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Prevalence of coral diseases in the coastal waters of Kota Kinabalu: The potential of microbial and environmental agents

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ABSTRACT

Aims: The Indo-Pacific coral populations are under increasing threats from bleaching events and coral disease outbreaks. However, there is a significant gap in data and research on coral diseases in Malaysian waters. This study aimed to assess the prevalence of coral diseases and signs of compromised health at 27 reef sites in the coastal waters of Kota Kinabalu, Sabah.
Methodology and results: We conducted coral surveys using the Coral Video Transect (CVT) method and measured the prevalence using Coral Point Count with Excel Extension (CPCe) software. Our findings indicated that the majority of reefs appeared healthy (82.9% ± 1.8), while a smaller percentage displayed signs of disease (5.0% ± 0.6) or compromised health (12.1% ± 1.5). Reef sites exposed to higher levels of human activities exhibited a greater prevalence of coral diseases (e.g. yellow band disease, ulcerative white spots and skeletal eroding band) and signs of compromised health (e.g. sediment necrosis, skeletal damage and algal overgrowth). A total of 51 scleractinian hard coral genera were affected, with *Porites* and *Acropora* being the most predominantly affected by sediment necrosis and skeletal damage, respectively. A review of molecular approaches identified various coral pathogens, including *Vibrio* spp., which could potentially contribute to the occurrence of coral disease.
Conclusion, significance and impact of study: Unsustainable coastal development with unregulated human activities can exacerbate the severity of coral diseases and signs of compromised health. Therefore, effective management plans by relevant authorities are required to sustainably manage coral reefs in Kota Kinabalu.

Keywords: Coral compromised health, coral disease, CVT method, east Malaysia, *Vibrio* spp.

INTRODUCTION

Coral reefs host numerous marine organisms and provide goods and services for coastal communities worldwide (Hoegh-Guldberg *et al*., 2017; Hoegh-Guldberg *et al*., 2019). In Malaysia, coral reefs are mainly found in fringing, patch, or platform formations, covering approximately 4006 km^2 (Praveena *et al*., 2012), with the majority located in Sabah (Burke *et al*., 2012). Sabah is home to about 471 coral species (Waheed *et al*., 2012), with 207 species from 74 genera reported in Kota Kinabalu coastal waters (Marine Research Unit of Sabah Parks, 2005; Liu, 2013). Unfortunately, over 40% of Malaysia's coral reefs face serious threats, with blast fishing and marine litter pollution being the major culprits in Sabah (Burke *et al*., 2011; Waheed and Hoeksema, 2013; Santodomingo *et al*., 2021). Additionally, several bleaching events have been reported on Malaysian islands (Tan and Heron, 2011), including Tunku Abdul Rahman Park (TARP) in Kota Kinabalu, Sabah (Aw and Muhammad Ali, 2012). Furthermore, land development, aquaculture and agricultural practices have led to nutrient eutrophication in Kota Kinabalu estuary, which could potentially harm the nearby coral reef ecosystems (Jakobsen *et al*., 2007; Sakari *et al*., 2012; Al Azad *et al*., 2022). All these factors, both natural and anthropogenic, contribute to the declining health of Malaysian coral reefs, resulting in a higher prevalence of coral diseases and signs of compromised health.

The term "coral disease" refers to various disorders and abnormalities that negatively affect coral health. These conditions may result from biotic and abiotic stressors, leading to morphological and physiological changes in affected corals (Woodley *et al*., 2016). Such signs and syndromes can occur due to the influence of microbial pathogens or the combined effects of

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environmental agents and microbes (Raymundo *et al*., 2008). Additionally, coral disease may be characterised by various unfamiliar syndromes that could impair coral health (Beeden *et al*., 2008). Multiple coral diseases have been identified in the Indo-Pacific reefs. For example, seven diseases have been identified in the Great Barrier Reef (Willis *et al*., 2004), while ten identified along the Japanese reefs (Wada *et al*., 2018). In other locations, twelve diseases and signs of compromised health have been reported in Hawaii (Aeby *et al*., 2011), Palau (Golbuu *et al*., 2005) and Thailand (Samsuvan *et al*., 2019), while seven reported in the Philippines (Kaczmarsky, 2006; Haapkylä *et al*., 2009) and Indonesia (Shidqi *et al*., 2018). Hence, the distribution of coral disease has thus varyingly been observed at different locations in the Indo-Pacific region.

In Malaysia, the study of coral disease is limited with coral surveys are primarily focused on the status of live coral cover (e.g. Shahbudin *et al*., 2017; Safuan *et al*., 2018; Akmal *et al*., 2019; Lau *et al*., 2019), rather than disease assessment due to the lack of coral and disease taxonomists (e.g. Miller *et al*., 2015; Khodzori *et al*., 2019; Akmal and Shahbudin, 2020; Khodzori *et al*., 2021; Akmal *et al*., 2023). In Sabah, coral disease prevalence has been reported in three National Parks, including TARP, where the reef sites located near coastal development and tourism had the highest prevalence (Miller *et al*., 2015). The prevalence of four coral diseases, namely white syndrome, brown band disease, black band disease and atramentous necrosis, as well as two compromised health states, bleaching and pigmentation response, were identified in these locations (Miller *et al*., 2015). However, the surveys were conducted at only a few reef sites that are insufficient to provide a representative understanding of the study area. In light of this, this study aimed to provide comprehensive data in terms of the prevalence of coral diseases and signs of compromised health at reef sites around the coastal waters of Kota Kinabalu. Moreover, the present study attempted to fill the knowledge gap by identifying the potential of microbial and environmental agents to contribute to the occurrence of coral disease in the study area. The outcomes of this study can have important implications for various stakeholders such as the Department of Fisheries (DOF), Sabah Parks and universities in updating their knowledge about the current status of coral health conditions, thus informing policy makers, authority bodies and management decisions to effectively protect and conserve the fragile marine ecosystems in Kota Kinabalu coastal waters. Furthermore, the findings can be used to update geographical information on coral disease prevalence in tropical reef ecosystems.

MATERIALS AND METHODS

Study area

The study area can be divided into two different locations, namely Tunku Abdul Rahman Park (TARP) and Sepanggar bay. TARP is situated off the western coast of Sabah in Kota Kinabalu and comprises five islands: Gaya, Manukan, Sapi, Sulug and Mamutik which are popular with tourists for day trips due to their proximity to the capital city. Meanwhile, Sepanggar Bay is home to a container terminal, a naval base for the Royal Malaysian Navy and an oil terminal. Currently, the area is undergoing significant development due to the expansion of Kota Kinabalu city, which may have a negative impact on the nearby coral reef areas. In this study, a total of 27 reef sites were surveyed at depths ranging from 3 m to 18 m around Kota Kinabalu coastal waters (Figure 1).

Coral video transect (CVT) method

Coral disease surveys were conducted using the Coral Video Transect (CVT) method developed by Liew *et al*. (2012) with some modifications (Akmal *et al*., 2019). For each reef site, a total of 120 m of transect line was laid down divided into 30 m by 4 segments with a 3 m interval between each segment at depths ranging from 3 m to 18 m. Video recording was performed using an Olympus compact underwater camera TG-6 with a 16:4 aspect ratio and a video resolution of 1980 × 1080 HD which was protected with a waterproof casing, Olympus PT-058. The camera was held at a perpendicular angle to the bottom and positioned approximately 50 cm above the substrates using a reference bar (Safuan *et al*., 2015). Video recording was conducted along the transect line at a speed of 6 min per segment to capture clear and sharp images. The additional still images of coral diseases and signs of compromised health were also taken in actual size and macro shots to aid in the identification and verification processes.

Video processing and image analysis

At each reef site, 240 images (60 per 30 m transect segment) were generated from the recorded videos. These images were analysed using the Coral Point Count with Excel extension (CPCe) software version 4.1 (Kohler and Gill, 2006), with 30 uniform points per image. The Indo Pacific Coral Finder Toolkit (Kelley, 2021) and the books of Corals of the World (Veron, 2002) were used to identify the scleractinian hard coral genera. Guidelines for assessing Indo-Pacific coral health by Beeden *et al*. (2008) and Raymundo *et al*. (2008) were utilised to identify all coral diseases and signs of compromised health.

