ORIGINAL ARTICLE

Assessing coral communities on underwater pinnacles as new marine protected areas at Ko Tao, Surat Thani Province

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Abstract. Coral reef ecosystem services include habitat provision for reef organisms, biogeochemical, social, and cultural services. However, continuing marine and coastal development have negative impacts on coral reefs and their associated ecosystems. This study assessed the potential of coral communities on underwater pinnacles at Ko Tao, Surat Thani Province, the Western Gulf of Thailand to be dive sites and new marine protected areas. Several important physical and biological factors and criteria were used to assess the potential of ecotourism development. Six coral communities at Ko Tao including Hin Samran, Hin Tung Ku, Hin Chumphon, Hin Khao, Hin Wong, and Hin Kong Sai Daeng were investigated. The result revealed that two underwater pinnacles, Hin Chumphon and Hin Khao presented a high potential for ecotourism dive sites. At Hin Chumphon, twenty-seven species of scleractinian corals were recorded. The dominant corals were Porites lutea, P. lobota, and Platygyra sinensis. At Hin Khao, seventeen species of scleractinian corals were observed. P. lutea, Diploastrea heliopora, and Acropora hyacinthus were the dominant corals. The density of macrobenthic invertebrates at Hin Chumphon was higher than that of Hin Khao. Hin Khao showed a high density and species richness of reef fish. Several underwater pinnacles in the Ko Tao area are high potential for marine ecotourism. The negative impacts of tourism development must be mitigated. This study proposes that the underwater pinnacles in the Ko Tao area should be established as marine protected areas under the Marine and Coastal Resources Management Promotion Act - B.E. 2558 (2015) for ecotourism and sustainable fisheries.

Keywords: coral community, ecotourism, Gulf of Thailand, marine protected area, underwater pinnacle

1. Introduction

Coral reefs occupy less than 1% of the oceans, however, they harbor over 25% of the world's biodiversity (Small et al. 1998; Plaisance et al. 2011; Strain et al. 2018). Millions of tropical coastal communities have relied on coral reef ecosystems (Teh et al. 2013; Chamchoy et al. 2018). Coral reef ecosystem services include habitat provision for reef organisms, biogeochemical, social, and cultural services, particularly recreational opportunities on SCUBA diving, snorkeling, surfing, and sight-seeing (Moberg and Folke 1999; Nyström et al. 2000; Brander et al. 2007; Ong and Musa 2012, Liquete et al. 2013 Weijerman et al. 2018; Wolf et al. 2019). Marine tourism has become a major economic growth and development in many countries globally, especially derived from coral reef ecosystem services. It represents a significant share of the industry globally (Balmford et al. 2009; Elliff and Kikuchi 2017; De Brauwer and Burton 2018; Robles-Zavala and Reynoso

2018). The SCUBA diving industry has grown significantly in the past decades, and a large number of SCUBA divers have been trained (Sombatsubsin 2015; Sumanapala et al. 2022). Coral reefs also play a major role in increased resilience to negative impacts (Mora et al. 2011; Sutthacheep et al. 2019).

Coral reefs are now globally degraded due to coral bleaching events, water pollution, sedimentation, direct destruction, and overfishing (Bellwood et al. 2004; Suraswadi and Yeemin 2013). Live coral cover of the world's coral reefs has decreased remarkably during the past decades because of severe coral bleaching causing mass mortality of corals in all tropical countries (Bruno and Selig 2007; Baker et al. 2008; Yeemin et al. 2009; Jackson et al. 2014; Hughes et al. 2017; Stuart-Smith et al. 2018; Sutthacheep et al. 2012, 2013, 2018). Uncontrolled tourism growth has resulted in negative impacts on coral reefs and associated ecosystems, undermining the long-term sustainability of the tourism industry (Abidin and Mohamed 2014). Many studies indicated that in some popular dive sites, divers unintentionally contact corals and cause physical damage resulting in negative ecological impacts, such as damaged corals and benthic organisms (Barker and Roberts 2004; Rouphael and Hanafy 2007; Toyoshima and Nadaoka 2015; Casoli et al. 2017; Cowburn et al. 2018).

Marine protected areas (MPAs) have been implemented to conserve coral reefs and their associated organisms (Selig and Bruno 2010; Soler et al. 2015; Cinner et al. 2016; Klinthong et al. 2019). Many marine protected areas aim to prevent fishing impacts in important areas. Several management interventions have been applied such as no-take regulations, bans on the use of some fishing gears, temporal closures of particular locations, size limits of target species, and quotas for fishing (Côté et al. 2001; Cinner et al., 2009; Yeemin et al. 2012; Emslie et al. 2015; Campbell et al. 2017). Following these management methods, some marine protected areas show increases in coral cover and herbivores because of limiting destructive habitats. (Bellwood et al. 2004; Mumby et al. 2006; Yeemin et al. 2013a). However, some marine protected areas do not contribution to the protection of coral reef ecosystems (Cox et al. 2017; Huntington et al. 2011; Toth et al. 2014; Strain et al. 2019).

