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ORIGINAL PAPER

High resilience of coral communities at Hin Ang Wang, Surat Thani Province and a proposed management strategy

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Abstract The 1998 and 2010 mass coral bleaching events caused coral degradation to be severe and extensive in the Gulf of Thailand, particularly the Western Gulf of Thailand. This study assessed the resilience potential of coral communities at Hin Ang Wang, the Western Gulf of Thailand, by conducting field surveys on benthic components, community structure of scleractinian corals, diversity and density of juvenile corals, composition and abundance of macrobenthic invertebrates and reef fish. The live coral cover was 44.2%, while dead coral cover was 3.7%, indicating that the coral community is very good condition. The dominant coral species were *Porites lutea*, *Pavona decussata* and *Montipora aequituberculata*. The total density of juvenile corals was 1.6 juveniles/m^2. The total density of 27 reef fish species was 937. 8±433.6 individuals/100 m^2. The most dominant reef fishes were *Neopomacentrus anabatoides*, *Chromis cineracens* and *Parioglossus philippinnus*. There were several target species of macrobenthic invertebrates and reef fish for aquaculture and fishing. Some are attractive to tourists and can be target species for marine ecotourism. Our results show that the coral communities at Hin Ang Wang had high resilience to coral bleaching events and human impacts. It should be established as a marine protected area under the Department of Marine and Coastal Resources. The management plan should be also developed and implemented. The resilience-based management is proposed to support natural processes and maintain coral reef resilience

Keywords: coral community, resilience, management, recruitment, Gulf of Thailand

1. Introduction

Coral reefs worldwide are degrading because of human and natural disturbances, especially land-based pollution, overfishing, ocean warming and ocean acidification (Yeemin et al. 2009; Yeemin et al. 2013a; Wear and Thurber 2015; Cheal et al. 2017; Hughes et al. 2017; Shantz et al. 2020). The future of coral reef ecosystems relies on the collaborative reduction of global greenhouse gas emissions and urgent actions that enhance coral reef resilience to climate change, particularly coral bleaching events (Kleypas et al. 2021; Shaver et al. 2021). The severe coral bleaching events have caused the majority of coral reefs in loss of living corals around the world (Eakin et al. 2019). Some coral reefs are vulnerable to collapse at the regional level and some ecoregions are critically endangered (Obura et al. 2022).

The 1998 and 2010 mass coral bleaching events caused coral degradation to be severe and extensive in the Gulf of Thailand, particularly the Western Gulf of Thailand. Scleractinian corals in the Gulf of Thailand are different in their susceptibility to coral bleaching, which is an essential aspect of coral reef research because it can significantly lead to coral community changes

(Yeemin et al. 2012; Sutthacheep et al. 2012). Knowledge concerning the synergistic effects of coral bleaching and anthropogenic impacts on the ecological functions and processes of coral reefs, especially coral recruitment, is very important for establishing a management strategy for enhancing the resilience of coral reefs (Manikandan et al. 2017). High coral recruitment and survivorship of juvenile corals are essential factors in maintaining coral populations after mass mortality from bleaching events (Hughes et al. 2002; Doropoulos et al. 2015; Yucharoen et al. 2015). Therefore, coral recruitment is usually applied as a bioindicator of coral reef recovery and resilience after severe coral bleaching events. Several environmental factors influence coral recruitment, particularly sedimentation, water pollution and overfishing (Yeemin et al. 2013b).

The capacity of coral reefs to resist or recover from degradation and to maintain their ecosystem services are defined as coral reef resilience (Mumby et al. 2007). Resilience-based management of coral reefs assesses spatial variation in resilience potential and implementing proper management plans. Several resilience indicators have been developed and used for assessing the ecological resilience of coral reefs, including the assessment of the resilience potential of inshore and offshore coral communities in the Western Gulf of Thailand (Sutthacheep et al. 2019). This study quantitatively assessed the coral reef resilience potential at Hin Ang Wang, Surat Province, the Western Gulf of Thailand, based on scientific surveys in early 2022.

2. Material and Methods

2.1 Study site

The study site is located at Hin Ang Wang (9°23'27.80"N, 100° 1'31.01"E), Samui Island, Surat Thani Province, the Western Gulf of Thailand. The coral reef area is approximately 78,000 square meters.

