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Original Research

Reef health assessment of Pulau Payar Marine Park during the Covid-19 pandemic in Malaysia

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Abstract

Pulau Payar Marine Park (PPMP) consists of four islands, namely Pulau Payar, Pulau Kaca, Pulau Lembu and Pulau Segantang. This study was carried out in PPMP from June 2020 to February 2021, during the implementation of Malaysia's Movement Control Order in response to the Covid-19 pandemic in the country. The purpose of this study was to determine the species, coverage and biomass of corals and fish present within the area and to assess its coral health status. Data were derived at 11 sites at depths of 5 to 10 m. The Point Intersect Line method was applied to record benthic communities for every meter across two 50-meter transect lines. The outcomes showed that benthic communities were dominated by scleractinian corals, with an average of 25% coverage at all islands. Pulau Payar, Pulau Kaca, Pulau Lembu and Pulau Segantang were characterized by 37%, 33%, 25% and 37% live coral cover respectively. A total of 14 families, 30 genera and 49 species of scleractinian coral species were identified, giving the latest comprehensive species list for this marine park. The most common species recorded was *Porites lutea*, followed by *Physogyra lichtensteini*. The fish survey revealed a total of 39 fish species from 23 genera, encompassing 16 families, with Lutjanidae being the dominant group. Fish biomass values varied between 20 g/m^2 and 183 g/m^2 at each site. Shannon-Wiener diversity (H), Evenness (E) and coral health index (CHI) were calculated for each island. The H values ranged between 2.03 and 3.01. Pulau Payar had the highest value of H, at 3.01, and the highest number of species. The E values ranged from 0.75 to 0.85, showing that the scleractinian corals of PPMP were relatively evenly distributed. CHI at each site ranged from 0.17 to 0.24. Overall, the health condition of the coral reefs in PPMP was considered degraded. This study provides valuable insights into the benthic and fish communities of PPMP through its health assessment.

Malaysia is a maritime nation blessed with rich marine biodiversity and extensive coral reefs that create an amazing underwater forest (Misni and Jarami, 2021; Misman *et al.*, 2023). Coral reefs and their associated habitats are biologically and economically important in Malaysia. They provide food for local people, a shelter for marine animals, coastal protection, and recreational and tourism activities (Praveena *et al.*, 2012). Although the corals are widespread in Malaysia, its coral reefs are among the most threatened in the world (Arai, 2015; Safuan *et al.*, 2021). With the decreasing health of coral reefs globally and mounting ecological pressures, constant monitoring of the reef status is vital for good management and conservation practices. While most of the reefs in Peninsular Malaysia were considered poor or fair, some were in good condition, especially in marine protected areas (MPAs), highlighting the importance of MPAs, such as marine parks, in their conservation (Waheed, 2016; Ismail and Goeden, 2022).

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Many studies have been conducted on coral reef communities in Malaysia, especially in MPAs, to determine the health status of the reefs (Toda *et al.*, 2007; Safuan *et al.*, 2021; Ismail and Goeden, 2022; Yu *et al.*, 2023). This interest can be attributed mainly to the growing concern for the conservation and preservation of coral reef ecosystems (Misman *et al.*, 2023). However, there has been a steady decline in coral reef health over the last two decades (Praveena *et al.*, 2012; Kimura *et al.*, 2014; Rudra, 2018; Ismail and Goeden, 2022). All reefs in Malaysia are considered to be under heavy anthropogenic threat (Praveena *et al.*, 2012; Kimura *et al.*, 2014). The impact of tourism has been documented as one of the main reasons for the environmental degradation in MPAs (Ismail and Goeden, 2022). Fortunately, most reefs can recover with the help of good management, and such management involves regular monitoring of reefs to assess their health status (Rudra, 2018).

Coral health status provides information about the health and resilience of the coral reef ecosystems and aids in recognising and addressing the threats facing them (Misman *et al.*, 2023). Assessments of the health status of coral reefs have been conducted using a variety of environmental parameters. More commonly, coral reef condition has been determined using a single parameter, such as the live coral cover (Giyanto *et al.*, 2017). The assumption is that the higher the live coral cover, the healthier the reef will be.

During 2020, the Covid-19 pandemic led to strict lockdowns in many countries around the globe (Edward *et al*., 2021; Somchuea *et al*., 2022). In Malaysia itself, in response to the pandemic, the government implemented the Movement Control Orders (MCO), which started from 18th March 2020, and lasted for almost 20 months. During this period, human activities were limited and restricted (Chuan *et al*., 2021). The MCO was anticipated to have a positive impact on the aquatic ecosystem, including coral reefs (Chuan *et al*., 2021; Somchuea *et al*., 2022).

Prior to the Covid-19 pandemic, several studies were conducted at the Pulau Payar Marine Park on its coral reefs, but comprehensive information on coral health and reef communities remained insufficient (Sze *et al*., 2000; Jonsson, 2002; Ramli *et al*., 2016; Khodzori *et al*., 2019; Normah *et al*., 2021). Similarly, there was no information collected immediately following the pandemic that could clarify the reduced anthropogenic impacts on the reefs of the marine park. In order to successfully manage the future of coral reefs, an assessment of various aspects of the reef community structure is needed, and regularly updating the information on coral health status is the key to better managing marine park reef ecosystems. Thus, the objectives of this study were to assess the coral health and provide an up-to-date baseline reference on the coral and fish communities of Pulau Payar Marine Park.

