ORIGINAL PAPER

# Diversity of scleractinian corals, macrobenthic invertebrates and reef fish on underwater pinnacles in Surat Thani Province, Thailand

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**Abstract**. Underwater pinnacles in tropical countries provide important marine habitats which have ecological functions similar to coral reefs. Most of them have high potential to be established as marine protected areas. This study aimed to examine diversity of scleractinian corals, macrobenthic invertebrates and reef fish on underwater pinnacles in the vicinity of Ko Phangan, Surat Thani Province, the Western Gulf of Thailand. Five coral communities on underwater pinnacles, namely Hin Bai, Hin Ko Ma, Hin Hat Kruat, Hin Kong Nui and Hin Tae Nok were studied in early 2022. The highest percentage of live coral cover was found at Hin Bai while the lowest one was found at Hin Hat Kruat. The most dominant coral species were Porites lutea and followed by *Pocillopora acuta*. The highest species diversity index was observed at Hin Bai. The highest density of macrobenthic invertebrates was also found at Hin Bai while the lowest one was observed at Hin Tae Nok. The most dominant macrobenthic invertebrates were Diadema setosum and followed by *Spirobranchus giganteus*. The highest density of reef fish was observed at Hin Bai while the lowest one was found at Hin Ko Ma. The most abundant reef fish were *Neopomacentrus anabatoides* and followed by *Neopomacentrus cyanomos*. The two-dimensional non-metric multidimensional scaling (NMDS) plots of study sites based on the species compositions of coral species, macrobenthic invertebrates, and reef fish exhibited three different groups. The present study provides important scientific data and recommends that the underwater pinnacles must be properly managed through appropriate interventions, particularly establishing marine protected areas under the Marine and Coastal Resources Management Promotion Act -B.E. 2558 (2015), resilience-based management (RBM) and other effective area-based conservation measures (OECMs) for strengthening a policy on protecting 30% of global oceans by 2030 under the Kunming-Montreal Global Biodiversity Framework.

**Keywords**: Coral community, ecotourism, management, protected area, underwater pinnacle

## 1. Introduction

Coral reefs are biodiversity hotspots that provide millions of people with ecosystem services such as food provision, livelihood opportunities, carbon sequestration, and coastal protection (Rosenberg et al. 2007; Hughes et al. 2012; Laurans et al. 2013; Harris et al. 2014; Dunning 2015; Woodhead et al. 2021). Supporting services include important habitat and biodiversity services for the reef fisheries and the tourism industry (Masud et al., 2017; Nama et al., 2023). Coral reefs are productive and diverse tropical marine ecosystems framed by massive three-dimensional structures created by the deposition of calcium carbonate skeletons by individual coral colonies (Schwarz et al. 2008; Huggett et al. 2019; Alvarado-Cerón et al. 2022). Reef associated macrobenthic invertebrates are essential for the structuring and functioning of coral reef ecosystems (Stella et al. 2010; Villéger et al. 2012; ref MBRG). These organisms may also serve as indicators of environmental conditions, such as variations in water quality and exposure to waves and current (Kolasinski et al., 2016; Walag et al., 2016). They also provide aesthetically appealing colors and morphologies to coral reefs, attracting tourists (Walsh et al., 2017; Quimpo et al., 2018). The abundance and composition of fish communities is an important factor of reef resilience (Cortesi et al., 2020). Coral reef fishes are important for food security and as economic commodities, especially in fishing communities (Maddupp et al., 2014; Cortesi et al., 2020).
Many locations in the Western Gulf of Thailand are most important tourist destinations especially,

Ko Samui, Ko Tao, and Ko Phangan in the Surat Thani Province which attract millions of visitors each year. Marine tourism is an important sector that contributes to local and national economies. The number of tourists in coastal provinces seems to be increasing each year (Hall 2016; Lucrezi et al. 2017; Sutthacheep et al. 2020, 2022; Wongnutpranont et al. 2022). SCUBA diving is a form of adventure tourism that has high economic value (Haddock-Fraser & Hampton, 2012; Fossgard & Fredman, 2019; Zimmerhackel et al., 2019).

Underwater pinnacles within tropical regions serve as significant marine habitats, offering comparable functions and benefits to coral reefs. The configuration of these underwater pinnacles profoundly impacts the diversity and composition of organisms associated with reefs. These formations exhibit diverse characteristics, ranging from complete submersion to partial exposure above the water's surface. In Thailand, numerous underwater pinnacles are located in the Gulf of Thailand, with potential for development into captivating dive sites (Rangseethampanya et al. 2021; Pengsakun et al. 2022; Sutthacheep et al. 2022). Most underwater pinnacles have high potential to be considered as marine protected areas. To support an agreement on protecting 30% of global oceans by 2030 (Ocean 30 ×30) under the Kunming-Montreal Global Biodiversity Framework (Whomersley et al. 2022; Li et al. 2023). The objective of this study was to examine diversity of scleractinian corals, macrobenthic invertebrates and reef fish on underwater pinnacles in the vicinity of Ko Phangan, Surat Thani Province, the Western Gulf of Thailand to understand their conditions, tourism potential and management.