Figure 1. Map of the study site at Hin Ang Wang, Surat Thani Province, the Western Gulf of Thailand

2.2 Data collection and analysis

The study was conducted on coral communities at Hin Ang Wang in early 2022. The coral communities were found at approximately 0-10 m in depth. Live coral cover was recorded in three permanent belt-transects of 30x1 m^2 and scleractinian corals (>5 cm diameter) were identified to species level. The number of visible juvenile corals (1-5 cm diameter) was also measured in these three permanent belt-transects. All juvenile corals were identified to genus. (Veron 2000).

The numbers of each macrobenthic invertebrate species found on the coral communities were recorded and counted in three permanent belt-transects of 50x1 m^2 and they were identified to a species level, if possible.

Coral reef fishes were observed using a standard visual census technique (English et al. 1997). The belt transect, 50x5 m was conducted at each study site. SCUBA divers estimated fish abundance and identified species of reef fish along each transect. Species not recognized in the field surveys were photographed and video-recorded for identification in the laboratory. Fishes were identified to species level, if possible.

3. Results

The benthic components investigation revealed that live coral and rock were the major components of the substrates at Hin Ang Wang (Figure 2). The other components were sand, rubble, dead coral and other sessile invertebrates, including soft corals and sea anemones (Figure 3). The live coral cover was 44.2%, while dead coral cover was 3.7%, indicating that the coral community is very good condition. The dominant coral species were *Porites lutea*, *Pavona decussata* and *Montipora aequituberculata*. Many large colonies of *Diploastrea heliopora and Porites lutea* were also found at the deeper zone. The abundant coral species were *Acropora hyacinthus, Favites abdita, Galaxea astreata, Galaxea fascicularis, Goniopora columna, Lobophyllia hemprichii, Lobophyllia radians, Merulina ampliata, Pachyseris speciosa, Pavona cactus, Pocillopora acuta, Podabacia crustacea, Pectinia lactuca, Herpolitha limax* and *Turbinaria peltata.* (Figures 4 and 5).

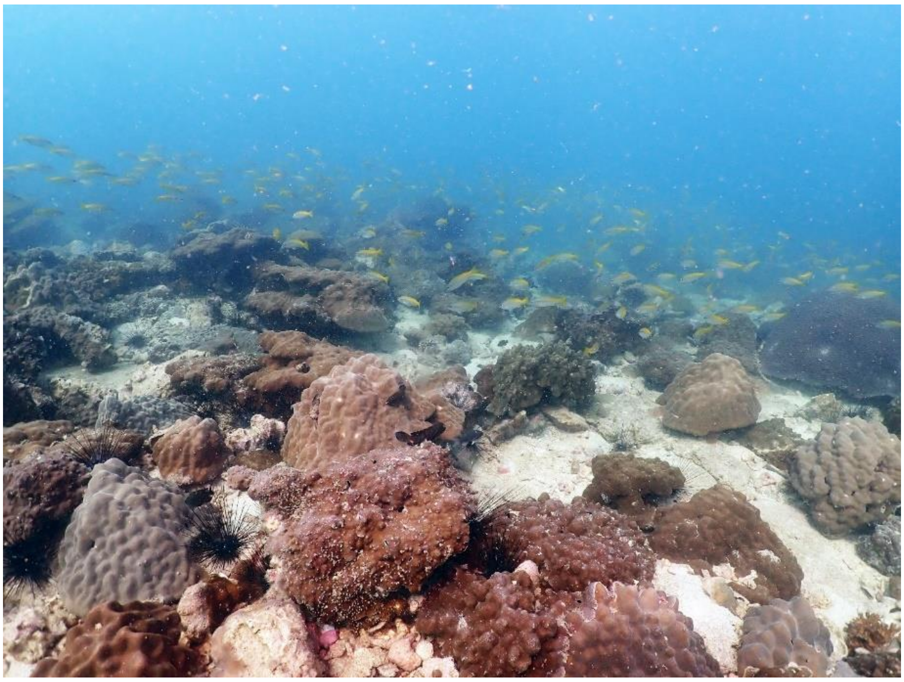

Figure 2. The coral reef community at Hin Ang Wang, Surat Thani Province, the Western Gulf of Thailand

