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Method for Calculating the Coral Health Index (Case Study: Mapur Island, Bintan, Indonesia)

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Abstract. This study evaluates the health and condition of coral reefs in the Mapur Island - Bintan Conservation Area, located in the Riau Islands Province, Indonesia. The research was conducted at 5 site locations using the Underwater Photo Transect (UPT) method, with a focus on hard coral cover and the Coral Health Index (CHI). Coral lifeform data were analyzed using Coral Point Count with Excel extensions (CPCe) software. The results revealed significant variability in coral cover, ranging from 14.47% to 59.27%, with an average of 39.36%, placing the coral reefs in the "Moderate" category. However, despite high hard coral cover at some sites, coral health varied, with certain locations exhibiting significant disease prevalence. Among the 5 sites surveyed for CHI, four were classified as "healthy," while one were categorized "diseased." Statistical analyses, including Welch's t-test and Bayesian inference, indicated no significant difference between the CHI and hard coral cover, suggesting that high coral cover does not necessarily imply a healthier reef. Diseases such as Pink-Blotch Syndrome, Black Band Disease, and White Syndrome were prevalent across several sites, highlighting the influence of environmental stressors on coral health. The study underscores the importance of regular coral health monitoring and the need for conservation efforts to mitigate the impact of coral diseases and climate change. These findings provide crucial insights into the status of coral reefs in the Mapur Island - Bintan Conservation Area and contribute to broader efforts to preserve marine biodiversity.

1 Introduction

Indonesia, as an archipelagic state, holds immense marine potential, boasting the world's second-longest coastline, extending approximately 95,000 kilometers, and encompassing a marine territory of around 5.8 million square kilometers [1–3]. This extensive marine environment is characterized by exceptional biodiversity, particularly within its coral reef ecosystems. Indonesia is home to more than 80 genera and approximately 450 species of reef-building corals, making it one of the most biodiverse coral reef regions globally [4]. The

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sustainable utilization of these coral reef resources through ecotourism is a vital approach to preserving ecosystem integrity while providing economic benefits [5,6]. Coral reefs, beyond their biodiversity value, serve critical ecological functions, acting as natural breakwaters that mitigate coastal erosion from wave action and oceanic currents [7,8]. Furthermore, they play an essential socio-economic role by supporting the livelihoods of coastal communities, which are highly dependent on marine resources for their economic survival, including fisheries, tourism, and coastal protection[9,10]. The degradation of these ecosystems, therefore, threatens not only biodiversity but also the resilience and sustainability of coastal economies [11–13].

Mapur Island is part of The Bintan Conservation Area, located in the seawaters of the Riau Islands Province, is also home to a relatively well-preserved coral reef ecosystem. This conservation area is renowned for its high biodiversity, similar to other coral reef regions in Indonesia, which are under threat from various factors that could jeopardize the sustainability of these ecosystems. The growing population, with its increasing economic demands, poses a significant threat to the condition of coral reef ecosystems, particularly in small island regions [14–18]. Consequently, frequent assessments of coral reef conditions are conducted to monitor the current status of the ecosystems within conservation areas [19–22].

The primary factors influencing coral growth include light intensity, oxygen availability, temperature, and water clarity [23]. According to [24], coral reef ecosystems are among the most productive and biodiverse on Earth, yet they face increasing threats from various anthropogenic activities, including overfishing, coastal development, agricultural runoff, and maritime activities. A variety of survey methods are employed to assess coral reefs, including the Manta Tow method [25–28], the Line Intercept Transect (LIT) method [28–30], the Point Intercept Transect (PIT) method [31], the Belt Transect method [32,33], the Quadrat Transect method [34], and the RIKA-R3DI method [21,35]. These methods are widely applied for identifying coral species and assessing the overall health and condition of coral reefs in a given area.

