ORIGINAL PAPER

Low impacts of coral bleaching in 2024 on the underwater pinnacles from Krabi Province, the Andaman Sea

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Abstract. Coral reefs are confronting some of the most severe and immediate dangers due to climate change, which is resulting in coral bleaching. Citizen science has emerged as an innovative data source that can be integrated into the framework of the Sustainable Development Goals. The objective of this study was to assess impacts of coral bleaching in 2024 on underwater pinnacles in Krabi Province, the Andaman Sea, by incorporating local citizen scientists. The results showed that the underwater pinnacles displayed a coral bleaching prevalence of only 13-18%, which was lower at the Hin Chao Mae compared to the Hin Chorakhe. Nine coral species experienced bleaching, with *Montipora aequituberculata*, *Acropora hyacinthus*, and *Porites lutea* found bleached at both study locations. This information reflects the high resilience and potential refuge of coral populations on Hin Chao Mae and Hin Chorakhe. Effective management strategies, particularly marine protected areas, resilience-based (RMB) and other effective area-based conservation measures (OECMs), are crucial for protecting the underwater pinnacles studied. These approaches can support policies to conserve 30% of the world's oceans by 2030 under the Kunming-Montreal Global Biodiversity Framework.

Keywords: coral bleaching, citizen science, conservation, resilience, underwater pinnacle

1. Introduction

Coral reefs flourish most effectively in warm tropical waters but can also be found beyond the tropics, reaching higher latitudes where warm currents flow from the tropical zone. Southeast Asia is recognized as the global hub for coral reefs, both in terms of their area and species diversity. Approximately 34% of the world's coral reefs are situated in Southeast Asian waters, which make up just 2.5% of the Earth's total ocean surface (Burke et al. 2002; Arai 2015). Coral reefs are among the most productive marine ecosystems in Thai waters, both in the Andaman Sea and the Gulf of Thailand (Phongsuwan et al. 2013). Underwater pinnacles in tropical areas also constitute important marine ecosystems, providing similar functions and advantages as coral reef habitats (Yeemin et al. 2022). Coral reefs are confronting some of the most severe and immediate dangers due to climate change (Mellin et al. 2024). Marine heatwaves that cause widespread coral bleaching are becoming more frequent and widespread due to human-driven climate change, threatening the survival of countless reef-associated species and the vital services they provide to both nature and people (Hughes et al. 2017; Mellin et al. 2022). Although coral bleaching events are expected to intensify in the coming decades, their spatial and temporal patterns remain uncertain, hindering efforts to safeguard coral reefs from climate change (Van et al. 2016; Dixon et al. 2022).

Reports of coral bleaching events on reefs worldwide have become increasingly frequent. (Glynn 1996; Wilkinson 2008; Burke et al. 2011; Yeemin et al. 2012). Before 2024, three recorded incidents of extensive intertidal and subtidal coral bleaching were recorded in the Andaman

Sea, occurring in 1991, 1995, and 2010 (Yeemin et al. 2012). All bleaching events occurred in May at the time of maximum seasonal sea surface temperature (SST). Coral species vary in their susceptibility to bleaching, and specific environmental factors, such as irradiance, can affect the impact of SST anomalies that lead to coral bleaching and potential mortality (Mumby et al. 2001; Coles and Brown 2003; McClanahan and Maina 2003). Many studies on the impact of bleaching stress on coral populations have primarily concentrated on mortality. However, the recovery of colonies that perish due to bleaching is fundamentally dependent on the reproductive output of the surviving corals (Loya et al. 2001; Pratchett et al. 2010; Guest et al. 2016; Johnston et al. 2020).

Marine biological diversity in Thai water is immensely rich, just as in the South China Sea. A preliminary assessment of the sea's biological diversity, not limited to coral reefs, indicates that it contains over 8,600 species of plants and animals, including at least 3,365 species of marine fish in the South China Sea (Ng and Tan 2000; Randall and Lim 2000; Arai 2015). From an ecological perspective, the coral reefs in Thai waters function as crucial sources of larvae and juveniles for numerous commercially significant reef fish species. The coral reef ecosystems in Southeast Asia also offer significant economic benefits through fisheries and tourism, serve as vital sources of food and essential protein, and contribute to protecting islands from storms and wave impacts (Buddumeir et al. 2004; Eghtesadi-Araghi 2009; McLeod et al. 2010; Praveena et al. 2012).

Citizen science has been acknowledged as an innovative data source that can be integrated into the framework of the Sustainable Development Goals (SDGs) (Fritz et al. 2019; Figuerola-Ferrando et al. 2024). It plays a crucial role in monitoring coral reefs, contributing significantly to the effective management of marine protected areas (Lau et al. 2019; Yeemin et al. 2021). Citizen science may encompass various types of community-based monitoring initiatives, including projects where community members collect and manage data independently or with expert involvement, collaborate with experts in data collection, or provide occasional and opportunistic information to scientists and managers (Great Barrier Reef Marine Park Authority 2013). The application of citizen science approaches has been extensively employed in coral reef research across diverse geographic settings and research objectives, with a particular emphasis on investigating coral bleaching, mapping reef habitats, and monitoring and reporting on threats to these ecosystems (Siebeck et al. 2006; Branchini et al. 2015; Roelfsema et al. 2016; Done et al. 2017; Bauer-Civiello et al. 2018; Lau et al. 2019; Licuanan et al. 2021). An effective method for monitoring coral reefs by citizen scientists should be straightforward, accessible, cost-effective, and capable of providing accurate data essential for informed decision-making by managers (Licuanan et al. 2021). The collected data must be easily validated (Burgess et al. 2016). In this study, we aimed to monitor impacts of coral bleaching on underwater pinnacles in Krabi Province, the Andaman Sea, by incorporating citizen scientists in the assessment of coral communities.