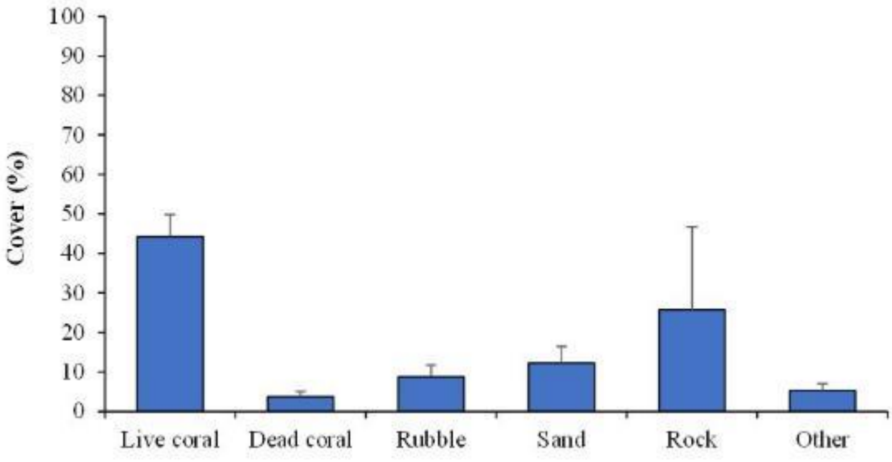

Figure 3. Benthic components at the study site (mean ± SD)

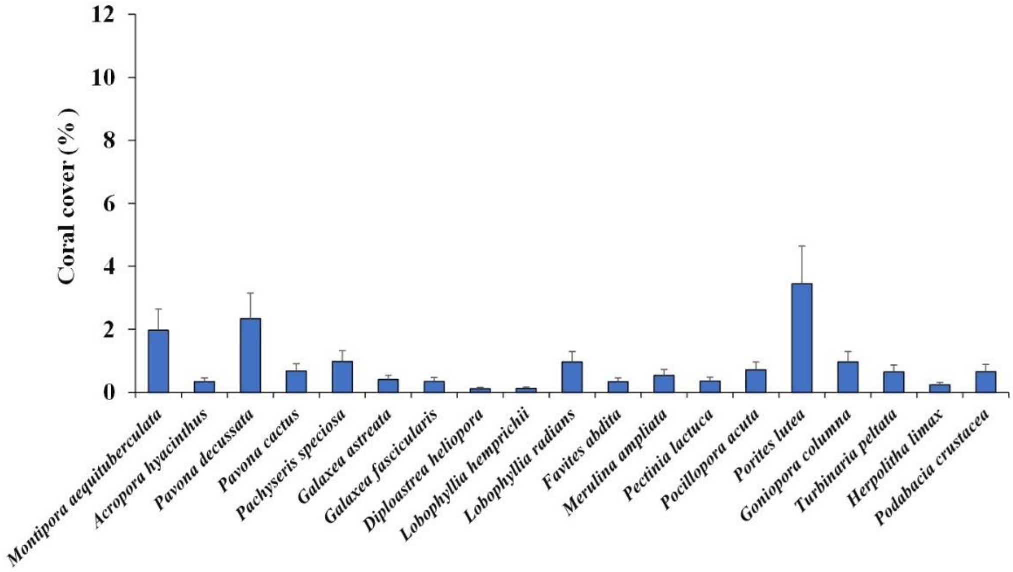

Figure 4. Species composition of live coral cover at the study site (mean ± SD)

Porites lutea *Pavona decussata* *Montipora aequituberculata*

Figure 5. The dominant coral species at the study site

The total density of juvenile corals at Hin Ang Wang was 1.6 juveniles/m^2. The most abundant juvenile coral was *Fungia*. The common juvenile corals were *Acropora*, *Ctenactis*, *Dipsastraea*, *Echinopora*, *Favites*, *Hydnophora*, *Litthophyllon*, *Montipora*, *Pavona*, *Platygyra*, *Pocillopora* and *Porites* (Figure 6).

