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Coral cover percentage and health condition in Tioman Island marine protected area, Pahang, Malaysia

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Abstract: Continuous evaluation and monitoring of coral percentage cover and health status is critical for enhancing coral reef resilience management. The present study aimed to determine the coverage and coral status at important sites of Tioman Island Marine Park, which include Renggis Island, Tiong Point and Tekek. Surveillance video recording and in situ observation were carried out using the Coral Video Transect (CVT) method, which were analyzed using the Coral Point Count with Excel extension (CPCe) software. The overall health status for the study area was considered as "fair" with 41.61% ± 4.46% of mean live coral coverage. Among the stations Renggis Island had the highest live coral coverage accounting for 50.71% ± 6.97%, which was classified as 'good'. In terms of coral diversity, a total of 11 families and 36 genera were identified for the three sampling sites. Family Acroporidae, which includes the *Acropora, Anacropora* and *Montipora*, dominated the coral reef within the study area with 17.09% ± 2.54% coverage. *Acropora* was the most abundant with 12.40% ± 3.66% coverage, followed by *Porites* (11.31% ± 1.33%), *Leptoseris* (5.12% ± 5.09%), *Montipora* (4.69% ± 3.43%) and *Sinularia* (2.58% ± 2.33%). In terms of conservation, Renggis Island and Tiong Point were categorized as Conservation Class 4 (CC-4), which indicates great diversity of species, while Tekek was in Conservation Class 2 (CC-2). Tiong Point has the highest diversity (H' = 1.64) and good evenness values (J = 0.64), but it also recorded a high mortality index (MI = 0.55). Tekek on the other hand, recorded the lowest diversity (H' = 1.26) and poor evenness (J = 0.44), with the highest mortality index (MI = 0.59). In conclusion, some of the reef areas on Tioman Island were not in the best condition, thus efforts should be taken to enhance coral reef resilience that may improve coral reef conservation and preservation.

Keywords: Coral Cover, coral health, coral video transect (CVT), diversity, sustainability

1. Introduction

Malaysia, known as the world's hub for marine biodiversity due to its abundance of diverse marine resources and where one of the richest coral reefs is located, has earned its recognition as a member of the Coral Triangle (Harborne et al. 2000; Toda et al. 2007; Veron et al. 2015). With more than 550 different species, the 4006 km^2 of coral reefs in Malaysia have supported the local economy in a variety of ways, including fisheries and tourism. Since Malaysian coral reefs are regarded as a significant coral biodiversity area globally, they are regarded as one of the most vulnerable ecosystems that are susceptible to both natural and anthropogenic threats that could cause coral reef degradation and bleaching (Praveena et al. 2012, Ismail & Goeden 2022).

The distribution of coral reefs has declined significantly in many areas over the past few decades (Rodriguez-Ruano et al. 2023). The two most prominent factors that have caused huge damage to Malaysia's coral reef ecosystems are climate change and anthropogenic activities (Praveena et al. 2012; Kimura et al. 2014). Many scientists believe that human-caused climate change poses a greater and more unpredictable risk to coral reefs now that they are under severe threat from a variety of threats (Mulhall 2009; Praveena et al. 2012). According to Reef Check Malaysia (2018), anthropogenic activities such as development and tourism are some of the main threats to coral reefs in Peninsular Malaysia. As a result of these threats, the resilience of coral reef is under the great pressure. Effective management efforts are required to support coral reef resilience in the face of the global warming crisis in Malaysia to prevent the continuous deterioration of coral reefs.

This study aims to evaluate the overall quality of coral reefs in Tioman Island Marine Protected Area, includ-

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ing coral cover percentages, coral reef health status, and mortality index. The coral of Tioman has recently been assessed by Kharina et al. (2016) and Khodzori et al. (2021), thus this study serves as continuity in monitoring the coral status around Tioman Island, which is important for the effective management of coral reef resilience in Malaysia.

