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Assessment of Coral Mortality in Mu Ko Chumphon National Park, Western Gulf of Thailand, Following the 2024 Mass Bleaching Event

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Abstract. Climate-induced coral bleaching poses a major threat to tropical reef ecosystems, driving rapid habitat degradation, altered community structure, and long-term biodiversity decline. Thermal anomalies in 2024 triggered mass bleaching across the Western Gulf of Thailand, including reefs within Mu Ko Chumphon National Park, Thailand. This study examined the extent of bleaching and coral mortality at Ko Ngam Noi, Mu Ko Chumphon National Park, following the 2024 bleaching event. Field observations recorded many scleractinian coral species distributed across the reef complex. During peak thermal stress, more than 80% of total live-coral cover exhibited acute paling to full bleaching, with the highest stress prevalence observed in branching *Acropora* and massive *Porites* functional guilds. *Acropora muricata* and *Porites rus* experienced the highest bleaching prevalence, indicating genus-level sensitivity patterns consistent with fast-growing, branching, and massive reef-building functional groups. Post-bleaching mortality accounted for 4.8% of the total reef area, with the greatest mortality concentration in *Acropora divaricata* and *Platygyra sinensis*, mapped as contiguous patches of recently dead colonies, tissue-loss skeletons, and algal overgrowth succession zones. Despite relatively low overall reef mortality compared to bleaching prevalence, clear species-specific divergence emerged in survival trajectories, bleaching remission, and early stress-recovery signals, demonstrating marked differences in bleaching tolerance, recovery capacity, and structural resilience. The results indicate that a small proportion of colonies incurred irreversible physiological failure, while most surviving colonies displayed sub-acute recovery responses, suggesting the reef is entering a regeneration phase mediated by heat-tolerant taxa and partial assemblage turnover. These findings underline the ecological significance of species-level resilience heterogeneity in buffering reef collapse, and reinforce the need for adaptive spatial governance, targeted coral-nursery reinforcement, and evidence-driven restoration planning to sustain reef functional recovery, enhance climate resilience, and safeguard reef-associated biodiversity critical for fisheries and ecotourism economies in Thailand.

Keywords: coral bleaching, coral mortality, Gulf of Thailand, Mu Ko Chumphon National Park, thermal stress

1. Introduction

Coral reefs are critical marine ecosystems that provide habitat for diverse species, coastal protection, fisheries production, and tourism revenue (Moberg & Folke, 1999). They also support rich microbial communities that produce bioactive compounds with potential anticancer, antimicrobial, and anti-inflammatory applications (Sang et al., 2018). Despite these ecological and socio-economic values, coral reef ecosystems are increasingly threatened by a combination of anthropogenic pressures and climate change, resulting in significant ecological and economic consequences. Local stressors such as sedimentation, overfishing, destructive fishing practices, and marine pollution intensify the impacts of global climate change, including rising sea temperatures and ocean acidification, which lead to coral bleaching and mortality (Good & Bahr, 2021; Ahmad et al., 2024; Edwards et al., 2024). Recent studies indicate that 29 percent of research identifies marine pollution as a major threat; while overfishing and tourism activities also contribute substantially to coral reef degradation (Ahmad et al., 2024). Although coral reefs generate substantial economic value, estimated at up to 350,000 USD per hectare annually, this potential is diminished when local environmental conditions deteriorate (Edwards et al., 2024).