Materials and methods

Study area

The Pulau (= island) Payar Marine Park (PPMP) is located on the west coast of Peninsular Malaysia, between Pulau Langkawi and the mainland of Kuala Kedah. It stretches 2 nautical miles, making up a cluster of four small islets namely, Pulau Payar (the largest), Pulau Kaca, Pulau Lembu and Pulau Segantang (the outermost island to the west of Pulau Payar). All the islands are uninhabited, except by on-duty management authorities from the Department of Fisheries, Malaysia. As a marine park, fishing and other resource extraction activities, either for hobby or commercial purposes, are strictly prohibited (Alias and Mohd. Saupi, 2000; Misni and Jarami, 2021). However, because of its proximity to the well-known tourism island of Langkawi, located approximately 50 km to the northwest of PPMP, this marine park became a very popular destination, and before the implementation of the MCO, the park was open to the public all year round.

This study was carried out from June 2020 to February 2021 during the implementation of the Malaysian MCO. During that period, PPMP was totally closed to the public. No activity was undertaken except for operational and research purposes employed by the management authorities. For this study, underwater surveys using the Self-Contained Underwater Breathing Apparatus (SCUBA) were carried out at 11 selected sites (Table 1 and Figure 1). All study sites were generally considered tourist spots for SCUBA diving activities.

Table 1. Location and depth profile of the survey sites.

Sampling site	Average depth (m)	Location	Coordinate (Lat. / Long.)
P1	5.5	Pulau Payar	6°3'45.68"N / 100°2'30.51"E
P2	7.0	Pulau Payar	6°3'21.96"N / 100°2'11.04"E
P3	6.0	Pulau Payar	6°3'53.02"N / 100°2'21.16"E
P4	7.0	Pulau Payar	6°4'7.76"N / 100°2'41.59"E
K1	5.5	Pulau Kaca	6°4'18.03"N / 100°3'4.42"E
K2	9.5	Pulau Kaca	6°4'21.53"N / 100°3'2.17"E
L1	6.5	Pulau Lembu	6°4'26.61"N / 100°3'26.88"E
L2	7.5	Pulau Lembu	6°4'22.19"N / 100°3'18.56"E
S1	9.5	Pulau Segantang	6°2'37.30"N / 99°55'29.90"E
S2	8.5	Pulau Segantang	6°2'37.46"N / 99°55'34.15"E
S3	7.5	Pulau Segantang	6°2'40.59"N / 99°55'34.20"E

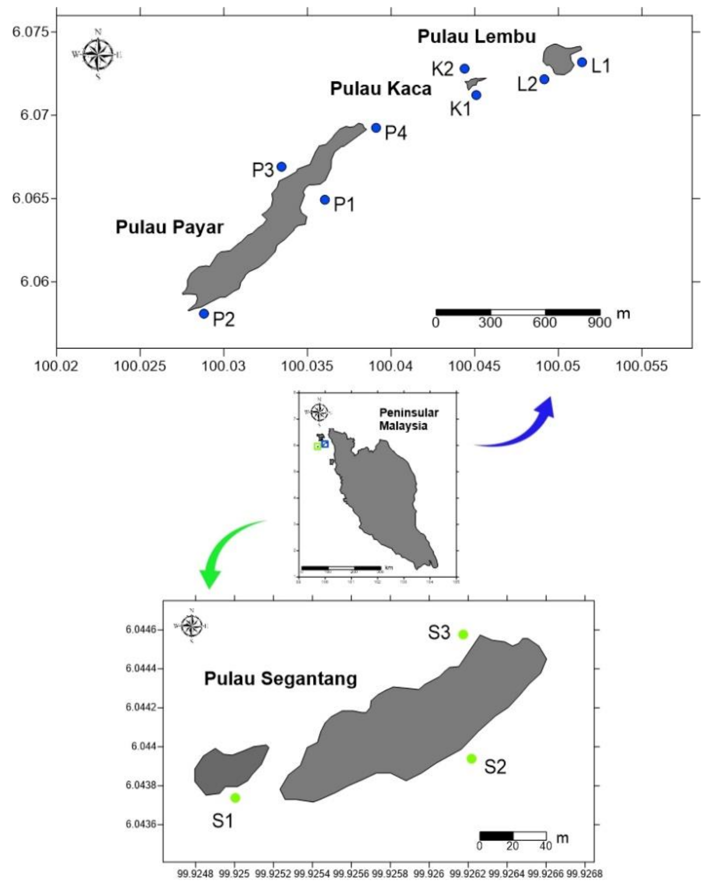

Figure 1. Map showing the sampling sites of Pulau Payar Marine Park: P1 (House Reef), P2 (Coral Garden), P3 (Lobster Garden), P4 (Porites Garden), K1 (Sunken Boat), K2 (Shark Point), L1 (Eastern Reef), L2 (Rock Point), S1 (Cupak Wall), S2 (Anemone Garden), S3 (Segantang Tip).