2. Materials and methods

Tioman Island is the largest island on the east coast of Peninsular Malaysia, with approximately 21 km in length and 12 km in width (Ng. et al. 1999). These coasts were comprised of 58% rocky headlands and cliffs, and 42% sandy beaches (DPMM 2011). The Tioman Island Marine Park (TIMP) has long been recognized as the most popular tourist destination for diving and snorkeling activities (Saad et al. 2015). The field study was carried out from the 28th to 30th of October 2022 at three stations along the western coasts of Tioman Island, namely Renggis Island, Tiong Point and Tekek. Renggis Island was among the most frequently visited sites in Tioman due to its location, accessibility, and vast coral reef areas. The survey location for Renggis Island was located at 2°48'37.52"N and 104° 8'9.60"E, with a water depth of around 10–12 m, and about 500 m from the coast. There are little coastal development activities were observed at this site. The Tiong Point site (2°49'49.12"N; 104° 9'45.10"E) is a shallow coastal area with a water depth of around 3–4 m and about 70 m from the coast. Meanwhile, the Tekek site (2°49'23.97"N; 104° 9'34.77"E) is around 7–8 m deep and located about 160 m away from the coast. Both Tiong Point and Tekek was considered under high stress due to its proximity to land mass, river outflows, human settlements, coastal development activities, and used as a convenience area. Generally, all three reef sites were considered as tourist hot spot areas where frequent snorkeling and diving activities were observed during this study.

The Coral Video Transect (CVT) technique was used in this study for coral reef assessment (Chou et al. 2002; Sweatman et al. 2004). A 100 m transect was laid parallel to the shoreline using a modified approach with 5 × 20 m segments without break (interval) between the segments. Video recordings of the benthic communities and coral genera were taken along the transect using an Olympus underwater camera TG-3 with a resolution of 1980 × 1080 HD to obtain high-quality and high-resolution images. The video recordings were taken at a speed of 10 m per min, with the height of the camera was maintained at approximately 50 cm from the substrates. Additional still images of corals and corallites were captured to aid in the identification process. The scleractinian coral species were identified based on Kelley (2022), Veron (2000), and website of World Register of Marine Species (WoRMS).

2.1. Data analysis

The recorded videos of benthic communities along the transect lines were converted to picture frames. A total of 150 pictures were analyzed using Coral Point Count with Excel extension (CPCe) software (Kohler and Gill, 2006) with a uniform grid of 30 points to calculate the percentage cover of benthic communities. The coral condition indicated by total percentage of benthic categories that include hard coral, soft coral, recently dead coral, turf algae, macroalgae, crustose coralline algae, sponge, and abiotic substrate (Kohler & Gill, 2006). The coral condition was classified based on the percentage cover of live corals following Chou et al. (2002) as poor (0% to 25%), fair (26% to 50%), good (51% to 75%) and excellent (76% to 100%). The numbers of coral genera were directly counted along the transect lines from the video recorded. Coral genera were identified following the Indo-Pacific Coral Finder Toolkit (Kelley, 2022) supported by Corals of the World (Veron, 2000).

Coral reef morphology was identified and classified into r-K-S groups (Table 1), with conservation classification based on Edinger and Risk's (2000) ternary diagram. The r-K-S group was divided into ruderal (r), competitors (K), and stress-tolerators (S). The coral morphology conservation classes of Conservation Class 1, Conservation Class 2, Conservation Class 3, and Conservation Class 4 were assigned to each reef site according to its placement on the r-K-S ternary diagrams.

Acropora, Millepora, and *Heliopora* have more than 50% coverage were assigned in Conservation Class 3 (ruderal). Reef dominated by more than 50% branching non-Acropora corals, free living Fungi*a* corals, and encrusting and foliose corals, categorized as competitor type of corals (K) were assigned as Conservation class 2. Massive, submassive, and platy massive corals with more than 60% coverage are classified as stress-tolerators (S) and were assigned as Conservation class Class 1. Mixed coral morphology reefs represented in approximately equal proportions of these ruderal, competitor, and stress-tolerator types of corals were assigned as Conservation class Class 4. Table 1 showed coral morphology categories of the r-K-S group, adopted from Edinger and Risk (2000).