The primary climate driven mechanism of coral reef decline is mass bleaching, which occurs when sustained anomalous sea surface temperatures disrupt the mutualistic association between scleractinian corals and their endosymbiotic dinoflagellates in the family Symbiodiniaceae. Prolonged thermal stress causes the loss or expulsion of these symbionts, leading to the characteristic whitening of corals, with high ultraviolet exposure further intensifying bleaching severity (Bosch & Miller, 2016). This collapse of symbiosis compromises coral survival and threatens the broader reef ecosystem that supports regional biodiversity and human livelihoods. The physiological mechanisms underlying bleaching involve the accumulation of reactive species that disrupt cellular homeostasis, reflecting the complex interplay between coral hosts and their symbionts during thermal stress (Roberty & Plumier, 2022). As climate change accelerates, mass bleaching events are projected to increase in frequency and severity, highlighting the urgent need for strategies that enhance coral thermal tolerance, including the application of resilient Symbiodiniaceae strains (Hoegh-Guldberg et al., 2018; Humanes et al., 2024). Persistent or extreme heating reduces autotrophic energy supply, impairs metabolic functioning, and ultimately results in extensive mortality (Hughes et al., 2018; Sully et al., 2019). The global rise in marine heatwaves has shortened recovery intervals between disturbances, pushing many reefs toward ecological tipping points (Setter et al., 2022; Emslie et al., 2024; Woesik & Kratochwill, 2024). Declines in live coral cover subsequently drive habitat loss, reduced structural complexity, altered trophic dynamics, and diminished ecosystem services that include fisheries productivity, coastal protection, and tourism revenue (Eddy et al., 2021).

In parallel with bleaching, coral diseases have become an increasingly significant threat to reefs worldwide. Coral diseases, including white band disease (WBD), black band disease (BBD), and white plague, are significantly influenced by diverse microorganisms. WBD, primarily affecting Acropora species, has been linked to pathogenic bacteria such as Vibrio and Rickettsia-like organisms, which alter the coral's microbial community and contribute to disease progression (Rosenberg & Kushmaro, 2011; Gignoux-Wolfsohn & Vollmer, 2015; Gignoux-Wolfsohn et al., 2020). In contrast, BBD is associated with cyanobacterial mats that serve as reservoirs and vectors for pathogens, facilitating their transmission to corals (Cissell et al., 2022). White plague, another serious coral disease, has been connected to *Aurantimonas coralicida*, highlighting the role of specific bacteria in coral health decline (Sutherland et al., 2004; Rosenberg & Kushmaro, 2011). Thermal anomalies, nutrient enrichment, and physical disturbances often exacerbate outbreaks by weakening coral immune defenses (Bruno et al., 2007; Burge et al., 2013; Gignoux-Wolfsohn et al., 2020). A global meta-analysis of 108 studies revealed that mean coral disease prevalence has nearly tripled over the past 25 years, reaching approximately 9.9 percent worldwide (Burke et al., 2023). Rising sea surface temperatures and cumulative heat stress were strongly associated with this increase, underscoring the influence of climate change on disease emergence. Severe outbreaks have also been documented on high latitude reefs previously considered low risk. An example is the event at Norfolk Island which affected about 60 percent of a *Montipora* community following combined heat stress and water quality deterioration (Page et al., 2023b). These patterns highlight the synergistic interactions between warming, pollution, and disease in accelerating reef decline and reinforce the need to understand resilience processes under recurrent thermal stress.

The Southeast Asian region, which includes much of the Coral Triangle and is the global epicenter of marine biodiversity, has experienced particularly strong thermal stress in recent decades. The Gulf of Thailand, a shallow semi enclosed basin, is especially thermally sensitive, and sea surface temperatures have increased at rates exceeding the global average (Wetchayont et al., 2024). The 2024 El Niño Southern Oscillation event intensified these conditions, generating strong positive thermal anomalies and triggering a synchronous regional scale bleaching event documented from nearshore reef flats to offshore archipelagos (Matsuda et al., 2020). This challenges the assumption that spatial protection alone can buffer reefs from large climatic stressors (Bruno et al., 2007; Bruno et al., 2018) and provides a natural opportunity to examine taxon specific bleaching and mortality patterns under acute thermal stress.

Bleaching responses vary widely among coral taxa and are influenced by differences in morphology, physiology, genetics, and symbiont community composition (Grottoli et al., 2014; Grottoli et al., 2018; Matsuda et al., 2020). Highly susceptible branching *Acropora* species often contrast with more thermally tolerant massive genera such as *Porites* and *Dipsastraea* (Loya et al., 2001). Post bleaching outcomes, however, depend not only on initial susceptibility but also on species specific recovery capacity and mortality dynamics, which may not align directly with bleaching severity (Grottoli et al., 2014; Matsuda et al., 2020; Page et al., 2023a). These differential trajectories influence community reassembly, functional diversity, and long-term resilience under increasing thermal stress (Chan et al., 2024). Despite recurrent marine heat stress and rising disease risk, species level data on bleaching prevalence, severity, mortality, and early recovery remain limited for many reefs in the Gulf of Thailand, although such information is essential for forecasting ecological trajectories and informing management (Yeemin et al., 2013). To address this gap, this study examined the impacts of the 2024 regional bleaching event on the coral community at Ko Ngam Noi in Mu Ko Chumphon National Park. The objectives were to quantify species and functional group level bleaching severity at peak thermal stress, assess partial and whole colony mortality to identify the most vulnerable taxa, and document early signs of recovery or further decline to improve understanding of post disturbance community dynamics.

