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Original Research

Prevalence of Coral Disease on Reefs in Paraja Bay Waters, Banten Province, Indonesia

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Abstract

This research examines the function changes around the coral reef ecosystem caused by coral disease in Paraja Bay. The research aims to identify coral disease and the correlation between diseases and reef coral species. These identifications of coral diseases can be used to assess corals' growth process, reproduction, and structural changes. The in-situ data was collected in February 2022 at 16 stations on each side of four small islands. The closeness relationship analysis was performed using PCA and XLstat. The results show that the disease prevalences in four small islands are varied, namely Badul Island (17.2%), Mangir Island (6.96%), Oar Island (2.66%), and Umang Island (4.86%) with an average of 7.91%. The coral diseases found in all stations were Trematodiasis and White Syndrome. Corals with Trematodiasis symptoms were *Favia* sp., *Favites* sp., and *Platygyra* sp., while ones with White Syndrome were *Acropora* sp., *Favites* sp., and *Pavona* sp. The existence of the diseases indicates the need for ecosystem restoration to include environmental aspects and community activities. This restoration action can accelerate the process of habitat and associated biota recovery.

Keywords: coastal ecosystem, coral reef, disease, insufficient data, Paraja Bay

Introduction

Coral reefs in Indonesia have reported a 30% to 60% decline in coral species diversity due to land-based pollutants over 15 years [1]. Meanwhile, coral reefs in Indonesia are home to approximately 51% of coral reefs in Southeast Asia and 18% of the world [2, 3]. Data updated by the Indonesian Institute of Sciences (LIPI) in 2021 reported that [4] Indonesia has 3,257,483 km^2 of coral reefs, 99,093 km of coastline, and 13,466 islands. Indonesian coral reefs have more than 569 species of scleractinian corals from 83 genera [2-4]. However, as a similar trend worldwide, Indonesian coral reefs are in decline and suffer from bleaching and disease outbreaks [5]. In recent national surveys, approximately 33.82%

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of Indonesia's coral reefs have been classified as "in poor condition" [3, 4]. In addition to the global trend of both increased sea surface temperatures and ocean acidification being caused by climate change [6], reef ecosystems are also some of the most threatened by human disturbance, both on a local scale from overfishing and land-based pollution and on a local to global scale from climate change and ocean acidification [7].

The coral reef ecosystem is a habitat with a high diversity of biota and minerals; however, it is vulnerable to climate change and anthropogenic impacts from coastal areas [8]. Ecologically, this ecosystem is capable of playing an essential role in the survival and the life cycle of fish and other organisms that require a coral reef environment to function. In recent decades, coral reef ecosystems have tended to experience a decline that has renewed the interest in reef communities in coastal environments, as they have the potential to function as resilience centers and shelters from climate change [9]. These also provide greater insight into how coral reefs can be sustained in the changing marine environments [10], and how fish resources depend on coral reefs. The dependency between reef fish and their ecosystems is because coral reefs are habitats and spawning grounds. Coral reefs in coastal areas also have essential roles, including beauty value, protecting the beach from waves, being a source of medicinal materials, and acting as a place for breeding [11]. In addition, coral reefs can improve coastal communities' social and economic welfare by supporting education and research activities, as well as tourism [12].

The coral reef ecosystem must function for organisms to survive [13], while the changes are due to the status of the coral ecosystem itself. Environmental quality changes in coastal areas is one factor contributing to the decline in the function of ecological systems in coral reefs. Changes in coral reefs other than in terms of human activity can also be caused by the presence of pathogenic organisms attached to the surface of corals that may cause coral death in a particular accumulation of time. An example is Ulcerative White Spot (UWS), one of the coral diseases found in the Indo-Pacific caused by non-predation, where the loss of coral focal tissue and the sensitivity were visually visible as bleaching spots [14]. Some other common coral diseases are Black Band Disease (BBD), White Syndrome (WS), Atramentous Necrosis, Skeletal Eroding Band (SEB), Trematodiasis, and Brown Band (BrB) [15].

In general, coral disease refers to a condition of infection in corals caused by pathogens [16, 17]. This condition can be seen from the changes in color on the surface of the infected corals. Other than by pathogens, coral disease can also be caused by predation and stress, as well as other factors such as abnormal coral growth [16]. Other explanations for the presence of various diseases in coral reefs include pathogen attacks, environmental conditions that are not suitable for corals, such as eutrophication, ocean acidification, algae competition, and radiation, as well as coral immune conditions that are weak [17-19].