3. Results and discussion

3.1. Percentage cover of benthic communities and coral condition

Results showed that all reef sites were in fair condition, with the highest percentages cover of benthic communities (Table 2) are dead corals (42.64% ± 6.93%) followed by live corals (scleractinian and non-scleractinian coral) with 41.61 ± 4.46 (Table 2). This agreed with previous studies by Harborne (2000), Toda et al. (2007), and Khodzori et al. (2021) that have demonstrated the coral reefs in various

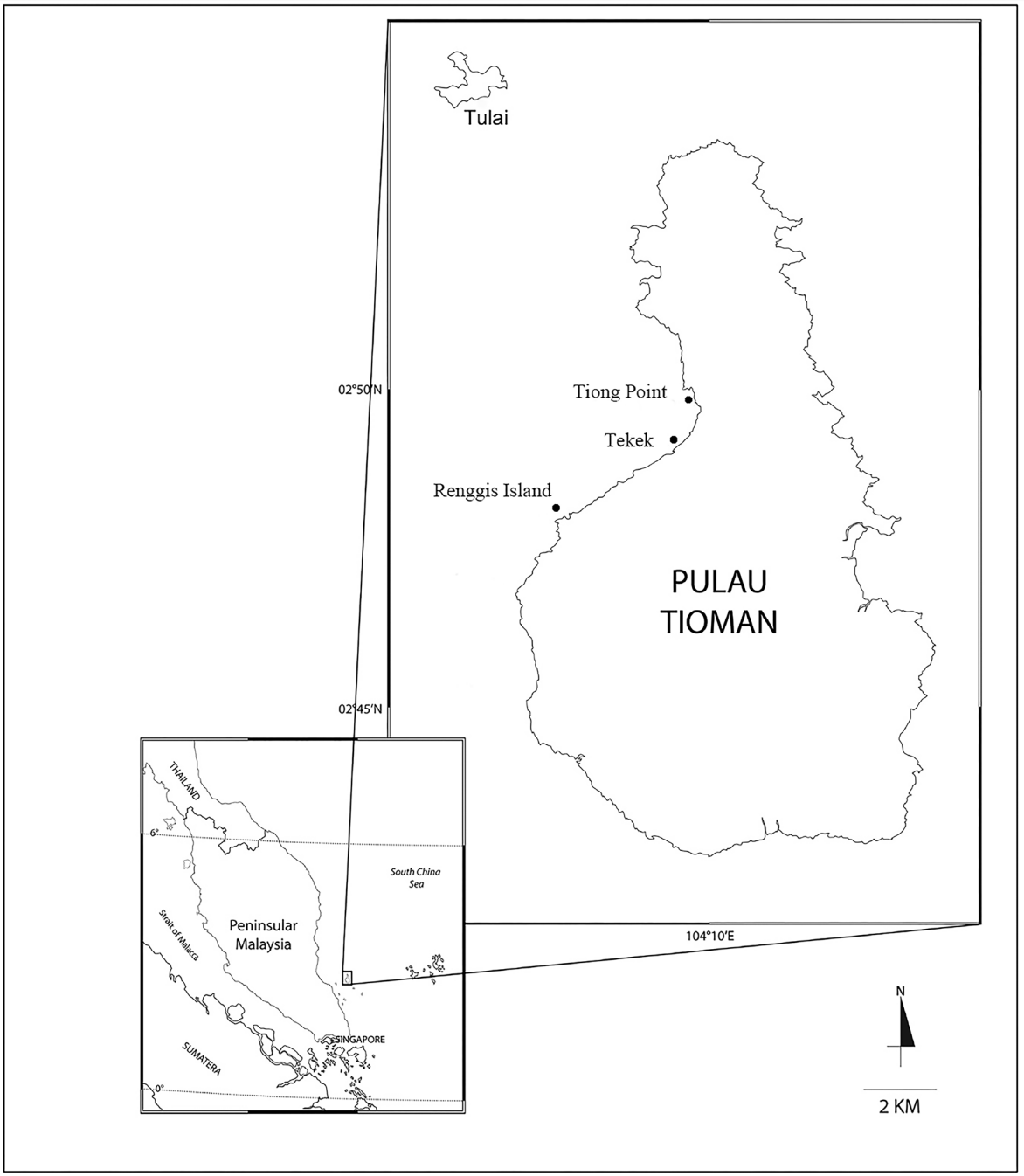

Figure 1. The location of the study sites [Tiong Point (2°49'49.12"N; 104° 9'45.10"E), Tekek (2°49'23.97"N; 104° 9'34.77"E) and Renggis Island (2°48'37.52"N, 104° 8'9.60"E)] in Tioman Island, Pahang, Malaysia.

parts of Tioman Island ranged between fair to good condition.

Among the three sampling sites, Renggis Island showed the highest percentage of live corals with 50.71% ± 6.97% cover, which thence showed the lowest percentage of dead coral at 29.42% ± 7.86%. Recently, Khodzori et al. (2021), however reported slightly lower live coral cover of 45.6% ± 3.4% and higher dead coral cover of 40.6% ± 4.9% in Renggis Island, which was in fair condition. The good condition for Renggis Island in the current study could be attributed to low human impact, as there is no human settlement nearby and little coastal development activity is observed.

Table 1. Coral morphology categories of r-K-S group. Adopted by Edinger and Risk (2000).

Morphology	Description	Group
Acropora	Various morphology of *Acropora* corals including branching, corymbose, digitate and tabular	r
Millepora	Various species of *Millepora* (fire corals)	r
Heliopora	Blue corals (hydrocoral)	r