2. Methodology

2.1 Study Site

The field surveys were conducted at Ko Ngam Noi, a nearshore coral reef site within Mu Ko Chumphon National Park in the western Gulf of Thailand. Mu Ko Chumphon National Park, managed by the Department of National Parks, Wildlife and Plant Conservation, comprises approximately 40 islands that support extensive coral reef habitats in relatively good ecological condition and with high potential for marine tourism, particularly snorkeling and SCUBA diving. Ko Ngam Noi is located about 20.5 kilometers offshore at coordinates 10°29.200′ N, 99°25.060′ E (Figure 1). The site consists of a sheltered fringing reef situated in clear waters with depths ranging from 8 to 12 meters. Water transparency is consistently high, and the reef is subject to varying levels of anthropogenic influence, characterized by intense tourism activity and relatively low fishing pressure.

2.2 Coral community surveys

Live coral cover and benthic composition were quantified following the standard survey procedures described by English et al. (1997). At the study site, three permanent belt transects measuring 30 × 1 meters were established on the reef, with each transect positioned to represent the dominant benthic community at the depth surveyed. Along each transect, quadrats were placed at fixed intervals and photographed using an underwater camera to enable post-survey verification and ensure consistent classification of benthic components. Each quadrat measured 50 × 50 centimeters and was analyzed to estimate the percent cover of major benthic categories, including live hard coral, recently dead coral, rubble, sand, rock, and other substrate.

Coral colonies visible within quadrats and along the belt transects were identified to species level whenever possible, and otherwise to genus. Coral bleaching was initially assessed in May 2024, coinciding with the peak of the thermal anomaly. Bleaching status of each colony was visually scored in situ using three ordinal categories: unbleached (normal pigmentation), partially bleached (pale or patchy loss of pigmentation), and bleached (marked or complete loss of pigmentation). Follow-up surveys were conducted in July 2024 using the same permanent transects and photographic protocol to evaluate subsequent coral mortality and early signs of recovery. During this second survey, colonies were classified as healthy, partially bleached, bleached, or recently dead based on visible tissue integrity, pigmentation, and the presence or absence of living tissue on the skeleton.

Seawater temperature was monitored at the study site using autonomous temperature data loggers (HOBO Pendant MX temperature/light logger, model MX2202; Onset Computer Corporation, Bourne, MA, USA) deployed at the same depth as the surveyed coral communities. The loggers recorded in *situ* seawater temperature continuously throughout the study period and were used to characterize the thermal conditions associated with the bleaching event.

2.3 Data Analysis

Statistical analyses were conducted to assess differences in key ecological variables between the two survey periods. Before running the analyses, all datasets were checked for normality, and transformations were applied where needed to meet the assumptions of parametric testing. Normality and homogeneity of variance were verified prior to carrying out inferential tests. Differences in mean ecological metrics, including live coral cover and bleaching prevalence, were examined using Student's t tests. All statistical analyses were performed in R (version 2025.05.1+513).