Disease prevalence equation

Disease prevalence was measured based on the proportion of healthy, diseased or compromised corals to the total measured population of coral colonies. It was quantified as:

$P = a/A \times 100\%$

Where P = Disease prevalence; a = Total number of healthy, diseased or compromised coral colonies; A =

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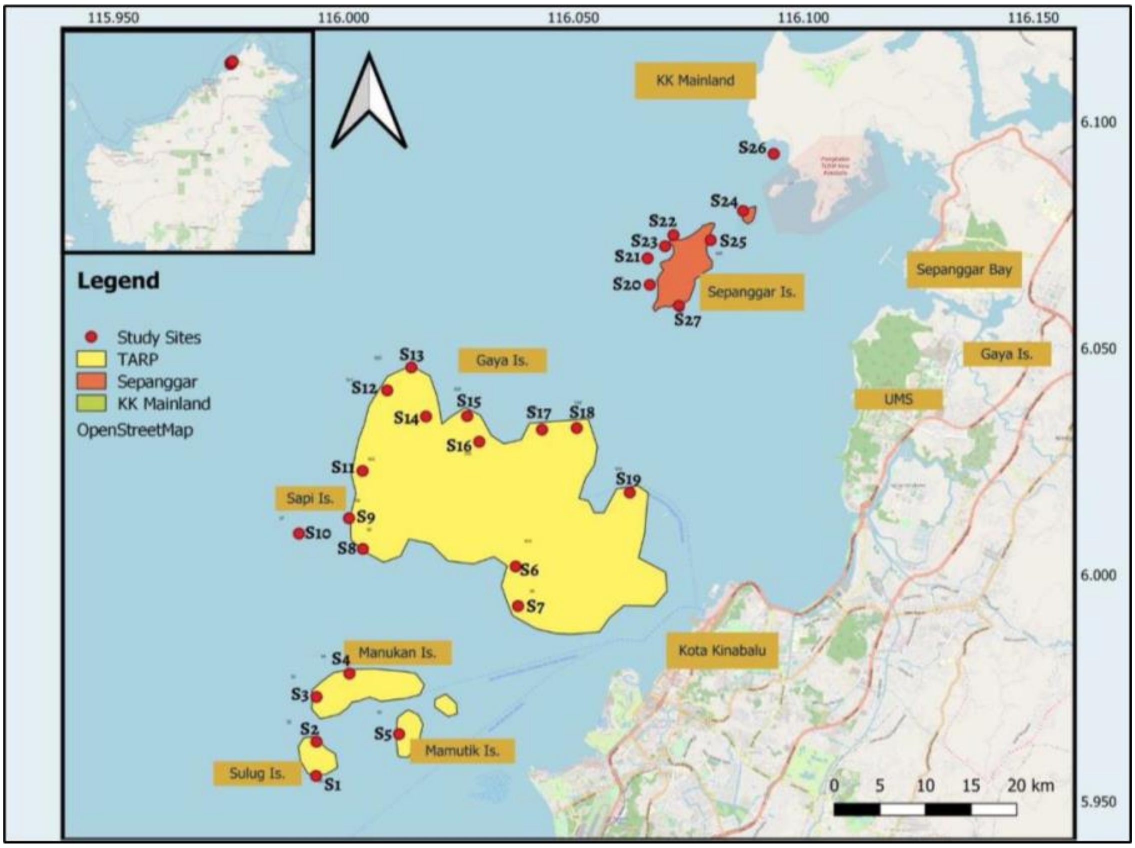

Figure 1: The locations of 27 sampling stations around Kota Kinabalu coastal waters.

Total number of coral colonies (healthy, diseased and compromised).

Relative disease abundance

Rating scale from one to five crosses (+) was used to represent disease abundance among scleractinian hard coral genera based on total mean prevalence of individual infected coral genus where + = one or few, covering <5% colonies; ++ = uncommon, covering 6-10% colonies; +++ = common, covering 11-20% colonies; ++++ = abundant, covering 21-30% colonies; and +++++ = dominant, covering >30% colonies.

Statistical analyses

Statistical analyses were performed to compare the mean prevalence of healthy, diseased, and compromised corals across different reef sites. A parametric one-way analysis of variance (ANOVA) was used, followed by post-hoc Tukey HSD tests. Normal data distribution was confirmed using Kolmogorov-Smirnov (Lilliefors, 1967) and Shapiro-Wilk (Shapiro and Francia, 1972) tests. To explore similarities in disease and compromised health types among reef sites, cluster analysis was employed, utilising log (x + 1) transformed data and the Bray Curtis method (Bray and Curtis, 1957). A non-metric multidimensional scale (nMDS) plot was used to visualise similarities among reef sites based on the data interaction derived from the cluster analysis. To estimate the mean similarity of diseases and compromised health composition between different groups as illustrated in the nMDS plot, Similarity percentage (SIMPER) analysis was used. All statistical analyses were conducted using Paleontological Statistic (PAST) software version 3 (Hammer *et al*., 2001).

RESULTS

Prevalence of diseased, compromised and healthy coral colonies

A total of 27 reef sites were investigated for signs of coral diseases and compromised health in Kota Kinabalu coastal waters. The majority of coral colonies were found to be healthy, with a mean prevalence of 82.9% ± 1.8. Compromised health and diseased coral colonies had mean prevalence of 12.1% ± 1.5 and 5.0% ± 0.6, respectively (Figure 2). The ANOVA test indicated significant differences in the mean prevalence of healthy (F: 7.322, p<0.05), compromised (F: 4.037, p<0.05) and diseased (F: 5.362, p<0.05) corals among the surveyed reef sites. Post-hoc test revealed that the mean prevalence of coral diseases ranged from 1.0% at S24 to

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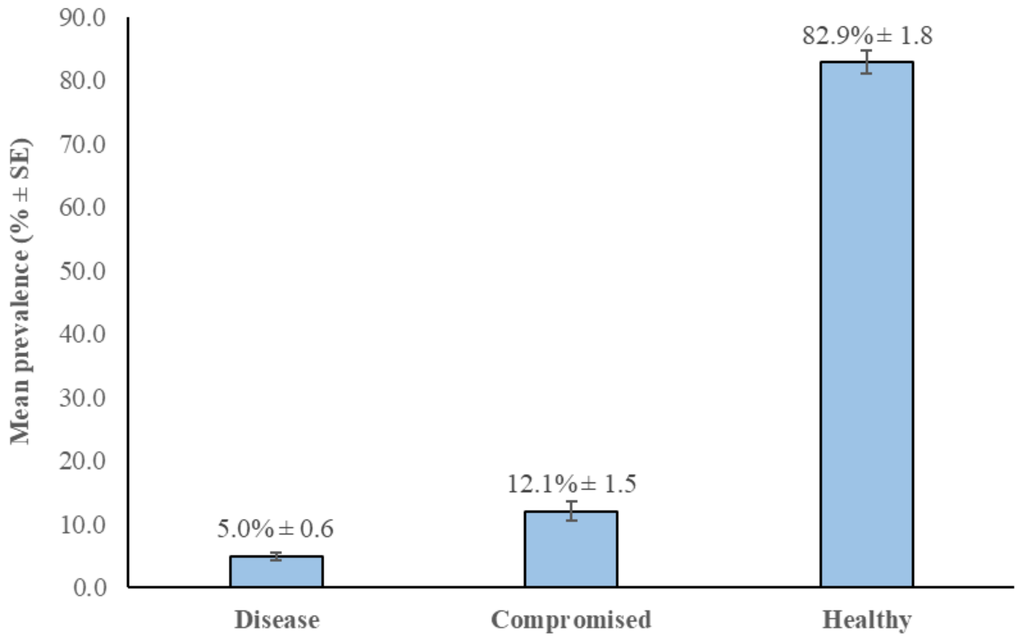

Figure 2: Mean prevalence (% ± SE) of diseased, compromised and healthy coral colonies in Kota Kinabalu coastal waters.

Table 1: Mean prevalence (% ± SE) of diseased, compromised and healthy coral colonies at 27 reef sites in Kota Kinabalu coastal waters.

Reef sites	Islands	Diseased (%)	Compromised (%)	Healthy (%)
S1	Sulug	8.4 ± 0.6	14.8 ± 1.3	76.8 ± 0.7
S2	Sulug	4.0 ± 0.2[b]	7.1 ± 0.6[b]	88.8 ± 0.5[b]
S3	Manukan	6.4 ± 0.4	7.9 ± 0.6[b]	85.8 ± 0.9[b]
S4	Manukan	7.7 ± 0.4	9.0 ± 0.4[b]	83.3 ± 0.5
S5	Mamutik	3.1 ± 0.1[b]	9.5 ± 0.2[b]	87.4 ± 0.2[b]
S6	Gaya	12.0 ± 0.4[a]	24.9 ± 0.2[a]	63.1 ± 0.3[a]
S7	Gaya	4.8 ± 0.1[b]	31.5 ± 2.5[a]	63.7 ± 2.5[a]
S8	Sapi	7.2 ± 0.2	13.8 ± 0.6	79.1 ± 0.6
S9	Sapi	3.4 ± 0.2[b]	9.9 ± 0.4b	86.7 ± 0.5[b]
S10	Sapi	5.6 ± 0.4[b]	17.3 ± 0.5	77.1 ± 0.4
S11	Gaya	1.9 ± 0.1[b]	3.2 ± 0.1[b]	95.0 ± 0.1[b]
S12	Gaya	2.0 ± 0.1[b]	3.2 ± 0.1[b]	94.9 ± 0.1[b]
S13	Gaya	2.5 ± 0.1[b]	3.5 ± 0.1[b]	94.0 ± 0.1[b]
S14	Gaya	4.8 ± 0.3[b]	19.7 ± 3.3	75.5 ± 3.5
S15	Gaya	3.0 ± 0.1[b]	23.5 ± 1.2[a]	73.5 ± 1.3
S16	Gaya	11.0 ± 0.2[a]	19.1 ± 0.1	69.9 ± 0.3
S17	Gaya	3.7 ± 0.5b	19.1 ± 1.2	77.2 ± 1.5
S18	Gaya	2.0 ± 0.2[b]	16.2 ± 0.8	81.8 ± 0.7
S19	Gaya	5.6 ± 0.3[b]	9.0 ± 0.5[b]	85.4 ± 0.4[b]
S20	Sepanggar	2.6 ± 0.1[b]	1.9 ± 0.1[b]	95.5 ± 0.1[b]
S21	Sepanggar	3.0 ± 0.2[b]	3.2 ± 0.2[b]	93.8 ± 0.4[b]
S22	Sepanggar	1.9 ± 0.1[b]	1.1 ± 0.1[b]	97.0 ± 0.1[b]
S23	Sepanggar	4.0 ± 0.2[b]	10.8 ± 0.2	85.2 ± 0.4[b]
S24	Uda Besar	1.0 ± 0.1[b]	5.4 ± 0.2[b]	93.6 ± 0.1[b]
S25	Sepanggar	2.8 ± 0.2[b]	15.8 ± 0.8	81.4 ± 1.0
S26	Sepanggar	11.1 ± 0.4[a]	11.3 ± 0.7	77.6 ± 1.1
S27	Sepanggar	9.5 ± 0.3	14.6 ± 0.9	76.0 ± 0.6