The development of new methods in coral reef research continues to diversify, aimed at facilitating easier data collection for researchers. One such method currently in use is the Underwater Photo Transect (UPT) method [36,37], which utilizes software such as Coral Point Count with Excel extensions (CPCe) for data analysis [38,39]. This method is an advancement of the Line Intercept Transect (LIT) technique [28], with the specific aim of calculating live coral cover at research sites. To date, the method for calculating the Coral Health Index (CHI) has often been linked to various parameters, including hard corals, benthos, reef fish, algae, rubble, resilience levels, and microbial communities [23,40]. However, a high percentage of hard coral cover is not always indicative of reef health, as diseased coral may still be prevalent. Conversely, locations with abundant herbivorous fish may show low hard coral cover and high levels of rubble. In light of these observations, this study focuses on quantifying the number of lifeforms and diseased lifeforms along predefined transects to determine the percentage of diseased coral within the surveyed area. By doing so, it will be easier to accurately calculate the Coral Health Index (CHI), providing a more reliable assessment of coral reef health.

2 Research Methodology

2.1 Research Site Locations

The research was conducted in May 2022 at five (5) site locations within the seawaters of the Mapur Island - Bintan Conservation Area. To assess coral health, the researchers selected using purposive sampling, designed to meet the objectives of this study. Field observations

were carried out in situ using survey methods. All site locations were located within the Mapur Island - Bintan Conservation Area. The site map of the research area is presented in Figure 1.

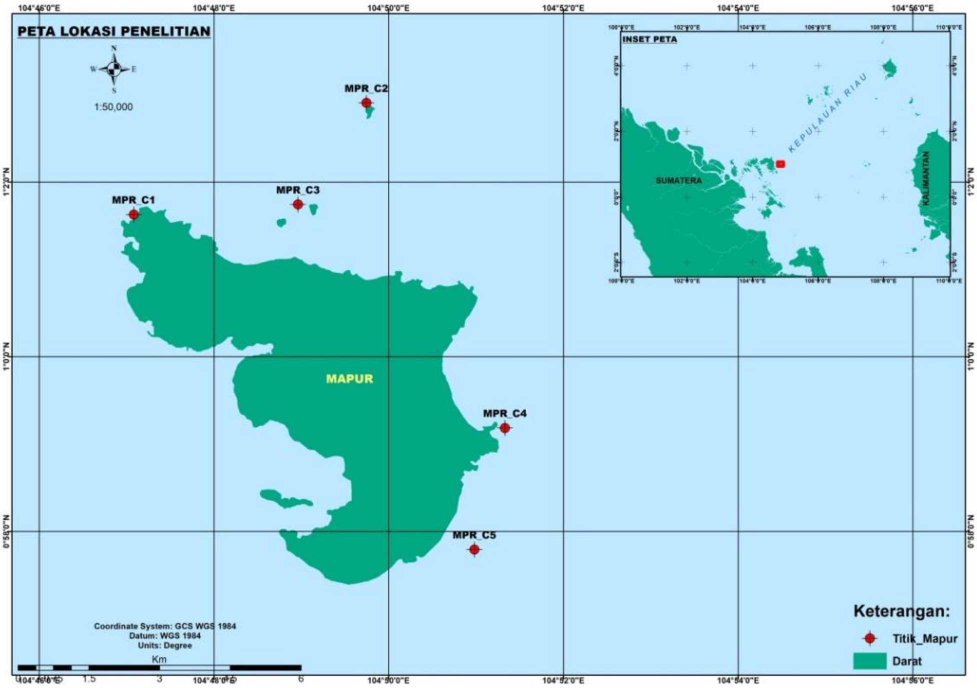

Fig. 1. Research Site Location for Coral Reef Condition Assessment

2.2 Coral Reef Data Collection

The coral lifeform data at the research site was collected using the Underwater Photo Transect (UPT) method [36,41]. This involved taking photographs along a transect line using a frame measuring 44 x 58 cm. Photographs were taken at regular intervals from the 1st meter to the 50th meter, with a 1-meter gap between each shot. Photographs at odd-numbered meters, such as at 1 meter (Frame 1), 3 meters (Frame 3), and so on, were taken to the left of the transect line (closer to the shore), while even-numbered meters, such as 2 meters (Frame 2), 4 meters (Frame 4), and so on, were photographed on the right side of the transect line (further from the shore). This procedure is illustrated in Figures 2 and 3 below.