2. Materials and Methods

2.1 Location of study sites

The study was carried out on the coral communities of the underwater pinnacles of Hin Chorakhe and Hin Chao Mae at Krabi Province, located in the Andaman Sea (Figure 1). The research was carried out during the period spanning from February to June 2024. These small underwater pinnacles are situated near the island of Ko Ngai, approximately 15-18 km from the mainland. Hin Chorakhe is characterized by its exceptional water clarity and well-developed coral communities, which extending depths ranging from 5 to 16 m. Nevertheless, the area has been subjected to the effects of fishing activities, as it falls outside the boundaries of the marine national park, potentially impacting the overall health and diversity of the coral ecosystem. The coral reef communities at the Hin Chao Mae site extend a depth range of 7 to 13 m and contain several well-developed coral communities that possess significant tourism value, particularly for snorkeling and SCUBA diving activities. Nonetheless, this area has experienced adverse impacts from elevated sedimentation originating from the adjacent mainland as well as fishing operations. The location, environmental conditions, and anthropogenic disturbances at each study site are summarized in Table 1 and Figure 2.

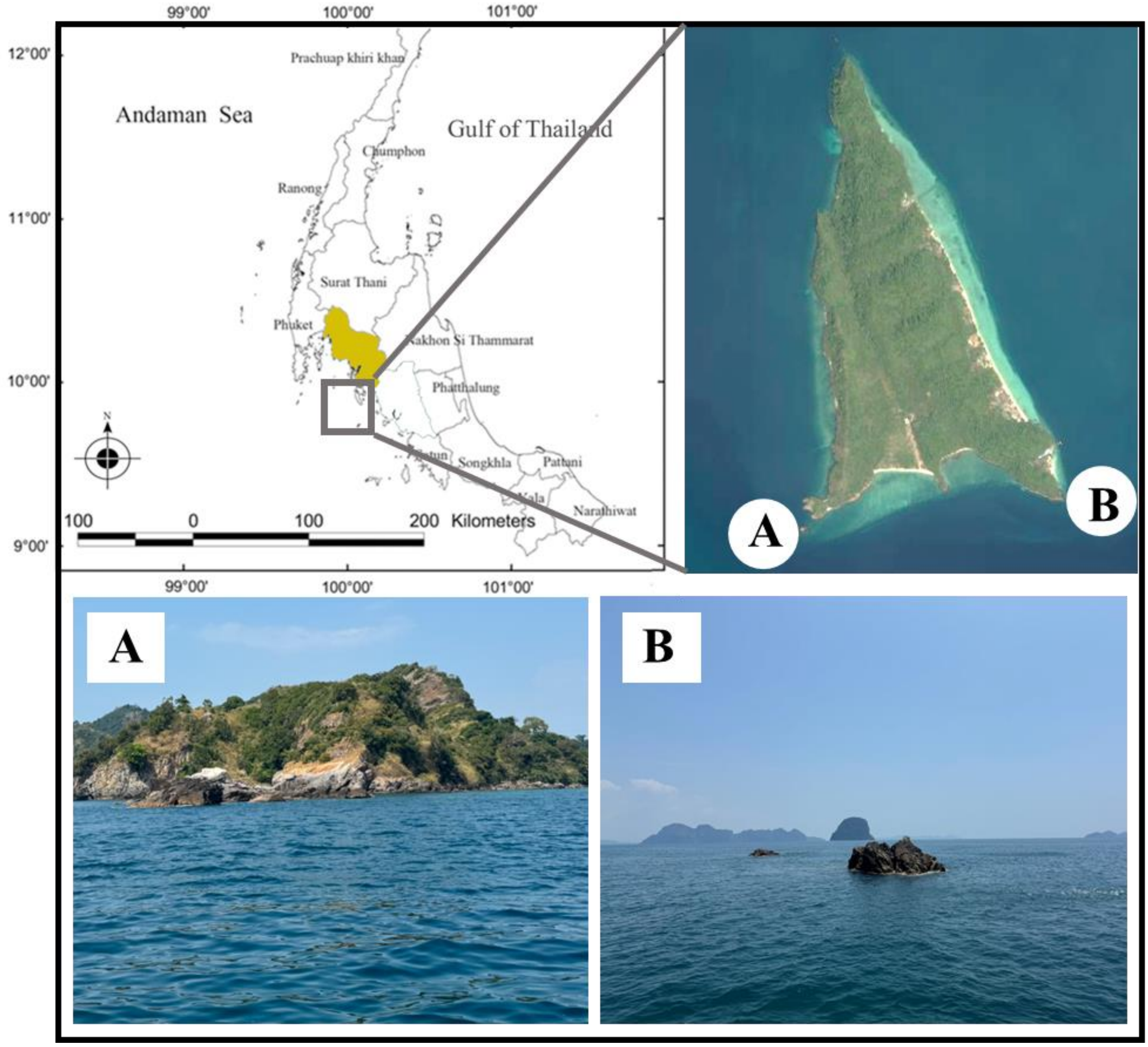

Figure 1. Map of the study sites at the underwater pinnacles: Hin Chorakhe (A) and Hin Chao Mae (B)