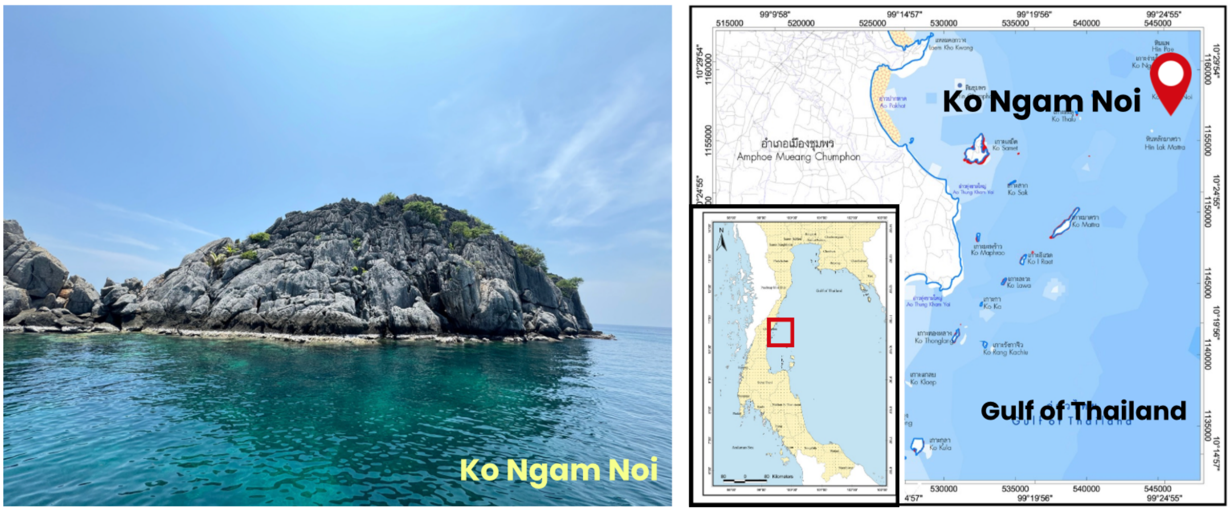

Figure 1. Map of the study site at Ko Ngam Noi, Mu Ko Chumphon National Park.

3. Results

Benthic composition at Ko Ngam Noi was dominated by live hard coral and sandy substrata. Live hard coral exhibited the highest mean cover at 47.95±1.53%. Sand was the second most abundant component at 29.64±0.53%. Consolidated rock accounted for 10.71±0.46% cover. Other benthic categories occurred at lower proportions, with dead coral and the combined other category averaging 4.31±0.29% and 4.64±0.34%, respectively, while rubble had the lowest mean cover at 2.74±0.14% (Figure 2).

Overall, the benthic assemblage at Ko Ngam Noi was characterized by a high proportion of live coral and stable hard substrata during the survey period

In May 2024, the coral assemblage exhibited a high incidence of bleaching. Partially bleached colonies accounted for the greatest proportion of cover at approximately 20.61±0.98 percent, and fully bleached colonies contributed a further 11.67±1.69 percent. Unbleached colonies comprised only about 15.50± 1.17 percent of total cover at this time. By July 2024, the bleaching pattern had shifted markedly. Unbleached colonies became the dominant category, increasing to 27.35±1.95 percent cover. In contrast, partially bleached and fully bleached colonies declined to 1.44±0.17 percent and 1.31±0.14 percent, respectively. Statistical comparisons between months indicated a marked recovery trend, with unbleached cover increasing significantly while both partially bleached and fully bleached cover declined significantly (*t*-tests, $p < 0.05$) (Figure 3).