The ecosystem condition of coral reefs around the small islands of the Paraja Bay region is dominated by hard coral lifeforms, including Acropora and Non-Acropora groups. Coral reefs in the Paraja Bay area are found around five small islands, namely Badul Island, Oar Island, Mangir Island, Sumur Island, and Umang Island. Along the coast, only barrier reefs were found. Significant changes in the distribution of coral reefs in Paraja Bay are thought to have occurred because of this location being vulnerable to tsunamis and earthquakes [20]. The tsunami that occurred in Paraja Bay, Pandeglang Regency, Banten Province, made differences in habitat conditions before and after the tsunami [20, 21]. In addition, coral health is vulnerable in this area because fishers are still actively using the type of fishing gear operated by pulling on the bottom of the waters. In terms of fisheries, the Paraja Bay waters provide high fisheries potential. The potential for fishing in the Sunda Strait waters, including Paraja Bay, reaches 60,000 tons and provides 50.46% of the total fisheries production for the Banten province [22].

The Paraja Bay waters are one of the areas that are candidates for Marine Protected Areas, referring to the Zoning Plan for Coastal Areas and Small Islands (RZWP3K in Indonesian abbreviation) of Banten Province. The location selection is based on small islands with coral reefs in the Teluk Paraja area, which act as a buffer zone for the biodiversity of Ujung Kulon National Park (TNUK in Indonesian abbreviation) [20]. The Paraja Bay area still has "poor data", so data and information are needed to support the primary material for determining policies for managers [23]. This study aims to assess the prevalence of coral disease in Paraja Bay, Banten. It is expected to be the latest data and information on the condition of coral reefs from the point of view of their disease susceptibility.

Material and Methods

Time and Location

In-situ data on reef genera, coral diseases, and reef quality were collected in February 2022 at 16 stations in the Paraja Bay Waters Area, Pandeglang Regency, Banten Province (Fig. 1). Preliminary studies have collected information related to the research location through literature studies. The preliminary study results indicated the existence of coral reef ecosystems on the small islands of Paraja Bay, Banten, with a record of the post-tsunami incident (22nd December 2018), which damaged the ecosystem at that location. Reef flats in small islands in the Paraja Bay region "Badul Island, Mangir Island, Oar Island, and Umang Island" were generally developed around all existing islands, both coastal Paraja Bay and small islands [20]. One of the small islands in the Teluk Paraja region

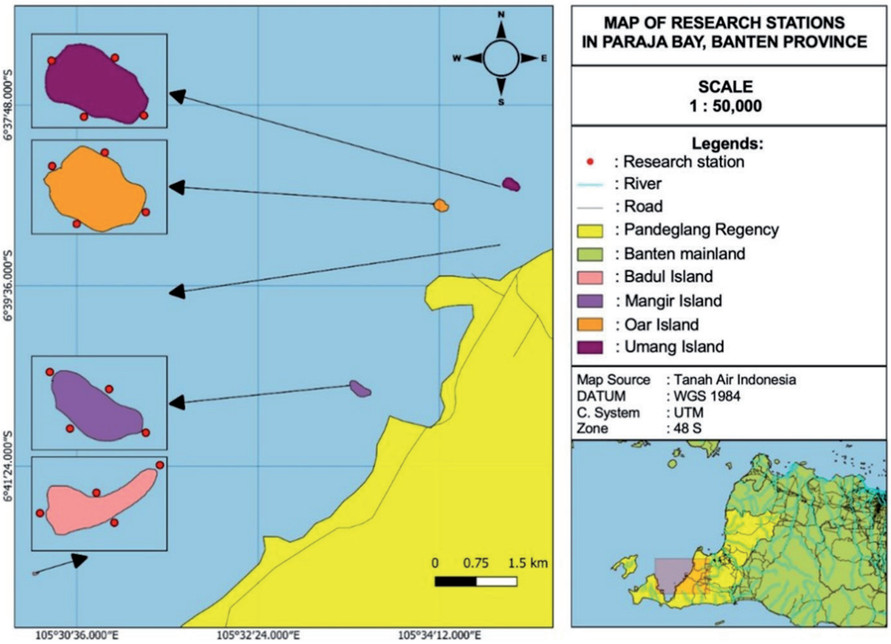

Fig. 1. Map of Research Stations at Paraja Bay, Pandeglang Regency, Banten Province.

was experiencing three-sided siltation, so it cannot represent the results obtained and identified. Observations have been made at four island stations with 4 points (Table 1).

Coral Disease Data Collection

The observation of coral colonies showing symptoms of coral disease, in the form of reef disease types in coral colonies and coral species susceptible to coral disease, was carried out using the Benthic Transect technique with a 1x1 m^2 size at intervals of every 5 m along 25 m [15]. Reef data collection on benthic transect areas was carried out in line with data collection on coral disease types. Reef identification used the Coral Finder 2021 reference book [24], and photos were taken on the transect area to be identified when on the surface in anticipation of bias found when making direct identification.