Table 1. Location and information of the study sites at Hin Chorakhe and Hin Chao Mae in Andaman Sea

	Hin Chorakhe	Hin Chao Mae
Latitude (N),	7° 23.842'N	7° 24.050' N
Longitude (E)	99° 11.699'E	99° 13.027'E
Exposure condition	Exposed	Exposed
Distance from the shore (km)	18.2	15.7
Water transparency	Clear	Moderately turbid
Depth (m)	5-16	7-13
Anthropogenic disturbances	Fishery	Fishery, Tourism

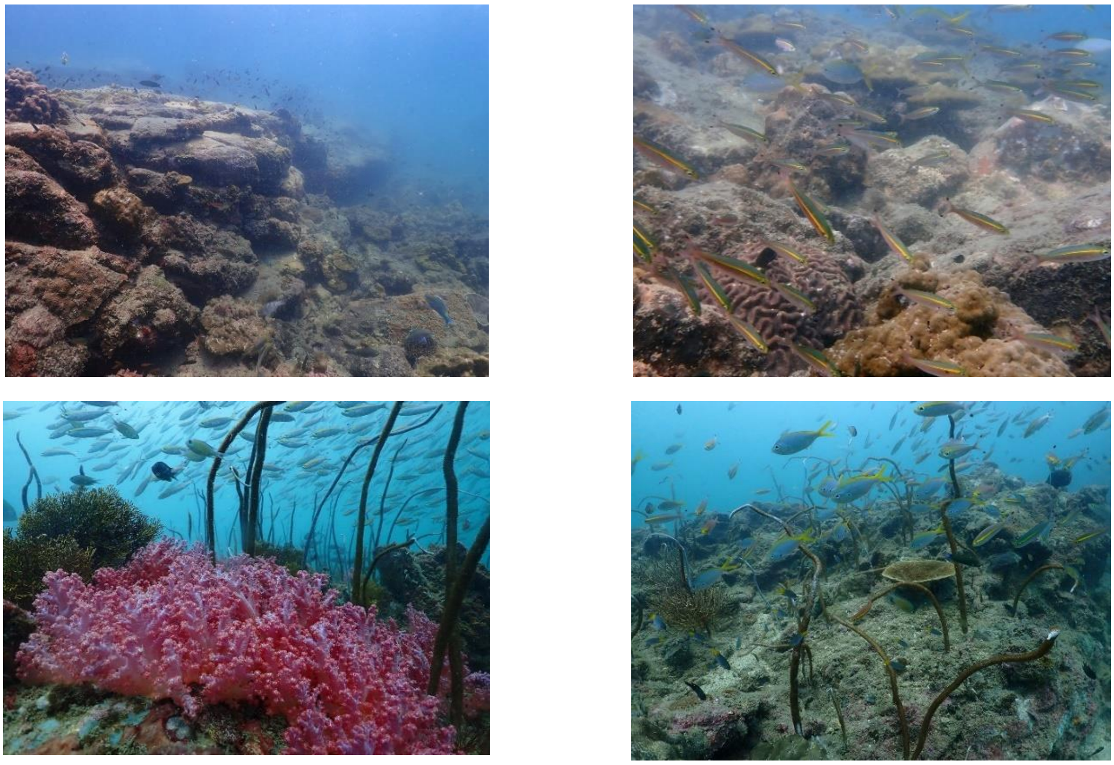

Figure 2. Underwater photographs showing the underwater pinnacles components at Hin Chorakhe (top) and Hin Chao Mae (below)

2.2 Seawater temperature anomalies

The coral bleaching threshold refers to the specific temperature level that can induce thermal stress in corals, potentially leading to a phenomenon known as coral bleaching. We examined the data from the NOAA OI SST V2 High Resolution Dataset at the study site in 1998, 2010 and 2024. In 1998, sea surface temperatures started to increase in March, reached their peak on May 26, and then began to decline in August with Degree Heating Week (DHW) values exceeding in 3.56 °C- weeks in June and July. Similarly, in 2010, sea surface temperatures commenced their rise in March, peaked on May 19, and started to fall in July with DHW values exceeding in 8.56 °C- weeks in June and July. For the year 2024, the same pattern emerged, with temperatures beginning to rise in March, peaking on April 29, and starting to decrease in July with DHW values exceeding in 11.94 °C- weeks in June. (Figure 3).

