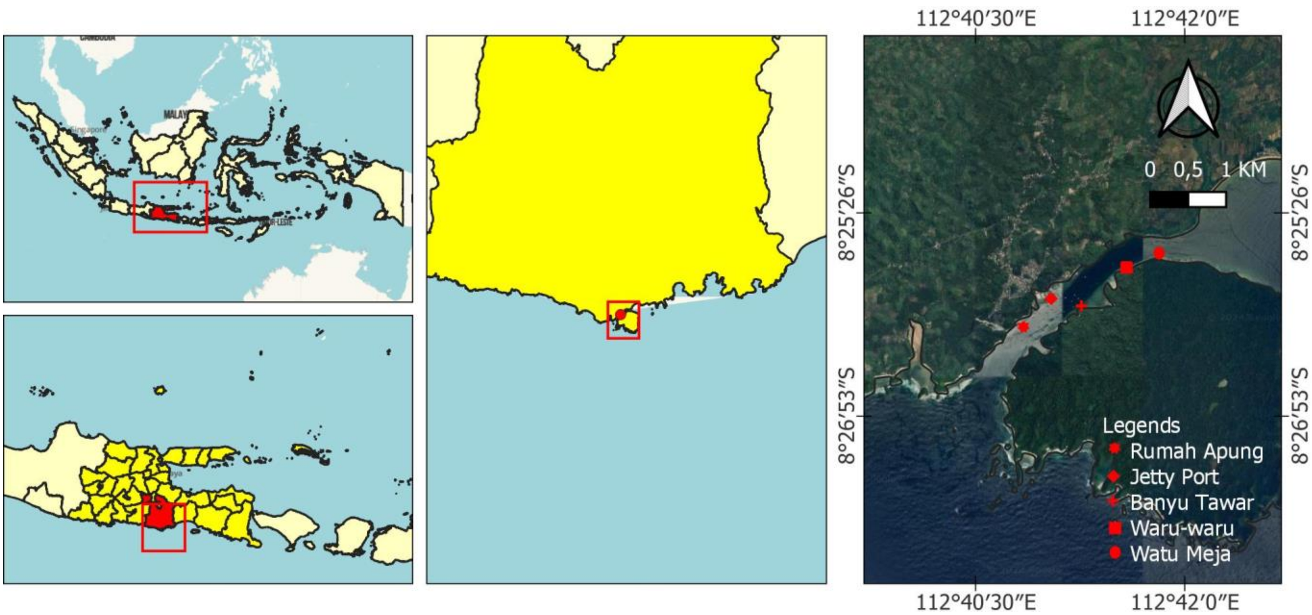

Figure 1. The five sites of observation in Sempu Strait, Malang District, East Java, Indonesia

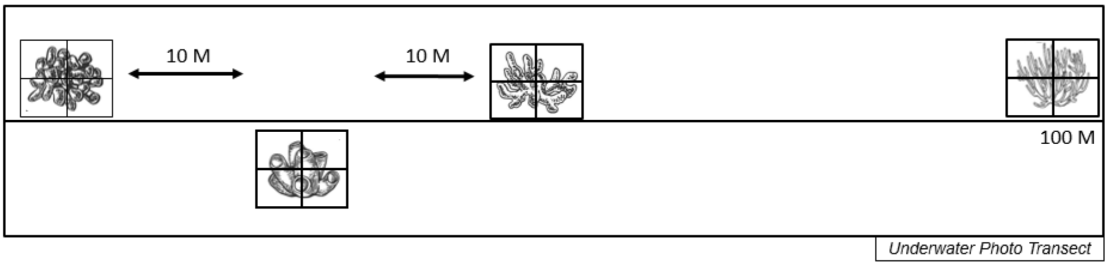

Figure 2. Underwater photo transect

Despite the importance of knowing about disease and compromised health in corals, we must have an understanding of the factors that increase the disease rate, such as the corals' proportion that develop disease signs over a certain period, the prevalence of marking the progression of disease and the compromised health in coral colonies (Renzi et al. 2022). Prevalence is the percentage of colonies infected with the disease/disturbance with the amount of coral colonies in water (Beeden et al. 2008).