Ko Tao is an offshore island in Surat Thani Province, the Western the Gulf of Thailand, with an area of 18.73 km2. Since the island has a diverse ecosystem and abundant marine resources, it is now one of the most popular tourist destinations (Wongthong and Harvey 2014; Hein et al. 2015). Presently, the diversity of marine resources and the environment in Ko Tao are deteriorating due to many factors such as land-use changes, wastewater discharged from the coastal communities, and unregulated marine activities. The important issue is digging soil on the steep slope which causes soil erosion into the sea. In the past, studies on marine resources and the environment of Ko Tao have been limited and the information is ambiguous and inconsistent (Office of Marine and Coastal Resources Conservation 2013; Monchanin et al. 2021). Developing and improving marine ecotourism through evaluating dive sites and zoning marine and coastal areas are effective strategies for reducing damages at popular dive sites. Proper site assessment methods are needed before developing marine ecotourism to determine the suitability of potential areas for utilization activities. (Heeger and Sotto 2000; Rhormens et al. 2017). This study assessed the potential of coral communities on underwater pinnacles at Ko Tao to be dive sites and new marine protected areas.

2. Materials and Methods

2.1 Location of study sites

This study was undertaken across coral communities on underwater pinnacles at Ko Tao, the Western Gulf of Thailand. Six coral communities at Ko Tao including Hin Samran, Hin Tung Ku, Hin Chumphon, Hin Khao, Hin Wong, and Hin Kong Sai Daeng were investigated in early 2022 (Figure 1).

2.2 Coral community survey

The coral communities were investigated using a 30-meter-long belt transect with 3 replicates by SCUBA diver. The quadrats were photographed with an underwater camera to investigate the substrate cover and composition, and macroinvertebrate communities. The substrate composition including live coral, dead coral, sand, rock, rubble, and other were recorded (English et al. 1997). The coral species were identified following Veron (2000) to species level, if possible. The macroinvertebrate communities were assessed and identified to species level, if possible. Coral reef fish communities were assessed in a 2-meter wide transect (200 m²) and identified to species level, if possible, following Allen et al. (2015).

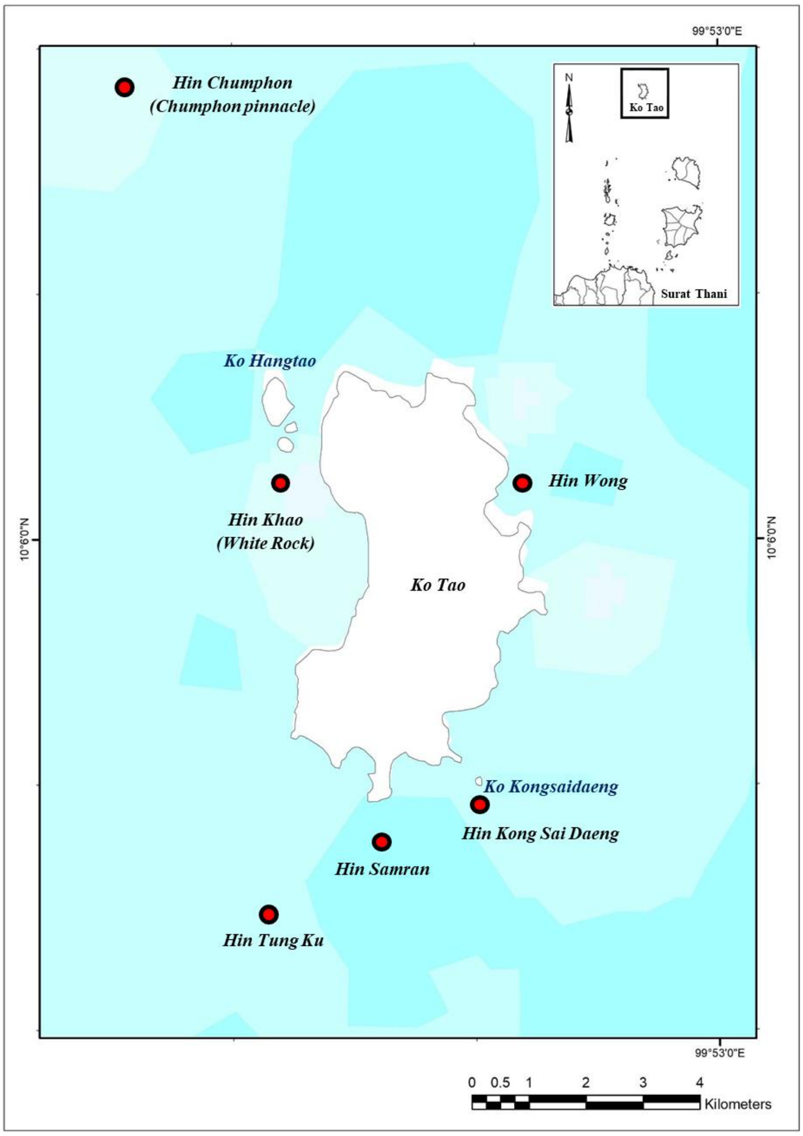


Figure 1. Location of the study sites at Ko Tao, the Western Gulf of Thailand

2.3 Criteria for assessing the potential level of the underwater pinnacles

2.3.1 Assessing the potential level of underwater pinnacles by physical and biological factors

The criteria for evaluating the potential for ecotourism level of underwater pinnacles by physical and biological factors by experts adapted from the study of Flores-de la Hoya et al. (2018) are divided into 2 main factors including physical factors (30%), consisting of depth, slope, topographic complexity, sand cover, rock cover, topographic prominence, seawater transparency and temperature, tides, wave height, distance from shore, and site accessibility. The biological factors (70%) are organisms that are targeted for tourist visits including hard corals, soft corals, macrobenthic invertebrates, coral reef fish, and endangered marine animals such as sea turtles, dolphins, whales, and whale sharks. Five evaluation criteria (Ri), from 1 - 5, are considered in comparison with the established evaluation criteria and a weight value (Wi), taking into account the impact on coral reefs and the underwater pinnacle for sustainable ecotourism (Table 1). Data obtained from the evaluation were then analyzed by weighting score equation (Flores-de la Hoya et al. 2018; Wongnutpranont et al. 2020) as follows:

$$\text{Weighting score equation ENTSP} = \frac{\sum W_i R_i}{\sum W_i}$$

$$\text{ENTR} = \frac{W_1R_1 + W_2R_2 + W_3R_3 + \ldots + W_nR_n}{W_1 + W_2 + W_3 + \ldots + W_n}$$

ENTR = The potential level of natural tourism resources

W_i = The weight value of indicator factors

R_i = The potential score of indicator factors

The scores were then compared with the potential levels, which were divided into 3 levels from the stratification formula as follows:

$$\text{Stratification} = \frac{\text{Total score}}{\text{Number of indicators}}$$

2.3.2 Assessing the potential level of underwater pinnacles by examining the level of beauty and interest of scuba diving tourists

The assessment method was adapted from the study of Pert et al. (2020). Providing assessment criteria with an online questionnaire for scuba diving tourists using photographs of underwater pinnacles that can represent the characteristics of underwater pinnacles at each study site. It allowed respondents to rate the attractiveness level of underwater pinnacles on a scale of 1 to 10 based on the live coral cover, coral reef complexity, algal cover, coral reef fish abundance, and seawater transparency. The score obtained from the questionnaire were divided into 3 potential levels which are low (1.0 - 4.0), medium (4.1 - 7.0), and high (7.1 - 10.0).

Table 1. Criteria for assessing the potential level of the underwater pinnacles for tourism utilization

Indicator factors		The potential score of indicator factors (Ri)					W_i
		1	**2**	**3**	**4**	**5**	
Physical factors (30%)	Depth (for diving) (m)	<1 .5	1 .5-2	2-2.5	2.5-3	>3	0.1
	Slope (degrees)	>40	31-40	21-30	10-20	<10	0.005
	Topographic complexity	Very low	low	Moderate	High	Very high	0.005
	Sand cover (%)	>90	61-90	31-60	10-30	<10	0.005
	Rock cover (%)	>90	61-90	31-60	10-30	<10	0.005
	Topographic prominence	Very low	low	Moderate	High	Very high	0.025
	Seawater transparency (m)	<1	1-2	2-3	3-4	>4	0.100
	Seawater temperature (°C)	<20	20.0-22.5	22.6-25.0	25.1-28.0	28.1-30.0	0.005
	Tide (m/s)	> 2.5	2.1-2.5	1.6-2.0	1-1.5	<1	0.010
	Wave height (m)	>1.5	1-1.5	0.5-1	0-0.5	0	0.005
	Distance from shore (km)	>10	8-10	6-8	3-5	<3	0.010
	Site accessibility	Very difficult	Difficult	Moderate	Easy	Very easy	0.025
Biological factors (30%)	**1. Hard corals**						
	Live coral cover (%)	<5	625	25-50	50-75	>75	0.025
	Acropora spp. *Turbinaria* spp. *Plerogyra* spp. *Symphyllia* spp. *Fungia* spp. *Goniopora* spp. (%)	<5	6-25	25-50	50-75	>75	0.085
	2. Soft coral and macrobenthic invertebrates						
	Soft coral (%)	<5	6-25	25-50	50-75	>75	0.025
	Gorgonian (colony/10 m^2)	<1	1.0-2.0	2.1-3.0	3.1-4	>4	0.025
	Sea whip (colony/10 m^2)	<1	1.0-2.0	2.1-3.0	3.1-4	>4	0.025
	Sponges (colony/10 m^2)	<1	1.0-2.0	2.1-3.0	3.1-4	>4	0.025
	Nudibranch (ind/m^2)	<1	1.0-2.0	2.1-3.0	3.1-4	>4	0.025
	Christmas tree worm (ind/m^2)	<1	1.0-2.0	2.1-3.0	3.1-4	>4	0.025
	Giant clam (ind/m^2)	<1	1.0-2.0	2.1-3.0	3.1-4	>4	0.025
	Sea anemone (ind/m^2)	<1	1.0-2.0	2.1-3.0	3.1-4	>4	0.030
	3. Coral reef fish						
	Butterflyfish (ind/100 m^2)	1.0-5.0	6-10	11-15	16-20	>20	0.040
	Parrotfish (ind/100 m^2)	1.0-5.0	6-10	11-15	16-20	>20	0.025
	Anemonefish (ind/100 m^2)	1.0-5.0	6-10	11-15	16-20	>20	0.040
	Ribbontail stingray (ind/100 m^2)	1	2	3	4	>4	0.030
	Grouper (ind/100 m^2)	1.0-5.0	6-10	11-15	16-20	>20	0.020
	Snapper (ind/100 m^2)	1.0-5.0	6-10	11-15	16-20	>20	0.020
	Angelfish (ind/100 m^2)	1.0-5.0	6-10	11-15	16-20	>20	0.020
	Barracuda (ind/100 m^2)	1.0-5.0	6-10	11-15	16-20	>20	0.030
	4. Occurrence of endangered animals						
	Sea turtle, Dolphin, Whale, and whale shark (time/year)	1	2	3	4	>4	0.15

Remark: The rating scale, significance, and weights of each factor were obtained from the opinions of experts with at least 1,000 dive experiences in coral reefs in Thailand and abroad. The weights of each factor were not equal.