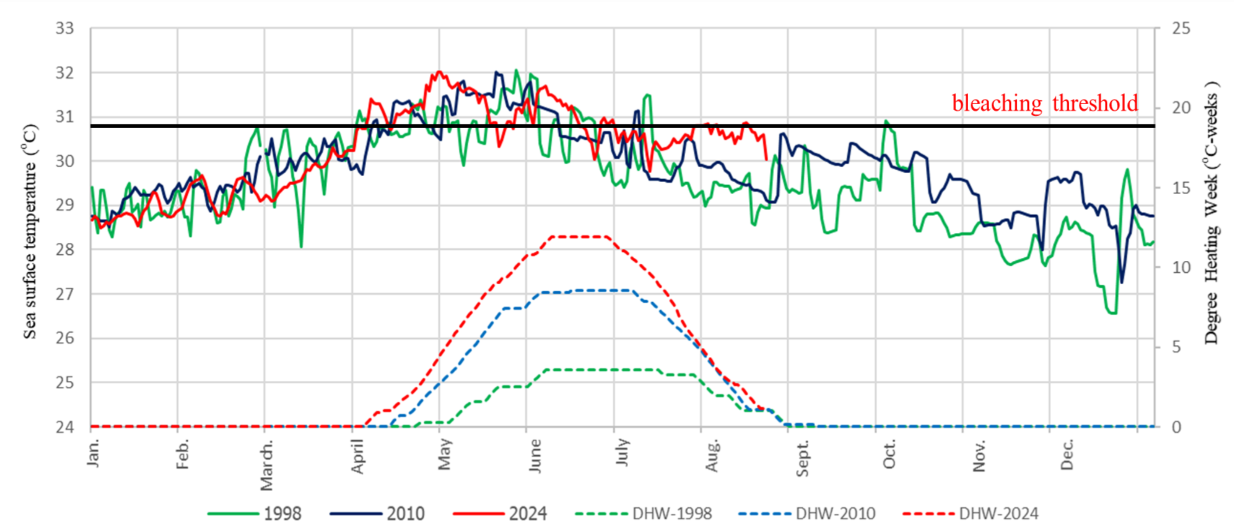

Figure 3. Surface temperature (SST) and Degree-Heating Weeks (DHW) for the significant coral bleaching years of 1998, 2010, and 2024 at the study sites, black line represents the bleaching threshold for the region adopted from NOAA Coral Reef Watch satellite data

2.3 Reef surveys

The study volunteers were diving instructors and owners of diving tourism companies who regularly visited the underwater pinnacles, approximately 3-4 times per month. These experienced divers conducted coral surveys at the site, capturing at least 30 underwater photographs from a distance of around 2 m above the reef. The images, taken either directly facing the reef or at a slight angle, provided a comprehensive representation of the coral reef ecosystem without capturing redundant or overlapping scenes (Yeemin et al. 2021). Finally, marine biologists thoroughly analyzed all the underwater photographs to accurately quantify the live and dead coral cover, as well as the benthic components.

2.4 Data analysis

The live coral cover and coral bleaching data were examined for homogeneity of variances and then transformed using a logarithmic approach. Student's t-test analysis of variance was conducted to assess the impact of study sites on the live coral cover and coral bleaching.

3. Results

The benthic component investigation revealed that rock was the major component of the substrates at the study sites. The other components were live coral, dead coral, sand, rubble, and other sessile invertebrates, including sponges, sea whips, sea fans, and sea anemones. The live coral cover at Hin Chao Mae (15.26%) was higher than that at Hin Chorakhe (13.36%). On the other hand, dead coral cover was found at Hin Chorakhe (3.68%), which was higher than that at Hin Chao Mae (2.43%) (Figure 4).

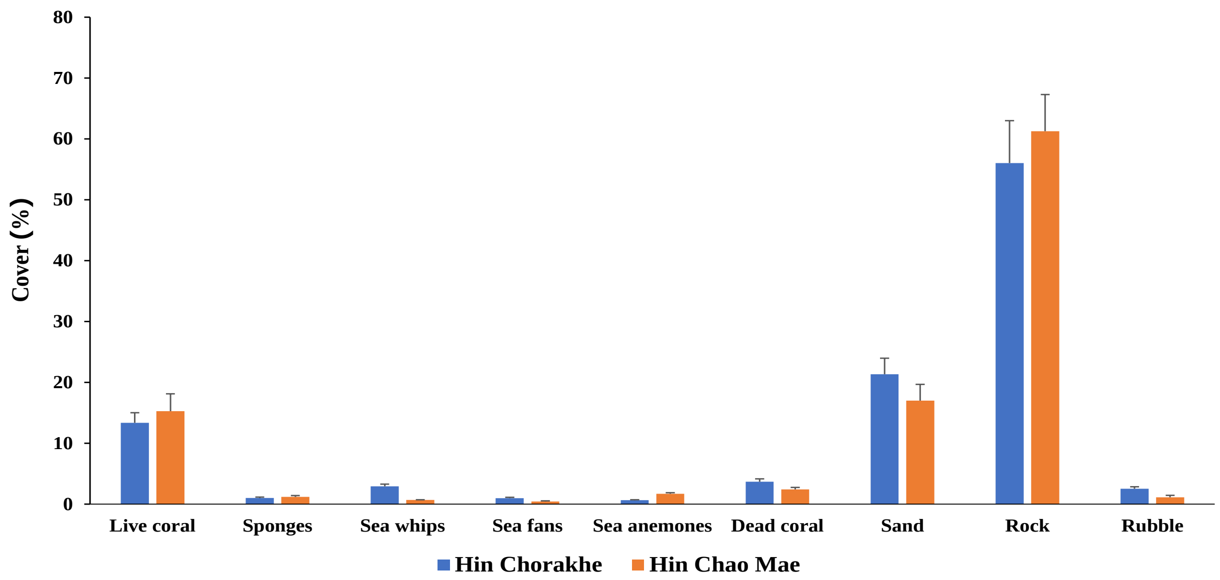

Figure 4. Benthic composition at the study sites (Mean ± SE)