Data collection is carried out in the transect location where the coral reef is found using AAQ RINKO, which has a quick response to collect the DO content, temperature, depth, salinity, and pH. At the same time, the sedimentation rate carried out by sediment trap, current speed carried out by current meter, and nitrate phosphate parameter carried out from the stations and observed in the laboratory using the spectrophotometer method. Water quality data measured at the site will be presented in tables and then presented based on the results of data processed using Microsoft Excel.

RESULTS AND DISCUSSION

Water quality

According to Indonesian Government Regulation Number 22/2021 concerning the Implementation of Environmental Protection and Management, most water parameter values (Table 1) in the location categories are not optimal for coral growth. The average salinity is 32.3 ppt, below standard; seawater's average salinity in tropical areas, such as Indonesia, is approximately 33-34 ppt (Badriana et al. 2021). Other sources stated the ideal salinity for coral growth is between 30-36‰ (Giyanto et al. 2017). The decrease in salinity can lead to a substantial reduction in fertilization success during coral spawning and a decrease in larval developmental success. It has been observed that a 20% decrease in salinity can decrease fertilization success by 86% during coral spawning and reduced larval developmental success by 50% (Carlson et al. 2019)

The average value of nutrient components, including nitrate and phosphate, in Sempu waters exceeds the recommended optimum limit for coral growth. High nitrate concentrations, combined with low phosphate availability, result in zooxanthellae lacking phosphate requirements, which increases the vulnerability of corals to bleaching due to heat and light stress (Rosset et al. 2017). The nutrient component enrichments (nitrate, ammonium, and phosphate) cause a decrease in coral resistance to disease induction through viruses and pathogenic bacteria (Zhao et al. 2021), thereby increasing the prevalence of disease and health problems in coral. Meanwhile, the average sedimentation rate is 62.2 mg/cm^2/day, categorized as very high-catastrophic. This high sedimentation caused a severely decreased in coral abundance, communities, recruitment, colonies, and invasion by opportunistic species, even slowing or stopping the regeneration (Pastorok and Bilyard 1985).

Table 1. Water parameters results in Sempu Strait, Malang District, East Java, Indonesia

Parameters	Unit	Station					Average	Threshold	Category
		RA	JT	BT	WW	WM			
Temperature	˚C	29.67	29.51	29.78	29.95	29.39	29.7	28-30[a]	Optimal
Salinity	‰	32.12	32.01	32.09	32.52	32.38	32.2	33-34 [a]	Not optimal
pH	-	8	8.1	8.22	8	8.1	8.1	7-8.5 [a]	Optimal
Dissolved oxygen (DO)	mg/L	6.35	6.37	6.33	6.32	6.36	6.3	>5 [a]	Optimal
Nitrate	mg/L	0.023	0.019	0.009	0.340	0.520	0.182	0.06	Not optimal
Phosphate	mg/L	0.018	0.019	0.007	0.290	0.320	0.131	0.015	Not optimal
Current	m/s	0.38	0.45	0.47	0.49	0.5	0.38	Slow: 0-0.25[b] m/s Moderate: 0.25-0.50m/s Fast: 0.50- 1 m/s Very fast: >100 m/s	Moderate
Sedimentation rate	mg/cm^2/day	45.44	73.04	53.93	84.93	53.50	62.2	1-10 slight-moderate[c] 10-50 moderate-severe >50 severe-catastrophic	Severe-catastrophic

Source: ([a]Pastorok and Bilyard 1985, [b]Ramlah et al. 2015, [c] Indonesia Government 2021)