## 2. Materials and Methods

### *2.1 Location of study sites*

This study was undertaken across coral communities on underwater pinnacles at Ko Phangan, the Western Gulf of Thailand. Five coral communities including Hin Bai, Hin Ko Ma, Hin Hat Kruat, Hin Kong Nui and Hin Tae Nok were investigated in early 2022 (Figure 1). Ko Phangan is a large Island off the east coast of Surat Thani Province in the Gulf of Thailand. It is located about 100 km offshore and 15 km north of Ko Samui. The location, environmental conditions, and anthropogenic disturbances at each study site are summarized in Table 1.

### *2.2 Data collection*

The coral communities were investigated by SCUBA diving along a permanent belt transect with three replicates. The substrate cover of live coral, dead coral, rubble, sand, and algae were recorded within 50 cm to each side of the line (English et al. 1997). The coral species were identified to species level if possible, following Veron (2000). An underwater camera took photographs for data recheck in the laboratory.

The macrobenthic invertebrate surveys were carried out at the same area (100 x 1 m), all macrobenthic invertebrates were counted as individual/unit areas and identified to species level if possible. Quadrats were also photographed with an underwater camera to investigate the data further.

Reef fish were recorded and counted in a 2 m wide transect (200 m$^2$) and identified to species level in situ with the further aid of underwater photographs and guide books for dubious taxa (Allen et al., 2015).

### *2.3 Data analysis*

At each study site, Shannon's diversity index (H') was calculated based on the number of individuals. A one-way A NOVA to test the differences in the species diversity index of coral species, macrobenthic invertebrates, and reef fish among the study sites. Where significant differences were found, the Tukey HSD (honestly significant difference) test was employed to determine which study sites differed. Cluster analysis and the non-multidimensional scaling method were performed to categorize study sites on the basis of the Bray-Curtis similarity, using PRIMER version 7.0.