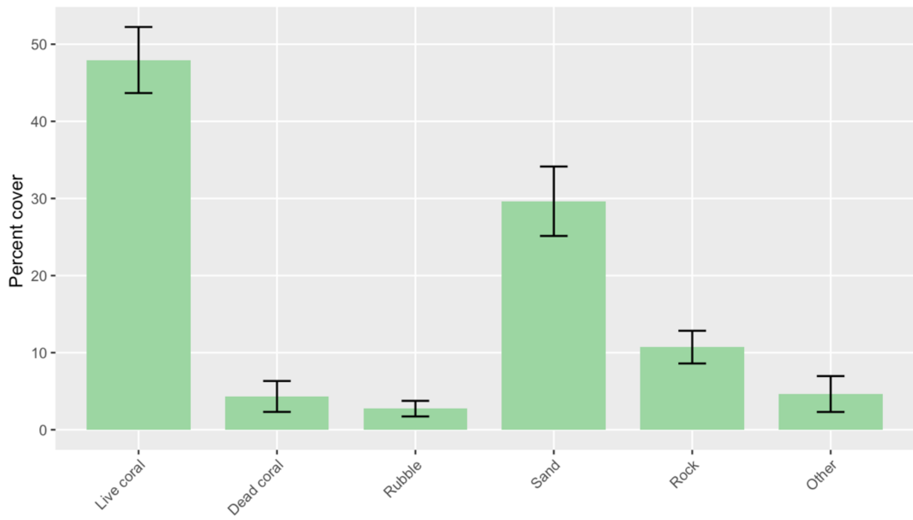

Figure 2. Mean percent cover of major benthic categories at Ko Ngam Noi, Mu Ko Chumphon National Park Bars show mean cover for each category with standard error, highlighting dominance of live coral and sand relative to dead coral, rock, rubble and other substrata.

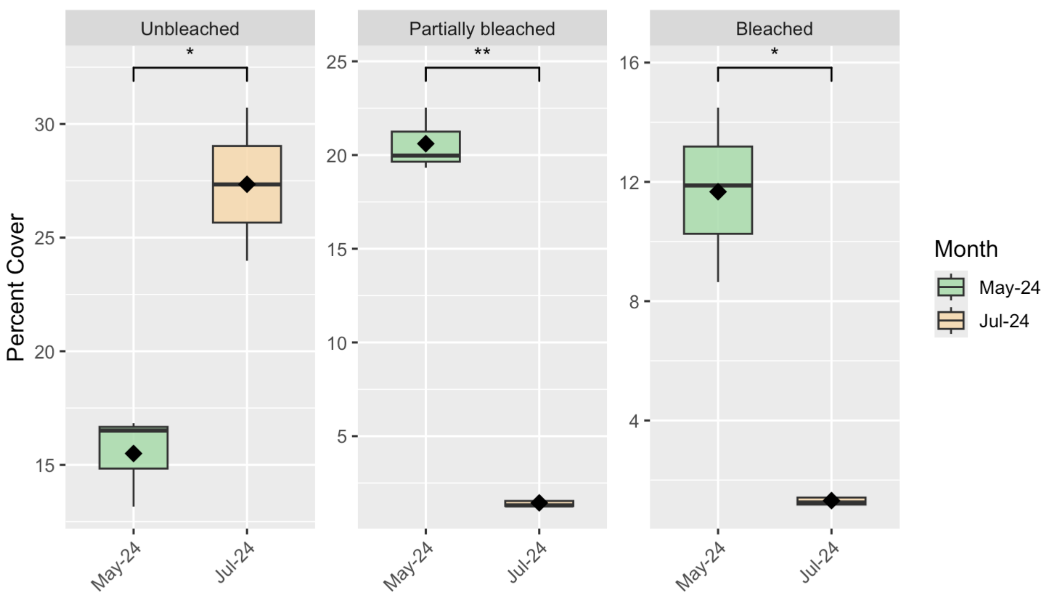

Figure 3. Percent cover of unbleached, partially bleached, and bleached corals at Ko Ngam Noi in May and July 2024; boxes show variability among transects and asterisks indicate significant differences between months (t-test, $p < 0.05$).

Species specific bleaching responses showed marked variation among taxa during the 2024 thermal anomaly. In May 2024, most species were dominated by partially bleached and fully bleached colonies, with only a small proportion of unbleached colonies for many taxa such as *Acropora divaricata*, *A. muricata*, *Cyphastrea microphthalma*, *Dipsastraea heliopora* and *Galaxea fascicularis*. Several massive and submassive species, including *Porites lutea*, *P. rus* and *Favites abdita*, retained higher fractions of unbleached colonies, although even these taxa still exhibited substantial partial bleaching. A few species such as *Echinopora lamellosa* and *Plerogyra sinuosa* showed relatively large proportions of unbleached colonies during the peak of the event, consistent with comparatively higher thermal tolerance at that time. By July 2024, the overall bleaching pattern had shifted markedly toward recovery across most taxa (Figure 4). Unbleached colonies became the dominant category for nearly all species, while the proportions of partially bleached and fully bleached colonies declined to low levels. Branching and plating taxa, including *Acropora muricata*, *Montipora aequituberculata*, and *Pocillopora acuta*, showed widespread return to normal pigmentation among surviving colonies by the follow-up survey. The July dataset also revealed species-specific mortality. Notably, *Acropora divaricata* and *Platygyra sinensis* exhibited comparatively higher post-bleaching mortality, whereas most other taxa showed little or no recorded colony loss.