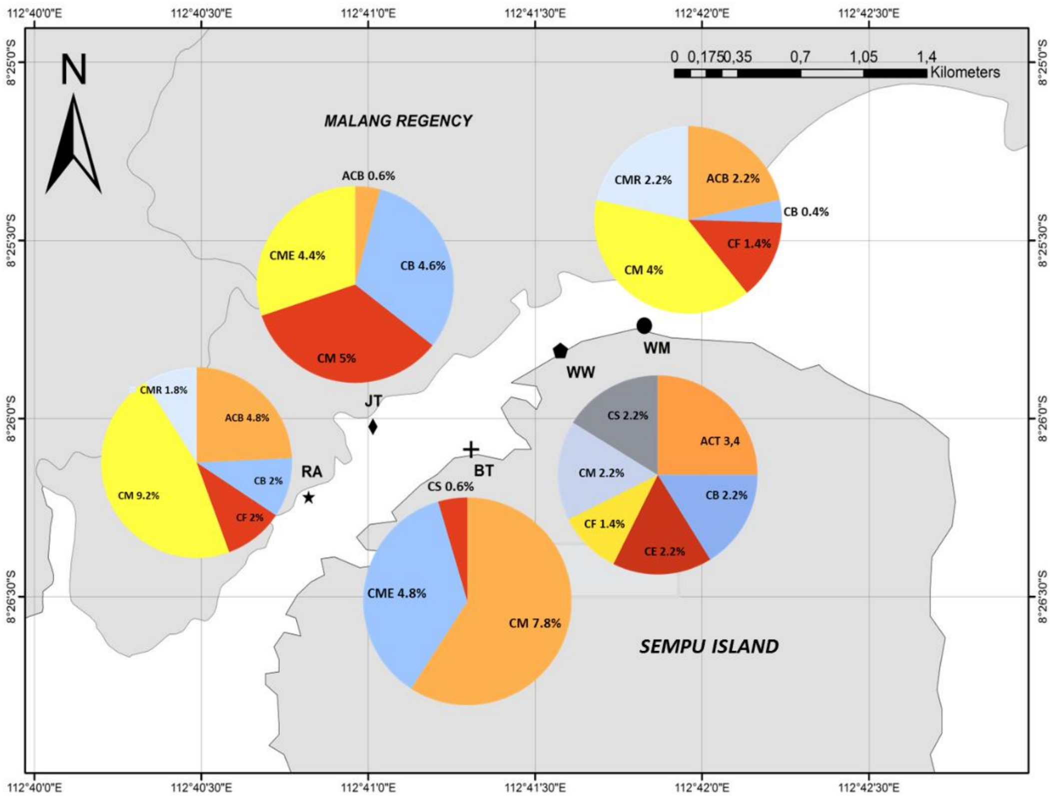

Figure 3. Live coral coverage percentage in Sempu Strait, Malang District, East Java, Indonesia. Note: RA: Rumah Apung; JT: Jetty Port; BT: Banyu Tawar; WW: Waru-Waru; WM: Watu Meja; ACB: Acropora Branching; CB: Coral Branching; CF; Coral Foliose; CM: Coral Massive; CMR: Coral Mushroom; CME: Coral Millepora; CS: Coral Submassive; ACT: Acropora Tabulate; CE: Coral Encrusting

Coral cover

The conditions of coral reefs in the Sempu Strait waters fall into the bad category, with coverage percentages ranging from 10.2-19.8% (

Figure **3**). The low percentage of coral coverage is due to sedimentation, marine activity such as port activity, tourism activities, and environmentally unfriendly catchment methods, causing low coral coverage in the waters of the Strait of Sempu.