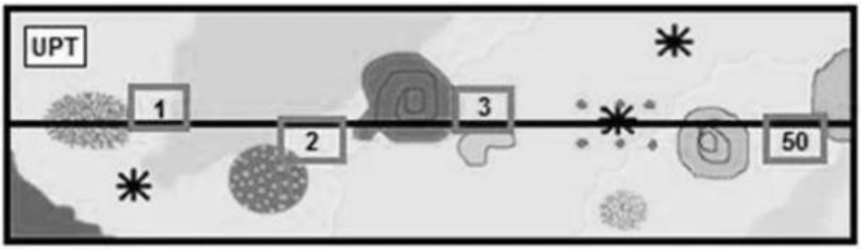

Fig. 2. Illustration of Underwater Photography Using the UPT Method

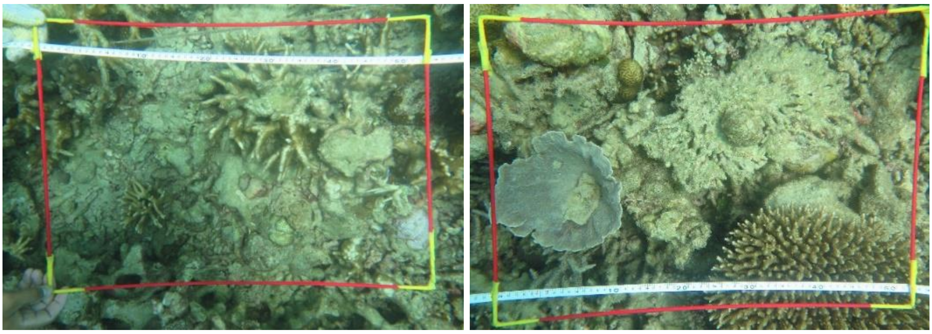

Fig. 3. Field photography using the UPT method: (a) the position of the scaled tape in odd-numbered frames, and (b) the position of the scaled tape in even-numbered frames.

2.2 Analysis

The software used to analyze the percentage of coral cover is Coral Point Count with Excel Extension (CPCe) [38]. CPCe is a standalone application that automatically performs random point analysis and calculates the substrate composition from underwater images. Additionally, CPCe can generate statistical analyses for each coral growth form directly in Microsoft Excel, as shown in Figure 4.

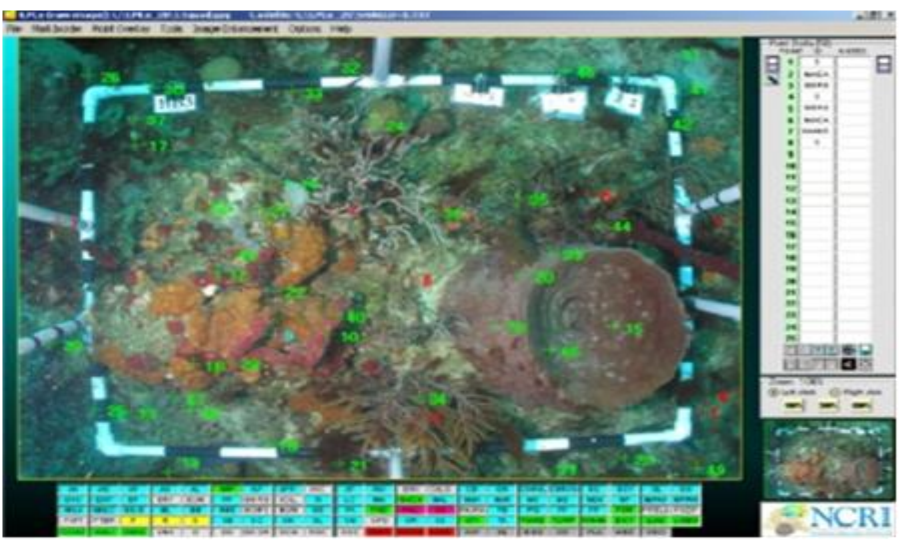

Fig. 4. Coral Data Analysis with is Coral Point Count with Excel Extension (CPCe) software

The percentage of live coral cover is calculated based on a specific formula, and the resulting data is categorized according to the formulation by [42], as shown in Table 1:

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Table 1. Coral Reef Condition Categories

No.	Percentage of Hard Coral (%)	Category
1	0 – 24,9	Damaged
2	25 – 49,9	Moderate
3	50 – 74,9	Good
4	75 - 100	Excellence

To assess coral health at the research site, the researchers calculated the total number of lifeforms found within 50 frames along a 50-meter transect line. Additionally, they quantified the number of diseased coral lifeforms within the same 50 frames along the transect line, as illustrated in Figure 5.