Coral Disease Prevalence

The coral disease prevalence was analyzed based on the number contained in 100 x100 cm benthic transect. The analysis results were presented using quantitative descriptive analysis. The analysis describes the results presented through visuals and distribution calculations [25]. Disease prevalence was calculated based on the total number ratio of infected colonies divided by all reef colonies found that were encountered at each station with the following equation [15].

$$\text{Prevalency } (P) = \frac{\sum \text{Identified colony}}{\sum \text{Sum of colony}} \ x\ 100\ \%$$

Coral Species Dominance Index

Dominance index analysis was conducted to determine the reef species' dominance affected by disease at 16 stations. The dominance index value has criteria that can be seen in Table 2. The dominance index value is used as a preference for coral disease per coral species susceptible to coral disease, which is determined by the individual number of reef-specific coral divided by the total individuals of all coral reef species found and then squared. The dominance index value can be determined using the formula [26, 27]:

$$C = \sum_{i=0}^{n} \left({}^{ni}\!/_{N} \right)^2$$

where C is the dominance index, ni is the number of individual species, and N is the number of total individuals of all species. The dominance index value has criteria, namely Low ($0.00<C\leq0.50$), Medium ($0.50<C\leq0.70$), and High ($0.75<C\leq1.00$) [26]. If the value tends towards 0 (lower), there is no dominant species, while if the value tends towards 1, there is a dominant species [28, 29]. The dominance index value is used as a preference for coral disease per reef species susceptible to coral disease, which is determined by the individual number of specific reef species divided by the total individuals of all reef species found and then squared.

Reef Species Susceptibility to Disease Presence

Further analysis was used to determine the relationship between coral species and the presence of

Table 1. Coordinates of research stations at Paraja Bay, Banten Province.

Station		Coordinate		The slope degree of the area observed in the coral reef ecosystem (±°)	SST (°)
		South Latitude	East Longitude		
Badul Island	Eastside	6° 42' 26.532"	105° 30' 15.336"	15-20°	29.2
	Southside	6° 42' 34.560"	105° 30' 10.584"	20-25°	29.3
	Westside	6° 42' 27.612"	105° 30' 04.500"	10-15°	29.5
	Northside	6° 42' 16.596"	105° 30' 08.604"	30-35°	29.4
Mangir Island	Eastside	6° 40' 37.128"	105° 33' 31.572"	20-25°	30.1
	Southside	6° 40' 43.788"	105° 33' 22.788"	20-25°	29.8
	Westside	6° 40' 35.364"	105° 33' 09.180"	10-15°	29.6
	Northside	6° 40' 28.632"	105° 33' 22.932"	30-40°	29.7
Oar Island	Eastside	6° 38' 47.112"	105° 34' 20.208"	25-30°	29.5
	Southside	6° 38' 56.760"	105° 30' 09.840"	20-25°	29.6
	Westside	6° 38' 43.224"	105° 30' 02.424"	10-15°	29.7
	Northside	6° 38' 39.480"	105° 30' 12.181"	30-35°	29.7
Umang Island	Eastside	6° 38' 37.644"	105° 35' 03.588"	30-35°	29.4
	Southside	6° 38' 42.108"	105° 34' 52.032"	20-25°	29.5
	Westside	6° 38' 30.156"	105° 34' 45.372"	20-25°	29.4
	Northside	6° 38' 26.808"	105° 34' 56.352"	30-35°	29.3

Notes: Data was collected in February. Indonesia is in the rainy season; *) SST = sea surface temperature (°) based on primary data ex-situ used Water Quality Checker HOTRIBA U52

disease species using Principal Component Analysis (PCA). PCA was analyzed using XLStat 2022 software, while the analysis of individual coral species at each station was presented in the figure using Microsoft Excel 2021. The PCA analysis was used to determine the closeness related to the vulnerability of coral species to the presence of coral disease species in the coral species. PCA is applied to various factors for the extraction process [30]. Each PC axis is rotated so that less critical variables are less influential [30, 31]. Each variable is analyzed because it has different units, so it must be standardized [32]. Data standardization, commonly known as the variable normalization process, is based on the zero unitization method, where variable characters are determined before normalization [33]. The correlation value shows the closeness of the relationship among variables. The Spearman correlation is one of the processes in PCA that is used to transform data on reef species' vulnerability to the presence of coral disease species to form a new coordinate system [34], which is illustrated. This analysis can identify the level of closeness between the reef species and the presence of coral disease. PCA has the advantage of simplifying data by classifying data more quickly [35-37]. The criteria for assessing correlation are related to the relationship of the closeness of each category [38], where the interval between 0.00-0.199 describes "very low," 0.20-0.39 describes "low," 0.40-0.59 describes "medium". Moreover, the "moderate" criterion is in the range of 0.60-0.79, and the "very strong" criterion ranges from 0.80 to 1.00.

Table 2. Dominance of disease-susceptible reef species in Badul Island.