Overall, the highest life form coverage on the five stations is coral massive (CM) at 28.2%, while the lowest coverage is coral submassive (CS) at 0.6%. The forms of hard coral growth in the swamp waters are dominated by massive coral, coral branching, coral foliose, and Acropora branching (Luthfi et al. 2018). The forms of coral growth provide information about the environmental conditions of the waters of a region. Edinger and Risk (2000) stated that the classification of the relationship between coral development forms and the water environment is divided into three: first, ruderals (r) are coral corals that easily adapt to their environment or quickly adapt to its damage; Competitors (K), both non-Acropora corals are foliose-shaped and branching that dominate water and have rapid growth though less rapidly compared to Acropora; third is the coral that has a stress-tolerant (S), which is all massive and submassive corals that have the ability to resist sedimentation and water eutrophication.

Coral diseases and compromised health prevalence

The study revealed the coral disease prevalences in each station (Figure 4**Error! No bookmark name given.**); the highest at Rumah Apung station was Pigmentation Response (PR) at 14.28%, and the lowest was Ulcerative White Spots at 3.57%. The highest type of disease at Jetty Port station is Fish Bite (FB) at 20% and the lowest Pigmentation Response at 2%. The highest disease at Banyu Tawar station was trematodiasis at 23.8%, and the lowest Ulcerative White Spots (UWS), Fish Bite (FB) and Pigmentation Response (PR) at 9.52%. The highest disease at Waru-Waru station was Non-Focal Bleaching (NFBL) at 29.41%, and the lowest was Fish Bite (FB) and Pigmentation Response (PR) at 17.64%. The highest disease at Watu Meja station is Non-Focal Bleaching (NFBL), with 13.63%, and the lowest Fish Bite (FB), with 9.09%. Coral disease prevalence has significantly increased under a changing climate, impacting coral community structure and functionality (Ampou et al. 2017). The impacts and ecology of coral diseases are unclear in most high-latitude reefs. High-latitude locations are vulnerable to climate change; therefore, identifying diseases and developing region-specific baselines are important for local management (Moriarty and Ainsworth 2022).

