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Research Article

Identification of Scleractinian (Hard) Coral Disease in Kepulauan Seribu, Jakarta

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Abstract

Kepulauan Seribu is designated as a marine conservation area in Kepulauan Seribu National Park and is one of high tourism development areas on the north side of Jakarta, the capital city of Indonesia. Anthropogenic sources from these nearby areas has reduced the health condition of coral reefs and increased the prevalence of coral diseases in the study area. This study aimed to determine the genus of coral infected by disease, the type of disease, and the relationship between the prevalence of disease and live cover in Kepulauan Seribu. Data was collected using the survey method. Coral cover is assessed using Underwater Photo Transect (UPT) and disease is assessed using Belt Transect methods, respectively. The result showed that 14 genera of coral species were infected and dominated by *Porites*, *Montipora*, and *Acropora*. Furthermore, there were 5 types of diseases, dominated by White Syndrome (WS), Atramentous Necrosis (AtN) and Ulcerative White Spots (S). The correlation analysis results showed a very low relationship between disease prevalence and live coral cover (r = 0.10). This research can be used as input or reference for more sustainable coral reef management, by improving an integrated coastal education system for the younger generation and developing more sustainable tourism activities in the future in Kepulauan Seribu.

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1. Introduction

Coral reefs are unique ecosystems in tropical waters with high levels of diversity (Hasim, 2021; Siringoringo *et al*., 2019). However, these species are highly susceptible to disturbances caused by changes in the aquatic environment, leading to a significant decline in health conditions (Page *et al*., 2023). The 31 study areas explored by the Research Center for Oceanography of the National Research and Innovation Agency of Indonesia reported moderate conditions in 2021 with a value of 33.99% (Giyanto *et al.,* 2021). Further observation showed that the conditions declined due to natural changes, human activities, and the local environment (Giyanto *et al.,* 2017). Anthropogenic factors and climate change also increased the frequency of coral stress, which could elevate disease-causing pathogens invading the ecosystems (Maynard *et al*., 2015).

Coral disease is a form of disturbance to health causing the physiological decline of coral tissue including interactions between host, pathogen, and environment (Raymundo *et al*., 2008; Work *et al*., 2008; Huang *et al*., 2021; Moriarty *et al*., 2020). This disease is divided into two factors based on cause, which are infection (biotic) and non-infection (abiotic factors) (Vega Thurber *et al*., 2020). Biotic factors can come from microbial pathogen infections (Soffer *et al*., 2015), such as bacteria, fungi, viruses, or protists that spread, thereby harming the host (Raymundo *et al*., 2008). A distinct pathogen causes each type of coral disease (Montilla *et al*., 2019). The spread of pathogens in coral poses a risk of death and rapid tissue loss, threatening the survival of polyps (Moriarty *et al*., 2020). Abiotic factors come from nutrient imbalances (Nelson and Altieri, 2019; Sabdono *et al*., 2019), an increase in water temperature (Johan *et al*., 2016), and sedimentation (Harvell *et al*., 2007). The occurrence of coral disease and bleaching is closely related to the decline in water quality, both on a local and global scale, because of their vulnerability to changes in environmental factors (Moriarty *et al*., 2020).

In Indonesia, coral reefs are widely distributed in Kepulauan Seribu in Java Sea, north of Jakarta Bay, where the island's land area covers 897.71 hectares and its surrounding waters of 6,997.50 square kilometers (km^2) (Estradivari *et al.,* 2009). This area has coral reef conservation area managed by the Kepulauan Seribu Marine National Park (Noviana *et al*., 2019). However, the species are exposed to the effects of development and the activities of Jakarta's residents, the capital city, which declined water quality (Baum *et al*., 2015; Arifin, 2016; Fahlevy *et al*., 2017). A significant factor contributing to the decline of coral reef ecosystems is anthropogenic activities (Thirukanthan *et al*., 2023; Fauzanabri *et al*., 2021). Anthropogenic sources in Jakarta include high nutrients from effluents due to increased human activities (Sabdono *et al*., 2019), ever-expanding capital city development (Johan *et al*., 2013), overfishing (Aeby *et al*., 2021), and sedimentation caused by reclamation (Baum *et al*., 2015). Additionally, tourism activities can significantly impact the overall condition of coral cover (Fahlevy *et al*., 2019).

Currently, studies on coral disease are being conducted worldwide (Morais *et al*., 2022). Morais *et al.* (2022) conducted a study in Caribbean Sea for 34% and in Indo-Pacific for 28.7% of all coral disease studies. According to Lamb and Willis (2011), disease phenomena in Australia's Great Barrier Reef had an average prevalence of 3.27%, while 11.4% was reported in Koh Tao Island, Thailand (Lamb *et al*., 2014). Another study in Red Sea of Saudi Arabia stated that the relationship between coral disease and cover did not have a significant value ($R = -0.06$; $p = 0.79$) (Aeby *et al*., 2021). In line with the development of further studies in Indonesia by Johan *et al.* (2015) stated that the dominant types of disease found in Kepulauan Seribu were Black Band Disease (BBD) and White Syndrome (WS). The latest report conducted by Rachmayanti *et al.* (2025) stated that the prevalence of WS was higher at 4.05% than BBD at 1.09% on Pari Island, Kepulauan Seribu. BBD is a coral disease with a dark brown to black band separating living tissue from infected tissue (Huang *et al*., 2021). WS is characterized by the presence of whitening tissue barriers on the surface, followed by tissue loss (Greene *et al*., 2020). Based on the report by Johan *et al.* (2016), the calculation of the prevalence of BBD obtained results ranging from 0.31% to 31.64%, indicating that 177 colonies predominantly infected the genus *Montipora* in Kepulauan Seribu. The study carried out by Arifin (2016) in the small islands of Jakarta Bay also showed that types of coral disease varied significantly, and the relationship between live cover and disease prevalence was substantial.