No.	Reefs	Number (Individuals)	Index of dominance (C)
1.	*Acropora* sp.	4	0.0204
2.	*Coscinaraea* sp.	1	0.0013
3.	*Echinopora* sp.	2	0.0051
4.	*Favites* sp.	6	0.0459
5.	*Favia* sp.	1	0.0013
6.	*Leptoseris* sp.	1	0.0013
7.	*Millepora* sp.	1	0.0013
8.	*Pavona* sp.	4	0.0204
9.	*Platygyra* sp.	6	0.0459
10.	*Porites* sp.	1	0.0013
11.	*Psammocora* sp.	1	0.0013
12.	*Sdanalolitha* sp.	1	0.0013

Results and Discussion

Coral Disease Composition

The analysis of disease species composition in the coral reef area at 16 selected stations found a total range of coral diseases in around 62 coral colonies. The highest number of disease types was found on Mangir Island, while the lowest number of diseases was found on Umang Island. Based on Fig. 2 and Fig. 3, the coral disease on each reef distribution composition in the Paraja Bay waters, Pandeglang, Banten found two types of diseases: White Syndrome and Trematodiasis. In Badul Island, White Syndrome was found in 22 coral colonies and Trematodiasis in six coral colonies. Reefs in Mangir Island had 18 coral colonies with White Syndrome and one colony with Trematodiasis. At Oar Island and Umang Island, there was only one type of coral disease, White Syndrome, found in 11 coral colonies and 4 coral colonies, respectively.

White Syndrome is the most dominant type of disease found at each station on the small islands of Paraja Bay. The occurrence of White Syndrome disease cannot indicate what types of pathogenic bacteria are found at each station in Paraja Bay. However, it is indicated that some pathogenic bacteria are found in White Syndrome disease, such as pathogenic bacteria *Vibrio owensii* [39], *Vibrio coralliitycus* [40], and *Pseudoalteromonas piratica* [41].

Dominance Index of Disease-Susceptible Coral Species

Badul Island

The dominance index analysis of coral species susceptible to disease at Badul Island is 28 individuals. At Badul Island, the dominance index value of each reef type is not high, as they found 12 genera of corals. *Favites* sp. and *Platygyra* sp., which are types of coral that are more susceptible

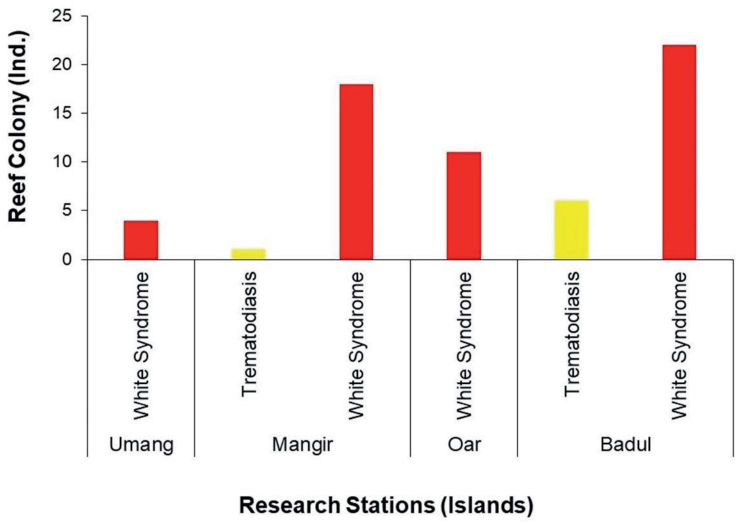

Fig. 2. Graphic Coral Disease Composition among the small islands in Paraja Bay.

(a)

b)

Fig. 3. Coral disease types Trematodiasis a), White Syndrome b) in Paraja Bay Waters.

to coral disease. They were found on Badul Island, with six individuals, the highest number. Some diseases appeared in one genus only, such as *Coscinaraea* sp, *Millepora* sp, *Porites* sp, *Leptoseris* sp, *Psammocora* sp, *Favia* sp, and *Sdanalolitha* sp. The prevalence of these genera also occurred in Palk Bay, India, where the dominant genera recorded along the Palk Bay region were *Porites* sp., *Favia* sp. [42], *Acropora* sp., *Platygyra* sp., *Goniastrea* sp., *Favites* sp. and *Siderastrea* sp. [43], which were affected by various diseases including bleaching, black band, white band, white spot, pink spot, white plaque, and yellow band disease [42]. The dominance index was categorized as low. The distribution of infected corals at the genus level is presented in Table 2.

Mangir Island

The analysis of coral species susceptible to disease at Mangir Island found 20 individuals of infected corals. At Mangir Island, the dominance index value of each type of coral found does not dominate. Coral species composition found at the genus level is presented in Table 3. There were 13 coral genera found with diseases, where the dominant ones were *Acropora* sp., *Goniastrea* sp., and *Leptoseris* sp. The *Acropora* genus affected by this type of disease was also found in Bunaken National Marine Park, where the total prevalence at 10 meters was 83.73%/location/genus sp with an average bleaching and dominant disease of the genus Acropora, Pocillopora and Montipora [44]. Each of these three genera gets three individuals. As for other species, only one individual was found in the quadrat area. Based on the results of the analysis, the waters of Mangir Island are in the low category.

Table 3. Dominance of disease-susceptible reef species on Mangir Island.