Overall, the species-level patterns observed in May and July indicate a heterogeneous response within the coral assemblage. Many taxa experienced extensive bleaching but subsequently returned to an unbleached state, whereas a smaller subset showed both high bleaching and elevated mortality (Figure 5 and Figure 6). These contrasting responses are likely to influence future community composition and the functional structure of the reef following the 2024 bleaching event.

Sea surface temperature (SST) showed clear seasonal variation throughout 2024. From January to March, temperatures remained relatively stable, fluctuating around 28–29°C. Temperatures began to rise in April, entering an extended warm period from late April through June. During this interval, SST consistently exceeded 30°C and reached a maximum recorded value of 32.3°C. Elevated temperatures persisted through mid-July before gradually declining. From August to November, SST stabilized at approximately 29–30°C with reduced short-term variability compared to the peak-warm period (Figure 7).

4. Discussion

The findings from Ko Ngam Noi present a nuanced picture of reef resilience, characterized by a dominant pattern of rapid post bleaching recovery underpinned by pronounced species specific heterogeneity in bleaching susceptibility and mortality. This pattern is consistent with both global observations and regional studies from Thailand, which demonstrate that although mass bleaching acts as a broadly synchronous stressor, ecological outcomes are strongly shaped by differential physiological tolerances and recovery capacities among constituent coral taxa (Yeemin et al., 2012; Sutthacheep et al., 2013; Grottoli et al., 2014).

The most compelling result from this study is the significant increase in unbleached coral cover, from about 16% to about 27%, accompanied by a sharp decline in both partially and fully bleached cover within a two-month period. This pattern indicates that the majority of coral colonies at Ko Ngam Noi, although exposed to acute thermal stress, either retained viable symbiont populations or successfully repopulated their tissues with symbionts and thereby avoided immediate mortality. Rapid reestablishment of symbiosis is increasingly recognized as a key component of coral resilience and may be facilitated by environmental conditions such as the alleviation of temperature stress, favorable light regimes, and hydrodynamic settings that enhance heterotrophic feeding (Grottoli et al., 2014). The low overall cover of dead coral and rubble, approximately 4–5% and 3% respectively, further suggests that the 2024 event functioned primarily as a severe but sub lethal physiological disturbance for most colonies at the time of the survey. This outcome highlights the need to consider both initial bleaching prevalence and subsequent trajectories of recovery or mortality when assessing impact severity, since high levels of bleaching at peak stress do not necessarily translate into catastrophic mortality, as previously documented for coral communities in the Western Gulf of Thailand following the 1998 and 2010 bleaching events (Yeemin et al., 2012; Sutthacheep et al., 2013; Yeemin et al., 2013)

The data reveal a clear species-specific response portfolio that is consistent with global patterns (Loya et al., 2001) and with previous assessments of coral resilience potential in both inshore and offshore reefs of the Western Gulf of Thailand (Sutthacheep et al., 2019). Taxa such as *Acropora muricata* exhibited high bleaching prevalence in May but showed remarkable recovery by July, suggesting a bleach tolerant or rapid recovery strategy. In contrast, *Acropora divaricate* and