Sampling procedures

Benthic substrate coverage was ascertained using a point interface transect method (Eleftheriou, 2013; Ilias, 2022). Data were collected at every 1 m interval on duplicated 50 m transects at depths of 5 to 10 m. For every 1 m, all benthos found within 0.25 m from that point were counted and their sizes recorded, following the method by Ismail and Khoo (2019). The benthic communities were categorized as biotics (scleractinian coral, non-scleractinian corals, coralline algae and fleshy algae) or abiotics (dead corals, rocks and sands). Dead corals consisted of white, clean coral skeletons without living tissues (Ilias, 2022). Coral species were also photographed individually for identification and verified up to species level using keys by Kelley (2016), Ismail (2021) and Veron *et al*. (2023).

Assessments of fish communities were conducted by visual census along the same 50-metre-long transects, following the method described by Eleftheriou (2013). The total lengths of fish were estimated in cm, which were later used to calculate biomass. Fish were photographed and identified up to species level using published references (Allen, 2020; Froese and Pauly, 2023).

Data analysis

The coral health was determined using a live coral coverage (LCC) value and a two-dimensional coral health index (2D-CHI), which was based on two parameters, namely benthos coverage and fish biomass (Ilias, 2022; Kaufman *et al*., 2011; Diaz-Perez *et al*., 2016). The value of LCC is considered poor, fair, good or excellent based on ranges of

0-25%, 26-50%, 51-75% and 76-100% respectively (Ilias, 2022). While the 2D-CHI value is categorized as very degraded, degraded, fair, healthy or very healthy based on the values of 0-0.19, 0.20-0.39, 0.40-0.59, 0.60-0.79 and 0.80-1.0 respectively (Kaufman *et al.*, 2011; Diaz-Perez *et al.*, 2016).

The relative abundance (RA) values for each species were determined following the method by Rilov and Benayahu (2000) and were categorized as Not Recorded (RA=0%), Rare (0<RA<0.1%), Uncommon (0.1<RA<1%), Common (1<RA<10%), Abundant (10<RA<20%) or Dominant (RA>20%). Coral diversity was calculated using the Shannon-Weaver index (H) and evenness index (E) (Ortiz-Burgos, 2016). The interpretation of the Shannon-Weaver index is that if H is a larger number, it is more diverse, and if E is closer to the value of 1, the species are more evenly distributed.

The biomass values of all fish were calculated using the length-weight relationship formula (Kulbicki *et al.*, 2005) as follows,

$W = a \times L^b$

Where "W" = weight (g); "L" = total length (cm); and "a" and "b" = constant.

The value of CHI for benthos was measured based on the proportion of live scleractinian coral cover and coralline algae over all substrates. The assessment of CHI for fish was measured by dividing the total fish biomass by the value of 500 g/m^2 (the maximum CHI value will be 1.0) (Kaufman *et al.*, 2011).

The total 2D-CHI was then calculated based on the formula listed by Kaufman *et al.* (2011), as follows,

2D-CHI = [(CHI benthos + CHI fish)/2]

Results and Discussion

Coral communities

A total of 22 transects were conducted within PPMP. The LCC of PPMP ranged between poor and fair conditions (20.00-49.69%) with an average value of 33.05 ± 4.89% (Table 2). Out of 11 sites, sites K1 and L1 were categorized as having poor coverage of live corals, while others were in the fair category. No sites were categorized as good LCC. The S1 site of Pulau Segantang and the L1 site of Pulau Lembu had the highest and lowest values of LCC, with 49.69% and 20.00% respectively. S1 also had the highest percentage of non-scleractinian corals (27.67%). The average LCC value of 33.05% was considerably higher than the previous study in 2014 at PPMP by Khodzori *et al.* (2019) at 15.70%. However, the result was lower than the earlier study in 2001 by Toda *et al.* (2007) and the recent study in 2021 by DOFM (2022), which recorded LCC of 50.00% and 44.88% respectively. This result could suggest that the restriction of human activities in PPMP may be associated with a rise in the percentage of LCC. This could also result from survey differences between this study and Toda *et al.* (2007), Khodzori *et al.* (2019) and DOFM (2022), who only surveyed 2, 7 and 5 sites respectively.

Dead corals within PPMP had an average cover of 16.07%. The highest percentage of dead corals can be found at the P1 site of Pulau Payar and the K1 site of Pulau Kaca, with 28.35% and 25.32% respectively. Based on regular observations, both sites were considered favorite tourist spots for snorkeling and diving. The high proportion of dead corals in popular locations within MPAs could be related to human use. Maidin *et al.* (2022) stated that water-related tourist activities have been identified as among the major stressors in coral reef areas. The average cover of dead corals was lower than the previous study by Khodzori *et al.* (2019) at 16.50%. Jonsson (2002) reported that the dead corals percentage was inversely related to the LCC. Thus, the lower percentage of dead corals in this survey was supported by the higher percentage of LCC.