However, coral disease has not been extensively investigated in Kepulauan Seribu. Furthermore, the primary factors contributing to the deterioration of coral reef ecosystem every year in this area are anthropogenic activities such as massive development in Jakarta, domestic waste, and tourism activities in Kepulauan Seribu. Therefore, this study aimed to determine the genus of coral infected by disease, the type of disease, and the relationship between the prevalence of disease and live cover in Kepulauan Seribu, Jakarta.

2. Materials and Methods

2.1 Material

2.1.1 The equipments

The equipment used in this live coral cover research includes SCUBA (Standard Pack SCUBA Set), Global Positioning System (Garmin GPS MAP 78s), and underwater camera (CANON Power shot G16 12 MP resolution), transect frame (58x44 cm) and 100 m measuring tape. While the coral disease collection uses a belt transect measuring 2 x 50 m (100 m^2), underwater writing tools (underwater board, waterproof paper and pencil) and identification book to help identify the species.

2.1.2 The materials

The materials used were documentation of data collection, such as 50 digital photographs of coral reef transects including images of healthy and diseased colonies.

2.1.3 Ethical approval

This study does not require ethical approval because it does not use experimental animals.

2.2 Method

2.2.1 Study area

This study was conducted in Kepulauan Seribu from November 2 to 12, 2021. Reef structure was arranged in a unique direction, extending from coastal area to the deeper waters in a patchy or fringing configuration (Noviana *et al*., 2019). Kepulauan Seribu are part of Kepulauan Seribu National Park and comprise a conservation or core, sustainable use, community access or utilization, and additional areas (Table 1). As shown in Figure 1, study areas are spread from north to south, covering Kepulauan Seribu National Park. These areas were determined based on coral reef health monitoring guidelines by COREMAP-CTI of Indonesian Institute of Sciences (LIPI) using a purposive sampling method in line with the study objectives (the presence of coral reefs and specific populations), safety factors, and accessibility when collecting data (Giyanto *et al*., 2014; Hazrul *et al*., 2016).

2.2.2 Data collection

The method used to collect coral cover data was Underwater Photo Transect (UPT) (Giyanto *et al*., 2014). Generally, UPT is defined as a method that uses digital camera technology and computer software technology development. Coral reefs can be visually observed through digital photographs to obtain data on live cover and other benthic features. Collecting live coral cover data began with the installation of piles and buoys to mark the data collection points at 14 research locations. A roll meter was stretched 50 m long with a depth of approximately 4-8 m parallel to the shoreline. Underwater photography using frames was carried out at a distance of 60 cm vertically from the 1st meter transect line to the 50th meter with a 1 m interval between photos. For each photo, the 1st meter frame was on the left side of the transect line, followed by the 2nd meter frame on the right side of the transect line. So that the odd-numbered frames were on the left side of the transect line, and the even-numbered frames were on the right side of the transect line (Figure 2). Subsequently, photographs obtained from UPT method are processed using CPCe (Coral Point Count with Excel extensions) software to obtain quantitative data such as the cover of each biota and substrate (%) (Giyanto *et al*., 2014).

The method used in collecting coral disease data is Belt Transect (English *et al*., 1997; Raymundo *et al*., 2008). Belt Transect is a method applied to group coral reefs in a transect area, such as a belt, measuring 2 x 50 m (100 m²), using a PVC pipe stick tool with a length of 1 m to form a square. Collecting coral disease data begin with a line transect (roll meter) drawn parallel to the shoreline at a depth of 4-8 m with a transect length of 50 m. The transect belt size is 2 x 50 m in one repetition. The belt uses PVC pipe with an observation width of 1 m to the left and 1 m to the right of the transect line. Observations start from 0-50 m to record the type and number of diseased and healthy coral colonies. Coral colonies affected by disease or other colony health problems are documented using an underwater camera for further identification. Coral damage and coral benthic forms can be observed to determine the health condition of the coral colony (Figure 3).

The data were obtained to calculate the presence of coral disease and other disturbances (Raymundo *et al*., 2008). At each transect, other benthic species, the number of coral reefs with disease, the number of healthy species, and predators were recorded. Subsequently, colonies with disease or other health problems were documented using an underwater camera. Water quality data was also assessed to provide comprehensive information about water conditions.

2.2.3. Identification

Coral identification to the genus level was conducted by examining morphology using the online reference website Corals of the World (https://www.coralsoftheworld.org/page/home/). In comparison, disease identification was carried out by recording the type of disease, as observed from the morphological characteristics of infected colonies. Furthermore, the condition of infected colonies was determined using the reference book "Coral Disease Handbook: Guidelines for Assessment, Monitoring, and Management" (Raymundo *et al*., 2008), and *Underwater Cards for Assessing Coral Health on Indo-Pacific Reefs* (Beeden *et al*., 2008). According to Beeden *et al.* (2008), coral infected with disease can be identified and grouped based on signs of tissue loss, such as the formation of specific wounds, changes in color, abnormal growth, and other indicators.

2.3 Analysis Data

2.3.1 Percentage of coral cover

Live coral cover was obtained based on UPT documentation analyzed through CPCe to achieve a percentage value of category calculated using the formula by Giyanto *et al.* (2014):

Cover (%) = Np/TNp x100…...……………………(i)

Where:
Np = Number of category points
TNp = Number of random point

The value of live coral cover was used to determine species condition by observing the category of live coral cover on Coral Reef Health Index in Indonesian waters as grouped by the Oceanographic Research Center of Indonesian Institute of Sciences (Oceanographic Research Center-LIPI) (Giyanto *et al*., 2023) (Table 2).

2.3.2 Coral disease prevalence

Disease prevalence can be defined as the proportion of infected colonies to the total population, expressed as a percentage according to Raymundo *et al.* (2008):

Prevalence (%) = Nc/TNc x100..…………………..(ii)

Where:
Nc = Number of infection colonies
TNc = Total number of colonies

2.3.3 Analysis of the relationship of coral disease prevalence and coral cover

An analysis was conducted to determine the relationship of coral disease prevalence on live cover using correlation coefficient in Microsoft Excel software. To determine the relationship between the percentage of live coral cover and the prevalence of coral disease in the Kepulauan Seribu, the correlation coefficient value obtained from the calculation results using correlation analysis was then determined using criteria (Table 3).