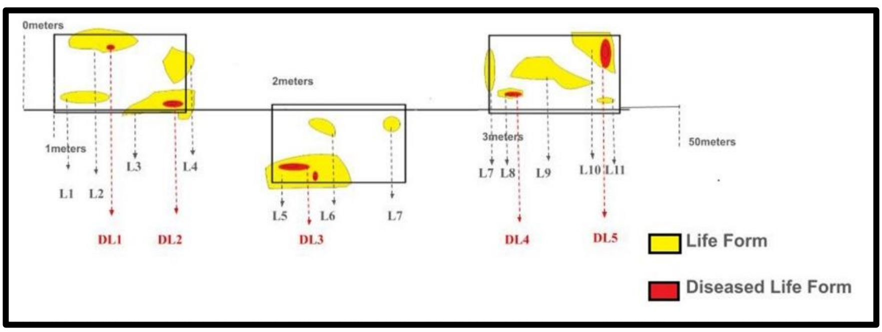

Fig. 5. Illustration of Lifeform and Diseased Lifeform Counting Along the Transect Line

The lifeform and diseased lifeform data collected from field surveys were subsequently calculated and analyzed using the following formulas:

$$Number\ of\ Lifeform\ (L) = L1+L2+L3+L4+L5,\ and\ so\ on \quad (1)$$

$$Number\ of\ Diseased\ Lifeform\ (DL) = DL1+DL2+DL3+DL4+DL5,\ and\ so\ on \quad (2)$$

$$Number\ of\ Healthy\ Lifeform\ (HL) = L-DL \quad (3)$$

The percentage value of the Coral Health Index (CHI) is calculated using the following equation:

$$CHI\ (\%) = (HL/L)\ x\ 100 \quad (4)$$

The data obtained from this equation are subsequently categorized according to a formulation derived from the modifications by [28,42]), as presented in Table 2:

Table 2. Coral Reef Condition Categories

No	Percentage of Coral Health Index (%)	Category
1	0 – 25	Disease
2	25,1 – 50	Fair
3	50,1 – 100	Healthy

3 Result and Discussion

3.1 Percentage of Coral Life form

The analysis conducted using the Coral Point Count with Excel Extension (CPCe) revealed that the percentage of hard coral cover varied from “Damage” to “Excellence” categories conditions, with values ranging between 7.07% and 77.93%. The overall average percentage was 52.06%. Based on this average percentage, the coral reefs at TMB_K are classified within the "Good" category according to the results of the average analysis at each observation station. Furthermore, the substrate coverage percentages at the 5 site location included live coral (HC), dead coral overgrown with algae (DCA), coral fragments (R), rocks (RK), sand (S), silt (SI), soft coral (SFC), sponge (SP), algae (A), and other biota (OF). The highest percentage was observed in hard coral (HC) with a value of 52.06%, while the lowest percentage was in silt (SI) with a value of 0%. These results are summarized in Table 3 below:

Table 3. Percentage of Coral Lifeform Found Across all Site Locations

Site Location	Hard Coral (HC)	Soft Coral (SC)	Other Fauna (OF)	Algae (A)	Sand (S)	Rubble (R)	Silt (SI)	Rock (RK)	Dead Coral (DC)	Dead Coral with Algae (DCA)
MPR_C1	30.60	1.93	0.00	0.00	40.07	11.33	0.00	0.00	16.07	0.00
MPR_C2	14.47	0.53	0.87	0.00	54.80	0.00	0.00	0.00	29.33	0.00
MPR_C3	36.46	1.07	0.00	0.07	27.20	0.00	0.00	0.00	35.13	0.07
MPR_C4	56.00	0.00	0.00	0.00	37.33	4.93	0.00	0.00	1.73	0.00
MPR_C5	59.27	0.20	0.13	0.00	36.33	0.13	0.00	0.00	3.93	0.00
Average	**39.36**	**0.74**	**0.2**	**0.01**	**39.14**	**3.27**	**0**	**0**	**17.24**	**0.01**