The present study recorded a total of 49 species, 30 genera and 14 families of scleractinian corals, and 7 genera of non-scleractinian corals in PPMP (Table 3). The total number of scleractinian coral species represented a large proportion of the 56 species that were documented by Waheed (2016) in the Straits of Malacca. The most common species recorded was *Porites lutea*, followed by *Physogyra lichtensteini*, a vulnerable species according to the International Union for Conservation of Nature's (IUCN) Red List (IUCN, 2024). *Porites lutea* was the only species that was found at all sites. The dominance of *Porites* and Physogyra in PPMP was confirmed by Khodzori *et al.* (2019). *Porites* was also found to be dominant on Langkawi reefs (Jonsson, 2002; Ismail *et al.*, 2022). Besides *P. lichtensteini*, five other vulnerable species were recorded, i.e., *Duncanopsammia peltata*, *Pachyseris rugosa*, *Pavona decussata*, *Turbinaria mesenterina* and *T. reniformis*.

Based on relative abundance (RA) values, *Porites lutea* was abundant at Pulau Payar, Pulau Kaca and Pulau Lembu, with 18.63%, 11.34% and 16.86% respectively. *Physogyra lichtensteini* was abundant at Pulau Payar (11.99%) and Pulau Lembu (11.66%). *Dipsastraea favus* was abundant at Pulau Kaca (10.13%), and *Acropora grandis* was dominant at the K1 site of Pulau Kaca. A rare species, *Podabacia lankaensis*, was uncommonly found on both the northern (P4) and southern (P2) tips of Pulau Payar (Figure 2). This species was previously recorded in the Andaman Seas (Ramakrishna *et al.*, 2010). No record of *P. lankaensis* was reported in Malaysian waters (Waheed, 2016). However, because PPMP is located adjacent to the Andaman Seas, some other common coral species of the Andaman Seas can also be found in PPMP. This species inhabits shallow, horizontal, protected and partly turbid environments (Veron *et al.*, 2023), which is the characteristic of sites P2 and P4. Seven non-scleractinian coral genera were also recorded, dominated by *Rhodactis* spp., particularly at Pulau Segantang (17.69%). Non-scleractinian corals were the most dominant coral type in Pulau Segantang, as reported by Sze *et al.* (2000). However, the total number of non-scleractinian coral genera recorded in this study (7) is relatively low compared to the 15 genera that were recorded by Mohammad *et al.* (2016) in the Straits of Malacca.

Figure 2. *Podabacia lankaensis* at Pulau Payar.

Thirty scleractinian coral genera recorded in this study were a decrease from the 36 genera reported in the previous study by Khodzori *et al.* (2019), although the number of non-scleractinian coral genera increased from that study. The existence of genera Acanthastrea, Blastomussa, Coeloseris, Coscinaraea, Gardineroseris, Herpolitha, Leptoria, Leptoseris, Montastraea, Polyphyllia and Stylophora were not confirmed by this study. This could either be due to declines in their populations or community differences among sampling sites. Diversity indices have often been used in coral reef studies and they have been recommended to complement the coral health assessment (Diaz-Perez *et al.*, 2016). Generally, the higher value of the Shannon-Weaver index (H) corresponds to a higher diversity of coral communities. Coral diversity showed the lowest and highest H values of 2.03 and 2.98 at Pulau Lembu and Pulau Payar respectively (Table 4). The Pulau Payar diversity value was supported by the highest species richness with 37 species. Lower coral diversity

Table 2. Percentage cover of live corals and other benthic substrates at PPMP.

Site	SC	NC	DC	CA	OA	OB	LCC	Coral condition
P1	39.37	0.79	28.35	2.36	24.41	4.72	40.16	Fair
P2	32.39	12.68	19.72	0	20.42	14.79	45.07	Fair
P3	23.03	7.27	9.70	6.06	38.18	15.76	30.30	Fair
P4	30.58	1.65	14.05	0	45.45	8.26	32.23	Fair
Payar (Mean)	31.34±5.81	5.60±4.79	17.95±6.97	2.11±2.48	32.12±10.13	10.88±4.58	36.94±5.97	Fair
K1	25.32	0.63	25.32	0	32.28	16.46	25.95	Poor
K2	27.95	11.80	17.39	4.35	31.06	7.45	39.75	Fair
Kaca (Mean)	26.63±1.32	6.22±5.58	21.35±3.96	2.17±2.17	31.67±0.61	11.95±4.50	32.85±6.90	Fair
L1	20.00	0	15.00	0	63.33	1.67	20.00	Poor
L2	27.63	2.63	23.68	0.66	43.42	1.97	30.26	Fair
Lembu (Mean)	23.82±3.82	1.32±1.32	19.34±4.34	0.33±0.33	53.38±9.96	1.82±0.15	25.1±5.13	Fair
S1	22.01	27.67	6.29	0.63	23.27	20.13	49.69	Fair
S2	18.25	11.11	7.14	5.56	16.67	41.27	29.37	Fair
S3	20.11	12.64	3.45	6.90	23.56	33.33	32.76	Fair
Segantang (Mean)	20.13±1.53	17.14±7.47	5.63±1.58	4.36±2.69	21.17±3.18	31.58±8.72	37.27±8.89	Fair
PPMP (Mean)	25.48±4.10	7.57±5.84	16.07±6.15	2.24±1.43	34.58±11.70	14.06±10.85	33.05±4.89	Fair

Notes: SC = Scleractinian corals; NC = Non-scleractinian corals; DC = Dead corals; CA = Crustose coralline alga; OA = Other abiota; OB = Other biota; LCC = Live coral cover (SC+NC).

has been related to a disturbed reef with a low value of LCC (Diaz-Perez *et al.*, 2016). Pulau Lembu had the lowest LCC of 25.13 ± 5.13% (Table 2). This island is the closest to the mainland and is potentially more exposed to coastal development and sewage runoff from the mainland. Diversity is a function of evenness and richness, and these vary on a coral reef with sample size and location (Ismail *et al.*, 2022). In terms of species evenness, the range of E between 0.75 and 0.85 showed that the corals of PPMP were very evenly distributed among the 49 species. In general, Pulau Payar had the highest value of species richness, the highest percentage of LCC and high value of E. This study categorized Pulau Payar as the most diverse and balanced coral reef ecosystem in PPMP.