Note: Superscripts a and b indicate significant level (p<0.05) based on post-hoc Tukey HSD test.

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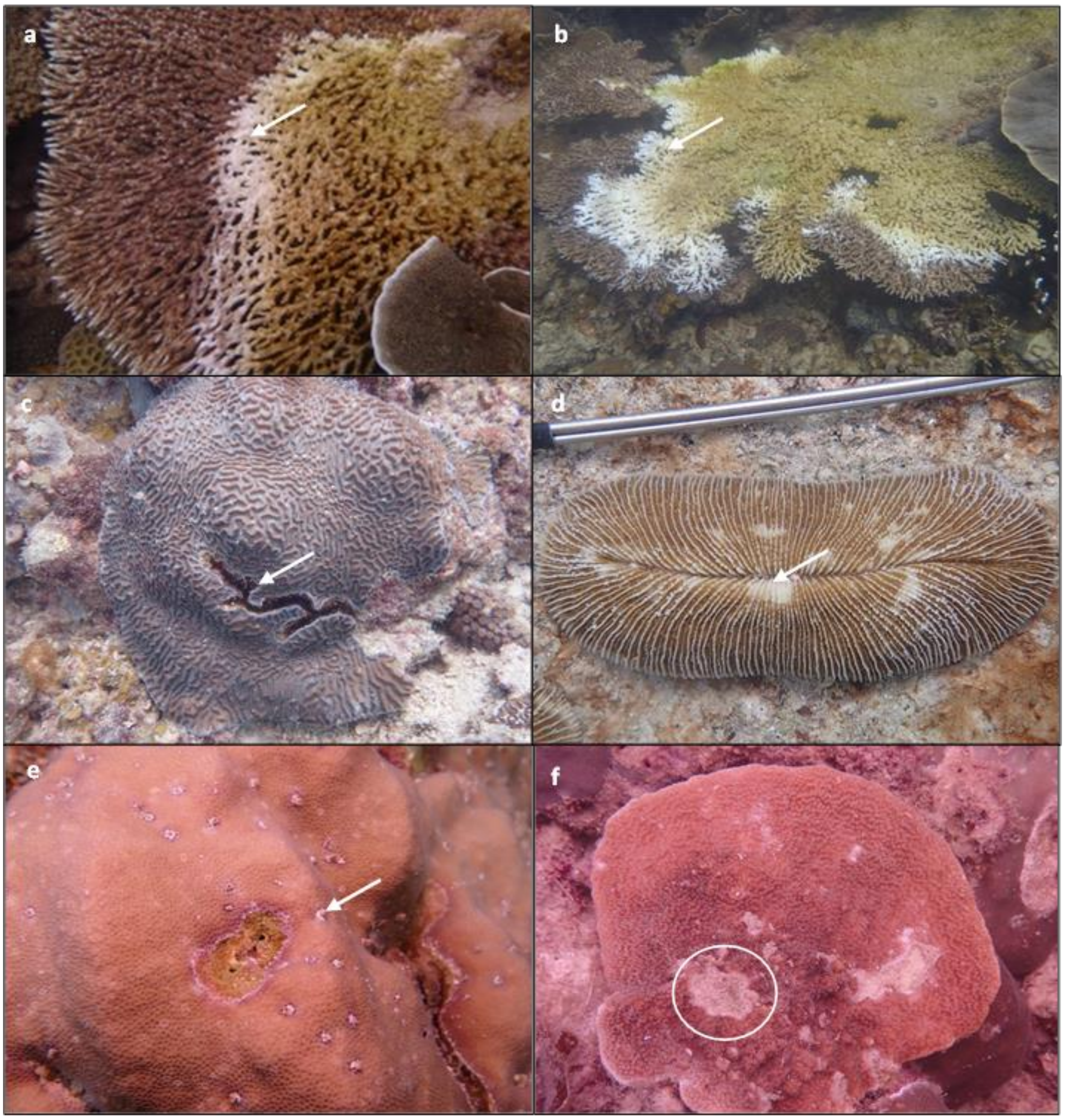

Figure 3: Coral diseases identified in Kota Kinabalu coastal waters include (a and b) white syndrome (WS), (c) skeleton eroding band (SEB), (d) yellow band disease (YBD), (e) ulcerative white spot (UWS) and (f) atramentous necrosis (AtN).

12.0% at S6, with significantly higher prevalence at S6 (12.0%), S26 (11.1%) and S16 (11.0%) than at other reef sites (Table 1). The mean prevalence of compromised corals ranged from approximately 1.1% at S22 to 31.5% at S7 and was significantly higher at S7 (31.5%), S6 (24.9%) and S15 (23.5%) than at other reef sites. In contrast, the mean prevalence of healthy corals ranged from 63.1% at S6 to 97.0% at S22 and was significantly lower at S6 (63.1%) and S7 (63.7%) than at other reef sites.

Prevalence of coral diseases and signs of compromised health

The surveys identified five coral diseases, namely white syndrome (WS), skeleton eroding band (SEB), yellow band disease (YBD), ulcerative white spot (UWS) and atramentous necrosis (AtN) in Kota Kinabalu coastal waters (Figure 3). Meanwhile nine signs of compromised health, namely focal bleaching (FB), pigmentation response (PR), algae overgrowth (AO), sponge overgrowth (SO), predation scar (PS), sediment necrosis (SN), skeletal damage (SKD), flatworm infestation (FW) and growth anomalies (GA) were identified in the study area (Figure 4). The highest mean prevalence of diseased corals was observed for SEB (2.24% ± 0.4), followed by UWS (1.28% ± 0.2) and YBD (1.19% ± 0.2) (Table 2). Meanwhile, SN had the highest mean prevalence of compromised corals (6.72% ± 1.0), followed by SKD (2.02% ± 0.5), AO (1.11% ± 0.3) and GA (1.10% ± 0.2) (Table 3). ANOVA test analysis revealed significant variations in the mean prevalence of all

