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Distribution, prevalence, and severity of coral syndromes on shallow reef flats in Chumphon Province, Thailand

Arirush Wongnutpranont[a], Wiphawan Aunkhongthong[a], Chinarong Ruangthong[b] Charernmee Chamchoy[a], Makamas Sutthacheep[a], Thamasak Yeemin[a*]

[a]Marine Biodiversity Research Group, Department of Biology, Faculty of Science, Ramkhamhaeng University, Huamark, Bangkok 10240, Thailand
[b] Chumphon Marine National Park Operation Center 1, Department of National Parks, Wildlife and Plant Conservation, Chumphon Province

*Corresponding author: *thamasakyeemin@gmail.com*

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Abstract. Shallow reef flats are in an extreme environment with high temperatures, light intensity, and sedimentation load, making some sensitive corals vulnerable to several threats such as ocean warming, human activities, pollution, and diseases. Coral disease has been an essential issue regarding coral health as it could promote the deterioration of coral reefs. The aim of this study was to assess coral health by detecting the severity of coral diseases on shallow reef flats in Chumphon Province, the Gulf of Thailand. The baseline survey was conducted in February 2021 at Ko Ngam Yai, Ko Mattra, Ko Rang Kachio, and Ko Kula to quantify and characterize coral diseases. Eleven coral diseases were found in eight coral species, consisting of partial mortality, pigmentation responses (pink lines, pink patches, pink spots, and pink borers), white syndromes (white syndromes, white patches, white bands, and ulcerative white-spots), and unusual bleaching patterns. The most common disease was uncreative white spots on *Porites* corals. White syndromes were highly severe with *Diploastrea heliopora* (10.04%) and the disease was only found at Ko Mattra. The highest severity of coral diseases was found on shallow reef flats at Ko Kula, which is located nearshore. Unmanaged coastal development and anthropogenic activities may intensify the severity of coral diseases. This study provides baseline information regarding coral diseases and signs of compromised health to support marine spatial planning (MPA) and coastal management, achieving coral reef resilience and sustainability.

Keywords: coastal, disease, distribution, Gulf of Thailand, shallow reef flat

1. Introduction

Coral reef ecosystems are essential spawning, nursery, breeding, and feeding grounds for numerous organisms. They are global biodiversity hotspots and the most diverse and productive ecosystems in the oceans (Yeemin et al. 2012). The coral reefs provide various benefits to society such as tourism, recreation, education, research, and other ecosystem services, contributing to livelihoods, well-being and economic development at local and national levels (Raymundo et al. 2008). Shallow reef flats are in an extreme environment with high temperatures, light intensity, and high sediment, making it impossible for some sensitive corals to survive (Hopley 2011). Natural threats such as climate change and anthropogenic activities, e.g., land- and marine-based pollution, habitat destruction and overfishing, have been threatening the sustainability of reefs (Raymundo et al. 2008).

Coral populations, competition, predation, parasitism, and diseases have long been considered significant marine and coastal ecological processes. Coral disease is one among them that plays a significant role, contributing to the decline of live coral cover. Reports and studies from several locations around the world have shown a high reduction in coral cover due to coral diseases. Generally, coral diseases can be caused by both biotic and abiotic stressors. Biotic stressors are induced by living entities (e.g., pathogens, parasites) and abiotic stressors are unfavorable environmental conditions (e.g., extreme changes in salinity, temperature, light). Meanwhile, anthropogenic activities of the present day have been accelerating these processes that generate some difficulties for corals to recover (Aeby 2006; Raymundo et al. 2008; Samsuvan et al. 2019; Williams et al. 2010).

The first report of coral diseases in Thai water in the Andaman Sea shows four categories of the diseases, including pink line syndrome, white syndrome, black band disease, and aspergillosis, which were found in eight coral genera (Kenkel 2008). A study in the inner and eastern Gulf of Thailand study reveals that most massive colonies, such as *Porites*, showed partial mortality in coral mainly due to the pink spot and white band syndromes. The coral diseases were also induced by the burrowing of several species, such as bivalves, trematode, and polychaetes, and the grazing of sea urchins. Various human activities are found in shallow reef flats in Thailand, particularly tourism and fishing. Intensive tourism activities, particularly diving, can cause coral physical injury, increasing the disease susceptibility of corals, based on the observation at Ko Tao (Lamb et al. 2014). Fishing activities, particularly fishing nets and fishing traps, as well as derelict fishing gears, generate some concerns of coral health, such as tissue loss, pale tissue, and diseases on corals in Chumphon Province (Wongnutpranont et al. 2021). Due to the lack of this information in Thai Waters, this study was designed to assess coral health by detecting the severity of coral diseases on shallow reef flats in the Gulf of Thailand.