The result of substrate composition across various sites in the Mapur Island - Bintan Conservation Area revealed notable variations in the percentage lifeform of different coral and substrate types. Hard coral (HC) coverage was highest at MPR_C5 (59.27%), while MPR_C2 exhibited the lowest HC coverage at just 12.47%. Soft coral (SC) was minimal across all sites, with the highest occurrence at MPR_C1 (1.93%) and MPR_C3 (1.07%).

Notably, the presence of dead coral (DC) and dead coral with algae (DCA) was significant, particularly at MPR_C3, where DCA reached 35.13%. The rubble (R) substrate was predominantly found at MPR_C1 (11.33%) and MPR_C4 (4.93%), indicating potential habitat degradation or disturbance. Other fauna (OF) and algae (A) were generally sparse, with OF detected at MPR_C5 (0.13%) and A peaking at MPR_C2 (0.87%) (Table 3).

3.2 Coral Healthy Index (CHI) for 12 site location

The Observations of the Coral Health Index (CHI) were conducted at five (12) site. The results revealed that the percentage of hard coral ranged from 14.47% to 59.27%, with the Number of Lifeforms (L) varying between 42 and 131, and the Number of Diseased Lifeforms (DL) ranging from 20 to 49. The average analysis of the five (5) site location indicated that the overall health status was classified as healthy. Eight (4) site locations were identified as “healthy”: MPR_C1, MPR_C2, MPR_C4, and MPR_C5. One (1) Site location were categorized as being in “diseased” condition, specifically MPR_C3. In terms of hard coral cover percentage, three (3) site locations were below 50%: MPR_C1 with a value of 30.60%, MPR_C2 at 14.47%, and MPR_C3 with a value of 36.46%. Despite having an average hard coral percentage below 50%, the health conditions of these site locations varied: MPR_C1, and MPR_C2 was classified as “healthy”, while MPR_C3 was identified as “diseased”. Conversely, the percentage of hard coral (HC) exceeding 50% was observed at two (2) site locations: MPR_C4, and MPR_C5. Among these two (2) sites locations with hard coral percentages categorized as “healthy”. These findings are presented in Table 4.

Table 4. Percentage of Coral healthy Index (CHI) in 12 sites location

Site	Hard Coral (HC) %	Number Of Lifeform (L)	Number Of Diseased Lifeform (DL)	Number Of Healthy Lifeform (HL)	Coral Healthy Index (%)	Categories
MPR_C1	30.60	50	21	29	58.00	Healthy
MPR_C2	14.47	42	20	22	52.38	Healthy
MPR_C3	36.46	47	36	11	23.40	Diseased
MPR_C4	56.00	131	49	82	62.60	Healthy
MPR_C5	59.27	127	25	102	80.31	Healthy
Average	**55.25**	**79.40**	**30.20**	**49.20**	**55.34**	**Healthy**

3.3 Coral Healthy Index (CHI) and Hard Coral (HC)

The figure presents a comparison between the Coral Health Index (CHI) and hard coral (HC) percentage across two categories, with sample sizes of 5 for each group. A parametric test, specifically Welch’s t-test, reveals no significant difference between the two groups ($t(7.91) = 1.29, p = 0.24$) indicating that the means of CHI and HC are statistically indistinguishable. The Hedges' effect size is small (0.73), with a 99% confidence interval ranging from -0.83 to 2.26, suggesting negligible practical significance. The mean values for CHI (55.34%) and

HC (39.36%) are closely aligned. Additionally, Bayesian analysis supports this lack of difference, with a Bayes factor (log_eBF_{01}=0.23) favoring the null hypothesis. The posterior difference estimate (0.23) with a 99% credible interval (-21.62 to 42.65) reinforces this conclusion, indicating no meaningful distinction between CHI and HC in terms of percentage cover. These findings suggest that hard coral percentage does not significantly influence the Coral Health Index in the sampled sites.