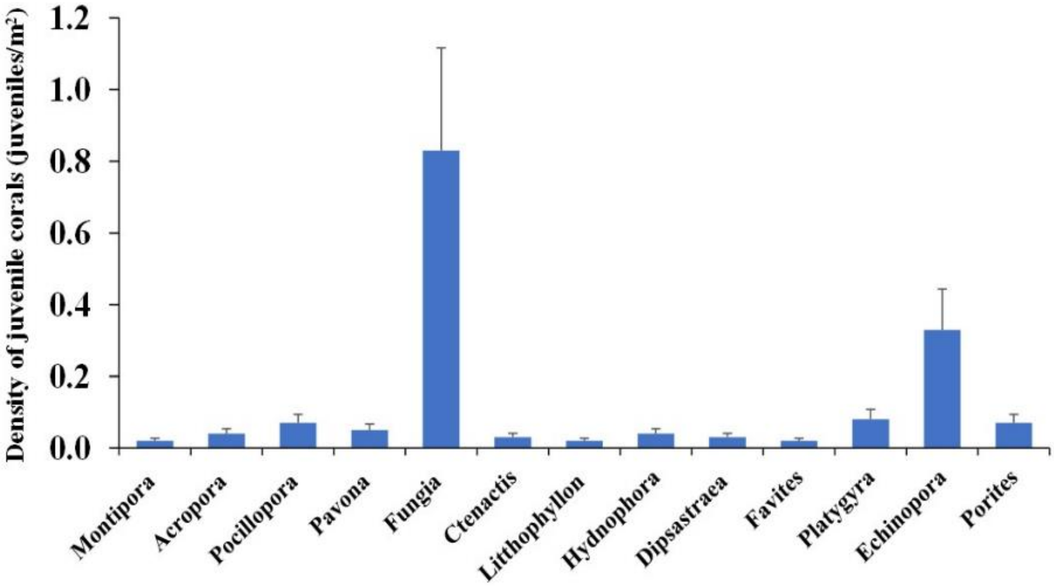

Figure 6. Density of juvenile corals on available substrates at the study site (mean ± SD)

The most dominant macrobenthic invertebrate at Hin Ang Wang was the Christmas tree worms, *Spirobranchus giganteus* (5.4 individuals/m^2). The other macrobenthic invertebrates were *Neopetrosia* sp., *Xestospongia* sp., *Rochia nilotica*, *Drupella rugosa*, *Phyllidia* sp., *Arca* sp., *Beguina semiorbiculata*, *Tridacna crocea*, *T. squamosa*, *Hyotisa hyotis*, *Chama* sp., *Pedum spondyloidum*, *Spondylus* sp. and *Diadema setosum*. Some macrobenthic invertebrates are attractive to tourists, such as *S. giganteus* and *T. squamosa* (Figures 7 and 8).