The results showed that the live coral cover on the underwater pinnacle at Hin Chao Mae (15.26 ± 0.08) was higher than that at Hin Chorakhe (13.36 ± 0.06). Twenty-one coral species were found at Hin Chao Mae (Figure 5), while twenty coral species were found at Hin Chorakhe (Figure 6). The dominant coral species at Hin Chao Mae were *Porites lutea*, *Galaxea fascicularis*, and *Diploastrea heliopore*, while the dominant coral species at Hin Chorakhe were *Porites lutea*, *Pavona decussata*, and *Favites abdita*. *Montipora digitata*, *Acropora digitifera*, *Acropora muricata*, *Gardineroseris planulata*, *Lobophylia flabelliformis*, *Dipsastraea speciosa*, *Hydnophora exesa*, and *Platygyra daedalea* were found only at Hin Chao Mae, while *Acropora millepora*, *Astreopora myriopthalma*, *Fimbriaphyllia ancora*, *Turbinaria mesenterina*, *Dipsastraea pallida*, *Merulina ampliata*, and *Pectinia lactuca* were found only at Hin Chorakhe. *Montipora aequituberculata*, *Acropora hyacinthus*, *Pavona decussata*, *Pavona frondifera*, *Galaxea astreata*, *Galaxea fascicularis*, *Diploastrea heliopora*, *Lobophyllia hemprichii*, *Lobophyllia radians*, *Echinopora lamellosa*, *Favites abdita*, *Porites lutea*, and *Dipsastraea favus* were found at both study sites.

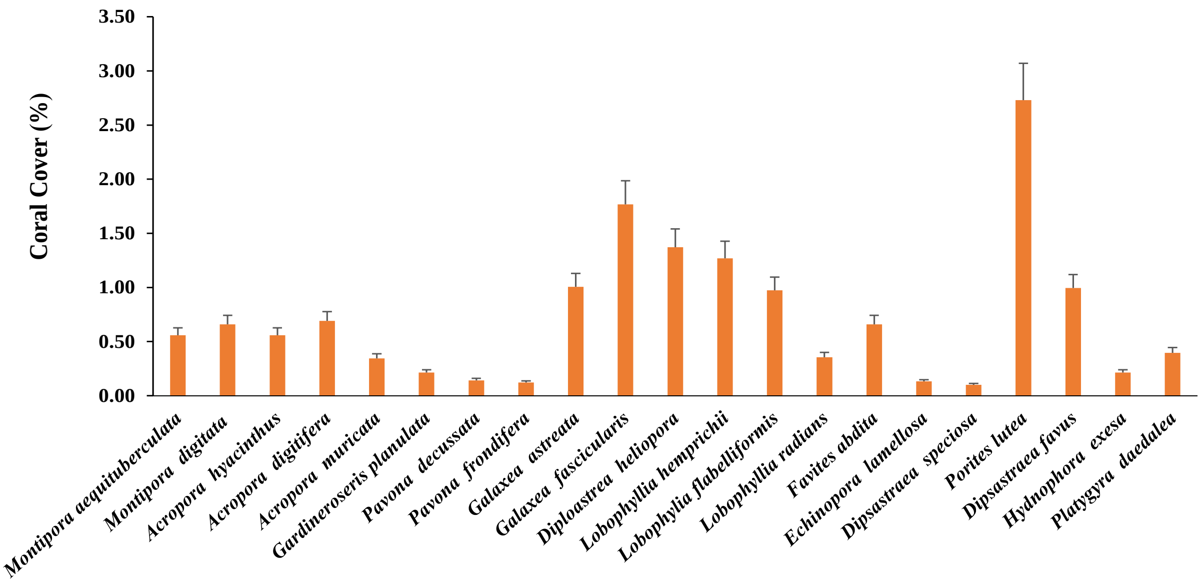

Figure 5. Species composition of live coral cover at Hin Chao Mae (Mean ± SE)

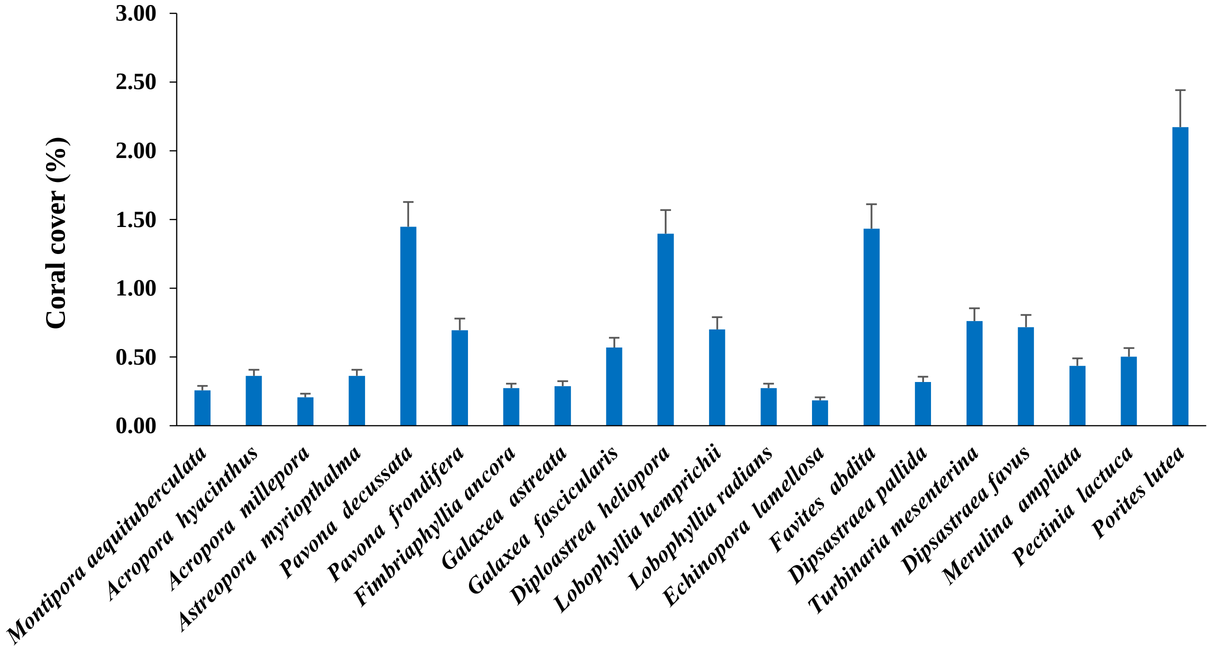

Figure 6. Species composition of live coral cover at Hin Chorakhe (Mean ± SE)