3. Results and Discussion

3.1 Result

3.1.1 Coral genus infected by disease

Hard coral *(Scleractinia)* infected with disease in Kepulauan Seribu are varied, totaling 15 genera (Table 4). As shown in Figure 4, species infected with disease were dominated by the genera *Porites* and *Montipora*, followed by *Acropora*. This was in line with the study by Cleary *et al.* (2016); Khuzma *et al.* (2016), where the dominant types of coral in Kepulauan Seribu were *Acropora, Porites,* and *Montipora*.

3.1.2 Types of coral disease

Coral disease prevalence depends on the number of healthy and diseased colonies in an area (Abrar and Bachtiar, 2012). The coral disease found in this study has the following characteristics:

a) Black Band Disease (BBD)

BBD was only found in two study areas and defined as disease attacking coral surface with a black band separating healthy tissue from infected tissue (Figure 5a) caused by bacteria (Huang *et al*., 2021). The prevalence of this disease in Kepulauan Seribu was 0.27% (Figure 7) and mainly found at KSBC06 by infected *Montipora* (Table 4 and 5).

b) White Syndrome (WS)

WS was found in 14 study areas (Table 5), as indicated by a whitening tissue barrier on the surface alongside tissue loss due to changes in environmental conditions (Figure 5b) (Greene *et al*., 2020). The prevalence of this disease in Kepulauan Seribu was 9.02% (Figure 7) and primarily found at KSBC08 (Table 5), infecting *Porites, Montipora,* and *Acropora* (Table 4). According to Beeden *et al.* (2008), WS is caused by pathogens or environmental variations, leading to a color change from white to brown due to tissue loss in coral.

c) Atramentous Necrosis (AtN)

AtN was found in 9 study areas (Table 5), characterized by an irregular pattern with visible skeletons. The eroded tissue area then shows a grayish-black spot (Figure 5c), caused by pathogen infection covering healthy tissue (Miller *et al*., 2015; Raymundo *et al*., 2008). The prevalence of AtN coral disease in Kepulauan Seribu was 1.23% (Figure 7), which was primarily found at KSBC10 (West Pamegaran Island) (Table 5), infecting *Montipora* (Table 4).

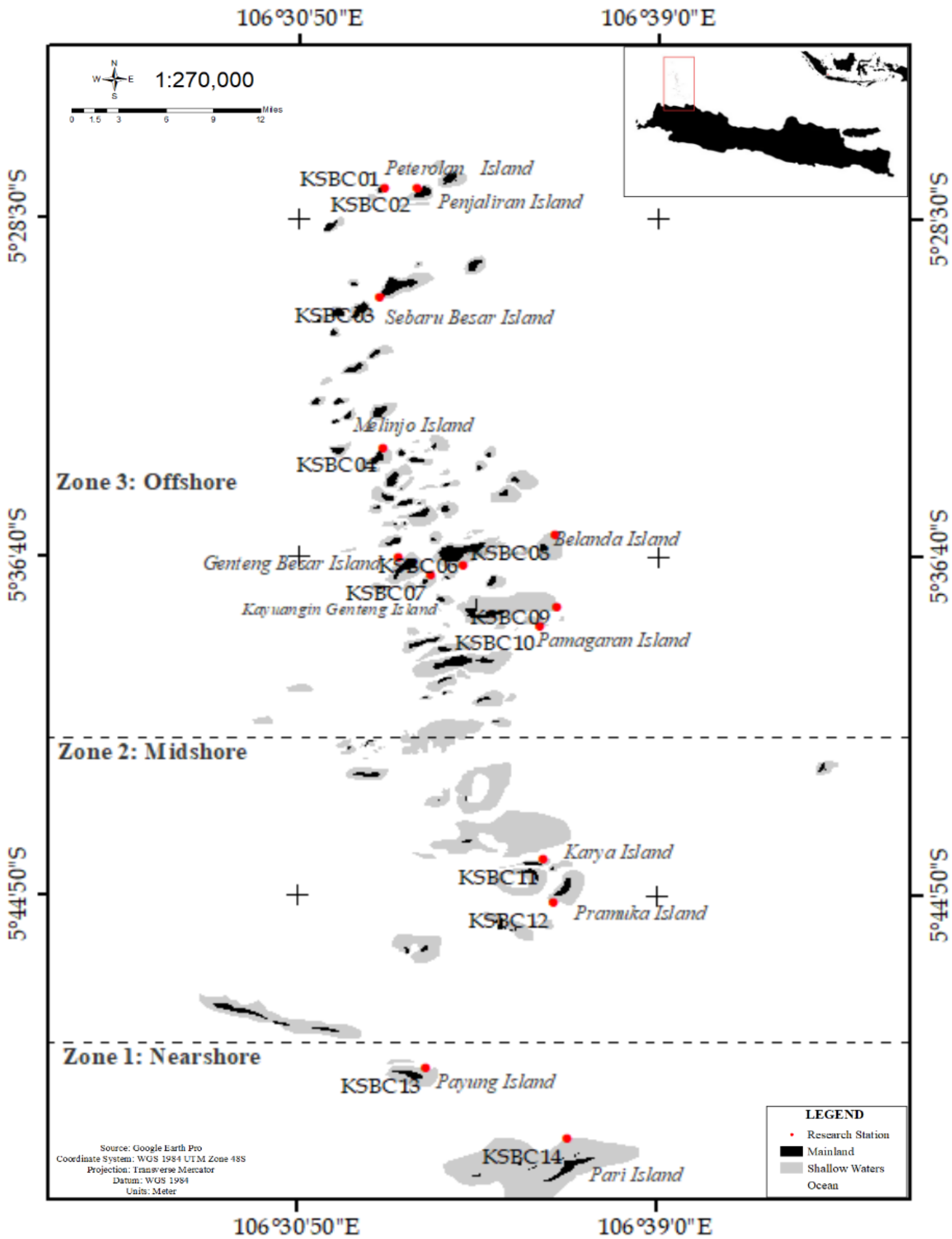

Figure 1. Map of the research stations in Kepulauan Seribu. There were 14 research stations starting from KSBC01 in the north until KSBC14 in the south.