2. Materials and Methods

2.1 Study sites

Four coral reef sites (Ko Ngam Yai, Ko Mattra, Ko Rang Kachio, and Ko Kula) were selected as study sites for this observation. These islands are located in Chumphon Province, the western Gulf of Thailand. Ko Kula is the nearest island from the shore (2.3 km from the shore), while Ko Ngam Yai is the farthest (17.4 km from the shore). Ko Ngam Yai is a small island off the coast within high tourism by SCUBA diving. Ko Mattra is a long-shape island where fishing and tourism activities are generally found. Ko Rang Kachio and Ko Kula are considered nearshore islands affected by fresh water and pollution from land and coastal development. Only tourism activities are found at Ko Rang Kachiu, while both tourism and fishing activities are found in Ko Kula. All of the four islands have been designated as marine protected areas, Mu Ko Chumphon national park.

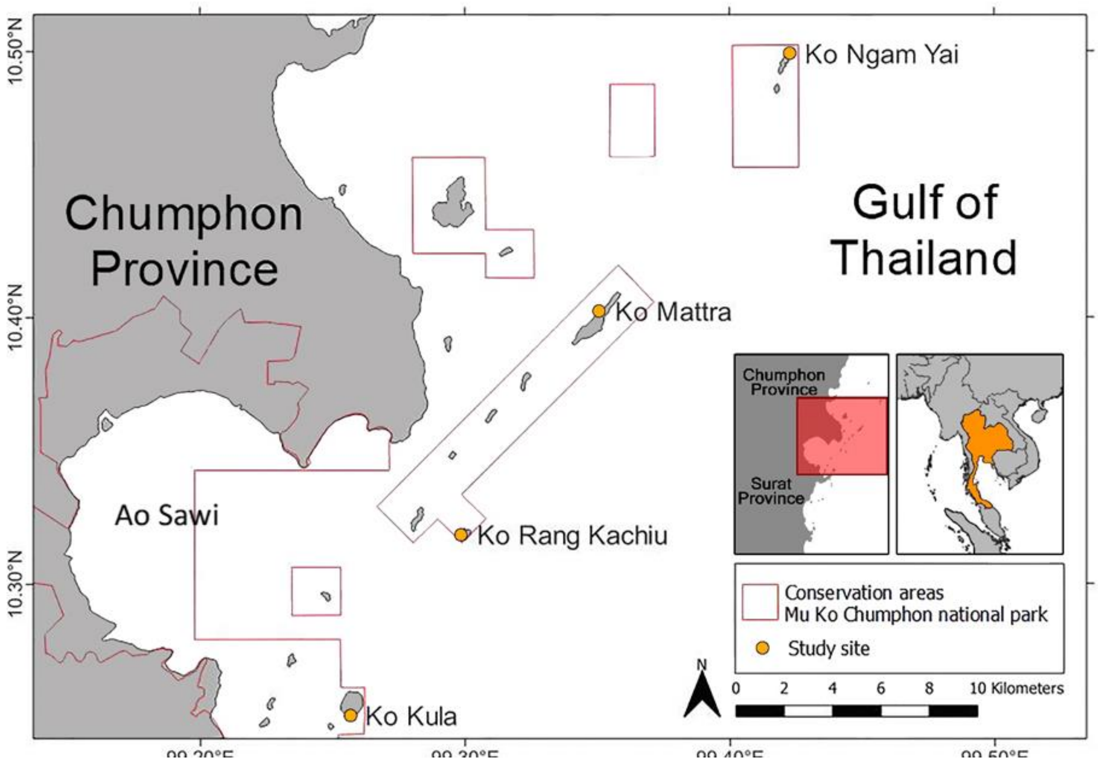

Figure 1. Location of the study sites in Chumphon Province in the Gulf of Thailand