3. Results

3.1 Potential level of underwater pinnacles

The assessment of the potential level of the underwater pinnacles on Ko Tao revealed high-level tourism potential at two underwater pinnacles, i.e., Hin Chumphon (3.75) and Hin Khao (3.63) (Figure 2). The coral conditions at both underwater pinnacles were good. There are several valuable and famous scuba diving sites that attract many tourists. Other underwater pinnacles in Ko Tao, including Hin Samran, Hin Tung Ku, Hin Wong, and Hin Kong Sai Daeng, showed middle-level tourism potential which can be used as SCUBA diving sites or fishing spots.

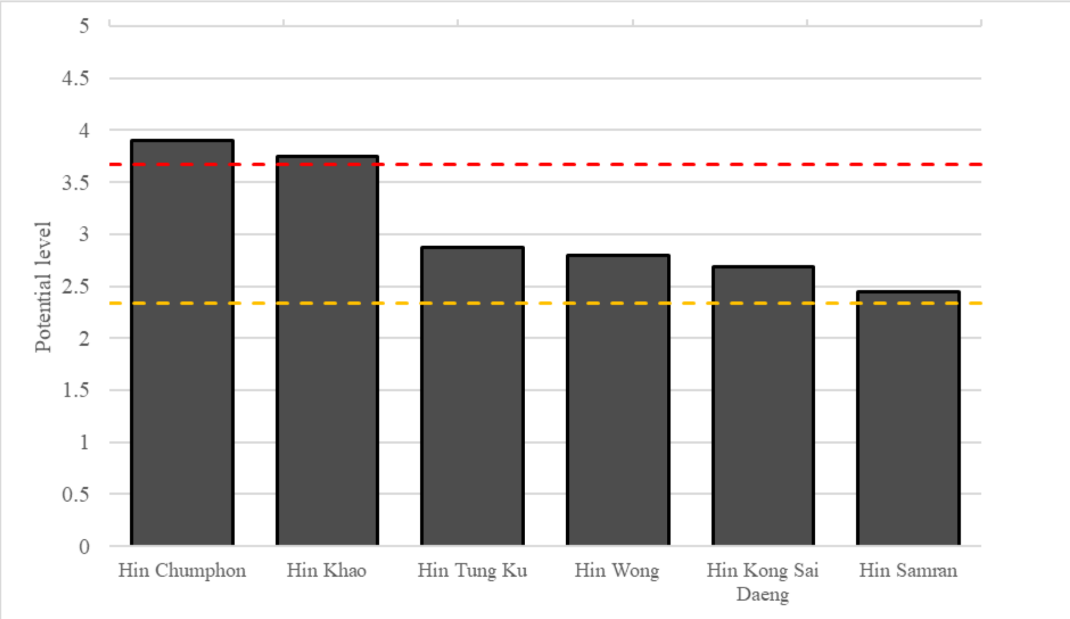


Figure 2. Evaluation of the potential level of the underwater pinnacle by physical and biological factors

3.2 Coral communities

The results of examining coral communities at the high-level tourism potential sites, Hin Chumphon and Hin Khao, are given in detail. Both underwater pinnacles presented high percentages of live coral cover (42.78% at Hin Chumphon and 41.09% at Hin Khao) (Figure 3). At Hin Chumphon, twenty-seven species from ten families of scleractinian corals were recorded (Figure 4). The dominant corals were *Porites lutea* (10.35±3.57%), *P. lobota* (5.36±1.85%), and *Platygyra sinensis* (4.68±1.61%) (Figure 5). At Hin Khao, seventeen species from nine families of scleractinian corals were observed (Figure 6). *Porites lutea*, *Diploastrea heliopora*, and *Acropora hyacinthus* were the dominant corals (Figure 7). The corals that had high potential to attract divers such as *Montipora aequituberculata*, *Acropora* spp., *Goniopora columna*, and *Turbinaria* spp. were observed at both underwater pinnacles.