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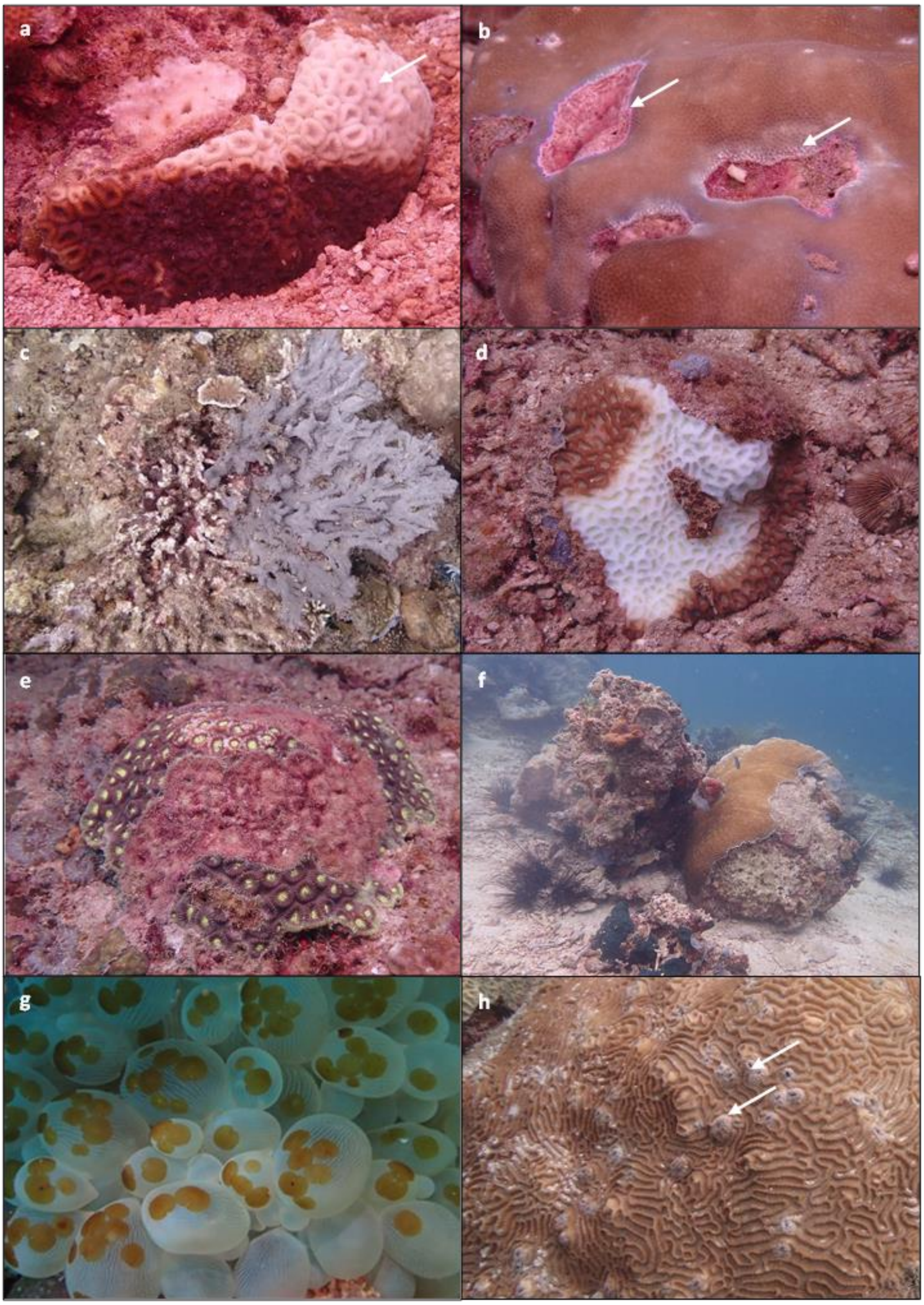

Figure 4: Coral compromised health identified in Kota Kinabalu coastal waters include (a) focal bleaching (FB), (b) pigmentation response (PR), (c) sponge overgrowth (SO), (d) predation scar (PS), (e) sediment necrosis (SN), (f) skeletal damage (SKD), (g) flatworm infestation (FW) and (h) growth anomalies (GA).

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Table 2: Mean prevalence (% ± SE) of coral diseases at 27 reef sites in Kota Kinabalu coastal waters.

Reef sites	Islands	WS	SEB	YBD	UWS	AtN
S1	Sulug	0.22 ± 0.1[b]	5.35 ± 0.7[b]	0.61 ± 0.1[b]	2.23 ± 0.2	−
S2	Sulug	0.20 ± 0.1[b]	1.61 ± 0.1[b]	1.49 ± 0.1[b]	0.52 ± 0.1[b]	0.20 ± 0.1[b]
S3	Manukan	0.92 ± 0.1	0.73 ± 0.1[b]	2.57 ± 0.1	2.02 ± 0.2	0.12 ± 0.0[b]
S4	Manukan	−	2.68 ± 0.2[b]	4.02 ± 0.3[a]	1.01 ± 0.1[b]	−
S5	Mamutik	0.11 ± 0.1[b]	1.29 ± 0.1[b]	1.54 ± 0.1[b]	0.09 ± 0.0[b]	0.09 ± 0.0[b]
S6	Gaya	0.06 ± 0.0[b]	10.05 ± 0.3[a]	0.39 ± 0.1[b]	1.49 ± 0.2	−
S7	Gaya	0.52 ± 0.0[b]	0.94 ± 0.1[b]	3.11 ± 0.1	0.24 ± 0.0[b]	−
S8	Sapi	−	3.95 ± 0.1[b]	0.28 ± 0.0[b]	2.95 ± 0.2	−
S9	Sapi	0.14 ± 0.0[b]	1.79 ± 0.1[b]	0.38 ± 0.0[b]	1.14 ± 0.2	−
S10	Sapi	0.09 ± 0.0[b]	1.84 ± 0.1[b]	0.75 ± 0.0[b]	2.90 ± 0.4	−
S11	Gaya	0.05 ± 0.0[b]	0.37 ± 0.1[b]	0.16 ± 0.0[b]	1.28 ± 0.1	−
S12	Gaya	0.11 ± 0.0[b]	0.93 ± 0.1[b]	0.08 ± 0.0[b]	0.85 ± 0.1[b]	−
S13	Gaya	−	1.57 ± 0.1[b]	0.05 ± 0.0[b]	0.92 ± 0.1[b]	−
S14	Gaya	0.20 ± 0.0[b]	2.11 ± 0.1[b]	1.94 ± 0.1[b]	0.52 ± 0.1[b]	−
S15	Gaya	0.16 ± 0.0[b]	1.17 ± 0.1[b]	1.45 ± 0.1	0.24 ± 0.0[b]	−
S16	Gaya	0.75 ± 0.0	7.32 ± 0.3	0.57 ± 0.0[b]	2.11 ± 0.1	−
S17	Gaya	−	1.95 ± 0.3[b]	0.51 ± 0.1[b]	1.20 ± 0.1	−
S18	Gaya	−	0.75 ± 0.1[b]	0.32 ± 0.1[b]	0.91 ± 0.2[b]	−
S19	Gaya	0.17 ± 0.0[b]	2.02± 0.2[b]	2.19 ± 0.2	1.14 ± 0.1[b]	0.03 ± 0.0[b]
S20	Sepanggar	0.04 ± 0.0[b]	1.66 ± 0.1[b]	0.11 ± 0.0[b]	0.81 ± 0.0[b]	−
S21	Sepanggar	0.11 ± 0.0[b]	1.89 ± 0.1[b]	−	1.02 ± 0.1[b]	−
S22	Sepanggar	−	1.23 ± 0.1[b]	0.11 ± 0.0[b]	0.52 ± 0.0[b]	−
S23	Sepanggar	−	1.66 ± 0.2b	1.39 ± 0.1[b]	0.91 ± 0.1[b]	−
S24	Uda Besar	−	0.26 ± 0.0[b]	0.17 ± 0.0[b]	0.60 ± 0.1[b]	−
S25	Sepanggar	−	1.04 ± 0.2[b]	1.28 ± 0.1[b]	0.32 ± 0.1[b]	−
S26	Sepanggar	0.27 ± 0.0[b]	3.23 ± 0.2[b]	2.03 ± 0.4[b]	4.40 ± 0.3[a]	1.20 ± 0.1[a]
S27	Sepanggar	1.54 ± 0.1[a]	1.15 ± 0.1[b]	4.62 ± 0.2[a]	2.18 ± 0.2	−
Kota Kinabalu		0.21 ± 0.1	2.24 ± 0.4	1.19 ± 0.2	1.28 ± 0.2	0.06 ± 0.0

Note: Superscripts a and b indicate significant level (p<0.05) based on post-hoc Tukey HSD test. white syndrome (WS), skeleton eroding band (SEB), yellow band disease (YBD), ulcerative white spot (UWS) and atramentous necrosis (AtN).

diseases among reef sites. Similarly, the mean prevalence for each type of compromised coral health significantly varied among reef sites, except for FB (F: 1.482, p: 0.110) and FW (F: 0.043, p: 0.843). In terms of coral disease, post-hoc test results indicated that S27 had the highest mean prevalence of WS (1.54% ± 0.1), whereas S6 and S27 had the highest mean prevalence of SEB (10.05% ± 0.3) and YBD (4.62% ± 0.2), respectively. S26 had the highest mean prevalence of UWS (4.40% ± 0.3) and AtN (1.20% ± 0.1). For signs of compromised health, S1 had the highest mean prevalence of PR (1.78% ± 0.2) and GA (4.13% ± 0.5). Meanwhile, S7 had the highest mean prevalence of SO (3.11% ± 0.5) and SKD (10.32% ± 1.1). Other signs of compromised health, such as AO, PS and SN, had the highest mean prevalence at S6 (4.99% ± 0.2), S3 (1.65 ± 0.2) and S15 (18.12% ± 2.5), respectively. No significant differences were found in the mean prevalence of FB and FW, although S18 and S7 had the highest mean prevalence of FB (1.62 ± 0.2) and FW (2.17 ± 0.4), respectively.