Table 1. Some information of the study sites

Study sites	Latitude (N),	Longitude (E)	Distance from the shore (km)	Anthropogenic activities
Ko Ngam Yai	10.498071°	99.423039°	17.4	Scuba diving
Ko Mattra	10.402197°	99.351128°	7.1	Tourism, Fishery*
Ko Rang Kachiu	10.318395°	99.299067°	4.7	Tourism
Ko Kula	10.251055°	99.255776°	2.3	Tourism, Fishery*

*small-scale fishery

2.2 Data collection

The field surveys were conducted in February 2021. At each study site, coral disease and signs of compromised health were observed on shallow reef flats in a belt transect (30 m x 1 m) with three replicates. Coral signs of compromised health were inspected for lesions causing morphological tissue changes, based on the identification guidelines of Aeby (2006) and Raymundo et al. (2008), which provide instructions for recording coral disease through observations. The prevalence and severities of coral diseases or signs of compromised health were calculated and expressed as a percentage of the disease prevalence, disease severity, and disease occurrence (Bruno et al. 2003; Samsuvan et al. 2019).

2.3 Data analyses

The total prevalence of disease surveyed is estimated based on the average number of colonies per square meter found within the belt transect using calculated as follows (Aeby 2006): *Disease prevalence* % =

$$\left(\frac{number\ of\ colonies\ with\ lesions}{total\ number\ of\ estimated\ colonies}\right) \text{x } 100$$

Severity of disease was calculated as follows: *Disease severity* % =

$$\left(\frac{area\ of\ disease\ presence}{the\ total\ area\ of\ estimated\ colonies}\right) \text{x } 100$$

Frequency of disease occurrence (FOC) was calculated as follows: FOC % =

$$\left(\frac{number\ of\ sites\ with\ disease}{total\ number\ of\ sites\ surveyed}\right) \text{x } 100$$

One-way Analysis of Variance (ANOVA) was used to detect the differences in disease severity among study sites and types of the diseases. Fisher's LSD test was selected for multiple comparisons when the ANOVA yielded significant results. All analyses were performed using R version 4.1.1.

3. Results

3.1 Coral community structure

A total of 29 coral species were found at all study sites. Ko Ngam Yai had the highest diversity of coral (19 species, Simpson's Diversity Index = 0.87), followed by Ko Kula (10 species, Simpson's Diversity Index = 0.69), Ko Rang Kachiu (7 species, Simpson's Diversity Index = 0.49), and Ko Mattra (6 species, Simpson's Diversity Index = 0.30). The highest average number of observed coral colonies was found at Ko Kula (294.34 ± 80.27 colonies), followed by Ko Ngam Yai (271.00 ± 98.51 colonies), Ko Mattra (197.00 ± 15.06 colonies), and Ko Rang Kachiu (182.33 ± 78.14 colonies). Ko Mattra had the highest live coral coverage (67.50 ± 8.09), followed by Ko Rang Kachiu (53.63 ± 6.43), Ko Ngam Yai (35.00 ± 4.20), and Ko Kula (29.67 ± 1.16) (Table 2).

The relative abundance of coral taxa varied among study sites. Ko Ngam Yai was dominated by *Porites rus*, whereas Ko Mattra and Ko Rang Kachiu were dominated by *Porites lutea*. At Ko Kula, *Pavona frondifera* is a dominant coral species (Figure 2). However, Ko Ngam Yai had the highest diversity of coral species compared to the other study sites.

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Table 2. Coral diseases information within study sites in Chumphon Province in February 2021