Branching coral	Branching non-*Acropora* corals mainly *porites, cylindrical* anss some species of *Isopora.*	K
Encrusting coral	Low spreading life forms especially *Montipora* and *Turbinaria.*	K
Foliose coral	Foliose, either horizontal or vertical, non-*Acropora*, especially *Montipora*, *Echinopora.*	K
Mushroom coral	Free living fungoid corals mainly *Fungia, Lithophyllon, Ctenactics, Herpolitha, Sandhalolitha* and *Polyphyllia* corals.	K
Massive coral	Massive or dome-like of all sizes such as *Porites* corals	S
Submassive coral	Submassive having multilobate or 'lumpy corals, and mixed massive-columnar especially *Goniopora* and *Galaxea.*	S
Massive-platy coral	Large massive platy-like coral with life forms short or long meandering corallites as known as *Platygyra, Euphyllia, Plerogyra, Physogyra*, and *Lobophyllia.*	S

Table 2. Mean percentage cover of benthic communities and coral condition.

Reef Site	Live coral	Dead coral	Others	Condition
Renggis Island	50.71% ± 6.97%	29.42% ± 7.86%	19.87% ± 8.15%	Good
Tiong Point	37.19% ± 5.27%	45.63% ± 6.75%	17.18% ± 5.90%	Fair
Tekek	36.93% ± 11.15%	52.87% ± 9.20%	10.34% ± 5.36%	Fair
	41.61% ± 4.46%	42.64% ± 6.93%	15.84% ± 2.95%	Fair

The other sampling sites, Tiong Point and Tekek recorded a lower percentage of live corals with 37.19% ± 5.27% and 36.93% ± 11.15% respectively, which were both classified as fair. Tiong Point has a lower percentage of dead coral than Tekek with 45.63% ± 6.75% and 52.87% ± 9.20% respectively. The low percentage of live corals and high percentage of dead corals in Tekek are most probably due to its proximity to the coast, and lower water depth, which might expose them to higher sedimentation rates and other disturbances.