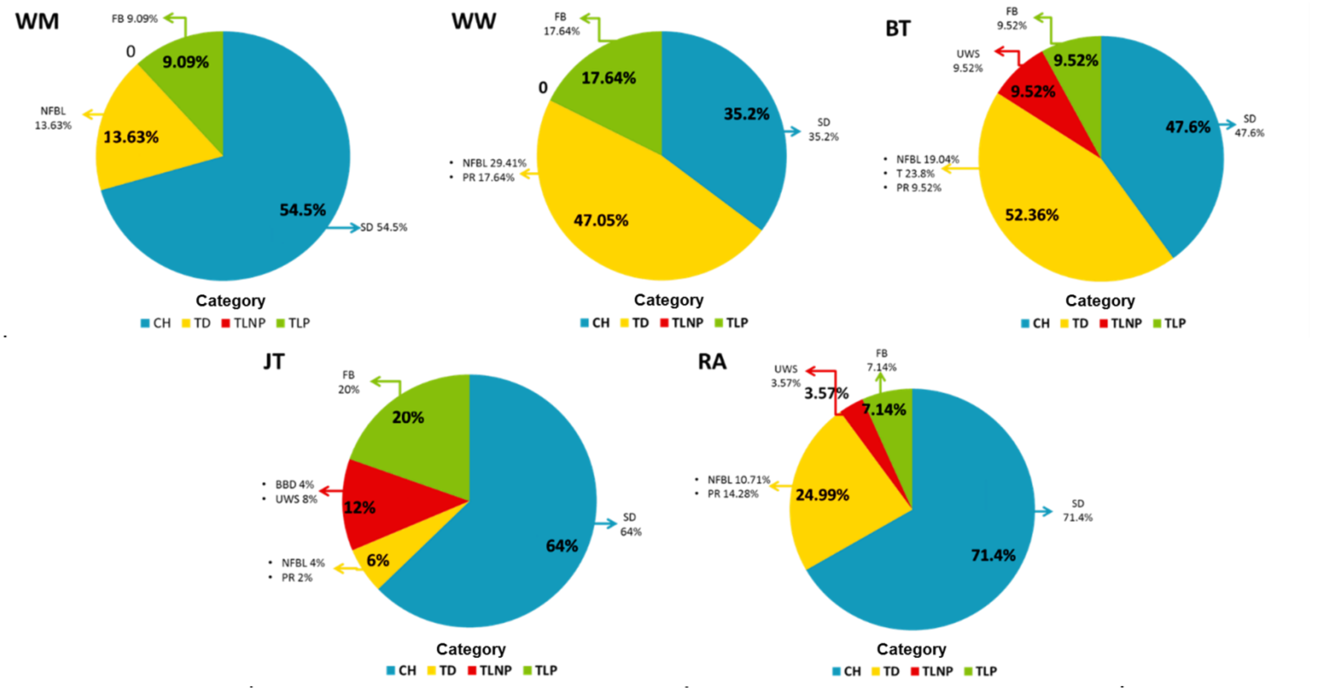

Figure 4. Compromised health and coral diseases prevalence in Sempu Strait, Malang District, East Java, Indonesia. Note: RA: Rumah Apung; JT: Jetty Port; BT: Banyu Tawar; WW: Waru-Waru; WM: Watu Meja; TLP: Tissue Loss Predation; TLNP: Tissue Loss Non-Predation; TD: Tissue Discoloration; CH: Compromised Health

Table 2. Coral diseases and compromised health

Category	Type	Description
TLP (Tissue Loss Predation)	Fish Bite	A fish bite causes injury, the wound characterized by white and rugged like a sharp object, sometimes found in a rectangle or line.
TLNP (Tissue Loss Non-Predation)	Black Band Disease	A black band with a width of 7-9 mm is located between a dead (white) skeleton and a living tissue. Algae found recover dead skeletons.
	Ulcerative White Spots	There are small white circles separated and spread across the colony surface.
TD (Tissue Discoloration)	Non Focal Bleaching	Coral bleaching forms a pattern that spreads on the coral body.
	Trematodiasis	Shaped of small pink-colored spots spreading on the coral body, and look slightly emerged.
	Pigmentation Response	The shape of pink spots was in the pattern spread or only at one point on the coral body.
CH (Compromised Health)	Sediment Damage	Diffuse area of tissue loss was associated with fine sediment accumulating in hollows on the coral surface and coral polyps and tissue.

The highest health disturbance caused by sediment damage (SD) was at the Rumah Apung Station at 71.4%, for the lowest percentage of compromised health was at Waru-Waru Station at 35.2%. Therefore, this study shows the Rumah Apung Station has the highest percentage of compromised health. This is due to the high level of coral damage caused by sedimentation, which is high in the Rumah Apung station due to high anthropogenic activity such as ship and fishing. In addition, the light-moderate sediment rate in the Rumah Apung Station is also the biggest factor that causes the low percentage of coral cover in Rumah Apung Station (Isdianto et al. 2021).

The observation in Sempu Strait shows 6 types of diseases were collected that are divided into 3 categories and 1 type of compromised health according to the cause of disorders in the coral (Raymundo et al. 2008). The disease categories include TLP (Tissue Loss Predation) with Fish bite; TLNP (Tissue Loss Non-Predation) with Black Band Disease (BBD) and Ulcerative White Spots (UWS); TD (Tissue Discolouration) with Non-Focal Bleaching (NFBL), Trematodiasis, Pigmentation Response (PR); CH (Compromised Health) with Sediment Damage (SD). Coral diseases and their characteristics found in the waters of the Sempu Strait are described in Table 2.