	Substrate (%)	Total of colony counts (colony)	Simpson's Diversity Index	Frequency of occurrence (%)	Occurrence of coral diseases (colony)	Prevalence (%)
Ko Ngam Yai						
Live corals	35.00 ± 4.20	271.00 ± 98.51	0.87	45.45	43.43 ± 2.52	15.87 ± 0.25
Dead corals	1.85 ± 0.22					
Rubble area	5.17 ± 0.62					
Sand area	40.89 ± 4.90					
Rock area	1.99 ± 0.24					
Other	15.10 ± 1.81					
Ko Mattra						
Live corals	67.50 ± 8.09	197.00 ± 15.06	0.30	42.42	62.20 ± 6.76	31.47 ± 3.70
Dead corals	28.40 ± 3.14					
Rubble area	1.02 ± 0.13					
Sand area	0.98 ± 0.12					
Rock area	1.12 ± 0.13					
Other	0.97 ± 0.03					
Ko Rang Kachiu						
Live corals	53.63 ± 6.43	182.33 ± 78.14	0.49	51.52	72.24 ± 7.53	39.56 ± 2.35
Dead corals	18.97 ± 2.27					
Rubble area	11.56 ± 1.44					
Sand area	13.86 ± 1.66					
Rock area	1.80 ± 0.21					
Other	0.18 ± 0.01					
Ko Kula						
Live corals	29.67 ± 1.16	294.34 ± 80.27	0.69	63.64	84.28 ± 5.37	28.57 ± 2.87
Dead corals	5.14 ± 0.62					
Rubble area	12.48 ± 1.55					
Sand area	18.92 ± 3.47					
Rock area	32.74 ± 4.99					
Other	1.05 ± 0.03					

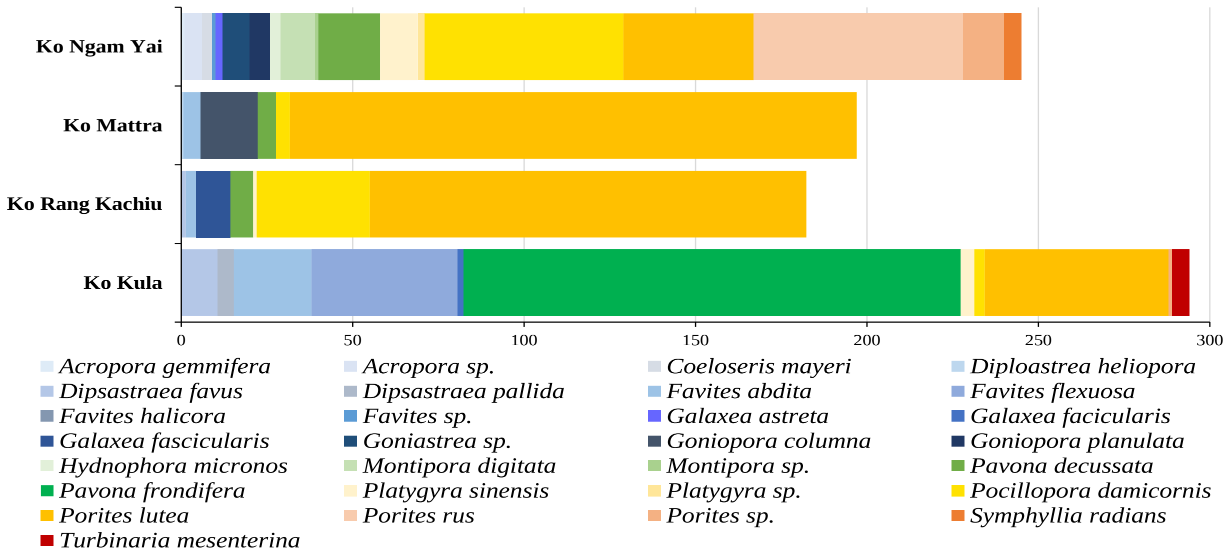

Figure 2. The proportion of coral species in Chumphon Province

3.2 Occurrence of coral diseases

Overall, the prevalence of coral diseases ranged from 15.87–39.56%, and Ko Rang Kachiu showed the highest prevalence. The occurrence of coral diseases varied from 43.43 - 84.28 %, and Ko Kula had the highest occurrence. In terms of the frequency of occurrence, the highest one was found at Ko Kula (FOC = 63.64%) and followed by Ko Rang Kachiu (FOC = 51.52%), Ko Ngam Yai (FOC = 45.45%), and Ko Mattra (FOC = 42.42%) (Table 1).

Based on the survey at the shallow reef flats, a total of eleven coral diseases were recorded in eight coral species, consisting of partial mortality, pigmentation responses (pink lines, pink patches, pink spots, and pink borers), white syndromes (white syndromes, white patches, white bands, and ulcerative white-spots), and unusual bleaching patterns. The Frequency of occurrence of coral disease ranged from 8.33-66.67%. Massive P. lutea had the greatest variety of diseases, in which uncreative white spots (UWS) showed the highest frequency of occurrence (Table 3).