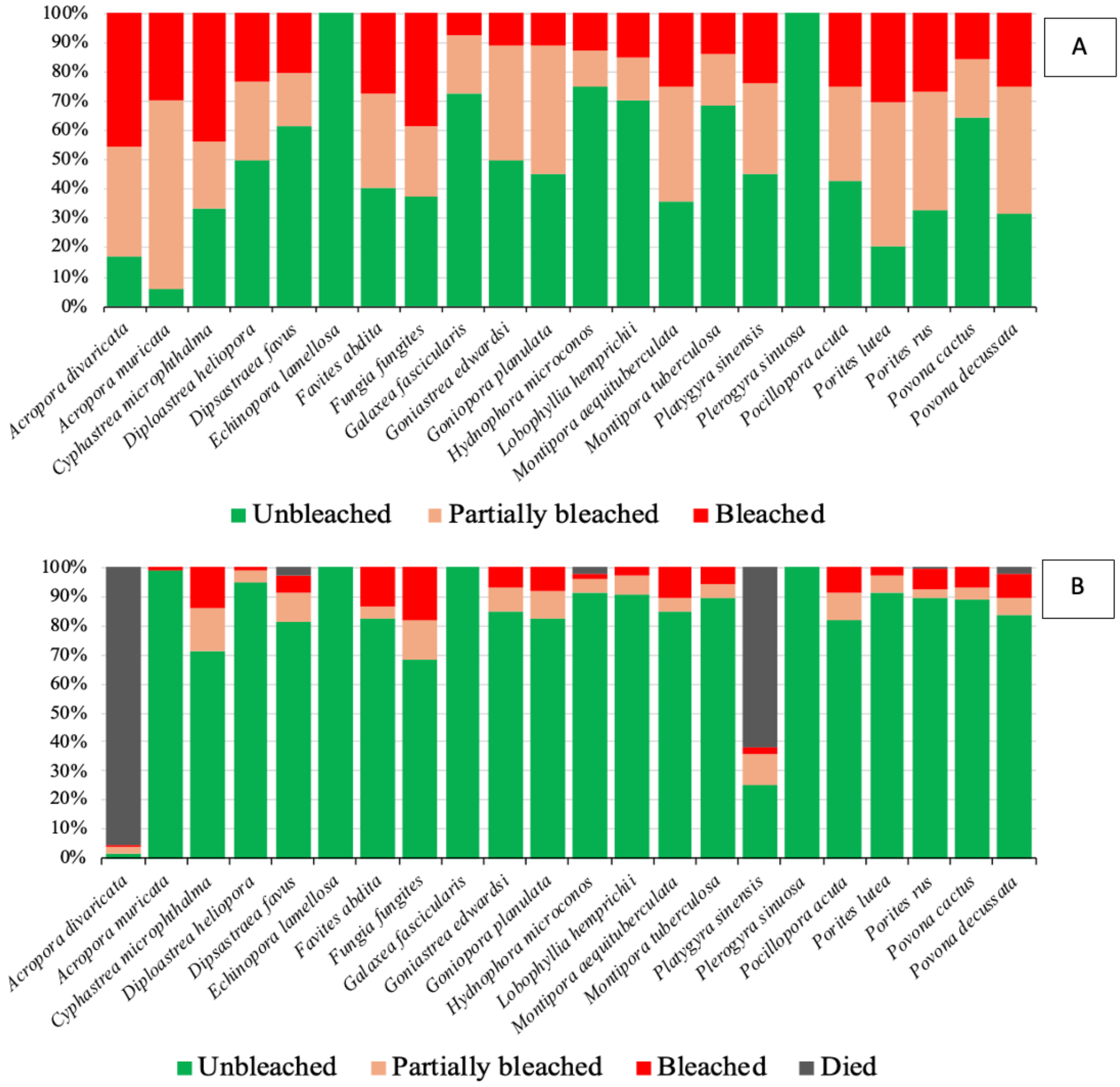

Figure 4. Species level bleaching status of dominant scleractinian corals at Ko Ngam Noi, Mu Ko Chumphon National Park, during (A) May 2024 and (B) July 2024. Stacked bars show the proportion of colonies in each condition category: unbleached (green), partially bleached (orange), bleached (red), and recently dead (grey). The plots illustrate extensive bleaching during peak thermal stress in May and widespread recovery of surviving colonies by July, with post bleaching mortality concentrated in a subset of species.

Platygyra sinensis experienced high post bleaching mortality, indicative of a high susceptibility strategy. This dichotomy is likely linked to underlying morphological and physiological traits. Elevated mortality in some *Acropora* species is consistent with their generally high metabolic demands and sensitivity to light and temperature stress, whereas the higher survival and recovery observed in massive taxa such as *Porites* and *Dipsastraea* may be related to greater tissue thickness, larger energy reserves and enhanced heterotrophic capacity (Grottoli et al., 2014). The case of *Platygyra sinensis*, a brain coral, showing substantial mortality is notable because the genus is often regarded as moderately tolerant. This finding implies that tolerance thresholds can be strongly species specific or even population specific, potentially shaped by local adaptation, acclimatory history or differences in prior exposure to thermal anomalies (Wetchayont et al., 2024).