Similarity composition of coral diseases and signs of compromised health in reef assemblages

Cluster analysis and nMDS plot revealed two groups (G1 and G2), characterised by five dominant coral diseases and signs of compromised health (Figure 5). The results of SIMPER analysis indicated that SN was the most dominant in both groups (G1 and G2), with a mean prevalence of 12.72% ± 0.0 and 11.80% ± 1.5, respectively (Figure 6). The second most dominant coral disease in G1 was SKD (10.32% ± 0.0), while in G2 was SEB (2.88% ± 1.1). Additionally, other prevalent coral diseases and compromised health signs, such as YBD (3.11% ± 0.0) and GA (1.63% ± 0.3), were among the most dominant in G1 and G2, respectively. Based on the similar composition of these coral diseases and signs of compromised health among the reef sites, most of the reef sites in Kota Kinabalu were in G1, with the majority of corals being affected by YBD, SO, SN, SKD and FW. In contrast, G2 comprised reef sites from S6, S16, S15, S17, S14, S25, S18, S10 and S23, with the majority of corals being affected by SEB, AO, SN, SKD and GA.

Prevalence and disease abundance among scleractinian hard coral genera

A total of 51 scleractinian hard coral genera were affected by various diseases and signs of compromised health (Table 4). The prevalence of disease varied among genera, with *Porites* had the highest mean prevalence at 10.54% ± 4.3, followed by *Acropora* (2.33% ± 1.1),

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Table 3: Mean prevalence (% ± SE) of signs of compromised health at 27 reef sites in Kota Kinabalu coastal waters.

Reef sites	Islands	FB	PR	AO	SO	PS	SN	SKD	FW	GA
S1	Sulug	0.28 ± 0.1	1.78 ± 0.2[a]	0.11 ± 0.0[b]	1.17 ± 0.2	0.73 ± 0.1	2.68 ± 0.1[b]	3.90 ± 0.5	−	4.13 ± 0.5[a]
S2	Sulug	0.52 ± 0.1	0.08 ± 0.0[b]	−	−	0.12 ± 0.0 [b]	5.13 ± 0.6	1.01 ± 0.2[b]	−	0.28 ± 0.1[b]
S3	Manukan	0.49 ± 0.1	0.24 ± 0.1[b]	0.73 ± 0.2[b]	0.37 ± 0.1[b]	1.65 ± 0.2[a]	3.85 ± 0.3[b]	0.24 ± 0.1[b]	−	0.31 ± 0.1[b]
S4	Manukan	0.28 ± 0.1	0.11 ± 0.1[b]	0.17 ± 0.1[b]	0.39 ± 0.0	0.22 ± 0.1[b]	6.03 ± 0.3	0.56 ± 0.1[b]	−	1.12 ± 0.2
S5	Mamutik	0.37 ± 0.1	−	3.65 ± 0.4	0.21 ± 0.0[b]	0.11 ± 0.0[b]	2.48 ± 0.2[b]	2.07 ± 0.2[b]	−	0.60 ± 0.1[b]
S6	Gaya	0.06 ± 0.0	0.19 ± 0.1[b]	4.99 ± 0.2[a]	−	0.32 ± 0.1[b]	16.15 ± 0.8	1.69 ± 0.2[b]	−	1.49 ± 0.1
S7	Gaya	0.38 ± 0.0	−	1.08 ± 0.1[b]	3.11 ± 0.5[a]	0.14 ± 0.0[b]	12.72 ± 0.6	10.32 ± 1.1[a]	2.17 ± 0.4	1.60 ± 0.2
S8	Sapi	0.12 ± 0.0	0.20 ± 0.0[b]	1.95 ± 0.2	0.64 ± 0.1	−	6.02 ± 0.9	3.63 ± 0.9[b]	−	1.20 ± 0.3
S9	Sapi	0.17 ± 0.0	0.14 ± 0.0[b]	0.28 ± 0.0[b]	0.65 ± 0.1	−	4.88 ± 0.4	3.03 ± 0.4[b]	−	0.76 ± 0.1[b]
S10	Sapi	−	−	0.68 ± 0.2[b]	0.54 ± 0.1[b]	0.05 ± 0.0[b]	11.20 ± 1.4	2.43 ± 0.2[b]	−	2.38 ± 0.2
S11	Gaya	0.05 ± 0.0	0.05 ± 0.0[b]	0.08 ± 0.0[b]	−	−	1.65 ± 0.2[b]	1.20 ± 0.1[b]	−	0.13 ± 0.0[b]
S12	Gaya	0.08 ± 0.0	−	0.43 ± 0.1[b]	0.11 ± 0.0[b]	−	1.68 ± 0.3[b]	0.80 ± 0.2[b]	−	0.05 ± 0.0[b]
S13	Gaya	0.10 ± 0.0	0.10 ± 0.0[b]	0.21 ± 0.0[b]	0.05 ± 0.0[b]	−	1.15 ± 0.1[b]	1.78 ± 0.2[b]	−	0.08 ± 0.0[b]
S14	Gaya	0.10 ± 0.0	0.05 ± 0.0[b]	1.12 ± 0.4[b]	0.17 ± 0.1[b]	−	14.00 ± 2.6	2.14 ± 0.3[b]	−	2.14 ± 0.3
S15	Gaya	−	−	1.37 ± 0.1[b]	0.28 ± 0.1[b]	−	18.12 ± 2.5[a]	1.41 ± 0.4[b]	−	2.33 ± 0.3
S16	Gaya	1.09 ± 0.1	0.38 ± 0.1[b]	4.53 ± 0.5	−	0.04 ± 0.0[b]	9.66 ± 0.4	1.09 ± 0.1[b]	−	2.30 ± 0.2
S17	Gaya	0.96 ± 0.2	0.12 ± 0.0[b]	1.35 ± 0.4[b]	0.15 ± 0.1[b]	0.15 ± 0.0[b]	14.88 ± 2.0	0.48 ± 0.0[b]	−	1.02 ± 0.0
S18	Gaya	1.62 ± 0.2	0.08 ± 0.0[b]	0.87 ± 0.2[b]	−	0.08 ± 0.0[b]	11.77 ± 1.0	0.83 ± 0.4[b]	−	0.95 ± 0.1
S19	Gaya	0.88 ± 0.2	0.10 ± 0.0[b]	0.71 ± 0.3[b]	0.07 ± 0.0[b]	−	4.95 ± 1.1	0.57 ± 0.2[b]	−	1.75 ± 0.4
S20	Sepanggar	0.18 ± 0.1	0.28 ± 0.1[b]	0.04 ± 0.0[b]	−	−	0.63 ± 0.1[b]	0.70 ± 0.2[b]	−	0.07 ± 0.0
S21	Sepanggar	0.61 ± 0.1	0.19 ± 0.1[b]	−	−	−	1.59 ± 0.3[b]	0.53 ± 0.2[b]	−	0.30 ± 0.1[b]
S22	Sepanggar	−	0.30 ± 0.1[b]	0.07 ± 0.0[b]	−	−	0.24 ± 0.1[b]	0.41 ± 0.0[b]	−	0.07 ± 0.0[b]
S23	Sepanggar	0.11 ± 0.1	0.16 ± 0.1[b]	0.32 ± 0.1[b]	−	−	8.88 ± 0.5	0.70 ± 0.2[b]	−	0.64 ± 0.2[b]
S24	Uda Besar	0.17 ± 0.0	0.14 ± 0.1[b]	0.57 ± 0.1[b]	0.03 ± 0.0[b]	−	3.51 ± 0.4[b]	0.66 ± 0.1[b]	−	0.34 ± 0.1[b]
S25	Sepanggar	−	−	0.24 ± 0.1[b]	0.32 ± 0.1[b]	−	11.68 ± 1.2	0.64 ± 0.3[b]	−	2.96 ± 0.5
S26	Sepanggar	0.38 ± 0.1	0.38 ± 0.1[b]	1.24 ± 0.1[b]	0.17 ± 0.1[b]	−	3.43 ± 0.9[b]	3.64 ± 0.8	1.65 ± 0.5	0.41 ± 0.1[b]
S27	Sepanggar	0.38 ± 0.1	−	3.21 ± 0.6	−	−	2.56 ± 0.6[b]	8.01 ± 1.4	−	0.38 ± 0.1[b]
Kota Kinabalu		0.35 ± 0.1	0.19 ± 0.1	1.11 ± 0.3	0.31 ± 0.1	0.13 ± 0.1	6.72 ± 1.0	2.02 ± 0.5	0.14 ± 0.1	1.10 ± 0.2

Note: Superscripts a and b indicate significant level (p<0.05) based on post-hoc Tukey HSD test. White syndrome (WS), skeleton eroding band (SEB), yellow band disease (YBD), ulcerative white spot (UWS) and atramentous necrosis (AtN).