Coral diseases and compromised health in Sempu Strait identification

The prevalence of disease and threats to corals has been used to assess coral reefs' resilience. This is supported by Linh et al. (2019), who developed 11 resilience indicators for assessing coral reefs, including coral disease, as a measure of resilience. Coral diseases threaten the reef-building coral species and can potentially reduce coral ecosystem biodiversity, loss of habitat, increased vulnerability to coastal hazards (Huang et al. 2021), and coral mortality (Spadafore et al. 2021). The ability of corals to resist diseases and recover after outbreaks is crucial for the long-term survival and persistence of coral reefs. Recent studies have highlighted the importance of understanding the mechanisms of resilience and resistance in coral reef restoration and conservation strategies (Libro and Vollmer 2016). The cascading effects caused by coral diseases on the entire reef ecosystem; for example, in the Caribbean, diseases have caused a reduction in the primary reef-building coral, *Acropora palmata*, and an important grazer, *Diadema antillarum*. These cascading effects include alterations in species composition, ecological processes, and the overall functionality of the reef ecosystem (McClanahan et al. 2002). The coral diseases and compromised health characteristics found in Sempu Strait are described in Figure 5.

TLP (Tissue Loss Predation) is a form of coral disease due to the disappearance of tissue caused by predation. Fish bites are classified based on lesion size, shape, presence of predators, and the development of lesions on the coral surface which the growth of macroalgae will later colonize (Aeby et al. 2020). The corals losing tissue also causes the coral body's susceptibility to disease (Raymundo et al. 2008). The Sempu Strait waters themselves have a variety of reef fish, according to Bintoro et al. (2023), which are 23 families of reef fish found in the Sempu Strait, which the Pomacentridae family dominates. The bite of the coral fish is usually white in the shape of a line with a tissue that has been scratched or lost (Beeden et al. 2008).

TLNP (Tissue Loss Non-Predation) is a disease caused by bacterial infection, water environment changes, or coral reef ecosystem pollution. The types of TLNP disease found in the Sempu Strait waters are Black Band Disease (BBD) and Ulcerative White Spots (UWS). BBD is a globally distributed and easily recognizable coral disease (Meyer et al. 2023) and develops at a growth rate of 3 mm/day (Buerger et al. 2016). More recently, Ulcerative White Spots (UWS), a presumed new "white-plague type" disease, killing large numbers of corals in a short time, was reported from southeastern Florida in 2014. Therefore, it is possible that the pathogen(s) could have been released from sediment disturbance, or that pathogen virulence and/or host susceptibility were affected by the high temperatures, or both (Weil et al. 2019). The appearance of white spots on the outer surface of the coral characterizes UWS. A feature of the disease makes small wounds <1 cm in diameter, round-shaped like eggs, regularly on the coral's outer surface, and the spotted wounds found on infected corals can merge and form large wounds (Raymundo et al. 2008).

TD (Tissue Discoloration) is a change in color in coral tissue due to biological activity within the coral body. The types of TD disease found in the Strait are Non-Focal Bleaching (NFBL), Trematodiasis, and Pigmentation Response. The TD found in coral are massive, submassive, coral branching, and acropora branching. The disease forms multifocal or diffuse wound patterns shown by a coral tissue color change to pink, purple, or blue. Pigmentation can be in lines, dots, bumps, or irregular shapes. This characteristic is a coral response to disorders such as drilling biota, competition, or algae attack (Beeden et al. 2008).