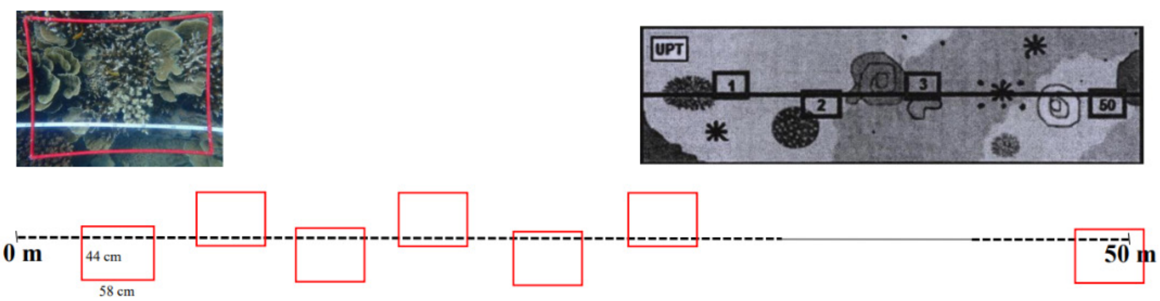

Figure 2. Illustration of data collection using UPT. This figure top right corner was taken from Giyanto *et al.* (2014).

Table 1. Coordinates of 14 island areas and management zones in Kepulauan Seribu. Research station numbers for each island in this study are also listed

No.	Area	Station	Zone	Longitude	Latitude
1.	West Peteloran Island	KSBC01	Conservation	106°32’47.76”E	5°27’47.52”S
2.	East Penjaliran Island	KSBC02	Conservation	106°33’6.840”E	5°27’46.80”S
3.	Sebaru Besar Island	KSBC03	Community Access	106°32’31.20”E	5°30’21.96”S
4.	Melinjo Island	KSBC04	Community Access	106°32’34.08”E	5°34’11.28”S
5.	Genteng Besar Island	KSBC05	Community Access	106°33’2.160”E	5°36’49.32”S
6.	Bira Besar Island	KSBC06	Community Access	106°34’40.44”E	5°36’54.36”S
7.	Kayuangin Genteng Island	KSBC07	Community Access	106°33’47.52”E	5°37’8.400”S
8.	Belanda Island	KSBC08	Conservation	106°36’19.08”E	5°36’11.88”S
9.	East Pamegaran Island	KSBC09	Community Access	106°36’15.48”E	5°38’9.240”S
10.	South Pamegaran Island	KSBC10	Community Access	106°35’27.24”E	5°38’20.04”S
11.	Karya Island	KSBC11	Other	106°36’12.60”E	5°43’55.20”S
12.	Pramuka Island	KSBC12	Other	106°36’41.04”E	5°45’6.120”S
13.	Payung Island	KSBC13	Other	106°33’34.56”E	5°49’3.720”S
14.	Pari Island	KSBC14	Other	106°36’45.72”E	5°51’4.680”S

Table 2. Coral reef condition grouping based on percentage cover using the Coral Reef Health Index in Indonesian waters as grouped by the Oceanographic Research Center of Indonesian Institute of Sciences (Oceanographic Research Center-LIPI)

Criteria	Category
Live coral cover < 19%	Low
19% ≤ Live coral cover ≤ 35%	Moderate
Live coral cover > 35%	High

Table 3. Relationship criteria based on correlation coefficient value

Scale of correlation coefficient	Value
$0 < r \leq 0.19$	Very low correlation
$0.2 \leq r \leq 0.39$	Low correlation
$0.4 \leq r \leq 0.59$	Moderate correlation
$0.6 \leq r \leq 0.79$	High correlation
$0.8 \leq r \leq 1.0$	Very high correlation

Table 4. Coral genus and its respective diseases in Kepulauan Seribu

Genus	Disease Coral				
	BBD	WS	AtN	UWS	GA
Acropora	-	+	+	-	+
Astreopora	-	+	-	-	-
Diploastrea	-	+	-	-	-
Echinopora	-	+	-	-	-
Favites	-	+	+	-	-
Galaxea	-	+	-	-	-
Isopora	-	+	-	-	-
Leptoseris	-	+	-	-	-
Montipora	+	+	+	+	-
Pavona	-	-	+	-	-
Platygyra	+	-	-	-	+
Pocillopora	-	+	+	-	-
Porites	-	+	+	+	+
Seriatopora	-	+	-	-	-
Turbinaria	-	+	-	-	-

Where = + = found; - = not found; BBD = Black Band Disease; WS = White Syndrome; AtN = Atramentous Necrosis; UWS = Ulcerative White Spots; GA = Growth Anomalies.

d) Ulcerative White Spots (UWS)

UWS was found in 7 study areas (Table 5) and was identified as coral disease characterized by white patches on coral tissue due to tissue loss (Figure 5d) (Hasma *et al*., 2019). The prevalence of UWS disease in Kepulauan Seribu was 0.91% (Figure 7). The disease was mainly found at KSBC02 (West Penjaliran Island) (Table 5) and dominantly infected the *Porites*.

Table 5. Presence of coral disease at each research station

Stations	BBD	WS	AtN	UWS	GA
KSBC01	1	16	1	3	0
KSBC02	0	18	1	4	0
KSBC03	0	6	0	2	0
KSBC04	0	23	6	1	0
KSBC05	0	2	0	0	0
KSBC06	4	5	2	0	0
KSBC07	0	23	1	2	0
KSBC08	0	43	1	3	0
KSBC09	0	9	0	0	3
KSBC10	0	11	7	0	2
KSBC11	0	5	3	0	1
KSBC12	0	17	1	0	0
KSBC13	0	3	0	0	0
KSBC14	0	2	0	2	0
Total Colonies	**5**	**183**	**23**	**17**	**6**

e) Growth Anomalies (GA)

GA was only found in 2 study areas (Table 5). Caldwell *et al.* (2020) stated that GA was a chronic disease, characterized by coral skeletons protruding like tumors with the potential to reduce survival rate (Figure 5e). The prevalence of GA in Kepulauan Seribu was 0.38% (Figure 7) and primarily found at KSBC09 (Table 5) in infected *Acropora* and *Porites* (Table 4).