No.	Reefs	Number (Individuals)	Index of dominance (C)
1.	*Acropora* sp	3	0.0225
2.	*Astreopora* sp	1	0.0025
3.	*Coscinaraea* sp	1	0.0025
4.	*Goniastrea* sp	3	0.0225
5.	*Leptoseris* sp	3	0.0225
6.	*Merulina* sp	1	0.0025
7.	*Montipora* sp	1	0.0025
8.	*Mycedium* sp	1	0.0025
9.	*Pachyseris* sp	1	0.0025
10.	*Pavona* sp	1	0.0025
11.	*Platygyra* sp	1	0.0025
12.	*Porites* sp	1	0.0025
13.	*Turbinaria* sp	1	0.0025

Oar Island

The dominance index analysis of coral species susceptible to the disease at Oar Island found 11 infected individuals. There was no dominance index value that dominates each type. The distribution of coral species is presented in Table 4. The results of the disease type dominance in Oar Island are shown in Table 6. They were found in eight genera, where each of *Acanthastrea* sp., *Goniastrea* sp., and *Leptoseris* sp., with two individuals, and each of five other genera appeared in one individual. The dominance index is in the low category. In general, the percentage of coral reef health is classified as moderate. The results [45] showed that the highest percentage of live coral cover was found on the west side of the island, with moderate healthy coral category coverage reaching 48.9%, which means that live coral cover at this station is included in the excellent category. According to the Minister Environment Decree No. 4/2001, 25-49.9% is included in a moderate condition. The diverse types of coral on each island were classified as uniform from all Acropora and Non-*Acropora* categories. In addition, the location of Oar Island is also sheltered between Mangir Island and Umang Island; these conditions are thought to impact the level of susceptibility to coral disease.

Umang Island

The analysis of the dominance index of coral species susceptible to disease at Umang Island included 4 infected individuals. At Umang Island, the dominance index value of each type of coral found does not dominate. The distribution of coral species is presented in Table 5. The results of the dominance index of coral disease types at Umang Island are shown in Table 5. All coral species found have the same number of

Table 4. Dominance of disease susceptible reef species in Oar Island.

No.	Reefs	Number (Colony)	Index of dominance (C)
1.	*Acanthastrea* sp.	2	0.0278
2.	*Favia* sp.	1	0.0069
3.	*Favites* sp.	1	0.0069
4.	*Goniastrea* sp.	2	0.0069
5.	*Leptoseris* sp.	2	0.0278
6.	*Mycedium* sp.	1	0.0069
7.	*Pachyseris* sp.	1	0.0069
8.	*Porites* sp.	1	0.0069

Table 5. Dominance of coral species susceptible to disease in Umang Island.

No.	Reefs	Number (Colony)	Index of dominance (C)
1.	*Acropora* sp.	1	0.0625
2.	*Coscinaraea* sp.	1	0.0625
3.	*Goniastrea* sp.	1	0.0625
4.	*Pachyseris* sp.	1	0.0625

susceptible to disease as one susceptible individual. The dominance index of disease-susceptible reef species is low. The low dominance value indicates that certain coral species do not dominate each side of the observation. The uniformity index indicates that the community is stable because of its low dominance value [46]. The low value of reef genus dominance was also found in the Karimunjawa National Park on each side of the small islands, showing the genera *Acropora* sp., *Fungia* sp., *Porites* sp., *Goniastrea* sp., *Montipora* sp., and *Heliopora* sp. Based on the analysis of the dominance index of reef biota in the coral reef community from 2 stations, both at station I and station II, the coral dominance index at station I with a depth of 1-2 m obtained a coral dominance index of 0.28 and station II with a depth of 3-5 m coral dominance index of 0.22 where the value is included in the low category [47].

Coral Disease Prevalence

Coral disease was found in 16 selected stations in the waters of Paraja Bay, with a focus location on each side of the small islands. Coral disease prevalence values found have a mean value range of 7.91% (see Fig. 4). The highest and most extreme prevalence mean value was found at Badul Island station, at 17.2% (Fig. 4). Meanwhile, the lowest mean prevalence value was found at Oar Island station at 2.66%. Anthropogenic causes can be used to indicate the size of the coral disease prevalence presentation value [48]. The prevalence of coral disease found can be caused by salinity values in the waters of Paraja Bay, which may be below the average standard set, as in the study of *Vibrio* infection in *Montipora digitata* due to low salinity values in Hawaiian waters [49]. In addition, dirty waters caused by marine debris surrounding Badul Island can trigger coral disease in corals [50]. Umang Island is one of the islands managed by private companies for tourism business as a place to stay and various other activities for tourism. However, the percentage value of coral disease prevalence obtained from the three islands is smaller than Badul Island, which is inversely proportional to the activities of residents often carried out on the three islands, namely Oar Island, Mangir Island, and Umang Island, compared to Badul Island, which is the most significant contributor to the prevalence value.