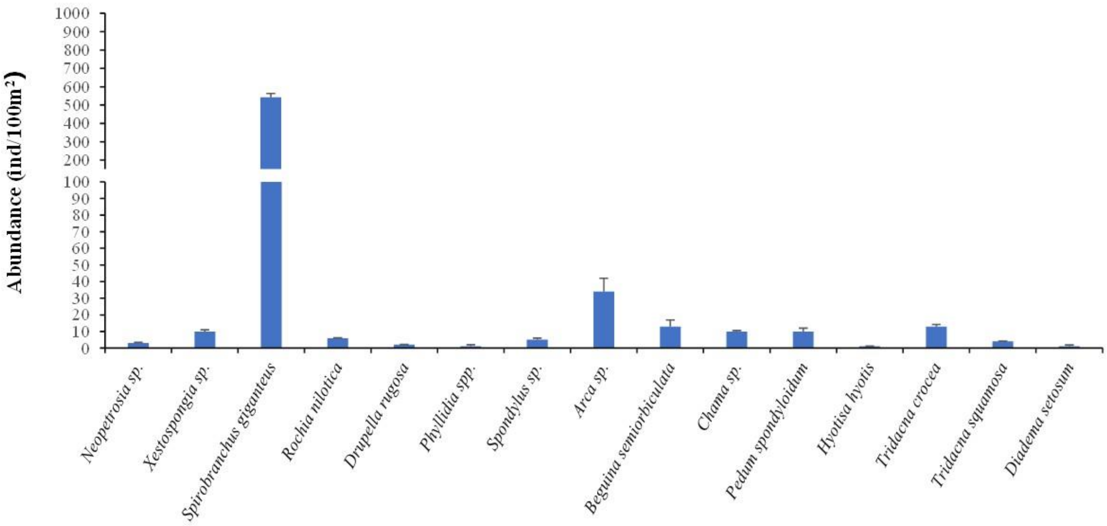

Figure 7. Abundance of macrobenthic invertebrate at the study site (mean ± SD)

Spirobranchus giganteus *Tridacna squamosa*

Figure 8. Some attractive macrobenthic invertebrates to tourists.

The densities of reef fish at Hin Ang Wang are shown in Figure 9. The total density of 27 reef fish species was 937. 8±433.6 individuals/100 m^2. The most dominant reef fishes were *Neopomacentrus anabatoides*, *Chromis cineracens* and *Parioglossus philippinnus*.

The fishing target was *Lutjanus carponotatus*, *Lutjanus russellii*, *Caesio cuning*, *Plectorhinchus gibbosus*, *Scarus rivulatus* and *Cephalopholis boenak*. Some reef fish are attractive to tourists, including *Sargocentron rubrum*, *Ostorhinchus endekataenia*, *Parioglossus philippinnus*, *Chaetodon octofasciatus* and *Chelmon rostratus* (Figure 10).

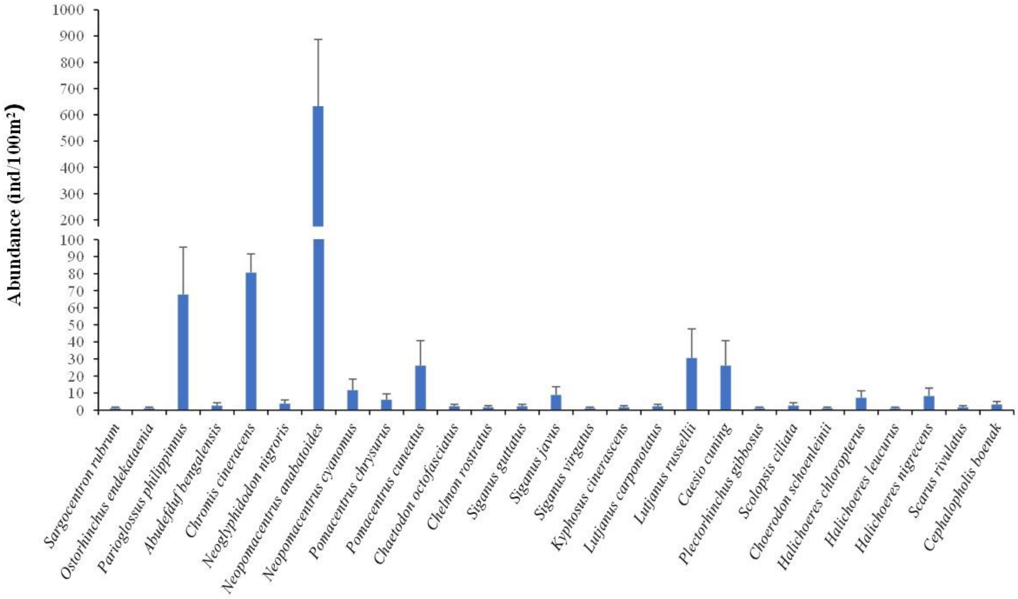

Figure 9. Species composition of reef fish at the study site (mean ± SD)

Chelmon rostratus

Sargocentron rubrum

Figure 10. Some attractive reef fish to tourists

4. Discussion

The community structure of scleractinian corals at Hin Ang Wang observed from this study showed high resilience after the severe coral bleaching events in 1998 and 2010. The high percentage of live coral cover and low percentages of dead coral and rubble were obviously recorded. The high susceptibility of *Pocillpora acuta*, *Montipora* spp., *Acropora* spp. and *Turbinaria* spp., in the Gulf of Thailand (Sutthacheep et al. 2010; Yeemin et al. 2010; Sutthacheep et al. 2013) were found at Hin Ang Wang. Some tolerant corals to the coral bleaching events, such as *Galaxea*, *Pachyseris*, *Turbinaria*, *Favites* and *Diploastrea* were abundantly recorded at Hin Ang Wang.