Fish communities

From the fish survey, only 39 fish species, 23 genera and 16 families were recorded at PPMP (Table 5). Pulau Payar had the highest diversity of fish species while Pulau Lembu had the lowest diversity, with 30 and 16 species respectively. The total species observed was low when compared to earlier studies by Lee *et al.* (2005) and DMPM (2013), with 55 and 48 species respectively. However, the current number was higher compared to the 25 species recorded in the latest study at Pulau Payar by Ramli *et al.* (2016). The results clearly showed that, although the number of species was reduced over time, it had increased during the MCO. Somchuea *et al.* (2022) suggested that the sudden removal of human activities related to marine tourism had a positive effect on the numbers, density and species richness of the associated fish population.

None of the recorded fish were classified as endangered in the IUCN Red List of threatened species. Only one vulnerable fish species (*Epinephelus fuscoguttatus*) was found at the K2 site of Pulau Kaca. A hybrid grouper (*Epinephelus* sp.) was recorded in Pulau Segantang waters. However, it was not sighted at other islands of PPMP. This fish probably escaped from the off-shore cage culture in Langkawi and made Pulau Segantang its new home.

Family Serranidae had the highest number of species, followed by family Lutjanidae with 8 and 7 species respectively. Both families were targeted as food fish and were heavily fished due to their high commercial value. Therefore, changes in the abundance and sizes of these species observed gave an indication of the fishing pressure in the surrounding areas (Arai, 2015). Butterflyfish (family Chaetodontidae), which are often used as a biological indicator for coral health (Andersson, 2002), were observed in small numbers at all sites. Only 3 species of this family were found at PPMP, i.e., *Chaetodon collare*, *C. octofasciatus* and *Heniochus acuminatus*. The number of species in this family was very low compared to earlier studies by Andersson (2002) and Yusuf and Ali (2004), who recorded 7 and 16 species respectively. The abundance and number of species in this family were significantly correlated with the live coral cover, as many depend on the live coral cover for food and shelter (Andersson, 2002). The declining number of species may indicate that the corals in the area were degraded.

One of the more important variables of coral reef fish communities is the total biomass of targeted fish or commercially important fish, including herbivores and carnivores (Giyanto *et al.*, 2017). The fish biomass at all 11 sites had values ranging from 19.56 g/m^2 to 182.62 g/m^2, with an average of 60.31 ± 45.34 g/m^2. A similar range of fish biomass (11.18 g/m^2 to 193.62 g/m^2) has been reported by Safuan *et al.* (2022) at Pulau Perhentian Marine Park, located on the east coast of Peninsular Malaysia. Site P2 of Pulau Payar presented the highest fish biomass (182.62 g/m^2), contributed mainly by bigeye snappers (*Lutjanus lutjanus*). Family Lutjanidae contributed the highest fish biomass, with an average of 10.73 g/m^2, followed by Serranidae with 7.31 g/m^2. MacNeil *et al.* (2015) stated that coral reefs that maintained 500 kg of fish biomass per hectare (about 50% of an average reef's carrying capacity or about 50 g/m^2) were found to maintain ecological functions while sustaining local fisheries, providing fishery managers with a critical target. With an average of 60.31 ± 45.34 g/m^2 fish biomass, PPMP is "marginally sustainable", but lower resilience could result in a shift of the fish community into an unsustainable situation.

Alias and Mohd. Saupi (2000) reported that members of the family Lutjanidae and Serranidae were among the key target fish caught by fishermen from the waters surrounding PPMP, giving an indication of spill-over effect by the marine park. The waters around these islands are important fishing grounds for both traditional and commercial fishermen from the mainland as well as from Langkawi. As mentioned by Andersson (2002), PPMP contributed to the recruitment and increased survival of fish before "exporting" them to the surrounding areas. However, there were no large species from the family Carangidae found in this study. Similarly, no sightings of any other large apex predators, such as sharks, give an indication of truncation of the trophic pyramid.

Two-Dimensional Coral Health Index (2D-CHI)

The results showed that two islands (Pulau Lembu and Pulau Segantang) had 2D-CHI values of less than 0.20 (very degraded), while Pulau Payar and Pulau Kaca had values of under 0.40 (degraded) (Table 6). The average 2D-CHI value of PPMP was 0.20, indicating that the marine park's health was in a degraded condition.

Table 3. Relative abundance (RA) and average percentage of coral colonies of PPMP.