3.3 Severity of coral disease

The most severity of coral disease were found at Ko Kula (7.11%), followed by Ko Rang Kachiu (3.02%), Ko Ngam Yai (1.94%), and Ko Mattra (1.32%). Most study sites had similar types of coral disease, but the severity of the diseases varied among study sites (Table 5).The highest severity of white syndromes was detected with *Diploastrea heliopora* (10.04%) at Ko Mattra. Pink spots were observed with a high severity at Ko Kula (2.40%). Ko Mattra showed a high severity of pink borers (0.47%) compared to other study sites. In the case of white patches syndrome and trematodiasis caused by trematode parasites, nearshore islands had more severity of the diseases than offshore.

The results from one-way ANOVA revealed the spatial variation of disease severity among study sites (*p*-value = 0.034). Fisher's LSD test illustrated that the severity of coral diseases at Ko Kula was significantly different from that at Ko Ngam Yai (*p*-value = 0.011) and Ko Mattra (*p*-value = 0.009). No significant difference in disease severity among other study sites (Table 5). In terms of the difference in disease types, one-way ANOVA revealed the variation of severity between study sites and coral diseases (p-value < 0.001). Fisher's LSD test illustrates that each character of coral disease affected corals was significantly different (p-value < 0.001). Overall, the severities of pink spots and ulcerative white spots were significantly different from other types of coral disease and compromised health (Table 6).

Table 3. Frequency of occurrence of coral disease on eight species in Chumphon Province

Species	PM	PL	PP	PS	PB	T	WS	WP	WB	UWS	UBP
Diploastrea heliopora	0	0	0	0	0	0	8.33	0	0	0	0
Goniastrea aspera	0	0	0	0	0	0	0	0	0	8.33	8.33
Goniopora columna	0	0	0	0	0	0	8.33	0	0	0	0
Pavona decussata	0	0	0	0	0	0	0	16.67	0	0	8.33
Platygyra daedalea	8.33	0	0	0	0	0	0	0	0	0	0
Porites lobota	0	0	0	0	0	16.67	0	0	0	0	0
Porites lutea	5.00	33.33	25.00	41.67	58.33	58.33	25.00	33.33	5.00	66.67	5.00
Porites rus	16.67	0	0	33.33	33.33	0	0	16.67	16.67	33.33	16.67

Remarks: PM = Partial mortality, PL = pink lines, PP = pink patches, PS = pink spots, PB = pink borers, T = Trematodiasis, WS = white syndromes, WP = white patches, WB = white bands, UWS = uncreative white spots, and UBP = unusual bleaching patterns