Our results show juvenile corals from many species, particularly *Acropora*, *Ctenactis, Dipsastraea*, *Echinopora*, *Favites*, *Fungia*, *Hydnophora*, *Litthophyllon*, *Montipora*, *Pavona*, *Platygyra*, *Pocillopora*, *Porites* were observed at Hin Ang Wang. These data imply the connectivity of some coral populations in the Western Gulf of Thailand. Further studies using molecular genetic techniques would confirm the coral genetic connectivity and self-seeding in this region (van Oppen et al. 2008; Klinthong et al. 2019). The density of juvenile corals reported in this study was 1.6 juveniles/m^2, which is comparable to previous reports in the Biscayne National Park (Miller et al. 2000), Mesoamerican barrier reef (Ruiz-Zarate and Arias Gonzalez 2004), and Indian Ocean reef (Manikandan et al. 2017).

Major macrobenthic invertebrates found at Hin Ang Wang are categorized into 5 classes, namely Demospongiae, Polychaeta, Gastropoda, Bivalvia and Echinoidea. Several species of macrobenthic invertebrates are from the Bivalvia, namely *Arca* sp., *Beguina semiorbiculata*, *Tridacna crocea*, *T. squamosa*, *Hyotisa hyotis*, *Chama* sp., *Pedum spondyloidum* and *Spondylus* sp. These bivalves have high potential to be commercial species in mariculture, particularly the giant clams *Tridacna* spp. The giant clam mariculture industry has been providing food and marine aquarium trade markets for over four decades (Militz et al. 2017). Research on artificial interspecific hybridization of two giant clams, *T. squamosa* and *T. crocea*, in the South China Sea revealed that the cross between *T. squamosa* and *T. crocea* was successfully carried out. The reciprocal hybrids showed larger growth heterosis, survival advantage and a beautiful mantle coloration. These hybrids exhibited high potential for application in the market and giant clam mariculture industry (Zhou et al. 2020). Our results also imply several target species of macrobenthic invertebrates and reef fish at Hin Ang Wang for aquaculture and fishing, especially *T. crocea*, *T. squamosa*, *Diadema setosum*, *Lutjanus carponotatus*, *L. russellii*, *Caesio cuning*, *Plectorhinchus gibbosus*, *Scarus rivulatus* and *Cephalopholis boenak*. Moreover, several species of macrobenthic invertebrates and reef fish at Hin Ang Wang, such as *Neopetrosia* sp., *Xestospongia* sp., *Spirobranchus giganteus*, *Phyllidia* sp., *Tridacna* spp., *Pedum spondyloidum*, *Sargocentron rubrum*, *Ostorhinchus endekataenia*, *Parioglossus philippinnus*, *Chaetodon octofasciatus* and *Chelmon rostratus*, are attractive to tourists and can be target species for marine ecotourism (Wongnutpranont et al. 2020; Rangseethampanya et al. 2021; Yeemin et al. 2021).

Coral reefs can be managed by using several management tools. Recently, resilience-based management (RBM) has been applied coral reef management with concentrating on the use of knowledge of existing and possible drivers that potentially influence the functions and structure of coral reef ecosystem, such as climate change, coral disease outbreaks, land-use change, coastal development and reef fisheries (Mcleod et al. 2019; Sutthacheep et al. 2022). Our results show that the coral communities at Hin Ang Wang had high resilience to coral bleaching events and human impacts. Hin Ang Wang should be established as a marine protected area under the Department of Marine and Coastal Resources to protect the healthy coral community. Our results also imply that Hin Ang Wang should implement its management plans properly to maintain its resilience. RBM may be used to support natural processes. Marine ecotourism should be promoted as it can protect the coral community and keep the tourist numbers below the carrying capacity of this tourist destination (Sutthacheep et al. 2019).

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