The coral disease prevalence percentage found in the Paraja Bay waters may be indicated due to coral vulnerability. The vulnerability of corals to coral disease is caused by three main factors: pathogens, the environment, and the host/coral itself. Factors in pathogens are implicated to be related to fungi, bacteria, nutrients, parasites, viruses, and toxins [51]. Environmental factors can be caused by predator introduction, plastic and marine debris entanglement, pollution, increased sedimentation, temperature changes, habitat destruction, and ocean acidification [21]. Host factors can be due to competition for space, decreased productivity, reduced development, tissue trauma, weakened resistance, and increased coral population density [52].

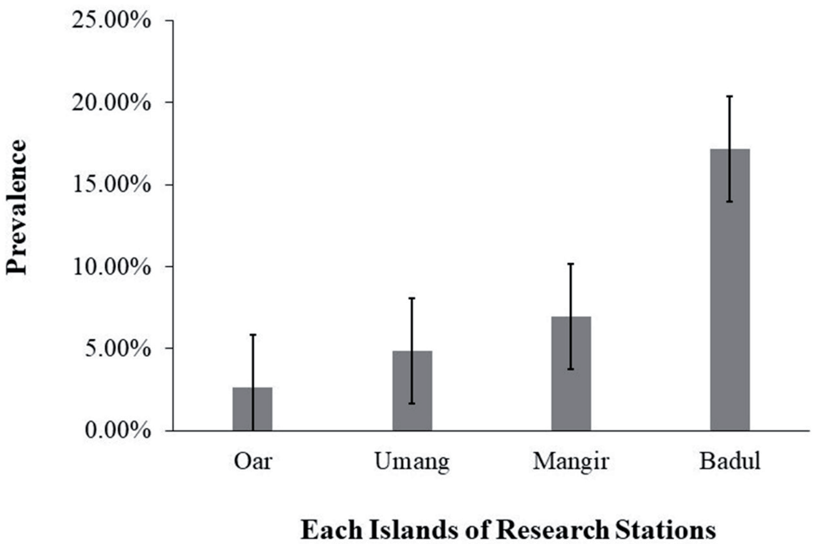

Fig. 4. Prevalence value of each research station.

The Closeness of Coral Disease on Coral Species Association

Principal Component Analysis of coral reef species against White Syndrome (WS) disease and Trematodiasis found a close relationship with each other. The PCA results of coral reef species against White Syndrome (WS) disease, as shown in Fig. 5, biplot axes F1 and F2 explain that the distribution of observation stations with the same coral species affected by white syndrome (WS) disease is 48.19%. The closeness between 21 coral species affected by White Syndrome (WS) disease in 16 observation stations can be seen from the variable square cosine value and the observation square cosine value. For Badul Island (westside and southside) and Mangir Island (eastside) stations, many coral species were found in *Acropora* sp., *Echinopora* sp., *Favites* sp., *Leptoseris* sp., *Millepora* sp., *Pavona* sp., *Platygyra* sp., *Porites* sp., *Psammocora* sp., and *Sandalolitha* sp. In contrast, Mangir Island (westside) station only found coral species of *Astreopora* sp., *Goniastrea* sp., *Merulina* sp., *Montipora* sp., and *Turbinaria* sp. *Acanthastrea* sp. and *Pachyseris* sp. Coral species affected by White Syndrome were found at Badul Island station (eastside and northside), Mangir Island (southside), Oar Island (eastside and northside), and Umang Island (westside, northside, and southside). At Mangir Island (northside) and Oar Island (westside and southside), the stations are characterized by coral species *Favia* sp., *Coscinaraea* sp., *Goniastrea* sp., and *Mycedium* sp. affected by White Syndrome. In 2003, White Syndrome disease was widely found throughout the Indo-Pacific [53-55]. White Syndrome occurs due to environmental and ecological factors such as thermal stress, Chl-a concentrations, and previous bleaching that can predict future coral disease risk [56].

Based on the Pearson correlation value, coral reef species that have a very strong to strong correlation with the type of coral disease White Syndrome are *Acropora* sp. (0.8509), *Favites* sp. (0.7200), *Echinopora* sp. (0.7136), *Pavona* sp. (0.6844), *Milepora* sp. (0.6079), *Platygyra* sp. (0.6079), *Psammocora* sp. (0.6079), and *Sandalolitha* sp. (0.6079). One of the coral species in Sempu Island Nature Reserve, Malang district, Indonesia, namely *Echinopora* sp., was affected by White Syndrome disease in 2022 [57].

The PCA analysis results of coral reefs against Trematodiasis disease, as shown in Fig. 6, biplot axes F1 and F2 explain that the distribution of observation stations with similar coral species affected by Trematodiasis disease is 100.00%. Based on the Pearson correlation value, coral species that have a very strong to strong correlation with the Trematodiasis disease type are *Platygyra* sp. (0.9354), *Favia* sp. (0.8685), and *Favites* sp. (0.8685). This is indicated by the very close (Euclidean) angle between the two (Fig. 6a). This is also shown on the territorial distribution map (Fig. 6b). The closeness of the relationship between variables is evidenced by the correlation value of all variables > 0.80, which means the relationship between variables is very strong (see Table 6).