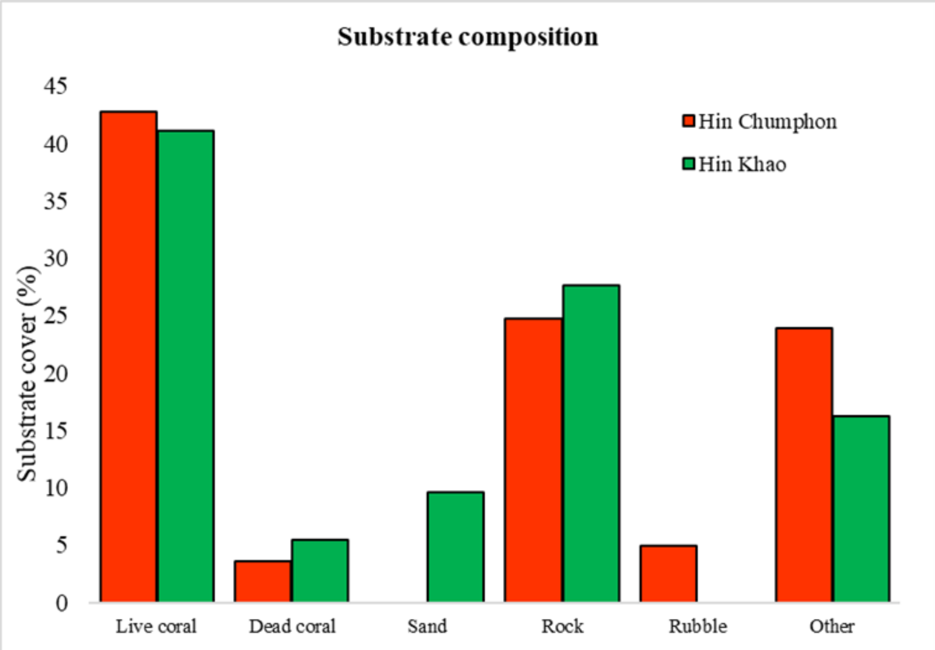


Figure 3. Benthic components at the study sites (mean ± SE)

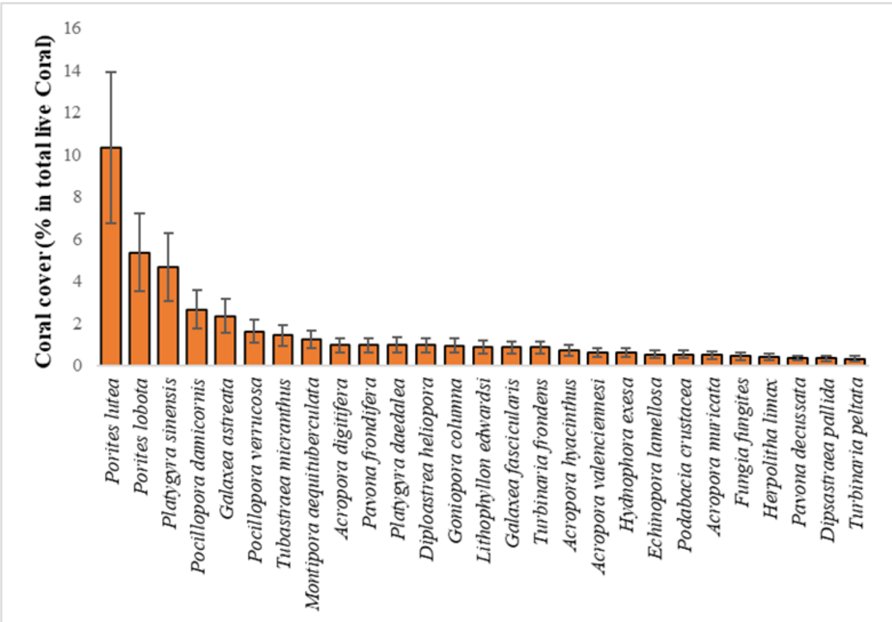


Figure 4. Species composition of live corals at Hin Chumphon

Porites lutea *Porites lobota* *Acropora hyacinthus*

Figure 5. Dominant corals at Hin Chumphon

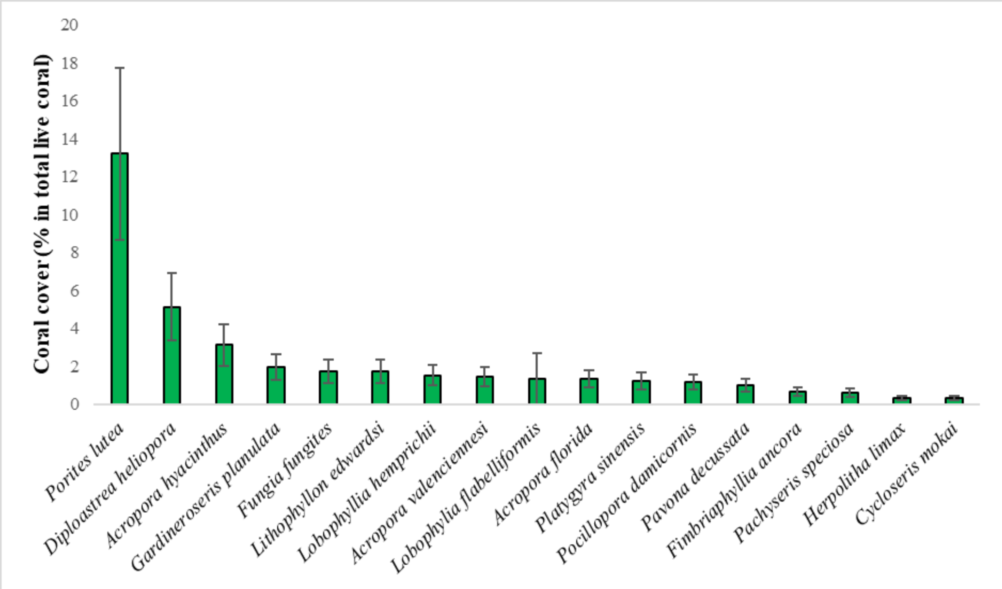
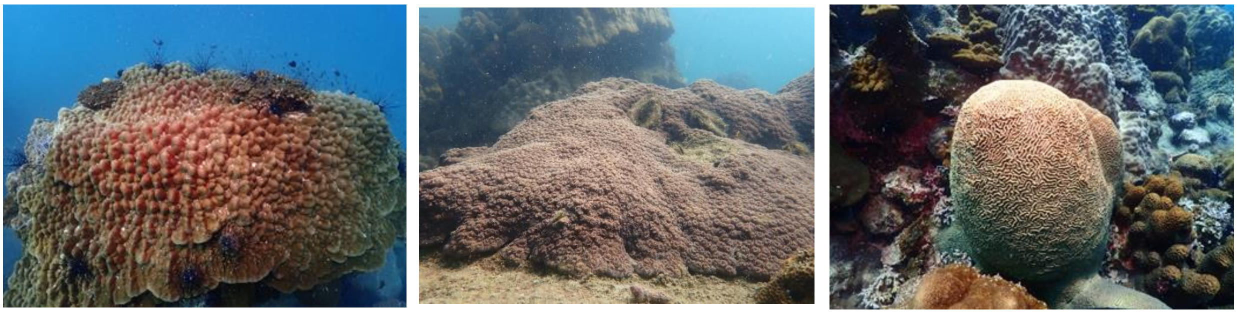