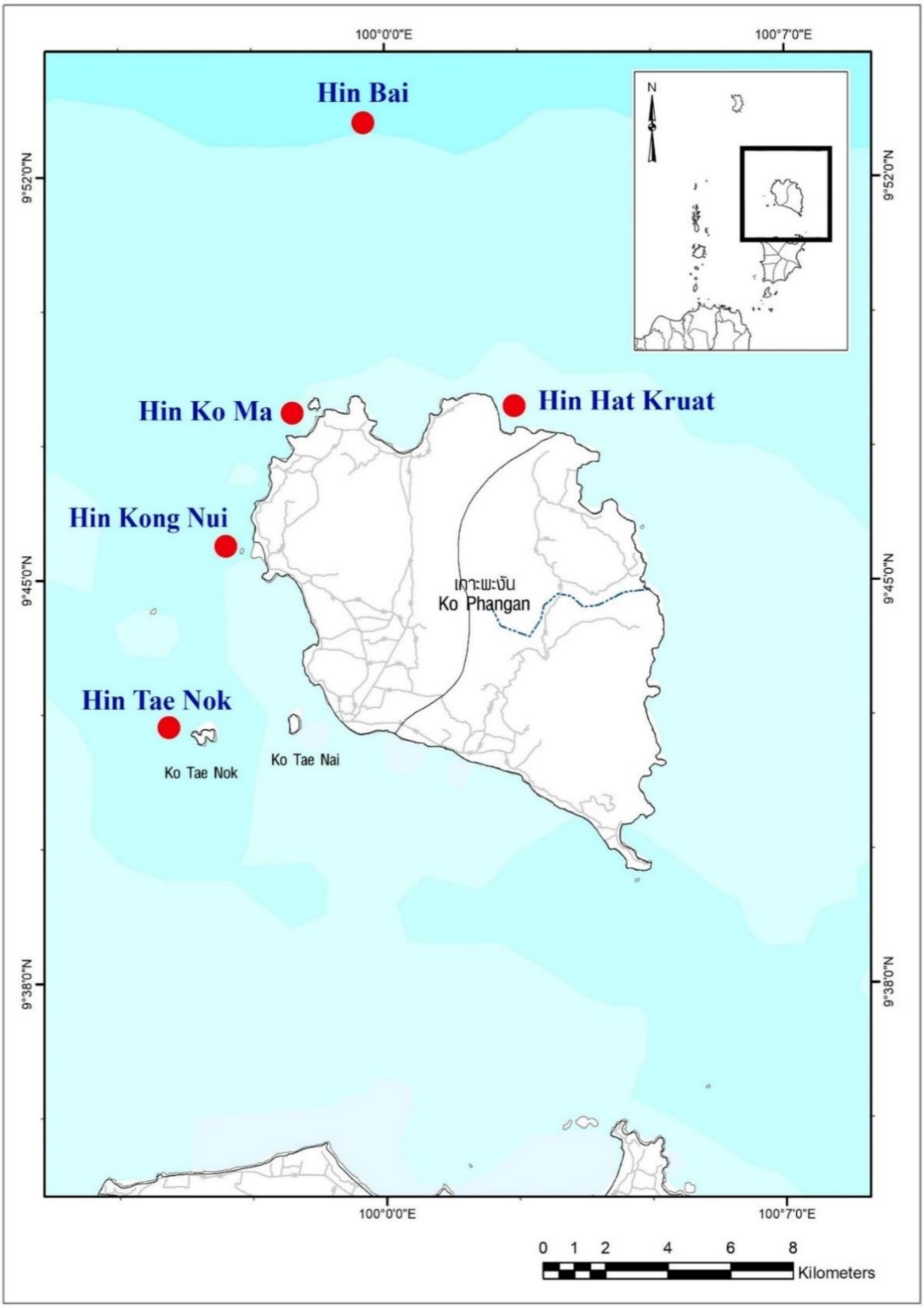



**Figure 1.** The location of study sites at Ko Phangan

**Table 1.** Location and information of the study sites at Ko Phangan

| Study Site | Latitude (N), Longitude (E) | Distance from the shore (km) | Depth (m) | Water transparency | Anthropogenic disturbances |
|---|---|---|---|---|---|
| Hin Bai | 9°56'41.49" 99°59'24.57" | 16 | 5-30 | Clear | Tourism (high) |
| Hin Ko Ma | 9°47'44.86" 99°58'33.02" | 0.5 | 8-10 | Turbid | Fishery (low) |
| Hin Hat Kruat | 9°47'51.84" 100° 2'9.59" | 0.4 | 7-9 | Turbid | Fishery (low) |
| Hin Kong Nui | 9°45'28.61" 99°57'10.19" | 0.85 | 10-15 | Turbid | Fishery (low) |
| Hin Tae Nok | 9°42'18.68" 99°56'25.92" | 4.50 | 10-17 | Turbid | Fishery (low) |

## 3. Results

### *3.1 Coral communities*

The results indicated that the highest percentage of live coral cover was found at Hin Bai (31.22±3.89), while the lowest one was found at Hin Hat Kruat (14.33±1.79) (Figure 2). A total of 30 coral species were found in the study sites. The most dominant coral species were *Porites lutea* and followed by *Pocillopora acuta*. Other dominant coral species were *Diploastrea heliopora*, *Galaxea astreata*, *Goniopora columna*, and *Lobophyllia radians*. The highest species diversity index was observed at Hin Bai. The statistical analysis revealed that the species diversity index was significantly different among the study sites (One-way ANOVA, F = 66.88, $p$<0.05) (Figure 3).

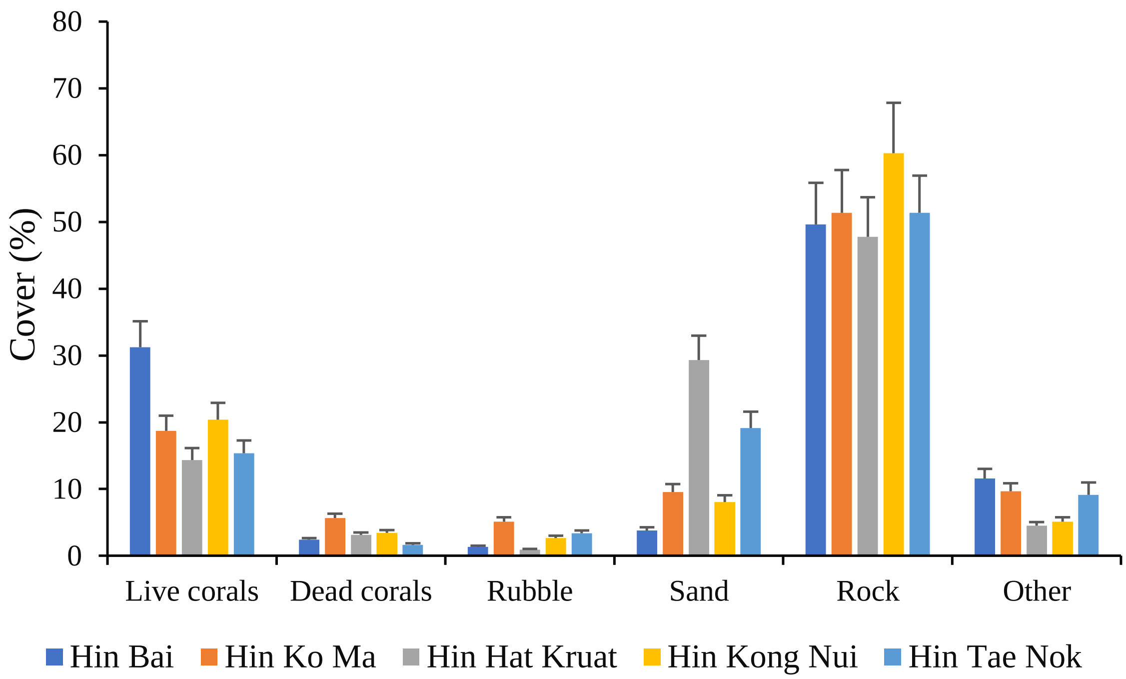



**Figure 2.** Average percentage cover of live corals, dead corals and other benthic components at the study sites. Error bars indicate standard error of the mean.