Unbeached coral at Hin Chao Mae was significantly lower than that at Hin Chorakhe (t=-9.827, p=0.03). The levels of partial and complete coral bleached at Hin Chao Mae (10.2 %) were also lower than those observed at Hin Chorakhe (18.9 %). Nine coral species experienced bleach, with *M. aequituberculata*, *A hyacinthus*, and *P. lutea* found bleached at both study locations. Additionally, *A. muricata* was seen in a bleached condition only at Hin Chao Mae, while *A. millepora*, *P. decussata*, *G. astreata*, *L. hemprichii*, and *D. favus* were found bleached solely at Hin Chorakhe.

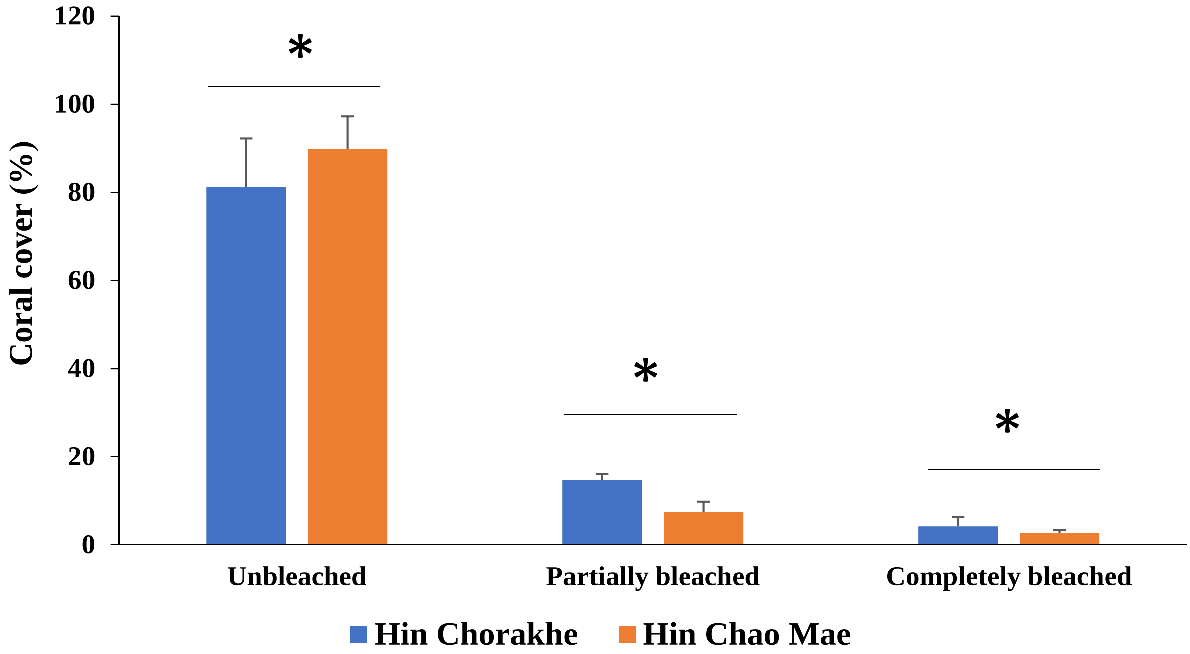

Figure 7. Coral cover of bleaching patterns at the study sites (t-test, *p<0.05)