Figure 6. Species composition of live corals at Hin Khao



Porites lutea *Diploastrea heliopora* *Platygyra sinensis*

Figure 7. Dominant corals at Hin Khao

3.3 Macrobenthic invertebrate communities

The density of macrobenthic invertebrates at Hin Chumphon was relatively high (701± 63 individuals/100 m^2) compared with Hin Khao (32±25 individuals/100 m^2) (Figures 8 and 9). The macrobenthic invertebrates at Hin Chumphon were dominated by bivalves, including *Beguina semiorbiculata*, *Lamarcka ventricosa*, and *Pedum spondyloideum* (Figure 8) while Hin Khao was dominated by the sea urchin *Diadema setosum* and the Christmas tree worm *Spirobranchus giganteus* (Figure 9). Other common macrobenthic invertebrates at the study sites included the sponges *Xestospongia* sp. and *Neopetrosia* sp., the sea whip *Junceella fragilis*, the polychaete worm *Sabellastarte* sp., the sea slug *Phyllidia* sp., the giant clams *Tridacna crocea* and *T. squamosa*, the bivalves *Beguina semiorbiculata*, *Arca* sp. *Hyotissa hyotis* and *Pteria penguin*, the sea star *Culcita novaeguineae*, and the sea cucumber *Holothuria leucospilota* The attractive macrobenthic invertebrates to SCUBA divers are the giant clams Tridacna squamosa and the sea whip *Junceella fragilis* (Figure 10).

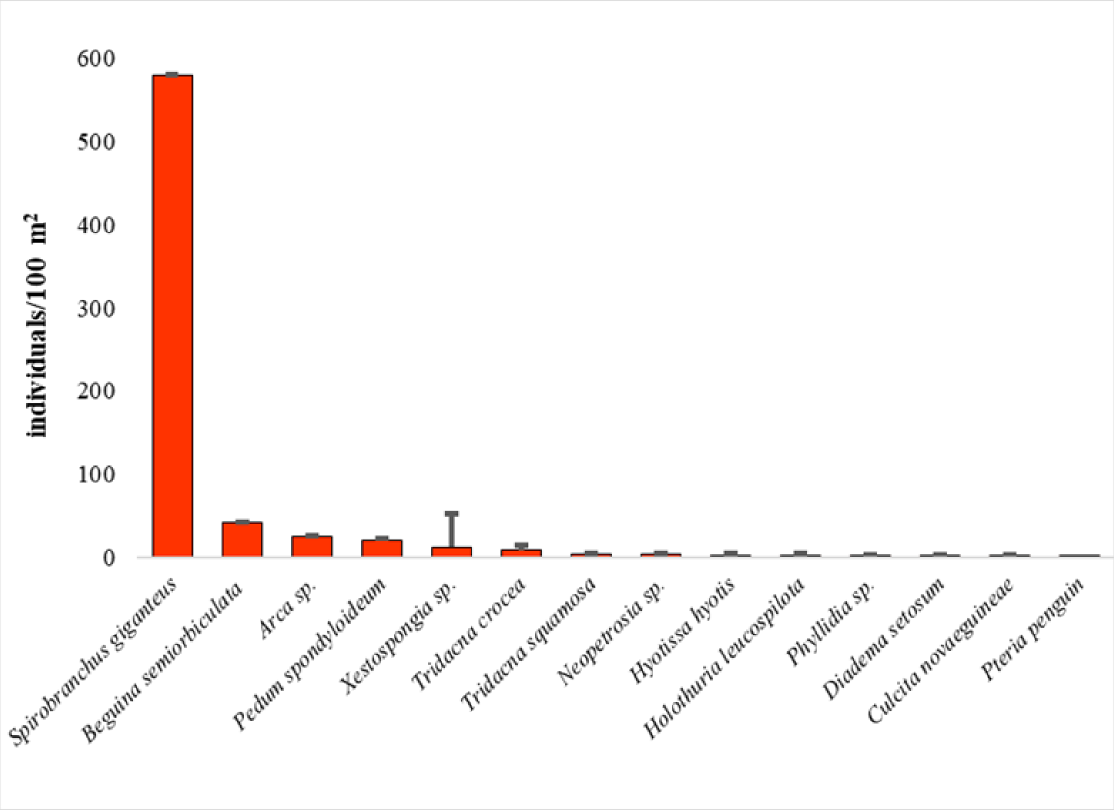


Figure 8. Abundance of macrobenthic invertebrates at Hin Chumphon (mean ± SE)