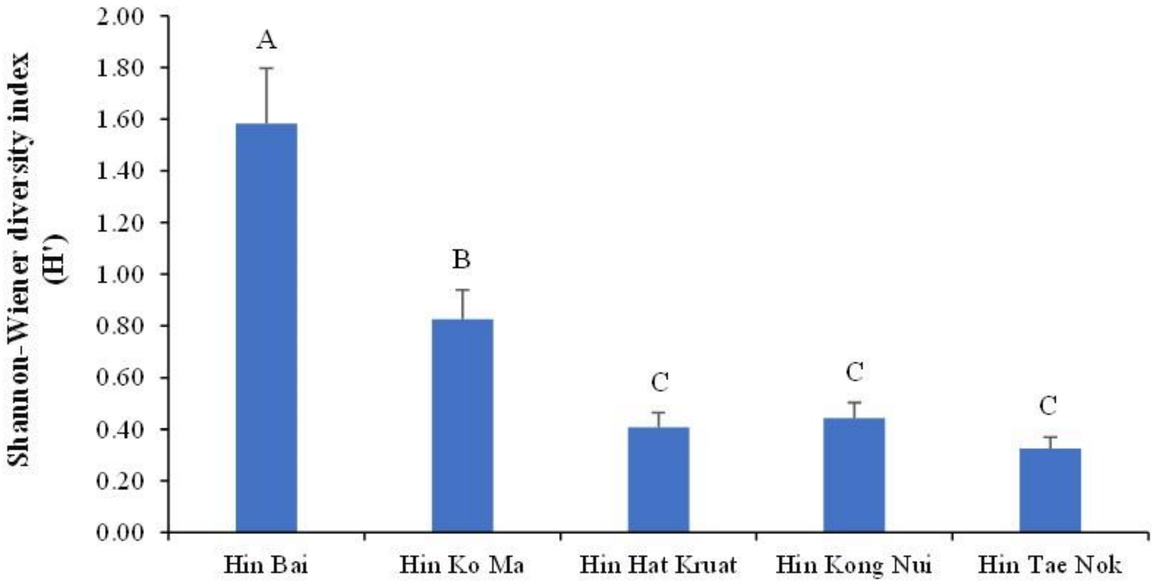
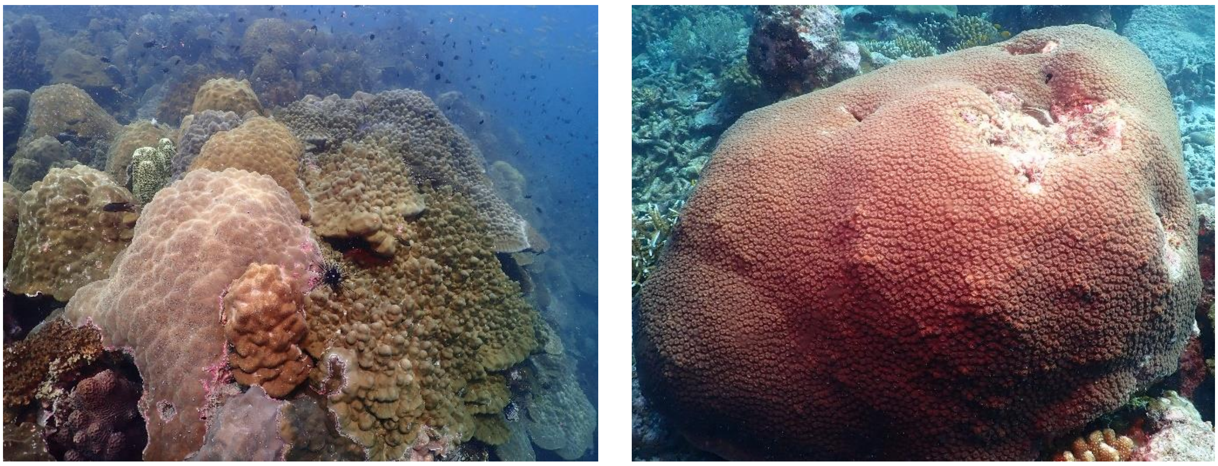



**Figure 3.** Shannon-Wiener index of diversity (mean + SE) of coral species for each study site (one-way ANOVA, $p < 0.05$). Different letters above indicate statistical differences ($p < 0.05$), as determined by Tukey's HSD.



*Porites lutea* *Diploastrea heliopora*

*Lobophyllia radians* *Pocillopora acuta*

**Figure 4.** Underwater photographs showing dominant coral species at the study sites

*3.2 Macrobenthic invertebrates*

The results showed that the highest density of macrobenthic invertebrates was observed at Hin Bai (1.66±0.22 ind.m$^{-2}$) while the lowest one was found at Hin Tae Nok (0.28±0.04 ind.m$^{-2}$) (Figure 5). The most dominant macrobenthic invertebrates were *Diadema setosum* and followed by *Spirobranchus giganteus*. Other dominant macrobenthic invertebrates were *Jorunna funebris*, *Junceella* sp., *Goniobranchus aureopurpureus* and *Phyllidia elegans*. The highest species diversity index was observed at Hin Bai. The statistical analysis revealed that the species diversity index was no significantly different among the study sites (One-way ANOVA, F = 2.10, $p$>0.05) (Figure 6).