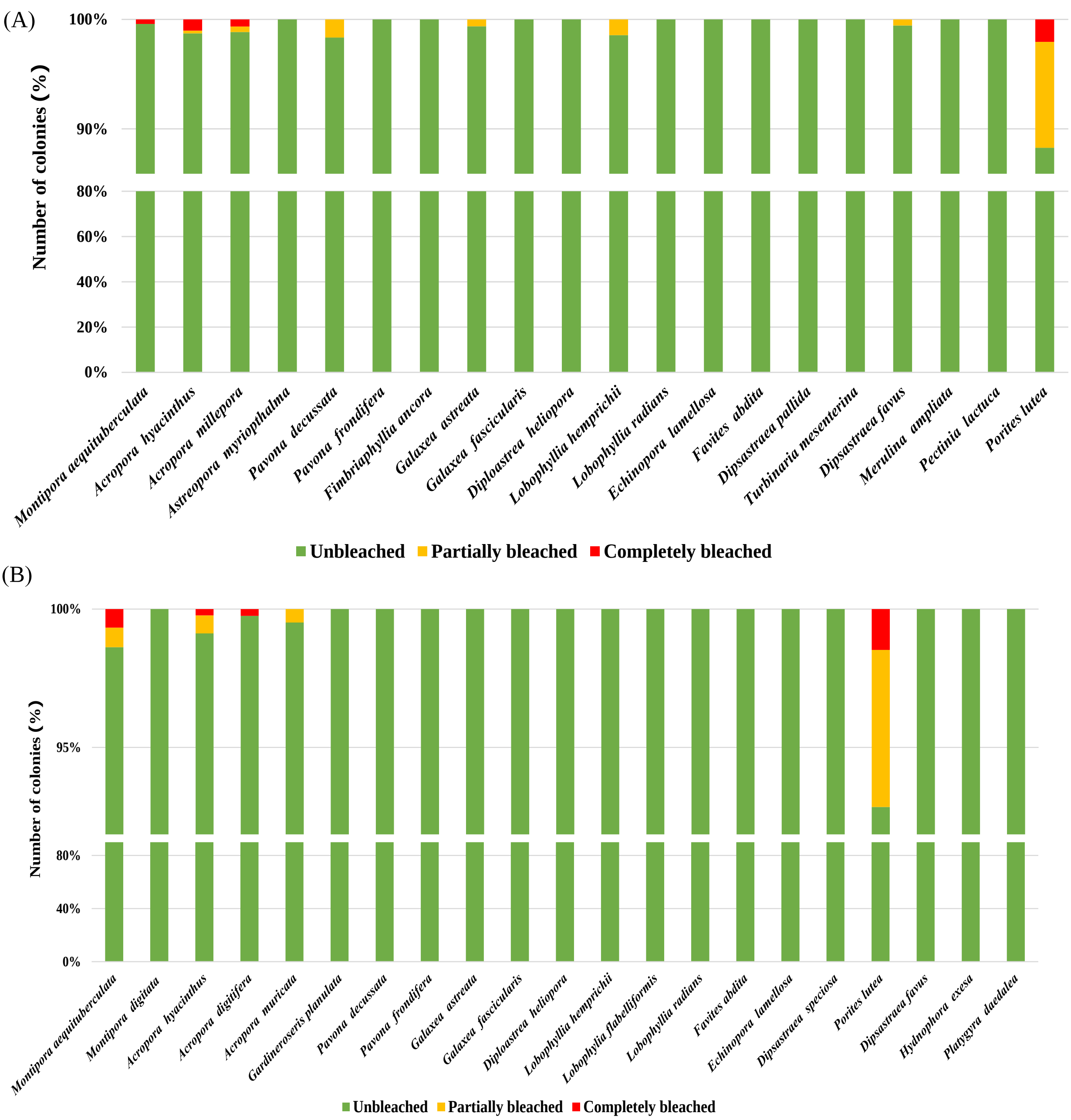

Figure 8. Percentages of coral bleaching for each coral taxa (A) Hin Chorakhe and (B) Hin Chao Mae

(A) (B) (C) (D)

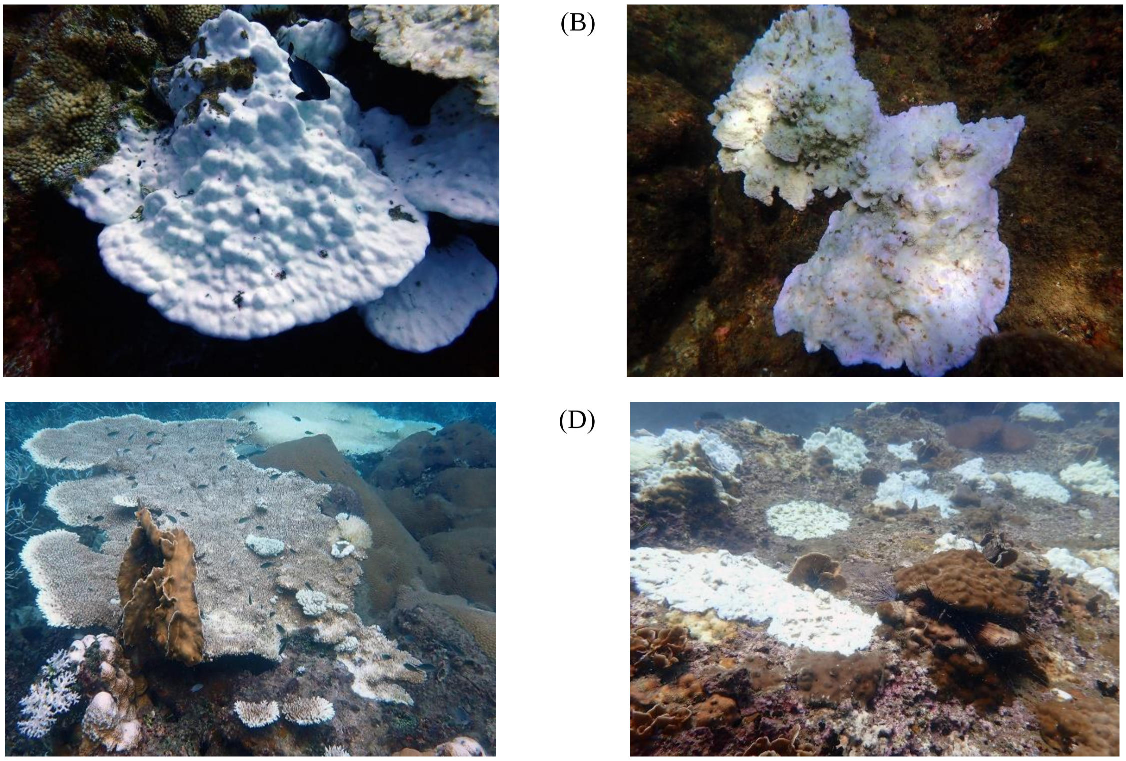

Figure 9. Underwater photographs at the study sites: (A) completely bleached *P. lutea*, (B) completely bleached *M. aequituberculata*, (C) partially bleached *A. hyacinthus*, (D) coral bleaching

4. Discussion

The results of this study showed that coral bleaching occurs because of sea surface temperature anomalies. The coral bleaching observed at the study site was consistent with the sea surface temperature data provided by NOAA/ NESDIS Coral Reef Watch. The NOAA/ NESDIS Coral Bleaching HotSpots model demonstrates a reliable ability to predict coral bleaching. However, as corals are anticipated to acclimatize to seawater temperature anomalies, more advanced models may be required to predict coral bleaching in the future. These models will also need continuous feedback from field surveys to enhance their accuracy (Yee and Barron 2010). Variations in the bleaching susceptibility of scleractinian corals in the Andaman Sea have been clearly reported (Yeemin et al. 2012 and Phongsuwan and Chansang 2012).