No	Species name	IUCN	P1	P2	P3	P4	Mean (%)	K1	K2	Mean (%)	L1	L2	Mean (%)	S1	S2	S3	Mean (%)
Scleractinian corals																	
Family: Acroporidae																	
1	*Acropora divaricate*	NT												**			0.22
2	*Acropora grandis*	LC	***	**	***		1.06	*****		16.91		***	1.00			***	1.01
3	*Acropora muricata*	NT				****	2.83										
4	*Astreopora gracilis*	LC	***				0.50										
5	*Montipora aequituberculata*	LC										***	1.00				
6	*Montipora hispida*	LC		***	***		1.54		***	0.75							
7	*Montipora verrucose*	LC			***		0.75							**			0.17
Family: Agariciidae																	
8	*Pavona decussata*	VU		***	**	***	1.46	**	***	1.36		***	1.00		**	**	0.67
9	*Pavona explanulata*	LC				**	0.13							***			0.44
Family: Dendrophyllidae																	
10	*Duncanopsammia peltata*	VU						**		0.33							
11	*Tubastraea aurea*	NE		**			0.13		***	0.70				***	***	***	3.55
12	*Tubastraea micranthus*	NE										***	0.99	***	**	***	1.60
13	*Turbinaria mesenterina*	VU							****	5.58		***	1.84	***			0.67
14	*Turbinaria reniformis*	VU		***		***	1.83		**	0.50							
Family: Diploastraeidae																	
15	*Diploastrea heliopora*	NT		***	**		1.29		***	1.45		****	7.66	***	***	**	2.55
	Euphyllidae																
16	*Euphyllia glabrescens*	NT				**	0.25										
17	*Galaxea fascicularis*	NT	***	**	***		1.38		**	0.50							
Family: Fungiidae																	
18	*Lithophyllon repanda*	LC										***	1.00				
19	*Podabacia crustacea*	LC							***	0.78					***		0.67
20	*Podabacia lankaensis*	NE		***		**	0.63							***	***	***	5.82
Family: Leptastreidae																	
21	*Leptastrea purpurea*	LC		***		**	1.93		***	2.88	***		1.00			***	0.67
22	*Leptastrea transversa*	LC	***		****		4.04		***	1.00				***	***	***	2.93
Family: Lobophylliidae																	
23	*Echinophyllia aspera*	LC		***			0.50										
24	*Lobophyllia agaricia*	LC							***	0.78							
25	*Lobophyllia radians*	LC	***				0.29		***	1.08		**	0.50			**	0.22
26	*Lobophyllia recta*	LC		***			1.55	**		0.50					***	***	1.89
Family: Merulinidae																	
27	*Cyphastrea chalcidicum*	LC		***	***	***	3.49									**	0.22
28	*Dipsastraea favus*	LC	**	***	***	***	3.77	****	***	10.13	***	***	5.99			**	0.17
29	*Echinopora lamellosa*	LC	***				1.00										
30	*Favites pentagona*	LC		***	***	***	1.46	***		1.75	**	**	0.83				
31	*Goniastrea pectinata*	LC		***	***	**	1.08							**		**	0.44
32	*Hydnophora exesa*	NT						**		0.34				**		***	1.00
33	*Hydnophora microconos*	NT	***	***	***		1.89	***	**	1.70				**			0.22
34	*Merulina ampliata*	LC	**				0.25										
35	*Mycedium elephantotus*	LC		**			0.23										
36	*Platygyra daedalea*	LC				**	0.17										

37	*Platygyra lamellina*	NT							***	1.70				***	**		0.89
Family: Plerogyridae																	
38	*Physogyra lichtensteini*	VU	****	***	**	*****	11.99	**	****	8.12	****	***	11.66	***	***		1.33
Family: Pocilloporidae																	
39	*Pocillopora damicornis*	LC	***	***	***	***	3.49	**	**	0.84		***	1.33	***	***	****	9.97
Family: Poritidae																	
40	*Goniopora columna*	NT			***	***	1.13		***	0.83		***	1.00				
41	*Goniopora lobata*	NT			**		0.25									***	0.67
42	*Goniopora tenuidens*	LC						***		1.50							
43	*Porites evermanni*	DD	**			***	0.67								***		0.67
44	*Porites lichen*	LC		***			1.91		***	3.81				**	***		2.00
45	*Porites lobata*	NT	*****				5.67								***		1.22
46	*Porites lutea*	LC	*****	****	****	****	18.63	****	***	11.34	***	*****	16.86	***	***	***	4.42
47	*Porites rus*	LC	***		***	**	1.09										
Family: Pachyseridae																	
48	*Pachyseris rugosa*	VU						***		1.00							
Family: Psammocoridae																	
49	*Psammocora nierstraszi*	LC		**			0.25	**		0.34							
No. of Sighted Species			15	22	18	18	37	14	20	28	5	14	14	17	15	17	28
Non-scleractinian corals																	
50	*Dendronephthya*	NE		***			0.63							*****			15.37
51	*Discosoma*	NE										***	1.00				
52	*Junceella*	NE												***			0.67
53	*Briareum (Pachyclavularia)*	NE			***		1.59										
54	*Palythoa*	NE			***		1.25	***	***	4.41		***	1.00				
55	*Rhodactis*	NE	**	****	**	**	5.75		****	5.09		***	1.34	***	*****	*****	17.69
56	*Zoanthus*	NE			**	**	0.38										
No. of Sighted Genera			1	2	4	2	5	1	2	2	0	3	3	3	1	1	3

Notes: " " Not recorded, "*" rare, "**" uncommon, "***" common, "****" abundant, "*****" dominant. IUCN Red List Status: VU = Vulnerable; NT = Near Threatened; LC = Least Concern; DD = Data Deficient; NE = Not Evaluated.