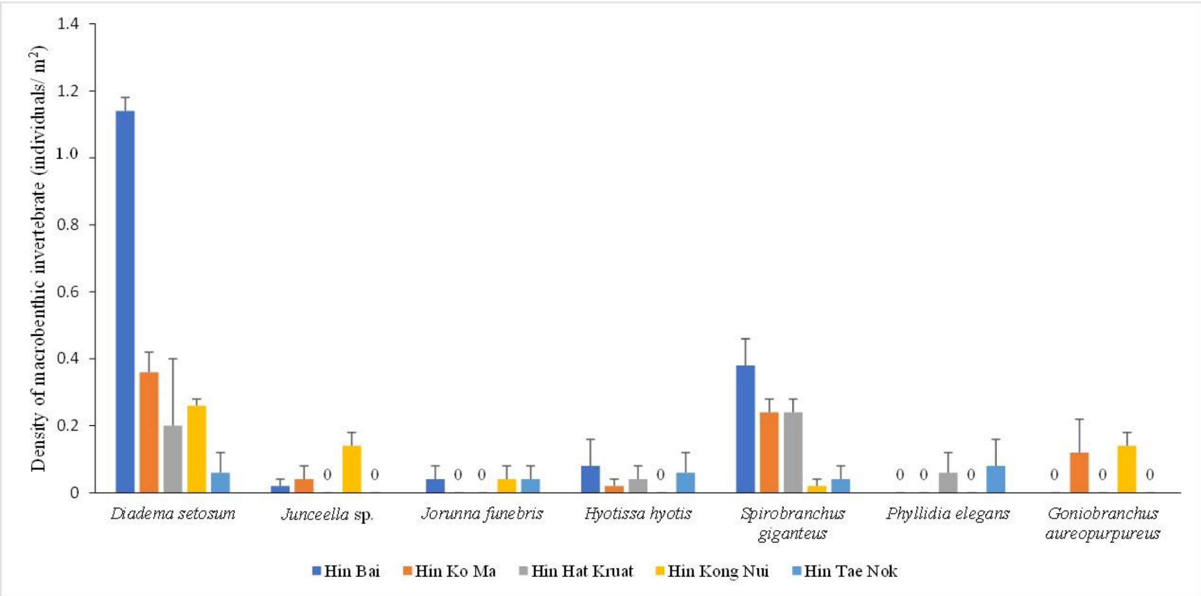



**Figure 5.** Population densities of macrobenthic invertebrates at each study site. Error bars indicate standard error of the mean.

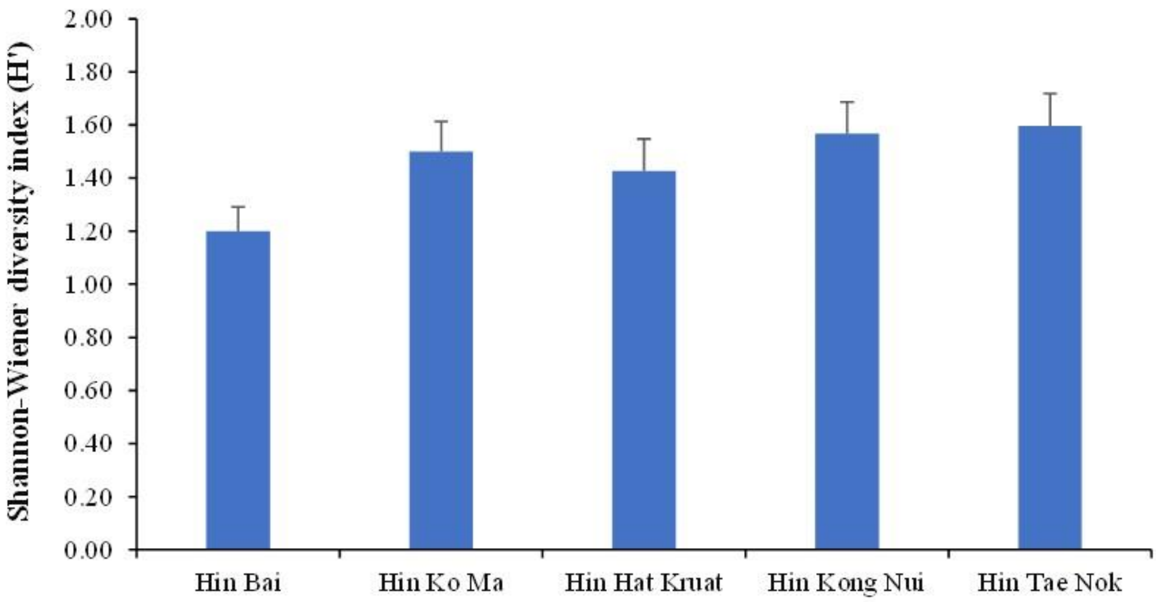



**Figure 6.** Shannon-Wiener index of diversity (mean + SE) of macrobenthic invertebrates for each study site (one-way ANOVA, $p$ > .05).