3.1.3 Coral disease prevalence and live coral cover in the Kepulauan Seribu

This study was conducted in 14 areas to determine the relationship between coral disease prevalence

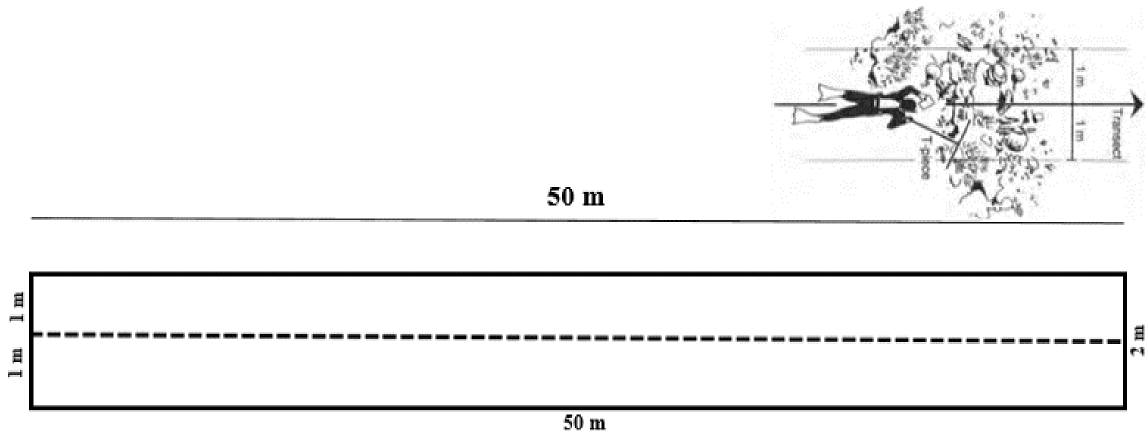

Figure 3. Illustration of data collection using Belt Transect. This figure right corner was taken from English *et al* (1997).

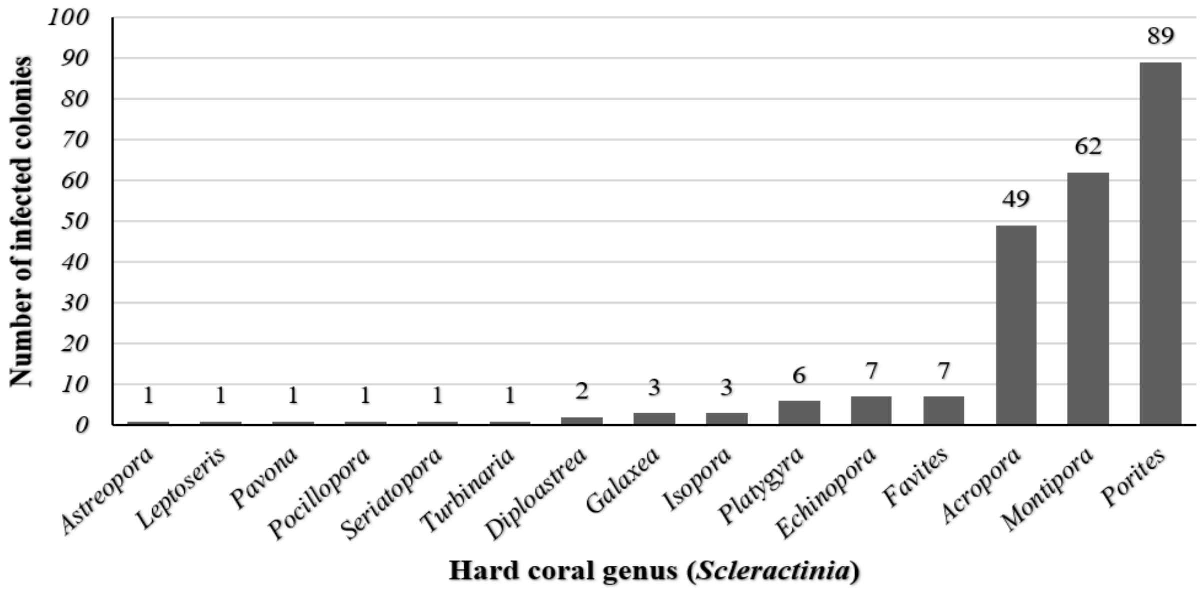

Figure 4. Disease-infected Scleractinian (hard) corals by genus in Kepulauan Seribu.

Table 6. Physics-chemical water parameters of Kepulauan Seribu

Parameters	Research Station								Optimum Range*
	PS.1 Control Point	PS.2 Lancang Island	PS.3 Pari Island	PS.4 Pramuka Island	PS.5 Semak Daun Island	PS.6 Harapan Island	PS.7 Tidung Island	PS.8 Dolphin Island	
Temperature (˚C)	29.40	29.45	29.55	29.05	29.1	29.2	29.5	29.1	28-30
Salinity (‰)	32.1	31.15	31.35	30.75	31.3	30.45	31.4	31.5	33-34
pH	8.095	8.205	8.205	8.005	8.2	8.16	8.21	8.17	7 – 8.5
DO (mg/L)	6.2	6.00	5.2	5.4	6.6	5.50	4.9	5.85	>5

Where = *= Water quality standard by Indonesian Government Number 22 of 2021 (Ministry of Environment and Forestry); DO = Dissolved oxygen