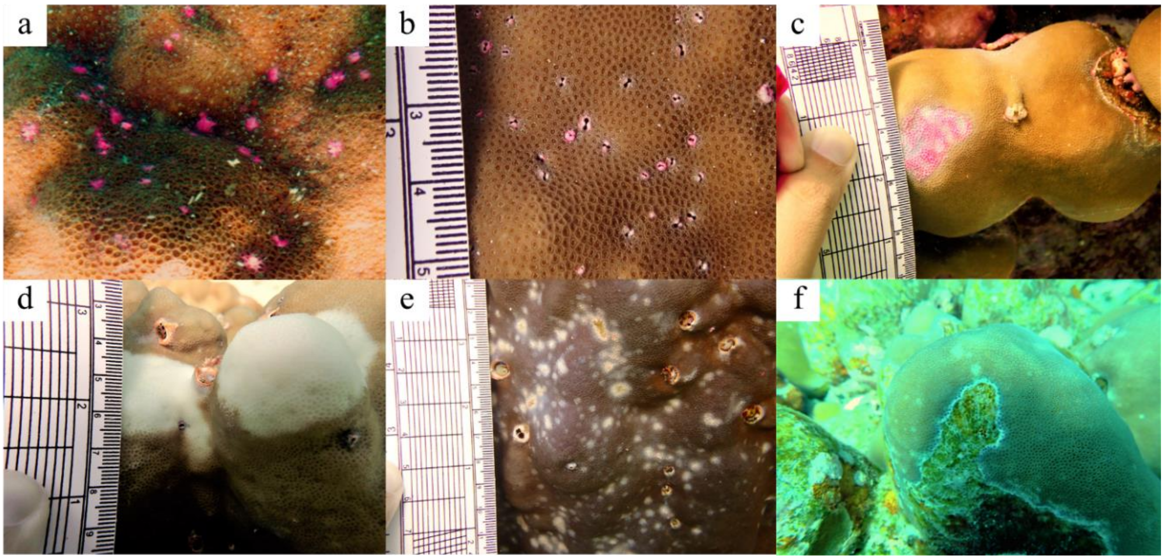

Figure 3. Characteristics of coral diseases: pink spots (a), pink borers (b), pink patches (c), unusual bleaching patterns (d), ulcerative white spots (e), and partial mortality (f)

Table 4. Severity of coral disease on eight species in Chumphon Province

Coral disease	PM	PL	PP	PS	PB	T	WS	WP	WB	UWS	UBP	Total
Species												
Diploastrea heliopora	0	0	0	0	0	0	10.04	0	0	0	0	**10.04**
Goniastrea aspera	0	0	0	0	0	0	0	0	0	4.86	0.64	**5.50**
Goniopora columna	0	0	0	0	0	0	0.60	0	0	0	0	**0.60**
Pavona decussata	0	0	0	0	0	0	0	0.73	0	0	0.14	**0.87**
Platygyra daedalea	2.72	0	0	0	0	0	0	0	0	0	0	**2.72**
Porites lobota	0	0	0	0	0	1.46	0	0	0	0	0	**1.46**
Porites lutea	0.17	0.08	0.01	1.11	0.27	0.50	0.03	0.05	0.18	1.16	0.11	**3.67**
Porites rus	0.14	0	0	4.51	1.00	0	0	0.17	0.08	4.08	0.06	**10.05**
Study sites												
Ko Ngam Yai	0.04	0.01	0.01	0.59	0.06	0.02	0	0.01	0.02	1.17	0.02	**1.94**
Ko Mattra	0.07	0.09	0	0.16	0.47	0.11	0.13	0.08	0.03	0.20	0.01	**1.35**
Ko Rang Kachiu	0.09	0.01	0	0.63	0.14	0.45	0.06	0.10	0.17	1.24	0.13	**3.02**
Ko Kula	0.35	0.13	0.04	2.40	0.17	0.62	0.11	0.15	0.50	1.89	0.77	**7.11**

Remarks: PM = Partial mortality, PL = pink lines, PP = pink patches, PS = pink spots, PB = pink borers, T = Trematodiasis, WS = white syndromes, WP = white patches, WB = white bands, UWS = uncreative white spots, and UBP = unusual bleaching patterns

Table 5. Results of one-way ANOVA and Fisher's LSD test examining the variation of severity among study sites

Source of Variance	df	Mean square	F	*p*-value
Between groups	3	0.246	3.179	0.034*
Within groups	40	0.077		
Ko Ngam Yai vs. Ko Mattra				0.976
Ko Ngam Yai vs. Ko Rang Kachiu				0.400
Ko Ngam Yai vs. Ko Kula				0.011*
Ko Mattra vs. Ko Rang Kachiu				0.383
Ko Mattra vs. Ko Kula				0.009**
Ko Rang Kachiu vs. Ko Kula				0.078

Remarks: * Significant difference p-value < 0.05; ** Significant difference p-value < 0.01

4. Discussion

4.1 Coral disease at shallow reef flats

The findings from the present study are important, enabling us to understand the prevalence and the severity of coral diseases on shallow reef flats and the impacts of anthropogenic activities. This study reveals the spatial variation in the prevalence of coral diseases between nearshores and offshore study sites.