3.2. Diversity and distribution cover of coral genera

A total of 11 families and 36 genera have been identified from the three reef sites in Table 3. The Acroporidae, which includes the *Acropora, Anacropora* and *Montipora* dominated the percentage of coral distribution with 17.09% ±2.54%. Poritidae was the second highest family with 11.54% ± 1.54% followed by Agariciidae (6.63% ± 5.91%), Merulinidae (2.99% ± 1.00%), non-Sclerectinian coral (2.68% ± 2.39%), Pocilloporidae (1.82% ± 0.26%), Fungiidae (0.61% ± 0.43%), Insertae (0.12% ± 0.06%), Psammocoridae (0.03% ± 0.03%), Dendrophylliidae (0.01% ± 0.01%), and Euphyllidae (0.01% ± 0.01%). Furthermore, within the Acroporidae the genera *Acropora* showed the highest percentage with 12.40% ± 3.66%. Other abundant coral genera include the *Porites* (11.31% ± 1.33%), *Leptoseris* (5.12% ± 5.09%), *Montipora* (4.69% ± 2.33%) and non-Sclerectinian coral *Sinularia* with 2.58% ± 2.39%. The other coral genera were distributed at a percentage cover of less than 2%.

The diversity and distribution of coral genera at the study sites are presented in Table 3. The # symbol was used to describe the diversity and abundance of coral genera in coral reef sites based on coral distribution percentages. The *Acropora, Montipora, Pocillopora, Stylopora, Porites, Leptoseris, Pavona, Oulophyllia,* and *Physogyra* were all covered in Tiong Point, Tekek, and Renggis Island. *Acropora* is the most widespread genus, accounting for 12.40% ± 3.66% of all reef sites. Tekek recorded the highest number of coral genera with 26 genera while Tiong Point and Renggis Island both recorded only 20 genera.

The coverage percentage and distribution of coral live growth cover at Tioman Island is presented in Table 4. The *Coral massive* has the highest percentage of live coral growth cover in all reef sites (20.62% ± 2.04%), followed by Acropora branching (25.64% ± 2.04%) and branching coral (25.31% ± 3.99%). Subsequently, live coral growth for coral foliose recorded 20.17% ± 3.55% followed by non-sclerectinian corals (15.49% ± 2.45%), *Acropora* tabulate

Table 3. Diversity and distribution of coral cover at Tiong Point, Tekek and Renggis Island in Tioman Island. The differences of the number of #: < 2% covering, ##: 1%– 5%, ###: 6%–10%, ####: 11%–20% and #####: > 20%.

Coral genera	Tiong Point	Tekek	Renggis Island	Mean (%) ± S.E.
SCLERECTINIAN				
ACROPORIDAE				17.09 ± 2.54
Acropora	###	###	####	12.40 ± 3.66
Anacropora	#	-	-	0.01 ± 0.01
Montipora	##	####	##	4.69 ± 3.43
POCILLOPORIDAE				1.82 ± 0.26
Pocillopora	##	#	#	0.92 ± 0.20
Seriatopora	-	#	#	0.04 ± 0.03
Stylopora	#	#	##	0.86 ± 0.23
PORITIDAE				11.54 ± 1.54
Goniopora	#	#	-	0.22 ± 0.21
Porites	###	####	###	11.31 ± 1.33
AGARICIIDAE				6.63 ± 5.91
Leptoseris	#	#	####	5.12 ± 5.09
Pachyseris	#	-	-	0.20 ± 0.20
Pavona	#	#	##	1.31 ± 0.94
MERULINIDAE				2.99 ± 1.00
Caulastraea	#	-	-	0.02 ± 0.02
Favites	-	-	##	1.31 ± 1.31
Goniastrea	#	-	#	0.09 ± 0.05
Hydnopora	-	#	#	0.03 ± 0.02
Leptoria	##	-	-	0.49 ± 0.49
Merulina	#	#	-	0.31 ± 0.27
Oulophyllia	#	#	#	0.19 ± 0.06
Pectinia	-	#	#	0.11 ± 0.10
Platygyra	##	-	#	0.44 ± 0.30
EUPHYLLIIDAE				0.01 ± 0.01
Galaxea	-	#	-	0.01 ± 0.01
FUNGIIDAE				0.61 ± 0.43
Ctenactis	-	#	-	0.02 ± 0.02
Cycloseris	-	#	-	0.01 ± 0.01
Danafungia	-	#	#	0.24 ± 0.16
Fungia	-	#	#	0.02 ± 0.01
Heliofungia	-	#	-	0.23 ± 0.23
Herpolitha	-	#	-	0.01 ± 0.01
Lithophyllon	-	#	#	0.08 ± 0.04
Sandalolitha	#	-	-	0.01 ± 0.01
DENDROPHYLLIIDAE				0.01 ± 0.01
Turbinaria	-	#	-	0.01 ± 0.01
PSAMMOCORIDAE				0.03 ± 0.03
Psammocora	-	-	#	0.03 ± 0.03