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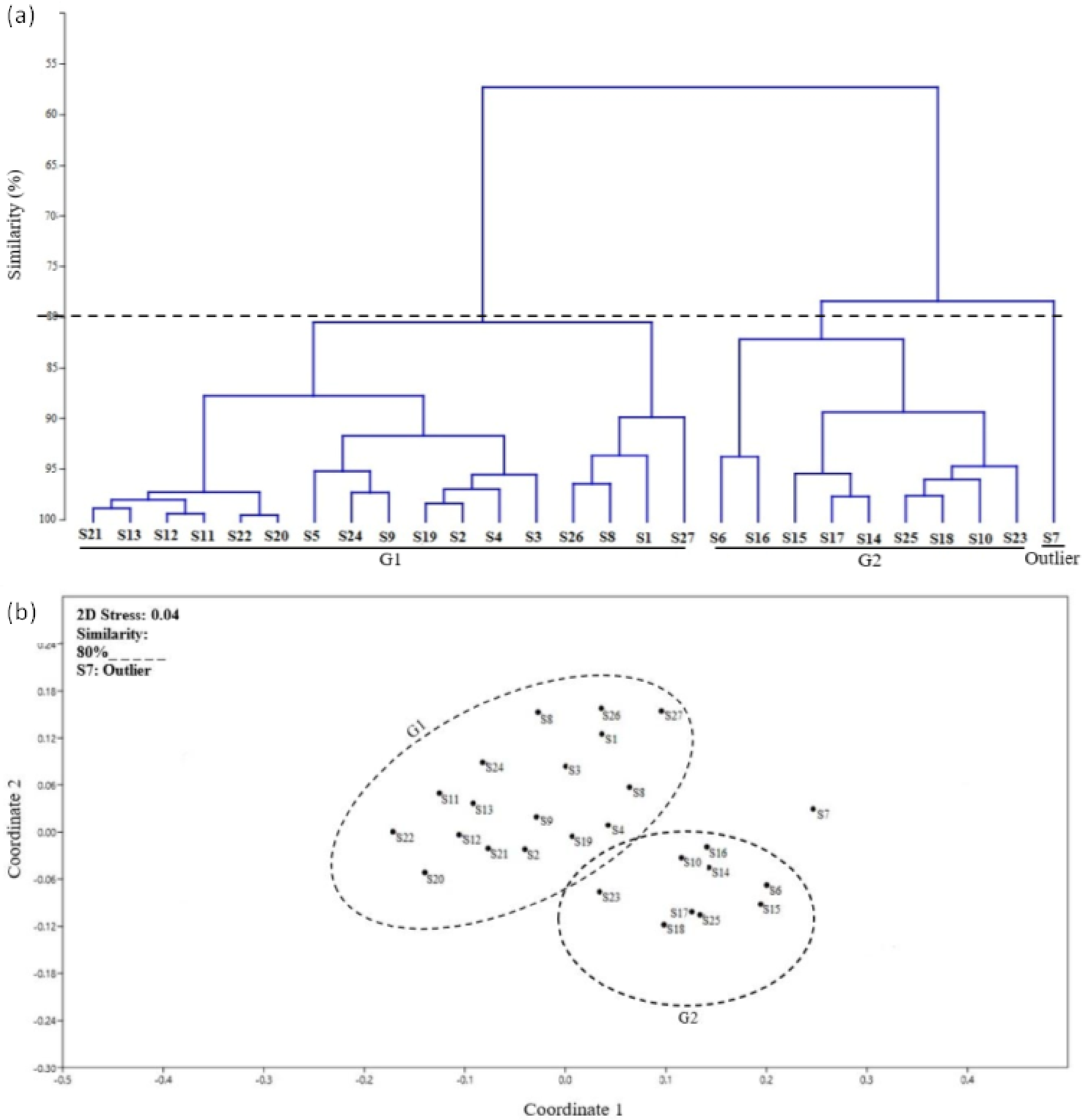

Figure 5: Dendrogram (a) and nMDS plot (b) were clustered all reef sites within two groups (G1 and G2) based on 80% similarity. Both groups were separated based on mean prevalence of coral diseases and signs of compromised health.

Dipsastrea (1.96% ± 1.0), *Fungia* (1.91% ± 1.5), *Platygyra* (1.4% ± 1.0), *Echinopora* (1.26% ± 0.7) and *Montipora* (1.05% ± 0.6). Other genera had a mean prevalence of less than 1%. Different diseases also variably affected coral genera. For example, eight genera were affected by YBD, including *Fungia*, *Ctenactis*, *Cycloseris*, *Halomitra*, *Herpolitha*, *Lithophyton*, *Pleuractis* and *Sandalolitha*. *Montipora* and *Porites* were affected by UWS and AtN, respectively. Meanwhile, WS and SEB affected 16 and 31 genera, respectively. Additionally, several genera showed compromised health, with *Plerogyra* being affected only by FW and most genera being affected by SN, GA and SKD. The abundance of affected corals varied by disease, with YBD primarily affected *Fungia* (21-30% colonies), while UWS affected *Porites* (21-30% colonies). SN primarily affected *Porites* (>30% colonies), followed by *Dipsastrea* and *Echinopora* with 11-20% of colonies affected. SKD primarily affected *Acropora*, *Pavona* and *Porites*, whereas GA affected *Porites* with 11-20% colonies.

DISCUSSION

Variation in coral health prevalence among reef areas

This study revealed that the intensive human-use reef sites in Kota Kinabalu coastal waters show a considerably high prevalence of diseased coral colonies, with the

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Table 4: Mean prevalence (% ± SE) and disease abundance among scleractinian hard coral genera in Kota Kinabalu coastal waters.

No.	Coral genera	WS	SEB	YBD	UWS	AtN	FB	PR	AO	SO	PS	SN	SKD	FW	GA	Mean
1	*Acropora*	+	+	−	−	−	+	−	++	+	+	+	+++	−	+	2.33 ± 1.1
2	*Alveopora*	−	−	−	−	−	−	−	−	−	−	+	−	−	−	0.01 ± 0.0
3	*Anacropora*	+	−	−	−	−	−	−	+	−	−	−	+	−	−	0.05 ± 0.0
4	*Astreopora*	−	+	−	−	−	−	−	+	−	−	+	−	−	+	0.04 ± 0.0
5	*Isopora*	−	+	−	−	−	−	+	+	+	−	+	+	−	−	0.20 ± 0.1
6	*Montipora*	+	+	−	−	+	+	−	+	+	−	++	+	−	+	1.05 ± 0.6
7	*Coeloseris*	−	+	−	−	−	−	−	−	−	−	+	−	−	+	0.02 ± 0.0
8	*Gardineroseris*	−	+	−	−	−	−	−	−	−	−	+	−	−	+	0.02 ± 0.0
9	*Leptoseris*	+	+	−	−	−	+	−	−	+	−	+	+	−	+	0.44 ± 0.3
10	*Pavona*	−	+	−	−	−	−	−	+	+	−	+	+++	−	−	0.81 ± 0.4
11	*Pachyseris*	+	+	−	−	−	−	−	+	+	−	++	+	−	+	0.70 ± 0.5
12	*Coscinaraea*	−	+	−	−	−	−	−	−	−	−	+	−	−	+	0.07 ± 0.1
13	*Turbinaria*	+	−	−	−	−	−	+	+	−	−	+	+	−	+	0.15 ± 0.1
14	*Diploastrea*	−	+	−	−	−	−	−	+	−	−	+	−	−	+	0.38 ± 0.3
15	*Euphyllia*	−	−	−	−	−	+	−	−	−	−	+	+	−	+	0.12 ± 0.1
16	*Galaxea*	+	+	−	−	−	+	−	+	+	−	+	+	−	+	0.59 ± 0.3
17	*Ctenactis*	−	−	+	−	−	+	−	−	−	−	+	−	−	+	0.08 ± 0.1
18	*Cycloseris*	−	−	+	−	−	−	−	−	−	−	−	−	−	−	0.01 ± 0.0
19	*Fungia*	−	−	++++	−	−	+	−	−	−	−	+	+	−	+	1.91 ± 1.5
20	*Halomitra*	−	−	+	−	−	−	−	−	−	−	−	−	−	−	0.01 ± 0.0
21	*Heliofungia*	−	−	−	−	−	−	−	−	+	−	+	−	−	−	0.03 ± 0.1
22	*Herpolitha*	−	−	+	−	−	−	−	+	+	−	+	−	−	+	0.23 ± 0.2
23	*Lithophyllon*	−	−	+	−	−	−	−	−	−	−	−	−	−	−	0.01 ± 0.0
24	*Pleuractis*	−	−	+	−	−	−	−	−	−	−	−	−	−	+	0.07 ± 0.1
25	*Sandalolitha*	−	−	+	−	−	+	−	−	−	−	+	−	−	−	0.03 ± 0.0
26	*Echinophyllia*	−	+	−	−	−	−	−	+	−	−	++	+	−	+	0.56 ± 0.4
27	*Homophyllia*	−	−	−	−	−	−	−	−	−	−	+	−	−	−	0.01 ± 0.0
28	*Lobophyllia*	+	+	−	−	−	+	−	+	−	+	+	+	−	+	0.28 ± 0.1
29	*Astrea*	−	+	−	−	−	−	−	−	−	−	−	+	−	−	0.01 ± 0.0
30	*Australogyra*	−	+	−	−	−	−	−	−	−	−	+	+	−	−	0.01 ± 0.0
31	*Caulastraea*	−	−	−	−	−	−	−	−	−	−	+	-	−	−	0.00 ± 0.0
32	*Coelastrea*	−	−	−	−	−	−	−	−	−	−	+	−	−	−	0.01 ± 0.0
33	*Cyphastrea*	+	+	−	−	−	+	−	+	+	−	+	−	−	+	0.20 ± 0.1
34	*Dipsastraea*	+	++	−	−	−	+	+	+	+	−	+++	+	−	+	1.96 ± 1.0
35	*Echinopora*	+	+	−	−	−	+	−	+	+	−	+++	+	−	+	1.26 ± 0.7
36	*Favites*	+	+	−	−	−	+	−	+	+	−	+	+	−	+	0.41 ± 0.2