The prevalence seemed to be higher in nearshore sites (Ko Mattra, Ko Rang Kachiu, and Ko Kula) than offshore (Ko Ngam Yai). The severity of coral diseases differed among study sites. Lower severity of coral diseases was found on shallow reef flats at Ko Mattra and Ko Rang Kachiu compared with the report of Samsuvan et al. (2019), who investigated disease severity at At Ko Mattra and Ko Rang Kachiu in 2019. They reported that the coral disease severities at At Ko Mattra and Ko Rang Kachiu were 4% and 3%, respectively, whereas the severities observed in the present study were only 1.35% and 3.02%. The prevalences at Ko Mattra and Ko Rang Kachiu were 31.47% ± 3.70% and 39.56% ± 2.35%, respectively (Table 2); however, Samsuvan (2016) found the higher prevalence at both study sites, which were 62% and 34%, respectively. Since both study sites are popular dive sites, the prevalence of coral disease on shallow reef flats might correlate with tourism activities (Table 1). Thus, the impacts of tourism activities should be focused and properly managed, particularly the physical damages caused by divers and anchoring as well as tourism-related pollution (Lamb et al. 2014; Samsuvan et al. 2019; Wongnutpranont et al. 2020).

Source of Variance	df	Mean square	F	*p*-value
Between groups	10	3953.352	25.987	<0.001**
Within groups	240	152.131		
PS vs. PM				<0.001**
PS vs. PL				<0.001**
PS vs. PP				0.001**
PS vs. PB				<0.001**
PS vs. T				<0.001**
PS vs. WS				<0.001**
PS vs. WP				<0.001**
PS vs. WB				<0.001**
PS vs. UBP				<0.001**
UWS vs. PM				<0.001**
UWS vs. PL				0.001**
UWS vs. PP				0.010**
UWS vs. PB				<0.001**
UWS vs. T				<0.001**
UWS vs. WS				<0.001**
UWS vs. WP				<0.001**
UWS vs. WB				<0.001**
UWS vs. UBP				<0.001**

Remarks: * Significant difference p-value < 0.05; ** Significant difference p-value < 0.01
PM = Partial mortality, PL = pink lines, PP = pink patches, PS = pink spots, PB = pink borers, T = Trematodiasis, WS = white syndromes, WP = white patches, WB = white bands, UWS = uncreative white spots, and UBP = unusual bleaching patterns

4.2 Future concerns about Porites coral

Massive *Porites* genera (including *P. lobota*, *P. lutea*, and *P. rus*) have been concerned about their health issues that might be more vulnerable to various threats in the future. Massive *Porites* genera (particularly *P. lutea* and *P. rus*) showed the higher FOC and the severity of pink borers, trematodiasis, and uncreative white spots, compared with other diseases. Pink borers and trematodiasis were caused by parasites, transmitting through water with high nutrient and suspended sediment (Bruno et al. 2003). *Porites* trematodiasis is caused by the larval stage of a digenetic trematode; however, the complete life cycle of this parasite is still unknown. According to the latest evidence, *Podocotyloides stenometra* has a complex life cycle; it is the first intermediate host before transmitting to *Porites* spp. which is the second intermediate host, and eventually transmiting to fish as the definitive host (Aeby 2016). Although the severity of diseases on *Porites* is not a critical point at present, the impacts of climate change and intensive anthropogenic activities may probably increase the severity in the future. Therefore, in-depth research on this issue and precautionary measures are required to increase their resilience to diseases (Kritsanapuntu and Angkhananukroh 2014; Lamb et al. 2014; Ramesh et al. 2019; Raymundo et al. 2008; Wongnutpranont et al. 2021).

4.3 The variation in disease severity at nearshore study sites

The high severities of coral disease on shallow reef flats were found at Ko Kula and Ko Rang Kachiu. These study sites are located near the coast and they have been influenced by rivers or canals, coastal development, and human activities along Ao Sawi Coast, Chumphon Province (Figure 1). The unmanaged coastal development and other anthropogenic activities can cause land-based pollution, which further promotes the frequency and severity of coral diseases on shallow reef flats located nearshore. Although coral diseases have been focused on among scholars, this issue is quite new among the public society and decision-makers. Therefore, coral reef managers should include this issue into their regular surveys to build up consistent monitoring information concerning the signs, prevalence, severity of coral diseases and signs of compromised health and their impacts. Such information will be useful for marine spatial planning (MPA) and coastal management to enhance coral reef resilience and sustainability (Samsuvan et al. 2019; Wongnutpranont et al. 2020; Yeemin et al. 2009; Yeemin et al. 2012).

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