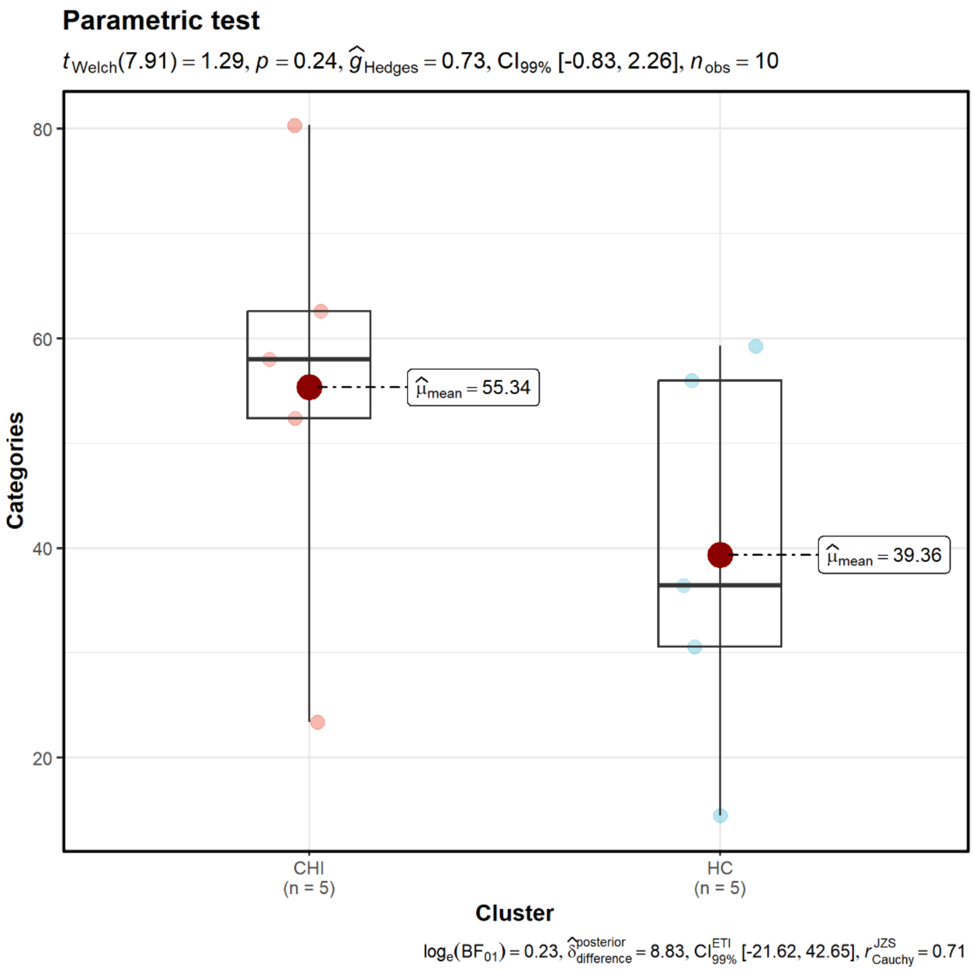

Fig. 6. Kruskall Wallis Analysis between Coral Health Index (CHI) percentage and Hard Coral (HC) percentage

3.4 Coral Disease Incident

The results of the analysis indicate that low hard coral cover does not always correlate with coral health, nor does high cover necessarily indicate healthy conditions in a given marine area. This is evident at observation point MPR_C2, where hard coral cover is 14.47% (categorized as damaged), yet the coral is in a healthy condition. In contrast, MPR_C3, with a hard coral cover of 36.46% (categorized as moderate), exhibits a diseased coral health index. This discrepancy is attributed to the prevalence of coral diseases such as Pink-Blotch

Syndrome (PBS), Black Band Disease (BBD), and White Syndrome (WS) observed at all stations, as shown in Figure 8.