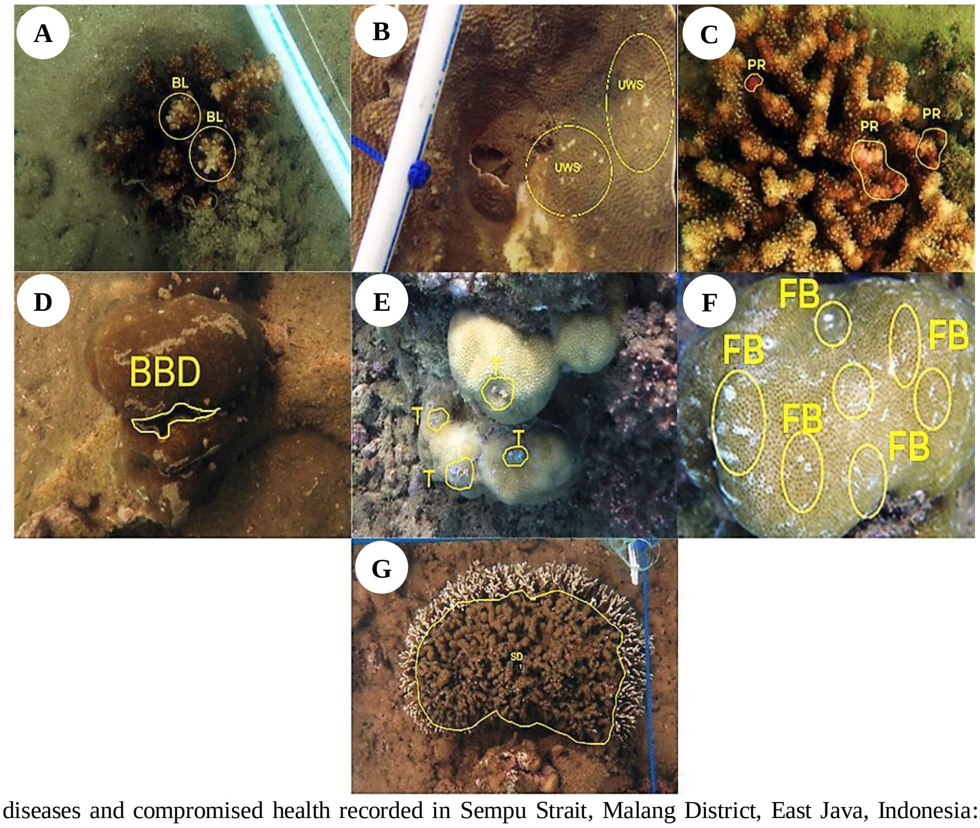

Figure 5. Coral diseases and compromised health recorded in Sempu Strait, Malang District, East Java, Indonesia: A. Bleaching; B. Ulcerative White Syndrome; C. Pigmentation Response; D. Black Band Diseases; E. Trematodiasis; F. Fish Bites; G. Sediment Damage

CH (Compromised Health) caused by sediments can cause the closure of coral polyps and inhibit the metabolic system. Sedimentation tends to settle easily, and covering coral polyps causes tissue necrosis, leading to their death (Permana et al. 2022). The organic materials, such as hydrogen sulfide in sediment, trigger microbial processes that can kill coral. Sediment and water samples may serve as potential transmission sources for stony coral tissue loss disease (SCTLD)-associated microbes (Rosales et al. 2020). Additionally, it highlighted that organic sediment enrichment increases microbial activity, causing anoxia and increased disease prevalence in corals (Ashey et al. 2023). Not only in matured corals, but sedimentation is also a stressor for corals just starting recruitment (Moeller et al. 2017). Sedimental damage in coral reefs in the waters of the Sempu Strait occurs due to the high anthropogenic activity and river flow that causes the sedimentation rate in the water to increase.

Discussion

Coral reefs face many global pressures, with climate change and ocean acidification identified as significant contributors to the worldwide coral reef ecosystem degradation (Lesser et al. 2016). The healthiness of coral reef is related to their presence of disease and compromised health` (Zakaria et al. 2021). Most lesions found on corals are not produced by infectious agents but by environmental factors such as physical influences (predation, abrasion, storms), environmental stressors (temperatures resulting in bleaching, sedimentation), or chemical influences (toxicants). Environmental stressors greatly influence the health of coral reefs (Patthanasiri et al. 2022). Water quality is essential to the coral reefs' health; thus, many thresholds have been established to determine the extent to which coral reefs may survive. Some water quality values in the Sempu Strait are not optimal, namely salinity, nitrate, phosphate, and sedimentation rate, so they can potentially reduce coral health.