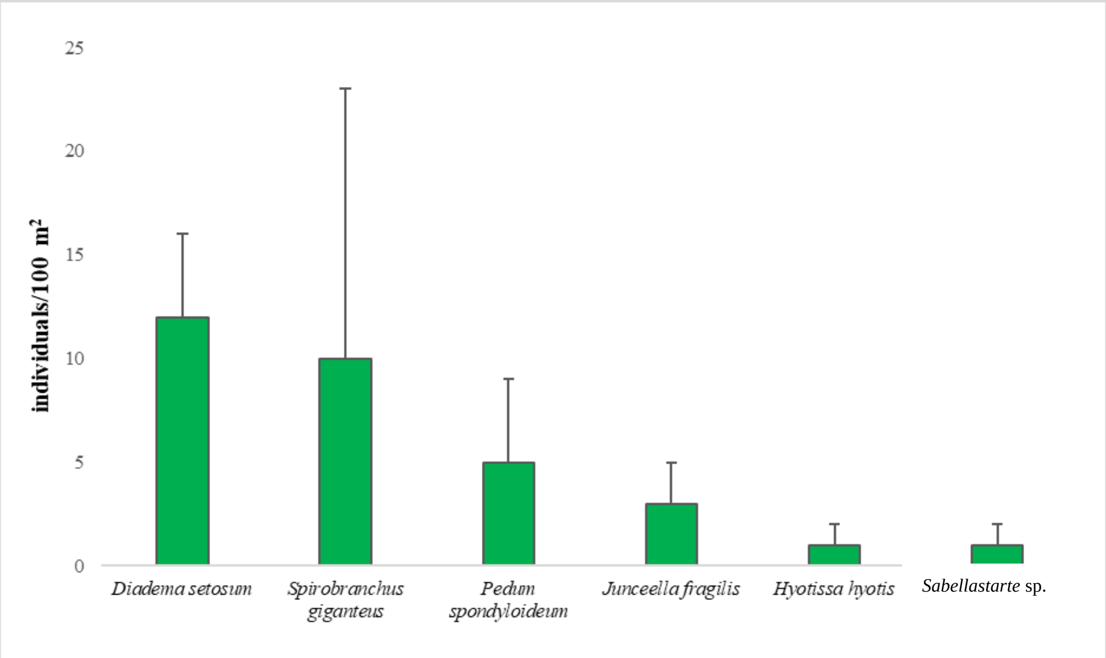


Figure 9. Abundance of macrobenthic invertebrates at Hin Khao (mean ± SE)


Tridacna squamosa


Junceella fragilis

Figure 10. Some attractive macrobenthic invertebrates to SCUBA divers at the study sites

3.4 Coral reef fish communities

Hin Khao holds a high density and species richness of coral reef fish. Sixty-three species from 20 families of reef fish with a density of 2,581.80±646.73 individuals/m^2 were recorded. The dominant fish were the damselfish including *Neopomacentrus anabatoides*, *Neopomacentrus cyanomos*, and *Chromis cinerascens*. Several ornamental fish were possibly seen here such as the ribbontail stingray *Taeniura lymma*, the pink anemonefish *Amphiprion perideraion*, the bluering angelfish *Pomacanthus annularis*, the Batfish *Platax orbicularis*, the butterflyfish *Chaetodon* spp., and the parrotfish *Scarus* spp. (Figure 11). Conversely, Hin Chumphon showed a lower in both density and species richness, with forty-nine species from sixteen families of reef fish. The reef fish density at Hin Chumphon was 1,482.22±359.11 individuals/m^2. The damselfish *Neopomacentrus anabatoides*, *Neopomacentrus cyanomos*, and the yellowtail barracuda *Sphyraena flavicauda* represented the most abundant fish. Ornamental fish such as the pink anemonefish *Amphiprion perideraion*, the butterflyfish *Chaetodon* spp., the parrotfish *Scarus* spp., and the lionfish *Pterois volitans* were also found (Figure 12). In addition, Hin Chumphon and Hin Khao are great places to spot the whale shark *Rhincodon typus*, as it has been frequently seen during March - April and August - October every year (Figure 13).