There are three things to note regarding the prevalence of the disease in the Paraja Bay waters. The first concern is that Paraja Bay waters are currently dominated by White Syndrome disease at 89% in each of the small islands of Paraja Bay, followed by other diseases. The second concern is that coral diseases found on corals in the Teluk Paraja waters are varied with around 20 coral taxa at the genus level, where the dominance is low both at each station and overall in Paraja Bay waters. The third concern is the closeness of coral species found to coral diseases in White

(a) b)

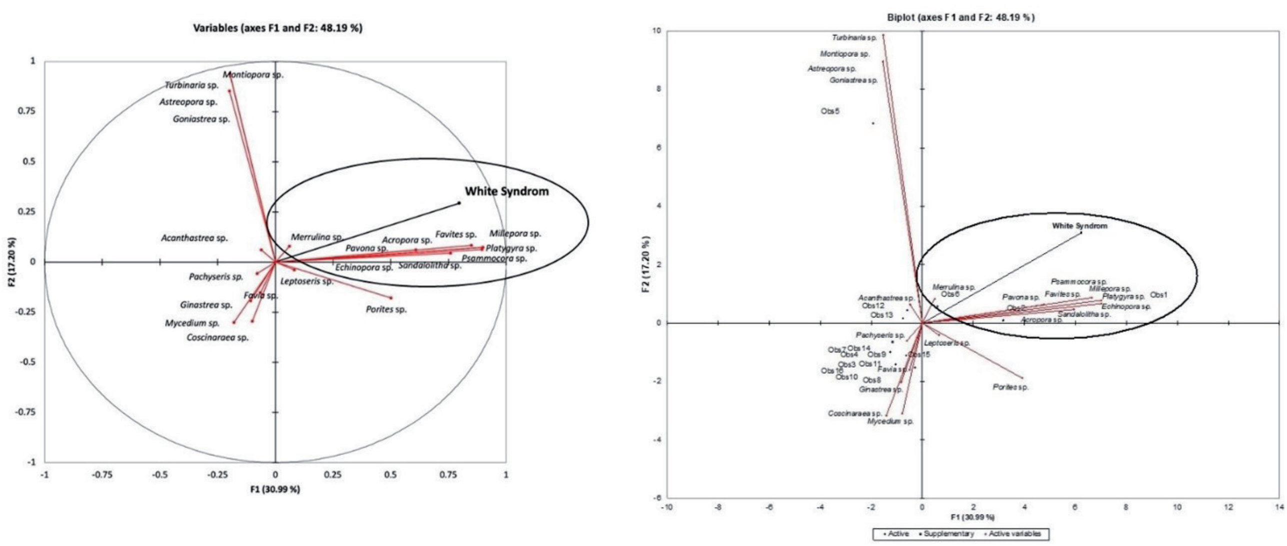

Fig. 5. Inter-relationship of closeness with White Syndrome and reef types: a) Correlation of F1 and F2 Factor components between White Syndrome and reefs, b) Territorial map of White Syndrome with reefs.

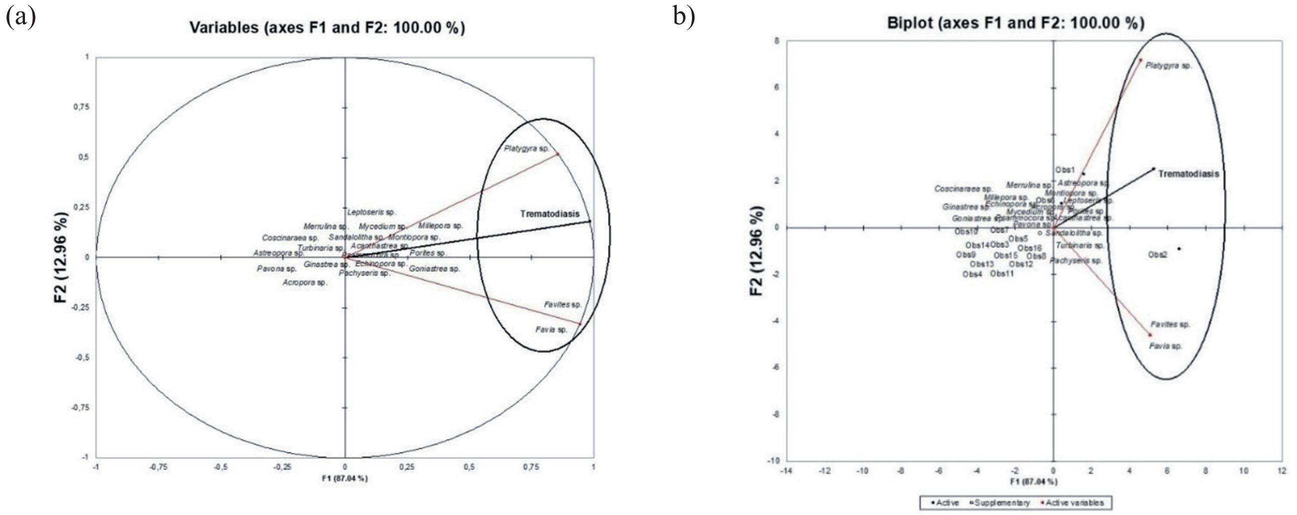

Fig. 6. Inter-relationship of closeness between *Trematodiasis* and reef types: a) Correlation of F1 and F2 Factor components between *Trematodiasis* and reefs, b) Territorial map of *Trematodiasis* with reefs.