Table 3. (Continued).

INSERTAE				0.12 ± 0.06
Physogyra	#	#	#	0.09 ± 0.07
Plerogyra	-	#	-	0.03 ± 0.03
NON-SCLERECTINIAN				2.68 ± 2.32
Lobophytum	-	-	#	0.01 ± 0.01
Sarcophyton	#	#	-	0.09 ± 0.05
Sinularia	###	#	-	2.58 ± 2.33
No. of genera	20	26	20	

Table 4. Coverage percentage and distribution of coral live growth cover at Tioman Island.

Live coral growth	Percentages of coral cover ± S.E (%)
Acropora branching	25.64 ± 2.04
Acropora tabulate	5.53 ± 0.92
Coral branching	25.31 ± 3.99
Coral encrusting	3.87 ± 0.58
Coral foliose	20.17 ± 3.55
Coral massive	33.98 ± 5.76
Coral submassive	2.19 ± 0.41
Mushroom coral	0.16 ± 0.04
Nonsclerectinian coral	15.49 ± 2.45

(5.53% ± 0.92%), coral encrusting (3.87% ± 0.58%), and submassive coral (2.19% ± 0.41%). Mushroom coral recorded the least percentage cover with 0.16% ± 0.04%.

The Diversity index is presented in Table 5, which described the diversity of coral reefs within each site. Tiong Point has the highest diversity index (1.64), followed by Renggis Island (1.61), and Tekek (1.26). Tiong Point also showed the highest evenness with 0.64, followed by Renggis Island (0.56), and Tekek (0.44). Despite the high value of the diversity index, Tekek also has a higher mortality index (0.59) compared to Renggis Island (0.37) and Tiong Point (0.55). According to Gomez et al. (1994), a mortality index value greater than 0.33 is considered very high and classified as poor.

Figure 2 shows the r-K-S diagram, which was used to classify the conservation of coral reef growth in Tiong Point, Tekek, and Renggis Island. Tekek is classified as a conservation class 2 (CC 2), with foliose coral morphology, free-living and branching non-*Acropora* cover. Both Tiong Point and Renggis Island were in conservation class 4 (CC 4), which means these reef sites have a mixed structure of coral growth. Both sites contained the greatest diversity of coral species and habitat richness and can provide ideal conditions for fish habitat. According to more species diversity and habitat complexity than other categories.

4. Conclusion

The current study reported the status and condition of selected reef sites in Tioman Island Marine Park, namely Tiong Point, Tekek and Renggis Island, which generally can be concluded as in fair condition. The diversity was relatively high where *Acropora*, *Montipora* and *Porites* were among the most diverse coral genera within the study areas. However, the result also indicated high mortality index in some areas that need further investigations. This study may assist the Department of Marine Parks Malaysia (DOF) and other related agencies in managing these highly important but fragile coral reef ecosystems of Tioman and Malaysia.

Table 5. Diversity index (H'), Evenness index (J), and Mortality index (MI) in Tioman Island.