**Figure 7.** Underwater photographs showing dominant macrobenthic invertebrates at the study sites

### *3.3 Reef fish*

The results revealed that the highest density of reef fish was observed at Hin Bai (4,337± 587.60 ind/100m$^2$) while the lowest one was found at Hin Ko Ma (703±95.25 ind/100m$^2$). A total of 79 reef fish species were found at the study site. The most abundant reef fish were *Neopomacentrus anabatoides* and followed by *Neopomacentrus cyanomos*. Other dominant reef fish species were *Halichoeres nigrescens*, *Caesio xanthonota*, *Siganus javus*, and *Siganus virgatus*. The statistical analysis showed that the species diversity index was significantly different among the study sites (One-way ANOVA, F = 10.28, $p$<0.01) (Figure 8).

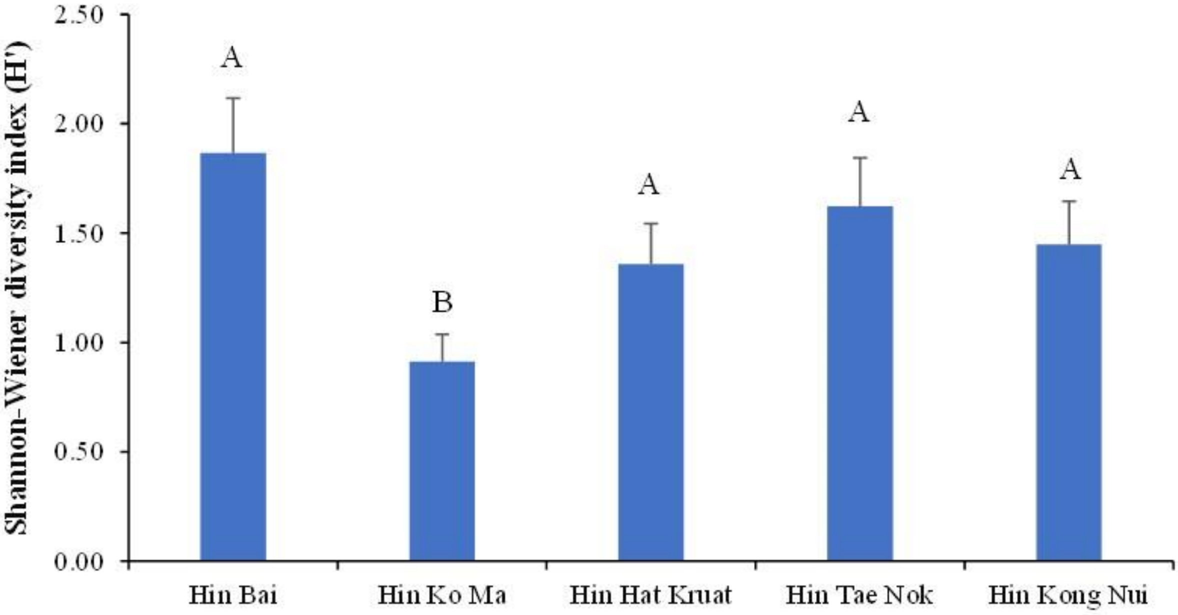
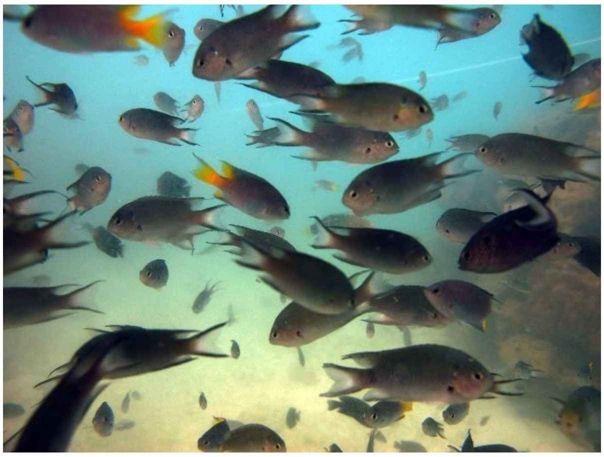


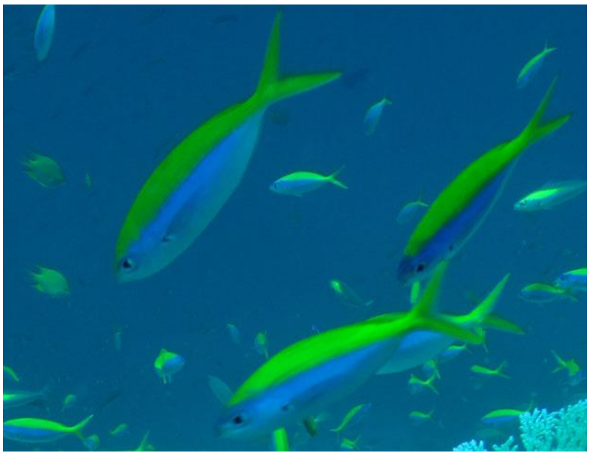

**Figure 8.** Shannon-Wiener index of diversity (mean + SE) of reef fish for each study site (one-way ANOVA, $p < .05$). Different letters above indicate statistical differences ($p < 0.05$), as determined byTukey's HSD.