Table 4. Diversity indices of scleractinian coral cover in PPMP.

Island	No. of Species	Shannon-Weaver Index (H)	Evenness (E)
Pulau Payar	37	3.01	0.83
Pulau Kaca	28	2.82	0.85
Pulau Lembu	15	2.03	0.75
Pulau Segantang	28	2.71	0.81
PPMP	49	3.14	0.81

This 2D-CHI value was similar to the combination of CHI values for benthos and fish of Pulau Anak Datai, Langkawi, at 0.21 (Ismail *et al.*, 2022).

The 2D-CHI method has been successfully conducted in the western Caribbean (Diaz-Perez *et al.*, 2016) and in Indonesia (Wulandari *et al.,* 2022). Assessment based on benthic coverage and reef fish assemblages was considered an important standard for coral management in Indonesia (Giyanto *et al.*, 2017; Wulandari *et al.*, 2022).

Table 6. Summary of Coral Health Index calculations for benthos and fish.

Island	Benthos	Fish	2D-CHI	Status
Pulau Payar	0.33	0.15	0.24	Degraded
Pulau Kaca	0.29	0.11	0.20	Degraded
Pulau Lembu	0.24	0.11	0.17	Very degraded
Pulau Segantang	0.24	0.10	0.17	Very degraded
PPMP	0.28	0.12	0.20	Degraded

The low values of CHI at all islands indicate that the coral reefs of PPMP were in a stressed condition and can be categorized as unhealthy reefs. Although the current LCC value (33.05%) was categorized as "Fair" (26%-50%), the average CHI value was still in the lowest range of degraded condition (0.20-0.39). The risk is high for the reefs to become more degraded in the near future, unless the stress factor is minimized. Tourism impact has been documented as one of the main reasons for marine life and environmental degradation in MPAs (Ismail and Goeden, 2022). The overcrowding of tourists with uncontrolled diving, snorkeling and boating activities has been the main culprit in various accumulated negative impacts on coral reefs (Khodzori *et al.*, 2019; Chuan *et al.*, 2021; Maidin *et al.*, 2022). Since its gazettement as a marine park in 1994, the number of visitors to PPMP has increased tremendously from about a thousand in the early years to over 100,000 tourists from 2013 onwards (Misni and Jarami, 2021). Thus, it is highly likely that the marine park has been subjected to excessive use, overcrowding and biological degradation.

The concept of resting periods could help coral reefs recover from constant stress and daily coral contact by tourists (Maidin *et al.*, 2022). It has been suggested that the health of coral reefs can be improved by removing human pressure (Somchuea *et al.*, 2022), even if temporarily. Thus, by adequately limiting the number of visitors to PPMP, the coral reefs of PPMP can be conserved and sustained. Since this study was conducted during the Covid-19 lockdown, which has been reported to cause a significant reduction in anthropogenic activities at coral reef areas around the globe (Chuan *et al.*, 2021; Edward *et al.*, 2021; Somchuea *et al.*, 2022), we believe that the brief closure might have at least a limited impact on the recovery of the coral reefs in PPMP.

Besides direct impacts from tourist activities, other anthropogenic disturbances such as coastal development, pollution and human-induced sedimentation were also among the factors that affected

Table 5. Estimated fish biomass (g/m^2) at all sites of PPMP.