	H'	J	MI
Renggis Island	1.61	0.56	0.37
Tiong Point	1.64	0.64	0.55
Tekek	1.26	0.44	0.59

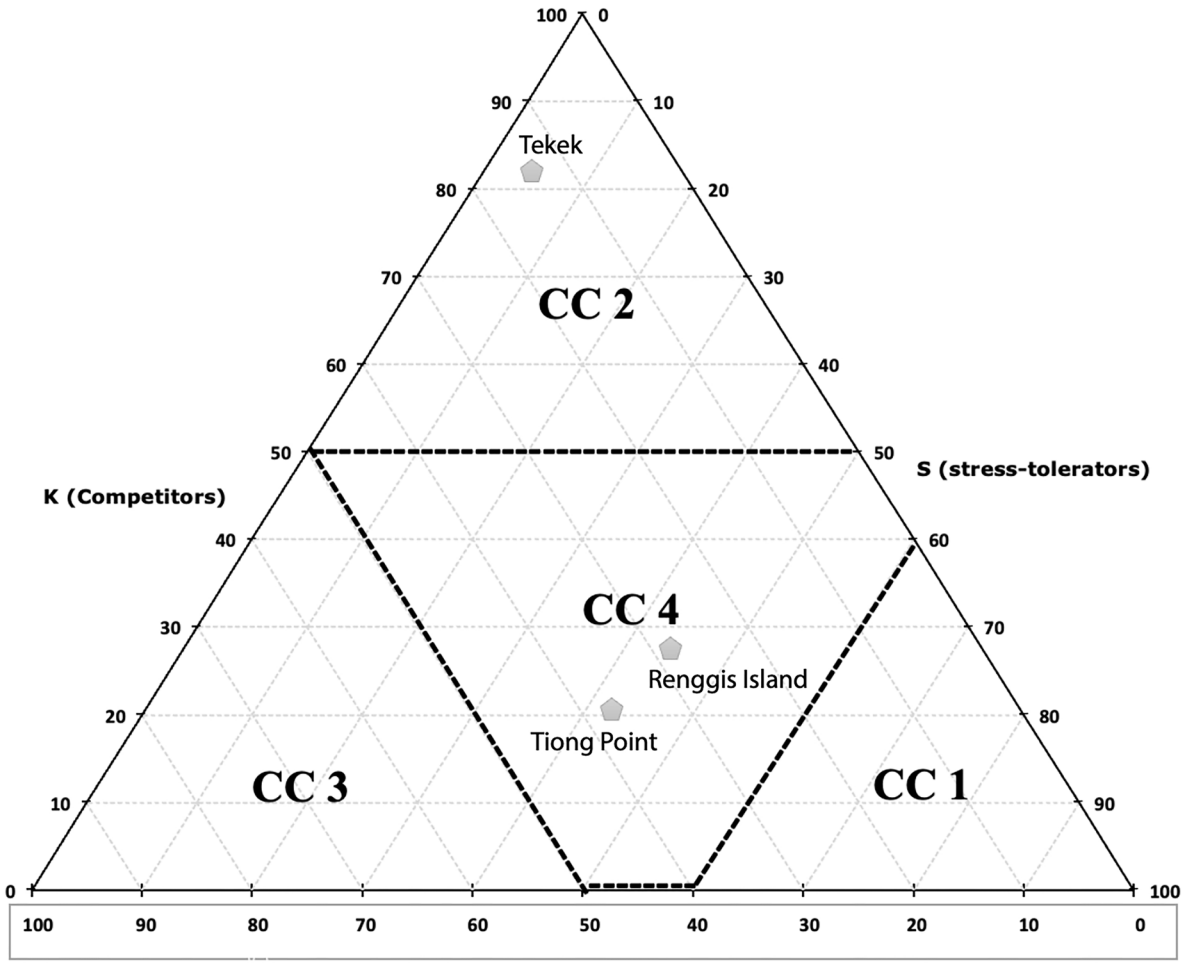

Figure 2. Classify the conservation of coral reef growth in Tiong Point, Tekek and Renggis Island.

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