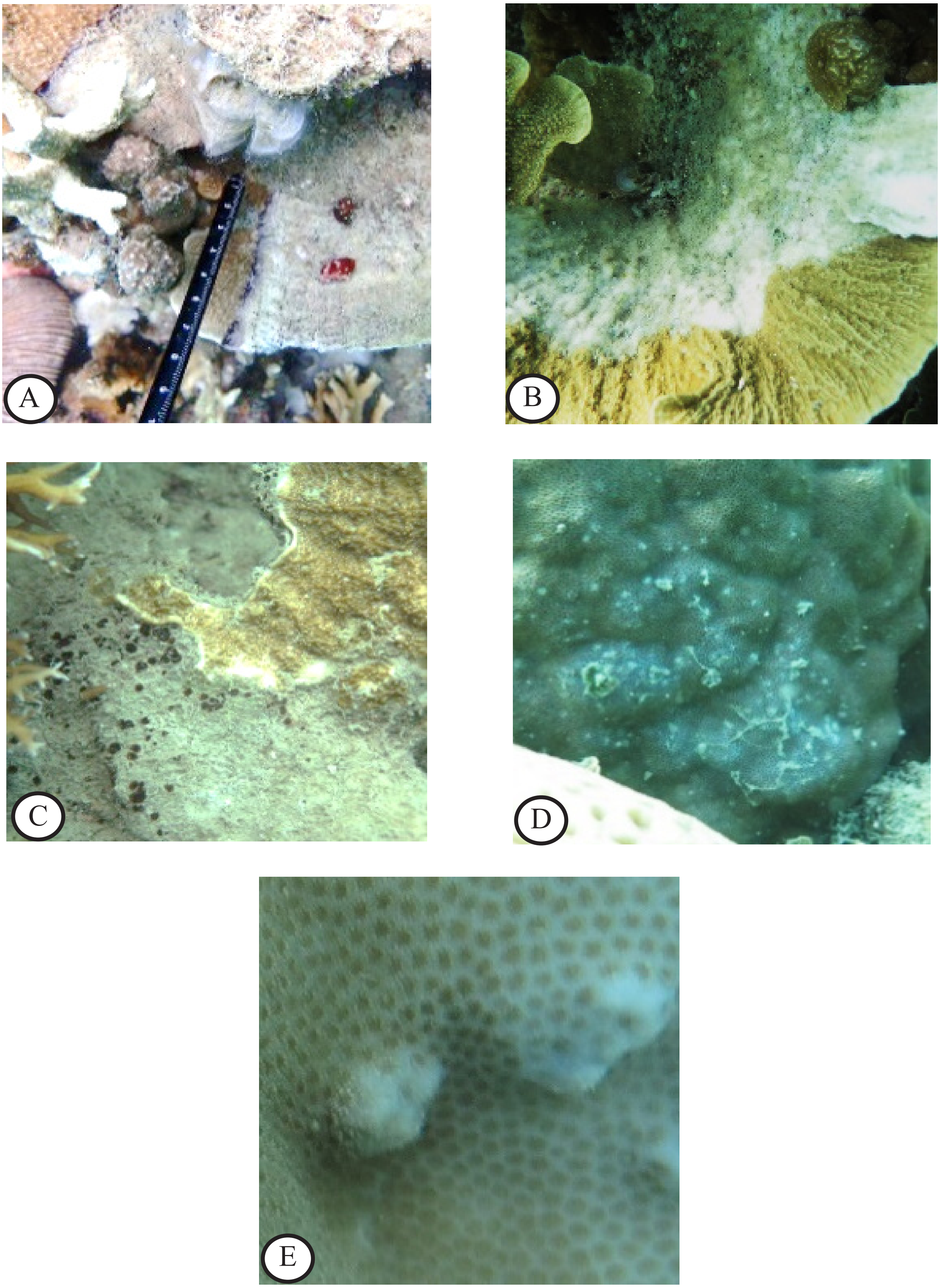

Figure 5. Type of coral disease found in Kepulauan Seribu during this study: **(A)** Black Band Disease; **(B)** White Syndrome; **(C)** Atramentous necrosis; **(D)** Ulcerative White Spots**;** **(E)** Growth Anomalies.

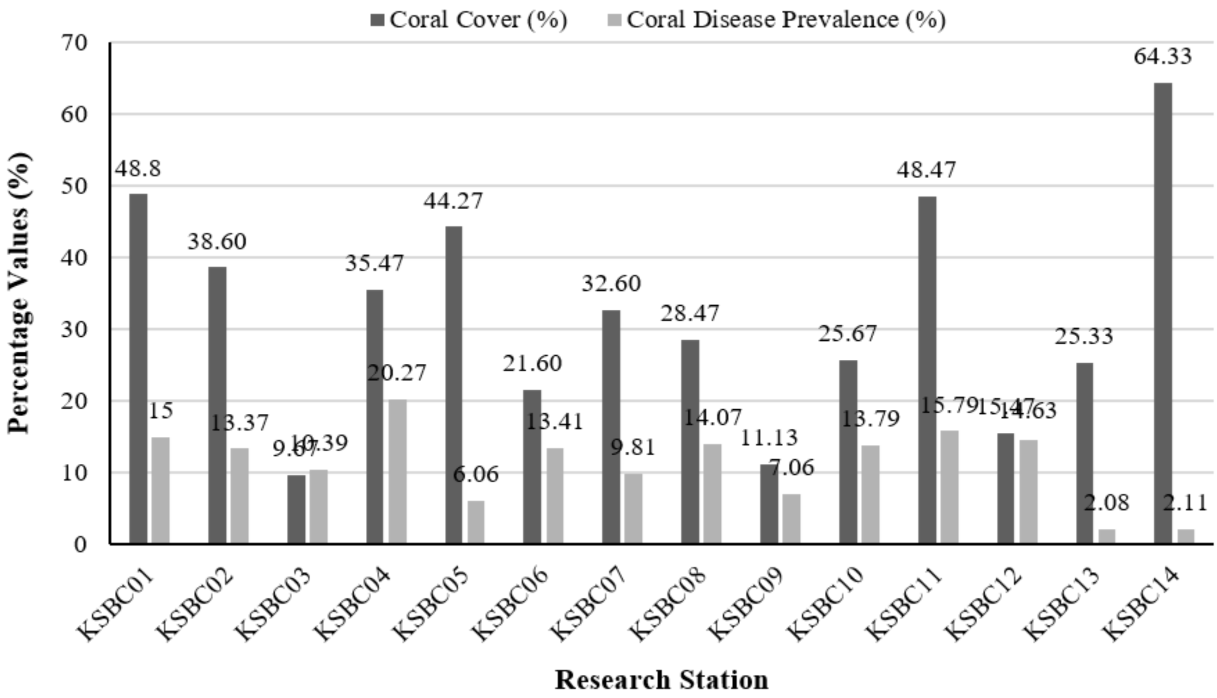

Figure 6. Values of live coral cover and coral disease prevalence at 14 stations.