*Neopomacentrus anabatoides*

*Siganus virgatus*

*Siganus javus*



*Caesio xanthonota*

**Figure 9.** Underwater photographs showing dominant reef fish at the study sites

The two-dimensional non-metric multidimensional scaling (NMDS) plots of study sites based on the species compositions of coral species, macrobenthic invertebrates, and reef fish showed three different groups of the study sites. The first group consisted of Hin Bai which is located far from Ko Phangan and the transparency is relatively high. Hin Ko Ma and Hin Kong Nui were in the second group, located near Ko Phangan in turbid waters. The third group included Hin Hat Kruat and Hin Tae Nok. SCUBA diving activities were observed at only Hin Bai. Small-scale fishing is commonly found at Hin Ko Ma, Hin Kong Nui, Hin Hat Kruat and Hin Tae Nok (Figure 10).

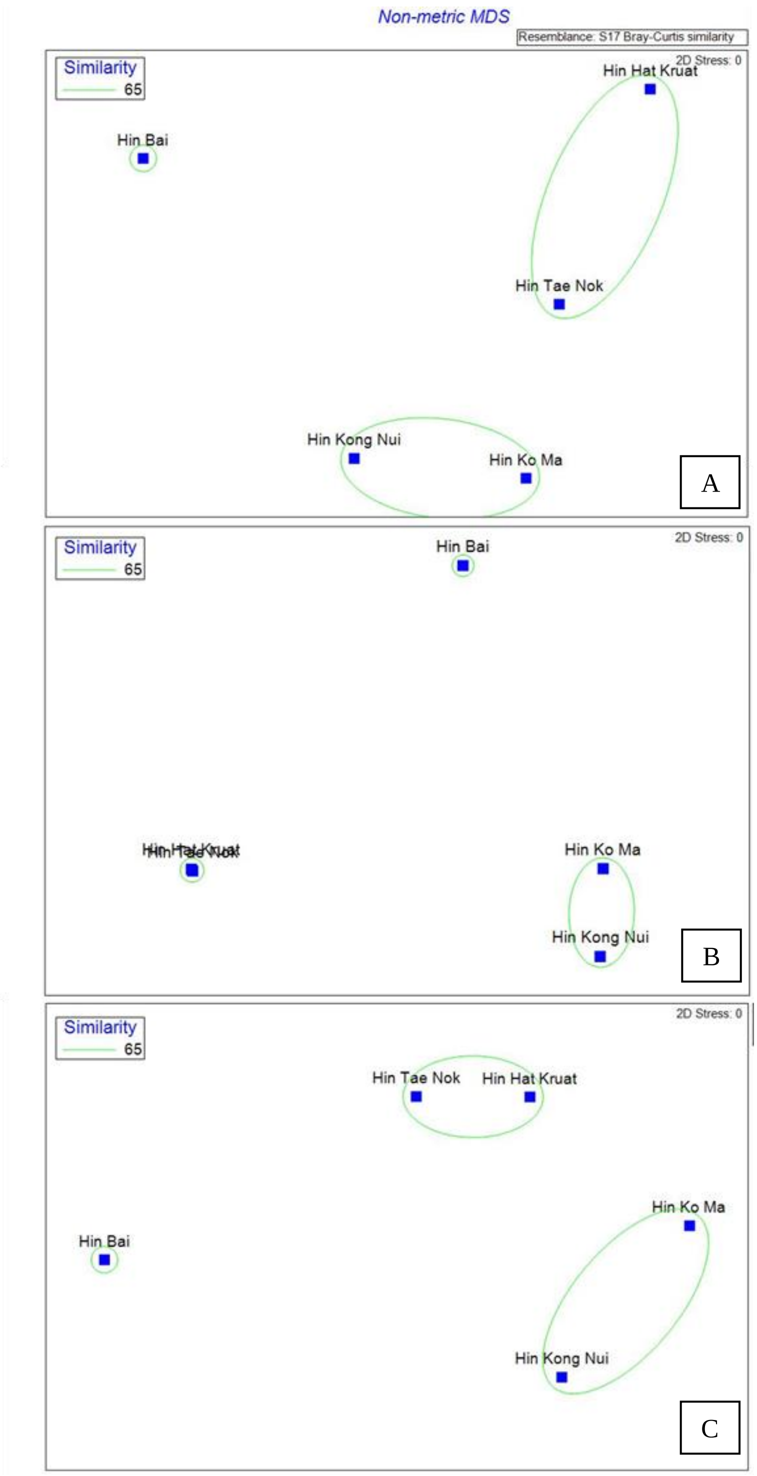



**Figure 10.** Two-dimensional non-metric multidimensional scaling (NMDS) plots of the species composition of corals (A), macrobenthic invertebrates (B), and reef fish (C) at the study sites.