According to the observation findings in five stations, the coral cover across all stations was categorized in the bad category, measuring 10.2-19.8%. This is also related to previous research in 2021 with the same location, showing an overall average of 11.47% in 3 observation periods (August, September, October) (Isdianto et al. 2023). Furthermore, this result is not significantly different from studies conducted in 2018, wherein coral cover was estimated to be between 8 and 30%, with an average of 20% categorized as poor (Luthfi et al. 2019). The low cover of live coral is partly caused by high sedimentation disrupting coral metabolism due to polyps blockage, leading to coral death. These results align with Luthfi et al. (2014) that sedimentation and nutrient supply play an important role in increasing the prevalence of coral health disorders. This follows the study results, which state that the most common health problems found in Sempu waters are caused by the deposition of sediment covering the coral surface, leading to the bleaching and death of several corals. Sedimentation, in part, is influenced by the current velocity that removes sediment from the coral surface. Sediment sorting can be influenced by current speed, water depth, and tidal range, influencing sedimentation (Amjadian et al. 2023). The current speed in the Sempu Strait is classified in the moderate category and is supported by sedimentation rate values which are in the severe-catastrophic category; this has the potential to damage coral health in the Sempu Strait because the moderate-speed currents category (0.25-0.50 m/s) are insufficient to reduce the rapid sedimentation rate in a body of water.

The disease category recorded most frequently in the waters of the Sempu Strait is Tissue Discoloration (TD), which includes non-focal bleaching, trematodiasis, and pigmentation response. This disease category can be observed by color changes on the coral's body, which is the coral's response to several disturbances such as drilling biota, competition, or algae attacks. The other leading cause of macroalgae's appearance is high nutrient levels in waters, such as nitrate and phosphate, so it can be concluded that high nitrate and phosphate levels can indirectly trigger disease development. This follows the statement of Siagian et al. (2022) in the research regarding the supply of nutrients from shrimp ponds, which states that there is a strong relationship between nitrate, phosphate, and ammonia on the prevalence of disease and coral cover. Sempu waters require attention regarding anthropogenic activities that have the potential to provide excess nutrient supply to the waters, especially related to port activities and waste from local settlements.

The Sempu Strait is part of a nature reserve that should be protected and become a conservation concern by the government; tourism activities, especially at Waru-waru station, pose a risk of coral damage. This includes kicking corals, holding corals, walking on corals, and lowering tourist boat anchors without considering corals sites. In addition, the sedimentation threat to coral health had previously occurred in the Sempu Strait, as was proven precisely in 2006-2009, when the expansion of Pondokdadap Harbor had a significant influence, resulting in a 50% reduction in coral cover (Luthfi et al. 2018). Based on the conditions previously explained, besides creating marine protected areas, other efforts to restore coral ecosystems are sinking artificial reefs or coral gardens. In 2013, the practice of immersing coral garden media in the Sempu Strait was implemented, notably at Watu Meja station; however, this practice wasn't maintained sustainably.

Global-scale influences, such as climate change, encompassing rising sea surface temperatures, ocean acidification, sea level rise, and intensifying storms, require study due to their ability to affect the health of coral reefs, potentially leading to a decline in coral cover. Studies have highlighted the importance of considering both global factors and anthropogenic factors in safeguarding coral health (Hoegh-guldberg et al. 2017; Tracy et al. 2024). Additionally, utilizing resilient coral species could enhance the efficacy and proactive nature of coral reef restoration techniques in response to climate change (Caruso et al. 2022). In conclusion, a holistic approach to coral condition issues needs to consider environmental conditions, potential stress triggers, long-term consequences of anthropogenic factors, as well as good integration between stakeholders in implementing conservation efforts. It is hoped that the final results of this research will be useful in providing insight to policymakers so that they can collaborate with relevant stakeholders to carry out appropriate conservation efforts to support the sustainability and resilience of coral reefs in Sempu Strait waters.

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