Amphiprion perideraion


Pterois volitans

Figure 11. Some attractive ornamental fish to tourists at Hin Khao


Amphiprion perideraion


Pterois volitans

Figure 12. Some attractive ornamental fish to tourists at Hin Chumphon

Figure 13. The whale shark *Rhincodon typus* at Hin Chumphon

4. Discussion

Our results showed that the diversity of attractive marine organisms and the facilities to travel led to high scores in the evaluation processes for the study sites, particularly Hin Chumphon and Hin Khao. The underwater pinnacle ecosystems of Ko Tao are complex and rich in biodiversity. They can provide a variety of ecological services, such as food sources, nurseries for many marine organisms, habitats for numerous aquatic animals, sources of revenue for fisheries, or serving as a medical resource. They are important tourist destinations with making a lot of income for local businesses in the area (Ruitenbeek et al. 1999; Spurgeon 1992; Spurgeon 1999; Yeemin et al. 1999; Yeemin et al. 2001; UNEP 2004; Letourneur et al. 2008; Wongthong and Harvey 2014; Hein et al. 2015; Tamayo et al. 2018; Giglio et al. 2020). Although the coral communities have faced several threats, especially the coral bleaching events in 1998 and 2010, the underwater pinnacles in the area are still in good condition (Sutthacheep et al. 2013; Aunkhongthong et al. 2021). The underwater pinnacles can adapt to climate change impacts because most underwater pinnacles are located far from the coast and deeper than the coral reefs in the nearshore area. Therefore, they are less disturbed by the impact of coastal activities and high seawater temperatures (Barros 2005; Stuart-Smith, et al. 2008; Yeemin, et al. 2012; Ortiz-Lozano et al. 2018). According to our findings, the underwater pinnacles of Ko Tao, Surat Thani Province, particularly Hin Chumphon and Hin Khao, are significant for ecology, socio-economy, fisheries, tourism, and advanced study of important and relevant scientific aspects (Yeemin et al. 2006; Morrison et al. 2013; Sutthacheep et al. 2022; Yeemin et al. 2022). At present, the ecology of the underwater pinnacles is lacking in systematic research, although many underwater pinnacles have a high potential for marine ecotourism and are interesting diving sites that can attract tourists and make high incomes for the local communities. However, due to lacking ecosystem research and the fact that their locations are still unknown, many underwater pinnacles are not properly utilized. Some underwater pinnacles in Surat Thani Province have been affected by human activities, such as sediment from coastal development, solid waste, wastewater, toxic substances used in fishing, and illegal fishing gear (Yeemin et al. 2013; Suraswadi and Yeemin 2013; Neumann et al, 2015; Toyoshima and Nadaoka, 2015; Chinfak et al. 2021).

There are many types of impacts on coral reefs and their associated organisms, particularly an increase in skeletal breakage of corals which is being applied as a key indicator of the level of recreational diving impacts. The number of coral fragments is usually an important parameter in coral reef monitoring programs because it is easily and clearly detected as a short-term impact of tourism activities (Jameson et al. 1999; Au et al. 2014; Worachananant et al. 2008; Wongnutpranont et al. 2020). The loss of live coral cover is an important indicator of the cumulative effect of diving impacts because of coral mortality. Changing the composition of benthic communities is also a key indicator for the long-term impacts of diving activities (Hawkins et al. 2005; Hasler and Ott 2008; Aunkhongthong et al. 2021). Recreational diving and the intensity of tourist activities have been linked to increased coral disease prevalence (Lamb et al. 2014; Samsuvan et al. 2019). Knowledge of coral diseases and diving activities is crucial for determining ecological carrying capacity and managing coral communities. Reef animals with fragile morphologies, particularly branching and plating corals, have been frequently damaged by recreational divers (Yeemin et al. 2006; Worachananant et al. 2008; Au et al. 2014; Giglio et al. 2018a). On underwater pinnacles at Ko Tao, the hard coral Acropora hyacinthus and the sea whip Junceella fragilis are dominant species and susceptible to diving activities. Therefore, tourist behaviors on the dive sites of Ko Tao must be carefully controlled.

There are many management strategies for interventions in recreational diving, mostly focusing on site-level management interventions, especially limiting the number of divers at particular sites and improving the low-impact diver behavior by providing information and assistance at dive sites (Samsuvan et al. 2012; Giglio et al. 2020). The international SCUBA diving certification companies can decrease the rates of reef contact and consequently the amount of damage to benthic animals by recreational divers (Hammerton 2016). Some management strategies, such as a pre-dive briefing, have been applied to reduce the negative impacts of divers (Camp and Fraser 2012; Webler and Jakubowski 2016; Giglio et al. 2018b; Huddart 2019). Various stakeholders have been involved in diving tourism management and provided action plans. The most important challenges are the lack of baseline data from coral community conditions previously to the diving impact and the long-term monitoring of coral communities. Early planning of recreational diving is very important for the effective management of underwater pinnacles (Giglio et al. 2020). Recreational divers are usually willing to pay user fees which can be spent on coral reef conservation programs and involvement in citizen-science based research and conservation activities (Casey et al. 2010; Hunt et al. 2013). The carrying capacity and the limit of acceptable change of particular dive sites must be continuously examined (Dixon et al. 1993; Davis and Tisdell 1995; Hawkins and Roberts 1997; Roman et al. 2007; Rouphael and Hanafy 2007; Leujak and Ormong 2008; Zhang et al. 2016; Wongnutpranont et al. 2020). Communications among relevant stakeholders must be established to support active and collaborative coral reef management (Sharma-Wallace et al. 2018; Yeemin et al. 2021).

Management frameworks of underwater pinnacles are required to have proper plans, policies, guidelines, effective enforcement, long-term monitoring programs, and activities to enhance environmental awareness and education. Management strategies for recreational diving should rely on the responsible use of natural resources, the socio-economic context of stakeholders, and a satisfying diving experience (Black et al. 2011; Wongthong and Harvey, 2014; Trave et al. 2017; Sutthacheep et al. 2022). Several underwater pinnacles in this study are a high potential for marine ecotourism. The negative impacts of tourism development in the Ko Tao area must be carefully considered. This study proposes that the underwater pinnacles in the Ko Tao area should be established as marine protected areas under the Marine and Coastal Resources Management Promotion Act - B.E. 2558 (2015) for ecotourism and sustainable fisheries.

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