Table 6. Correlation values between Trematodiasis disease types and several reef genera.

Variable	Trematodiasis	*Favia* sp.	*Favites* sp.	*Platygyra* sp.
Trematodiasis	1			
Favia sp	0.866	1		
Favites sp	0.866	1.000	1	
Platygyra sp	0.866	0.500	0.500	1

Syndrome from the lowest to the most substantial level and Trematodiasis. However, one coral species is close to the two coral diseases found, namely *Favites* sp. This condition can get worse if no prevention is done. It will damage the coral reef ecosystem, where coral diseases spread widely and kill corals [52].

The reef genus variable that has a direct relationship with each other is the Trematodiasis disease type, indicated by the angle (Euclidean) between the two, which is very close. It is also shown on the territorial distribution map. The complex relationship between variables is evidenced by the correlation value of all variables > 0.80, which means the relationship between variables is solid (see Table 6). The partial correlation pattern is a correlation model that can explain the relationship between one variable and one variable, and other variables are considered constant [58]. Partial correlation cannot only use a single control variable. Still, there can be more than one variable, and observational research shows a significant relationship between corallivore occurrence and coral disease prevalence [59]. In addition to coral reefs as an attachment medium, the strong association is also thought to be due to environmental changes due to stresses after the 2018 tsunami. Associations among marine organisms can be affected by abiotic variables, such as the influence of environmental conditions and sedimentation. In general, disease occurrence involves three interacting factors: disease-causing factors (agents), human and/or host factors, and environmental factors [60, 61]. The invasive biota presence on coral reef surfaces also depends on coverage in some areas [62]. The disease infections generally occur when corals are stressed due to environmental pressures, such as pollution, temperature extremes that tend to increase, sedimentation in coral ecosystems, high nutrient supply, especially nitrogen and carbon compounds, predators (such as reef-eating fish), competition from fast-growing algae, and weak physiological conditions after bleaching [15, 61, 62].

Conclusions

The coral reef ecosystem condition in the Paraja Bay region is a concern based on the prevalence values found on each side of the islands. Two coral diseases, Trematodiasis and White Syndrome, were found. Both types of coral diseases are dominant and attach to some corals commonly found in shallow waters. The most closely related to Trematodiasis were *Platygyra* sp. (0.9354), *Favia* sp. (0.8685), and *Favites* sp. (0.8685), while to White Syndrome were *Acropora* sp. (0.8509), *Favites* sp. (0.7200), *Echinopora* sp. (0.7136), *Pavona* sp.

(0.6844), *Milepora* sp. (0.6079), *Platygyra* sp. (0.6079), *Psammocora* sp. (0.6079), and *Sandalolitha* sp. (0.6079). These results indicate that the condition of coral reefs in Paraja Bay is in the poor category. This condition requires prevention efforts, even though the dominance of coral diseases found in each type of coral is relatively low. Moreover, the emergence of coral diseases dominated by White Syndrome (WS) followed by Trematodiasis found in Teluk Paraja, Banten, will impact the balance of the growth process, disrupt the reproductive process, and cause structural changes. Reef health covers disorders generally caused by coral bleaching, pigmentation response, and sediment damage. Damage disorders are thought to be related to vulnerable water areas affected by natural disasters, such as earthquakes and tsunamis. The tsunamis occurred in December 2018 and small earthquakes were still frequent every year from 2019 to 2022. The disease types found illustrate that future restoration needs to involve environmental aspects and community activities. These factors are related to the process of habitat recovery and associated biota. Coral disease management needs to be done by conducting continuous monitoring to obtain data related to coral diseases. It needs some actions to know how to control coral diseases that appear at that location. Unfriendly fishing activities found during the research are one of the concerns of future rehabilitation and restoration. In addition, the Paraja Bay region is prone to natural disasters and should be concerned with conservation programs, such as coral reef conservation.

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Author Contributions

Conceptualization: M.M, Y.S, & S.C.; Methodology: M.M., W.W., S.C., & A.A.; Data Curation: M.M, Y.S, & Y.S.; Writing-original draft preparation: M.M., C.C., Y.S., & A.R.S.; Writing-Review and Editing: W.W, R.C., & R.Rw.; Supervision: R.C. & G.S.; Funding Acquisition: R.R

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Conflict of Interest

The authors declare no conflict of interest.

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