## 4. Discussion

Our results indicated that the diversity of scleractinian corals, macrobenthic invertebrates, and reef fish, particularly at Hin Bai can provide several important ecosystem services in the Gulf of Thailand. Thirty scleractinian coral species were found at the underwater pinnacles and the most dominant coral species were *Porites lutea*, followed by *Pocillopora acuta*. The coral community structures of these underwater pinnacles are similar to those of coral reefs in the Gulf of Thailand (Yeemin et al. 2009; Sutthacheep et al. 2018). The live coral cover of over 30% at Hin Bai indicates that this coral community can survive after the severe coral bleaching events in 1998 and 2010 (Sutthacheep et al. 2013). A high susceptible coral to coral bleaching events, *Pocillopora acuta*, in the Gulf of Thailand (Sutthacheep et al. 2013), was also observed at some underwater pinnacles in the present study. Several underwater pinnacles exhibited high resilience because they have good environmental conditions and less susceptible to high seawater temperature anomaly, heavy storms and land-based pollution (Pengsakun et al. 2022; Sutthacheep et al. 2020, 2022 a, b; Wongnutpranont 2020). The dominant corals found on underwater pinnacles such as *Porites lutea*, *Diploastrea heliopora*, *Galaxea astreata*, *Goniopora columna*, and *Lobophyllia radians* are the key reef builders and can be shelters for benthic invertebrates and reef fish (Niyomthai et al. 2019; Rangseethampanya et al. 2021).

The dominant macrobenthic invertebrates observed at the study sites are *Diadema setosum*, *Junceella* sp., *Spirobranchus giganteus*, *Goniobranchus aureopurpureus*, *Jorunna funebris*, and *Phyllidia elegans*. Clearly, *Junceella* sp., *Spirobranchus giganteus*, *Goniobranchus aureopurpureus*, and *Jorunna funebris* are beautiful and attractive to tourists. These macrobenthic invertebrates are important resources for developing marine ecotourism programs in the Gulf of Thailand (Pengsakun et al. 2022; Sutthacheep et al. 2022a). Our results showed that the sea urchin *Diadema setosum* is a dominant macrobenthic invertebrate on the underwater pinnacles. It is possible that the sea urchins escape predators, particularly several reef fish species. Moreover, anthropogenic disturbances derived from overfishing and global change impacts can control the sea urchin populations (Yeemin et al. 2009; Aunkhongthong et al. 2020). Certain management strategies are required, especially exploitation of sea urchins and establishing of marine protected areas. The giant clams *Tridacna* spp. is important macrobenthic invertebrates on coral reef ecosystems in the Gulf of Thailand (Niyomthai et al. 2019), however the population densities of giant clams on the underwater pinnacles from the present study were very low. The giant clams in Thai waters have declined in the past decades and local extinction was reported from several reef sites (Niyomthai et al. 2019). However, the successful aquaculture program from Department of Fisheries of Thailand can increase population densities of the giant clams at several locations through the program for enhancement and restoration of giant clams which was initiated in 1993. Our results suggest that the giant clam restoration projects on underwater pinnacles are urgently needed to enhance population densities of the giant clams on coral communities in the Gulf of Thailand.

The high density of reef fish, 4,337±587.60 ind/100m$^2$, was found at Hin Bai. This reiterates the ecological function of underwater pinnacles as a shelter for reef fish. The abundant reef fish observed on the underwater pinnacles were *Neopomacentrus anabatoides*, *Neopomacentrus cyanomos*, *Halichoeres nigrescens*, *Caesio xanthonota*, *Siganus javus*, and *Siganus virgatus*. These reef fish can be important resources for tourism as well as fisheries (Rangseethampanya et al. 2021). We found that the abundance of reef fish at the offshore underwater pinnacle (Hin Bai) was significantly higher than that at nearshore underwater pinnacles (Hin Ko Ma, Hin Hat Kruat, Hin Kong Nui and Hin Tae Nok). Rangseethampanya et al. (2021) also reported that the abundance of a common ornamental fish, *Chaetodon wiebeli* in Mu Ko Chumphon Province had higher population density at the offshore islands compared to the nearshore island. The high abundance of reef fish at offshore locations may be resulted from low land-based pollution and low intensity of human activities from the coastal areas.

The present study showed that the underwater pinnacles in the vicinity of Ko Phangan, the Western Gulf of Thailand harbored diversity of scleractinian corals, macrobenthic invertebrates and reef fish, particularly at Hin Bai. These coral communities can provide several ecosystem services, especially food sources, nursery for many ecologically important species, microhabitats for marine organisms, incomes from fisheries and tourisms as well as a potential medical resources. Hin Bai is an important SCUBA diving destination and it is crucial for tourism business in Surat Thani Province (Wongthong et al. 2014; Sutthacheep et al. 2022b). However, some underwater pinnacles in Surat Thani Province have been influence by anthropogenic disturbances, particularly heavy sedimentation, destructive fishing and marine debris (Suraswadi and Yeemin 2013; Chinfak et al. 2021). There are several negative impacts of diving on underwater pinnacles such as coral fragmentation, loss of live coral cover, changing the composition of reef organisms, and coral diseases (Yeemin et al. 2006; Samsuvan et al. 2019; Aunkhongthong et al. 2021). It is recommended that diving behaviors on the coral communities at Hin Bai must be carefully monitored and regulated. The underwater pinnacles in this study must be properly managed through appropriate types of management interventions such as establishing marine protected areas under the Marine and Coastal Resources Management Promotion Act -B.E. 2558 (2015), resilience-based management (RBM) and other effective area-based conservation measures (OECMs) which are important strategies to strengthen a policy on protecting 30% of global oceans by 2030 (Ocean 30 ×30) under the Kunming-Montreal Global Biodiversity Framework (Sutthacheep et al. 2022b; Whomersley et al. 2022; Li et al. 2023).

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