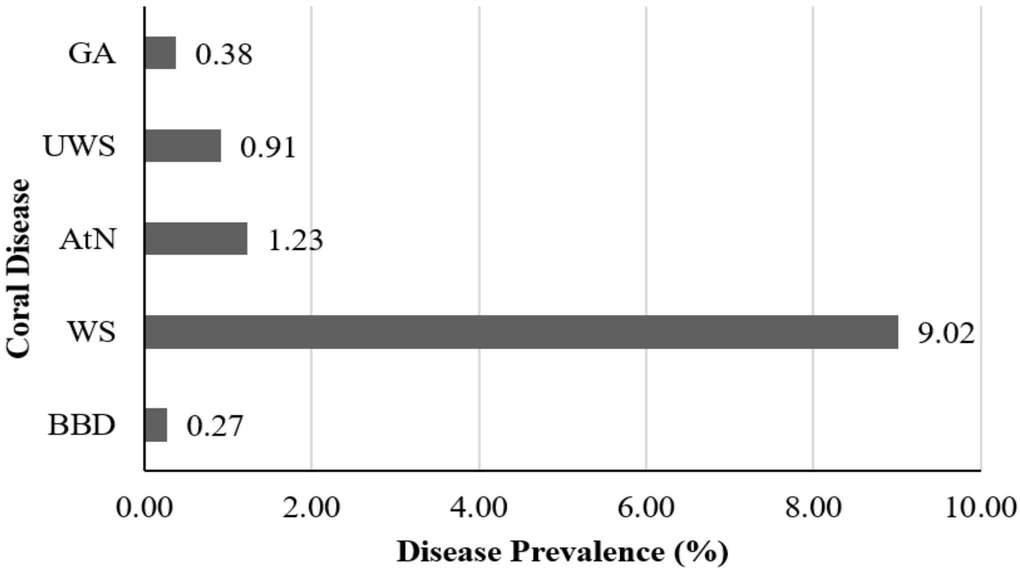

Figure 7. Prevalence values for each type of hard coral (*Scleractinia*) disease Black Band Disease (BBD), White Syndrome (WS), Atramentous necrosis (AtN), Ulcerative White Spots (UWS), and Growth Anomalies (GA).

and live cover (Figure 6). The results showed that live coral cover in Kepulauan Seribu ranged from the low to high category, with values of 9.67%-64.33% and an average of 32.13%. The highest percentage was recorded at KSBC14 at 64.33%, and the lowest of 9.67% was at KSBC03. Furthermore, the prevalence of coral disease ranged from 2.08% to 15.79%, with an average of 11.27%. The highest prevalence of 15.79% was observed at KSBC11 and the lowest of 2.08% was found at station KSBC13. The results showed that KSBC03 had higher prevalence values than their corresponding cover. The hard coral cover in the study area was in a low category (<19%), characterized by a mix of sand and coral fragments overgrown with macroalgae.

3.1.4 Water quality

Natural factors resulting from environmental changes can be observed in the supporting data. Water chemistry parameters, which serve as supporting data for the data collection in Kepulauan Seribu, are presented in Table 5.

Table 5 shows that the temperature, pH, and dissolved oxygen (DO) levels at the study areas are optimal for coral growth and development. However, the salinity is below the optimum range, so it can reduce the condition of coral reefs (low-moderate), this is thought to be caused by the overflow of the estuary of the Jakarta mainland river. Kepulauan Seribu are the final destination of 13 river estuaries originating from Jakarta Bay (Estradivari *et al.,* 2009). According to Zurba (2019), one of the limiting factors for coral to grow is low salinity. The effect of salinity on coral varies from one area to another, depending on the intensity of runoff and water conditions (Gassen *et al.*, 2024).

3.1.5. Analysis correlation

Based on the values of coral disease prevalence and live cover in the study areas, a correlation coefficient analysis was obtained. The correlation analysis showed r = -0.10 indicating a negative correlation between the variables in the analysis. The results showed that the correlation coefficient had a value of r = 0.10, suggesting a very low relationship between coral disease and live cover in Kepulauan Seribu.

3.2 Discussion

3.2.1 Disease-infected coral genus

The results of the study showed that BBD was often found in *Montipora,* this was in accordance with the statement from Johan *et al.* (2016) that BBD was a widely found disease infecting *Montipora*. WS was often found in *Acropora, Porites* and *Montipora*. This was in accordance with the statement from Zakaria *et al.* (2021), where the disease mainly infected *Acropora, Pavona, Porites,* and *Montipora*. AtN infected *Montipora*, this was in accordance with the statement from Raymundo *et al.* (2008), where the disease was most prevalent in Indo-Pacific, particularly in *Montipora*. UWS was often found in *Porites*, this was in accordance with the statement by Raymundo *et al.* (2008), who observed that UWS was characterized by white wound spots of less than 1 cm, primarily found in *Porites*, *Montipora,* and *Echinopora.* GA infected *Acropora* and *Porites*, this was in line with the study by Aeby *et al.* (2021), where the disease commonly infected *Acropora* and *Porites*.

Based on the results (Table 4), the genus *Montipora* is the type of coral that is most often infected with tissue loss diseases such as BBD, WS, Atramentous Necrosis (AtN), and Ulcerative White Spots (UWS). The genus dominates the waters by growing rapidly and close together between each colony, and this allow the transmission of pathogenic infections such as bacteria (Greene *et al*., 2020). The genus *Montipora* is recognized as one of the genera susceptible to infection by diseases (Delpopi *et al*., 2015). Furthermore, the morphology of small and smooth polyps can facilitate infection by pathogens (Shore-Maggio *et al*., 2015). Additionally, immunity declines with age, which allows infection by other organisms, bacteria, and environmental disturbances (van Oppen and Blackall, 2019). Abrar *et al.* (2012) also stated that various types of coral diseases infected *Montipora* and *Porites*.