In the Andaman Sea, the impact of coral bleaching has been categorized as mild (1998), moderate (1991, 1995, 2003), and severe (2010) (Phongsuwan and Chansang 2000, 2012). The 2010 bleaching event was the most extensive ever recorded in the Andaman Sea. During May 2010, the monthly mean sea surface temperature (SST) reached a peak of 31.74 °C, with 95 days where the mean daily SST exceeded 30.34°C (Phongsuwan and Chansang 2012).

M. aequituberculata, *A. hyacinthus*, *A. millepora*, *A. muricata*, *P. decussata*, *G. astreata*, *L. hemprichii*, *D. favus*, and *P.lutea* showed coral bleaching at Hin Chorakhe and Hin Chao Mae. Several coral species in the present study showed unbeaching, such as *P. decussata*, *P. lactuca*, *D. heliopora*, *L. hemprichii*, and *M. ampliata*, however they were highly susceptible to previous mass bleaching (Phongsuwan and Chansang 2012). Bleaching of *P. lutea* was found to be similar to 1998 and 2010, and that of *A. millepora* was similar to 1998 (Sutthacheep et al. 2013). Some published papers are consistent with the present study in showing the high susceptibility of *Montipora* spp., *Acropora* spp., and *P. daedalea* in the Gulf of Thailand (Sutthacheep et al. 2010; Yeemin et al. 2010), which is similar to this research. Despite exposure to the same temperatures as bleached corals in clear waters, the corals in high-turbidity areas showed minimal or no bleaching. This observation suggests that reduced light penetration may be a contributing factor

(Jokiel and Brown 2004; Manzello et al. 2007). The impact of prior experience on coral susceptibility to bleaching may play an increasingly important role in shaping coral responses to temperature and solar radiation stresses in the future (Brown et al. 2002). Our understanding of the potential for and extent of coral acclimatization, as well as the complex physiology and behavior underlying bleaching events has been improving. (Edmunds and Gates 2008; Brown and Cossins 2011; Helgoe et al. 2024).

In the present study, eighteen coral species, i.e., *A. myriopthalma*, *P. frondifera*, *F. ancora*, *G. fascicularis*, *D. heliopore*, *L. radians*, *L. flabelliformis*, *E. lamellose*, *F. abdita*, *D. pallida*, *D. speciosa*, T. mesenterina, *M. ampliata*, *P. lactuca*, *M. digitata*, *G. planulata*, *H. exesa*, and *P. daedalea*, were tolerant to coral bleaching events. Our data are consistent with the findings of Loya et al. (2001), who suggested that colony morphology influences bleaching vulnerability and subsequent mortality. Recent studies have developed models that integrate the proposed mechanisms of coral bleaching within a common analytical framework, accounting for the triggering factors, cascading effects, and final outcomes. (Brown and Cossins 2011; Helgoe et al. 2024).

Coral reefs have historically served as refugia, or protected areas, for a diverse array of marine life. These vibrant ecosystems have provided shelter and resources for countless reef-associated organisms, helping to sustain critical ecological services that benefit nature and human communities. Our finding found coral bleaching experienced less than 20% bleaching impact which can be refugia, and less coral bleaching resulted in more shelter space (Kim et al. 2219; Corazza et al. 2024). Previous research has indicated that certain coral reef systems located in southern Thailand, specifically within the regions of Ko Losin and Mu Ko Chumphon, have demonstrated a strong capacity for resilience against coral bleaching events and anthropogenic disturbances, despite exhibiting relatively low densities of juvenile corals (Sutthacheep et al. 2019). Hin Chorakhe and Hin Chao Mae can be categorized as highly resilient coral communities to bleaching. However, these underwater pinnacles are outside the national park boundaries, underscoring the need for effective and sustainable coral reef management. Relevant agencies, particularly the Department of Marine and Coastal Resources, the Department of National Parks, Wildlife and Plant Conservation, and the Department of Fisheries, should coordinate their efforts to address this challenge.

Appropriate management strategies, especially designating marine protected areas under the Marine and Coastal Resources Management Promotion Act B.E. 2558 (2015), implementing resilience-based (RMB) and other effective area-based conservation measures (OECMs), are crucial for the proper stewardship of the underwater pinnacles examined in this study. These approaches can contribute to strengthening policies aimed at protecting 30% of the world's 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).

This study successfully demonstrates the reliability of data collected by citizen science volunteers through the quantification of the percentage of affected coral bleaching colonies, thereby reinforcing the effectiveness, robustness, and potential of this approach in marine conservation efforts. Our findings emphasize the critical role of training, expert validation, and the support of a well-structured platform in ensuring the success of long-term citizen science projects, particularly those involving underwater sampling protocols for coral reef ecosystems.

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