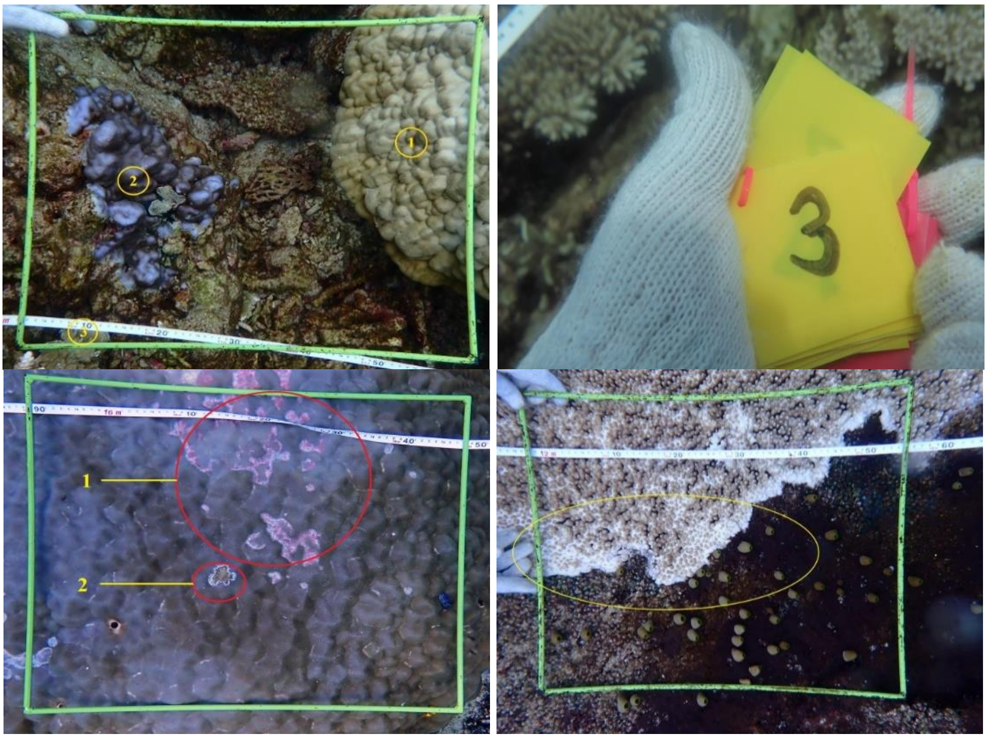

Fig. 7. The calculation of Number of Lifeform and Number of Disease and several disease condition that found

This disease can infect both massive and branching corals. Several coral diseases are associated with microbial disruptions, particularly by the cyanobacterium Phormidium corallyticum. A high prevalence of infected coral colonies can serve as an indicator of environmental changes in the marine ecosystem [43–46]. Currently, the outbreak of coral diseases such as DDB (Disease-Damaged Bleaching) has exacerbated coral degradation, especially in conjunction with rising sea temperatures, making these diseases valuable indicators of increasing ocean temperatures linked to climate change and global warming [43,45]. According to Roof (2006) [47] noted that rapid outbreaks of White Syndrome are a significant cause of high coral colony mortality. Some hypotheses suggest that the emergence of Pink Syndrome may be triggered by external disturbances, such as elevated CO_2 levels, which could disrupt the symbiotic metabolism between algae and their coral hosts [48]

4 Conclusion

This study provides a comprehensive assessment of coral reef health in the Mapur Island - Bintan Conservation Area, highlighting the diversity and condition of coral lifeforms across various site locations. The findings show a wide range of coral health statuses, from healthy to diseased, with hard coral cover percentages varying significantly between sites. The results

indicate that coral health, as measured by the Coral Health Index (CHI), does not always correlate directly with hard coral cover. For instance, some sites with damage hard coral cover exhibited healthy conditions, while others with higher coral cover were found to be in a diseased state. This emphasizes the importance of including health indicators beyond mere coral cover, such as disease prevalence, in coral reef assessments. The study further underscores the need for ongoing monitoring and the development of conservation strategies to mitigate the threats facing these vital ecosystems, particularly in the face of environmental stressors like coral diseases and climate change. These findings contribute to the broader understanding of coral reef ecosystems and support efforts to preserve the biodiversity and resilience of marine environments in Indonesia.

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