Family	Species	IUCN	P1	P2	P3	P4	Mean	K1	K2	Mean	L1	L2	Mean	S1	S2	S3	Mean
Balistidae	*Balistoides viridescens*	LC		3.51			1.17	1.76	6.30	4.03		1.76	0.88				
Caesionidae	*Caesio cuning*	LC	0.32		2.79		1.04		1.57	0.79	13.70		6.85	27.91			9.30
	Caesio caerulaurea	LC										2.35	1.18				
	Caesio teres	LC				10.72	10.72								17.86	1.39	9.63
	Pterocaesio chrysozona	LC				5.91	5.91									3.13	3.13
Carangidae	*Caranx melampygus*	LC				0.34	0.34										
Chaetodontidae	*Chaetodon collare*	LC	0.23	0.11			0.12							1.17		0.59	0.59
	Chaetodon octofasciatus	LC	8.25	0.23			2.83	0.59		0.29						0.23	0.08
	Heniochus acuminatus	LC		1.26	0.63	0.25	0.54	1.26	1.26	1.26	0.03	0.25	0.14	0.25		0.13	0.13
Haemullidae	*Plectorhinchus gibbosus*	LC	0.66				0.22										
Labridae	*Thalassoma lunare*	LC		0.57	1.21	0.11	0.47	1.92	1.15	1.53		0.34	0.17	1.21	0.43	5.73	2.46
Lutjanidae	*Lutjanus biguttatus*	LC			0.14	8.13	2.07		0.34	0.17				0.14			0.05
	Lutjanus decussatus	LC						1.18		0.59							
	Lutjanus johnii	LC		8.45			2.82										
	Lutjanus	LC		135.57	29.54	6.78	42.97	2.23		1.12				33.89	4.07		12.65
	Lutjanus kasmira	LC		1.19			0.40	1.19	1.19	1.19							
	Lutjanus vitta	LC			0.67		0.22				0.18	0.59	0.39	0.67			0.22
Nemipteridae	*Scolopsis vosmeri*	LC		2.48			0.83	1.24	1.24	1.24		0.37	0.19	0.14			0.05
	Scolopsis monogramma	LC		1.42	1.42	15.85	4.67	0.71	0.71	0.71	1.24	0.21	0.73	0.71			0.24
Pempheridae	*Pempheris* sp.	LC	0.23	0.56			0.26		1.39	0.70							
Pomacanthidae	*Pomacanthus annularis*	LC		2.57			0.86	1.28	1.28	1.28		0.43	0.21				
Pomacentridae	*Abudefduf saxatilis*	LC			1.23	0.28	0.38							1.23	1.24		0.82
	Amphiprion ocellaris	LC	5.03	2.30	0.10		2.48	0.69	0.69	0.69	0.01	0.41	0.21	0.04			0.01
	Amphiprion perideraion	LC		0.06	0.26		0.11							0.13			0.04
	Amphiprion sandaracinos	LC													12.59	2.30	7.44
	Dischistodus perspicillatus	LC		1.23			0.41	1.23	1.23	1.23		0.61	0.31				
	Neopomacentrus sp.	LC		7.77	0.60	0.16	2.13	5.18	5.18	5.18	0.13	1.29	0.71	3.61	1.58	1.29	2.16
Scaridae	*Scarus ghobban*	LC	1.01	0.28	0.73		0.68	1.40	3.28	2.34	1.31	0.56	0.94	0.73			0.24
Serranidae	*Aethaloperca rogaa*	LC		5.20			1.73		5.20	2.60							
	Cephalopholis boenak	LC		1.66	0.18	0.40	0.56		0.31	0.15				0.61	4.15		1.59
	Cephalopholis Formosa	LC		5.93		0.27	1.55	4.95	24.73	14.84	2.97	6.43	4.70	2.47	1.38	1.22	1.69
	Epinephelus erythrurus	LC						0.42		0.21							
	Epinephelus fuscoguttatus	VU							16.75	8.37							
	Epinephelus lanceolatus	DD										69.69	34.84				
	Epinephelus quoyanus	LC						0.62		0.31							
	Epinephelus sp.	LC													4.23	8.37	4.20
Siganidae	*Siganus canaliculatus*	LC			1.54	0.77	0.58		0.38	0.19				1.54			0.51
Tetraodontidae	*Diodon hystrix*	LC							6.93	3.47		3.47	1.73				
Zanclidae	*Zanclus cornutus*	LC	5.10	0.28	0.03	0.41	1.45	0.41		0.21				0.96	1.10	0.41	0.83
	TOTAL		20.84	182.62	41.07	50.38		28.25	81.11		19.56	88.78		77.41	48.62	24.80	

Notes: IUCN red list status: VU = Vulnerable; LC = Least Concern; DD = Data Deficient.

the growth of corals (Toda *et al.*, 2007; Praveena *et al.*, 2012; Safuan *et al.*, 2021). The impact of coastal development might have been very minimal during the Covid-19 lockdown; however, sedimentation has always been a serious problem, particularly along the west coast of Peninsular Malaysia. The degradation of coral reefs has been linked with continuous sedimentation, especially in the Straits of Malacca (Praveena *et al.*, 2012; Rudra, 2018). Understanding the major threats that affect the reef's ecosystem is vital for improving the management of coral reefs (Safuan *et al.*, 2021). Since this study was carried out during the MCO, the number of researchers was restricted by the local authorities for safety and security purposes. Hence, the number of studies was limited and the study sites were minimized. We believe, in the future, that it is important to extend this study to assess the growth and survival of corals in relation to sedimentation, pollution and other aquatic environmental parameters caused by tourism activities.

Conclusions

This study was conducted during the "mandatory" MCO in response to the Covid-19 pandemic. Thus, this is the first published record of the effects of the MCO on the coral community of PPMP. Our identification at the species level makes this study the most comprehensive assessment of coral diversity in PPMP to date. We concluded that the coral reefs of PPMP were in degraded condition. Because the growth of corals is a slow process, recovery may require longer periods of protection than that afforded by the MCO. Our results can serve as up-to-date data for the benthic community structure of PPMP, and the impact of continuing tourism can now be investigated. It is also our hope that this information on coral health, using the CHI method, will be useful for sustaining the balanced use of resources at PPMP. Our future studies and way forward are to expand the implementation of CHI assessment to the whole coral reef ecosystem in Malaysia.

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Data availability statement

Data supporting these findings are available within the article or upon request.

Ethical statement

Not applicable.

Informed consent statement

Not applicable.

Conflict of interest

The authors declare no conflict of interest.

Author contributions

Ismail MS: conceptualization, methodology, investigation, formal analysis, writing original draft, review and editing. **Ilias Z:** methodology, investigation, formal analysis, writing review and editing. **Ismail MN:** investigation, formal analysis, writing review and editing. **Khoo ML, Goeden GB and Yap CK:** writing review and editing.

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