Each colony morphology has differences in the process of spreading wounds and the recovery process (Caldwell *et al*., 2020). Among other genera, *Montipora* inhabits areas close to each colony, characterized by a smooth and foliose branching growth form with a faster growth rate (Zurba, 2019), showing the potential risk of transmitting disease infections such as tissue loss (Greene *et al*., 2020). Coral diseases primarily infect *Montipora* and *Porites*, as these genera are the most abundant in the waters (Abrar and Bachtiar, 2012; Caldwell *et al*., 2020). On average, the biological factors of these two genera, lead to large colony sizes and shapes compared to others, causing high vulnerability to disturbances or diseases (Greene *et al*., 2020; Caldwell *et al*., 2020). This vulnerability is also attributed to the decline in coral immunity that occurs due to age, typically after 35 years old (Caldwell *et al*., 2020).

3.2.2 Prevalence of coral disease

This study showed that five coral diseases infect hard coral in Kepulauan Seribu (Figure 7). The highest prevalence was observed for WS at 9.02%, followed by AtN, 1.23%, respectively. Most WS diseases infecting coral are presumably caused by the depletion of water quality such as decreasing salinity (Table 6), due to massive construction impacts in Jakarta and its surroundings. High nutrient effluents from anthropogenic activities, including rising temperatures also increase the risk of transmitting and developing bacteria. Thermal stress and resultant bleaching have previously been identified as a driver of coral disease, including high-mortality outbreaks (Greene *et al*., 2020). The diversity of coral species and growth forms in these areas also affects the distribution of specific pathogens (Caldwell *et al*., 2020). Coral species infected with WS in Kepulauan Seribu are predominantly *Porites, Montipora,* and *Acropora*, which are most vulnerable to heat elevation. Greene *et al.* (2020) stated that WS prevalence increased with a rise in nutrient and water temperature stress. This result was confirmed by Johan *et al.* (2020), where diseases occur due to the combination and interaction between the host, specific disease-causing agent factors (pathogens, including bacteria, viruses, fungi, and parasites), and stresses from adverse environmental conditions.

These areas were located in the community access zone of Kepulauan Seribu National Park, with tourism activities such as lodging and snorkeling or diving spots. Tourism activities can impact coral reef ecosystems and contribute to the high prevalence of coral disease. Sabdono *et al.* (2019) stated that tourism activities in marine national parks had the potential to change environmental conditions, thereby enlarging the pathogen's infections. According to Lamb *et al.* (2014), tourism could increase coral disease prevalence and live cover conditions through the construction of facilities, which elevate water nutrient composition levels, sediment buildup, and erosion due to the area of ship channels.

The results show that disease prevalence in Kepulauan Seribu is lower than in other areas in Indonesia. The disease prevalence of previous studies in Jakarta Bay reached 37.9% for SD (Arifin, 2016), Kepulauan Seribu was 31.64% for BBD (Johan *et al.*, 2016), and Jemeluk-Penuktukan, Bali, was 25.2% for PR (Mellani *et al.*, 2019). In Kepulauan Seribu, the prevalence of coral disease was presumed to have declined due to the low anthropogenic activity during the 2019-2020 pandemic (Ihsan *et al.*, 2022).

3.3.3 Relationship of coral disease prevalence and live coral cover

According to the analisys, only 10% of coral diseases are related to the condition of coral cover percentage, while other factors relation 90% due to variables not tested, such as competition for food and space (among fish, macroalgae, or other benthic biota) and water quality degradation from anthropogenic activities, including development, tourism, or overfishing. Similarly, Johan *et al.* (2020) stated that coral conditions and low cover occurred due to natural selection, disturbing factors, and other anthropogenic activities. The coefficient showed a negative correlation, characterized by a descending trend. This suggested that higher prevalence of coral disease led to lower live coral cover.

According to Lamb *et al.* (2011), there was no significant relationship between coral cover and disease prevalence. Aeby *et al.* (2021) also reported a negative correlation between each factor. This differed from Arifin (2016), where a close relationship with a positive correlation was observed between coral disease prevalence and live cover (close to 1), causing a significant influence on the degradation of coral reef ecosystems. Caldwell *et al.* (2020) also stated that the presence of disease prevalence had a positive correlation with live coral cover but not with a high risk of transmission. The differences in the results were due to several factors, including variations in the coral genus found in each area, the prevalence of specific coral disease, and differences in the study area. Both natural factors and human activities can cause the decline of coral reefs (Huang *et al.*, 2021).

Anthropogenic activities, such as massive sedimentation and the exploitation of marine resources using toxic materials and explosives, can lead to the deterioration of coral reefs. Furthermore, mining and marine transportation activities lead to environmental damage (Estradivari *et al.*, 2009; Hasim, 2021). The low level of education and economic development in Kepulauan Seribu affects the understanding of coastal communities. This poses a challenge for the government to provide an integrated education system about coastal knowledge to the younger generation and establish more sustainable tourism activities in the future. Suci *et al.* (2021) suggested to the local government to utilize the resources available in Kepulauan Seribu as the foundation for the economy and community welfare.

4. Conclusion

In conclusion, coral disease was found in 15 coral genera, with *Porites, Montipora*, and *Acropora* being the most affected. A total of 5 types of diseases were identified with WS being the most prevalent. A weak correlation was found between the prevalence of coral disease and live cover. This suggested that the prevalence of coral disease had only a slight impact on cover conditions in Kepulauan Seribu.

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Authors' Contributions

All authors have contributed to the final manuscript. Each author's contribution is as follows: Fari-

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Conflict of Interest

The authors declare no competing interests.

Declaration of Artificial Intelligence (AI)

The authors affirm that no artificial intelligence (AI) tools, services, or technologies were used in the creation, editing, or refinement of this manuscript. All content presented is the result of the independent intellectual efforts of the author(s), ensuring originality and integrity.

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