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No.	Coral genera	WS	SEB	YBD	UWS	AtN	FB	PR	AO	SO	PS	SN	SKD	FW	GA	Mean
37	*Goniastrea*	+	+	−	−	−	+	−	+	+	+	++	+	−	+	0.95 ± 0.5
38	*Hydnophora*	−	+	−	−	−	+	−	−	−	−	+	−	−	+	0.09 ± 0.0
39	*Leptoria*	−	+	−	−	−	−	−	−	−	−	−	−	−	+	0.01 ± 0.0
40	*Merulina*	−	+	−	−	−	−	−	+	−	+	+	+	−	+	0.41 ± 0.3
41	*Mycedium*	−	+	−	−	−	−	−	−	+	−	+	−	−	−	0.06 ± 0.0
42	*Oulophyllia*	−	+	−	−	−	−	−	−	−	−	+	−	−	+	0.01 ± 0.0
43	*Pectinia*	+	+	−	−	−	+	−	+	−	−	+	+	−	−	0.17 ± 0.1
44	*Platygyra*	+	++	−	−	−	−	−	+	+	+	++	+	−	+	1.46 ± 0.7
45	*Trachyphyllia*	−	−	−	−	−	−	−	−	+	−	+	−	−	−	0.02 ± 0.0
46	*Pocillopora*	−	+	−	−	−	+	−	++	+	−	+	+	−	+	0.17 ± 0.1
47	*Seriatopora*	−	-	−	−	−	+	−	+	+	−	+	+	−	−	0.10 ± 0.1
48	*Stylophora*	−	−	−	−	−	+	−	+	−	−	+	+	−	−	0.04 ± 0.0
49	*Goniopora*	−	+	−	−	−	+	−	+	−	−	+	+	−	+	0.18 ± 0.1
50	*Porites*	+	+++	−	++++	−	+	+	++	+	+	+++++	+++	−	+++	10.54 ± 4.3
51	*Plerogyra*	−	−	−	−	−	−	−	−	−	−	+	+	+	-	0.16 ± 0.1

Note. +: One or Few (<5% colonies); ++: Uncommon (6-10% colonies); +++: Common (11-20% colonies); ++++: Abundant (21-30% colonies); +++++: Dominant (>30% colonies). White syndrome (WS), Skeletal Eroding Band (SEB), Yellow Band Disease (YBD), Ulcerative White Spot (UWS), Atramentous Necrosis (AtN), Focal Bleaching (FB), Pigmentation Response (PR), Algal Overgrowth (AO), Sponge Overgrowth (SO), Predation Scars (PS), Sediment Necrosis (SN), Skeletal Damage (SKD), Flatworm Infestation (FW), Growth Anomalies (GA).

highest recorded at reef site in Gaya Island. Most reef sites in Gaya Island also exhibit a high prevalence of compromised coral colonies. Gaya is an island with settlements and villages that is close to the capital city of Kota Kinabalu. This proximity has led to constant waterway activities by fishermen and coastal communities (Shah and Selamat, 2016). Furthermore, Kota Kinabalu is currently experiencing rapid growth, resulting in physical infrastructure developments in the surrounding areas that have led to sedimentation and human effluent problems (Jakobsen *et al*., 2007). Gaya Island, situated less than 3 km from the city centre, has been particularly affected. As a consequence, some reef sites in Gaya Island have minimal live coral coverage, likely due to sediment and nutrient runoff from nearby residential areas (RCM, 2018). These human and anthropogenic activities could accelerate the growth of microbial populations (Vega Thurber *et al*., 2014) and reduce the capacity of coral immune defences against increased microbial virulence (Altizer *et al*., 2013).

Moreover, the high prevalence of compromised coral colonies in TARP is likely due to the intensive tourist activities such as snorkelling, diving and boating. In 2019, it was estimated that over 500,000 local and foreign tourists visited the marine park (Maidin *et al*., 2021). This number is comparable to other impacted reefs in regions experiencing rapid tourism growth, such as the western Gulf of Thailand (Larpnun *et al*., 2011) and the Red Sea (Zakai and Chadwick-Furman, 2002), which receive 400,000 to 500,000 visitors annually. These increased tourist activities have resulted in a higher prevalence of sediment necrosis and coral skeletal damage. There is also evidence of coral fragments breakages observed at many reef sites in TARP, suggesting significant damage caused by fish trawling, bombing, direct contact by fin divers and boat propellers. Numerous studies have reported that the physical impacts of diving and boating activities are highly associated with coral mortality caused by colony breakage (Wielgus *et al*., 2004; Hannak *et al*., 2011), sediment deposition (Zakai and Chadwick-Furman, 2002) and increased susceptibility to disease through bacterial infection of coral wounds and injuries (Lamb *et al*., 2014).

Additionally, the composition of coral communities in reef assemblages may influence the relative abundance of diseased and compromised coral colonies across the reef sites in Kota Kinabalu coastal waters. Field surveys indicate that *Porites*, *Fungia* and *Acropora* corals contribute significantly to

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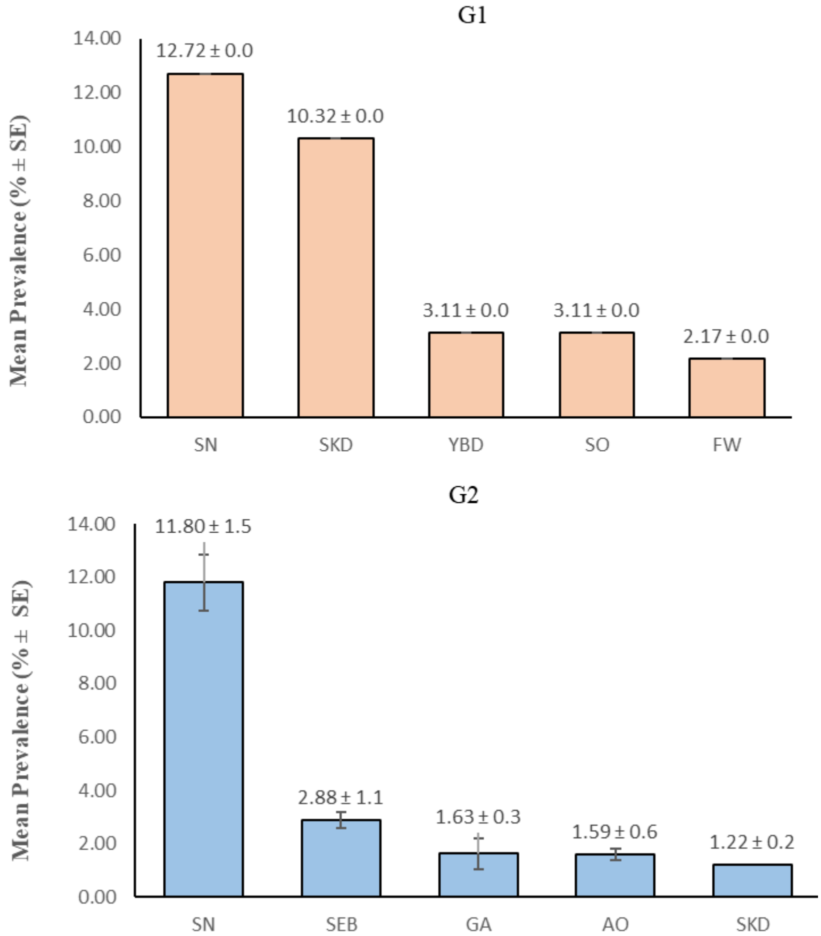

Figure 6: Two groups derived from Cluster and nMDS plot. Each group consists of five dominant coral diseases and signs of compromised health based on SIMPER analysis and values are indicated based on their mean prevalence (% ± SE).

the coral community composition at reef sites around TARP. Recent findings also indicate that these coral genera are the most impacted by various diseases and signs of compromised health. For example, *Porites* coral colonies were predominantly affected by YBD, SN, SKD and GA. Meanwhile, *Fungia* and *Acropora* coral colonies were mostly affected by YBD and SKD, respectively. Therefore, it can be postulated that the high occurrence of diseased and compromised corals around TARP is related to the substantial coverage of these coral genera in reef assemblages.

Coral diseases in Kota Kinabalu coastal waters

Five coral diseases were identified in Kota Kinabalu coastal waters, with yellow band disease (YBD), ulcerative white spots (UWS) and skeletal eroding band (SEB) being the most prevalent. These coral diseases were particularly common in reef sites exposed to tourism and located near the mainland. YBD was found to be most prevalent in S4, located in the tourist hotspot of Manukan Island and S27, situated in Sepanggar Island, close to the mainland. The surveys conducted revealed that more than 20% of *Fungia* coral colonies were affected by YBD, while other *Fungia* corals such as *Ctenactis*, *Herpolitha* and *Pleuractis* were also impacted by this disease. Irregular pale-yellow blotches were observed on the surface area of infected corals.

In the Indo-Pacific reefs, YBD has commonly affected *Fungia* corals, as recorded at Raja Ampat Island (Cervino *et al*., 2008; Donà *et al*., 2008) and Wakatobi Island (Subhan *et al*., 2020) in Indonesia. Additionally, a high prevalence of UWS has been reported in the Philippines (Kaczmarsky, 2006) and Indonesian (Subhan *et al*., 2020) reefs. Meanwhile, SEB was recorded as the most common disease on the Great Barrier Reef (Page and Wilis, 2008) and in the Red Sea (Winkler *et al*., 2004), accounting for more than 30% of all recorded disease cases in these areas. UWS is described as a multifocal pattern of tiny white lesions, with more than 20% of *Porites* colonies affected in the study area. Whereas SEB was observed as a diffused and speckled black or dark

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green appearance of ciliate growth on the coral skeletal surface, affecting many genera, particularly *Porites*, *Platygyra* and *Dipsastraea* corals.

The emergence of YBD and UWS is prompted by an increase in *Vibrio* bacteria with elevated sea surface temperature anomalies (Sussman *et al*., 2008). Mass bleaching events recorded in 1998 and 2005 have also resulted in the emergence of YBD, affecting *Montastrea* coral in the Caribbean reefs (Weil *et al*., 2009). It is believed that the high prevalence of YBD and UWS is driven by the synergetic effects of sedimentation and nutrient pollution, influencing the presence of *Vibrio* bacteria (Cervino *et al*., 2008). Therefore, the mass bleaching events of 2010 and 2012 recorded in Kota Kinabalu coral reefs might have influenced the occurrence of YBD and UWS. However, further studies on the presence of *Vibrio* bacteria or indicator microorganisms will need to be conducted in the near future.

Signs of compromised corals in Kota Kinabalu coastal waters

Nine signs of compromised coral health were identified in Kota Kinabalu coastal waters, with sediment necrosis (SN), skeletal damage (SKD) and algal overgrowth (AO) being the most prevalent. Similarly, most signs of compromised coral health were recorded at the reef sites exposed to human disturbances. For example, the highest prevalence of AO was recorded at S6, which is located nearby a village area in Gaya Island. The high prevalence of macroalgal in this area is likely related to nutrient input from adjacent terrestrial and coastal runoff. Genera *Acropora*, *Pocillopora* and *Porites* were the most impacted by AO, as they were overgrown by red filamentous and turf algae, covering the lower part of branching and upper part of tabular and massive colonies. Turf algae often exhibit competitive dominance over coral species, resulting in coral tissue loss and adverse impacts on coral assemblages (Renfro and Chadwick, 2017).

Moreover, a high prevalence of SN and SKD was also recorded at S6, which is exposed to multiple human disturbances such as tourism and boating activities. Genera *Acropora* and *Pavona* appeared to be more susceptible to breakage than others. They were frequently found fragmented at reef sites intensively used for snorkelling, diving and boating. Direct impacts of snorkelling and diving activities are known to cause fracturing and breakage of coral fragments due to trampling or accidental fin contact (Krieger and Chadwick, 2013). These activities, along with the regular boating of coastal communities, also significantly increased the resuspension of bottom sediment generated by wave propulsion of fins and propellers (Jones, 2011). Over time, the highly resuspended sediment on coral surface may limit the light penetration required by endosymbiotic *Symbiodinium* spp. within the coral polyps for photosynthesis (Erftemeijer *et al*., 2012). Consequently, this condition leads to necrotic coral tissue (Lamb *et al*., 2014) and allows the colonisation of the exposed coral skeleton by macroalgal (Renfro and Chadwick, 2017).

Apart from that, current surveys using the CVT method revealed a total of 14 coral diseases and signs of compromised health. This represents an increase compared to a previous by Miller *et al*. (2015), which recorded only four diseases (black band disease, brown band disease, white syndrome and atramentous necrosis) and three signs of compromised health (focal bleaching, pigmentation response and predation scar) using *in situ* transect surveys. However, the signs of black band disease and brown band disease were not observed in the captured videos. These diseases usually originate in the lower parts and may be partially or completely obscured by the upper parts of the coral colonies, especially for branching, tabular, and corymbose morphologies. Hence, lower estimates of certain disease in videos or photographs were due to insufficient image resolution and the inability to zoom in closely, which prevented a detailed examination of coral base lesions (Holmes *et al*., 2013; Page *et al*., 2017). Nonetheless, both methods have proven to be good predictors for measuring certain visible diseases and signs of coral compromised health.

Potential microbial and environmental agents

Various methods have been developed to identify marine microbial pathogens, including molecular approaches (Pollock *et al*., 2011; Zhenyu *et al*., 2013; Aeby *et al*., 2019), lipid measurements (Yamashiro *et al*., 2001), immunological tools (Palmer *et al*., 2008) and a variety of histological techniques (Pollock *et al*., 2011; Ushijima *et al*., 2012; Work and Meteyer, 2014; Wada *et al*., 2018). To date, several microbial pathogens have been confirmed as the causative agents of coral diseases. They include the rod-shaped Gram-negative bacterium *Serratia marcescens*, responsible for the sign of white patches that cause distinct and irregular white patches throughout the colonies of *Acropora palmata* (Patterson *et al*., 2002). Additionally, *Aurantimonas coralicida* is responsible for the sign of while plague type II, which results in whitening and tissue necrosis throughout the colony base of *Dichocoenia stokesi* and *Orbicella* (Denner *et al*., 2003), while *Thalassomonas loyana* is responsible for white plague type I, which causes a very similar sign to while plague type II in colonies of *Favia favus* (Thompson *et al*., 2006).

Another rod-shaped Gram-negative bacterium, *Vibrio* spp., particularly *V. shiloi* and *V. coralliilyticus*, is responsible for white syndrome, which leads to rapid and progressive tissue loss in coral colonies of *Acropora*, *Montipora* and *Pachyseris* (Sussman *et al*., 2008). *V. shiloi* and *V. coralliilyticus* have also been associated with coral bleaching in the coral colonies of *Oculina patagonica* (Kushmaro *et al*., 2001) and *Pocillopora damicornis* (Ben-Haim and Rosenberg, 2002), respectively. Additionally, *V. owensii* (Ushijima *et al*., 2012) and *V. alginolyticus* (Ushijima *et al*., 2012; Nugraha *et al*., 2019) have been identified as causative agents of

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Indo-Pacific white syndrome disease. A recent study conducted in Tioman island Marine Park also indicated the presence of several *Vibrio* spp., particularly *V. coralliilyticus*, as causative pathogens for white syndrome, which affecting *Acropora*, *Montipora* and *Pachyseris* corals (Khodzori *et al*., 2021).

In addition to the causative agents of microbial communities, environmental stressors such as elevated sea surface temperatures and nutrient enrichment have also been promoting the outbreaks of white syndrome, as reported in the GBR (Boyett *et al*., 2007; Bruno *et al*., 2007; Pollock *et al*., 2014) and other Indo-Pacific locations including the Northern Hawaiian Islands (Sandin *et al*., 2008; Aeby, 2016) and the Republic of the Marshall Islands (Jacobson *et al*., 2006). Therefore, in relation to Kota Kinabalu coral reefs, the occurrence of coral diseases, particularly WS, YBD and UWS might be related to the potential effects of microbial and environmental agents. Further research is required to examine the presence of pathogenic bacteria particularly the *Vibrio* spp. or indicator stressors in the future.

CONCLUSION

This study identified five coral diseases and nine signs of compromised health within the reefs of Kota Kinabalu coastal waters. Coral diseases with among the highest mean prevalence were yellow band disease (YBD), ulcerative white spots (UWS) and skeletal eroding band (SEB). Sediment necrosis (SN), skeletal damage (SKD) and algal overgrowth (AO) had among the highest mean prevalence of coral compromised health states. The overall findings suggest that the elevated prevalence of coral diseases and signs of compromised health, especially within concentrated tourist reef sites, could be attributed to the diverse impacts from the extensive coastal development and unregulated human activities. Furthermore, the presence of bacteria, predominantly *Vibrio* spp. raises the possibility as potential microbial pathogens, contributing to the occurrence of coral diseases. Therefore, additional research is essential to ascertain the causal agents, both microbial and environmental, responsible for the recorded coral diseases in this marine protected area of Kota Kinabalu, Sabah.

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