The differential mortality observed in this study has direct implications for reef structural complexity and ecological function. Losses of structurally complex branching species such as *Acropora divaricata*, even where spatially patchy, are likely to reduce architectural heterogeneity and thereby affect fish and invertebrate assemblages that depend on fine scale habitat complexity (Miller et al., 2021). At the same time, the survival and recovery of many framework building species, including other *Acropora* and several massive corals, provide an essential foundation for continued reef accretion and habitat provision. Similar patterns of post-bleaching survival and recovery, including among juvenile corals, have been reported from Thai reefs following the 2010 bleaching event, indicating that early life stages can also contribute to long-term reef resilience under favorable post-disturbance conditions (Yeemin et al., 2012). The benthic composition, which remains dominated by nearly 50% live coral cover and a high proportion of stable substrata, suggests that the reef still maintains substantial ecological functioning and a strong capacity for regeneration (Gopi et al., 2021). Nevertheless, this recovery appears to be proceeding through assemblage turnover, in which the relative abundances of species are reshuffled. A community increasingly dominated by more thermally tolerant but often slower growing massive corals is likely to exhibit altered growth trajectories, net calcification potential and species interactions, with important consequences for long term ecosystem dynamics and resilience to future disturbances (Chan et al., 2024).

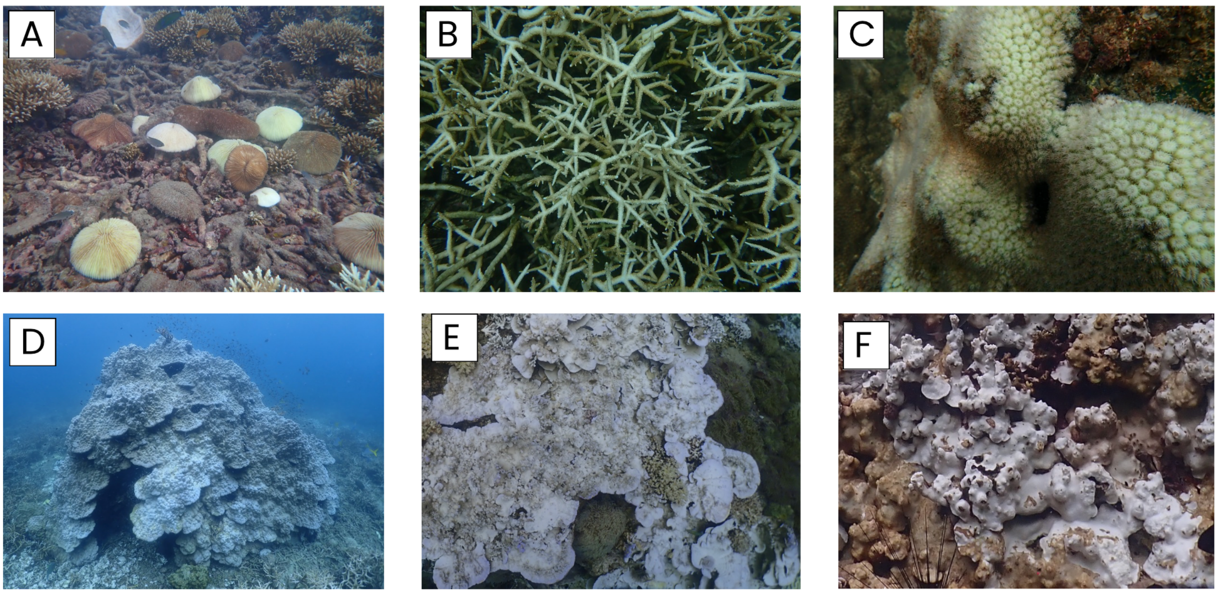

Figure 5. Coral bleaching observed at Ko Ngam Noi. Several species were affected, including *Fungia fungites* (A), *Acropora muricata* (B), and *Galaxea fascicularis* (C), *Porites lutea* (D), *Montipora aequituberculata* (E), *Porites rus* (F)

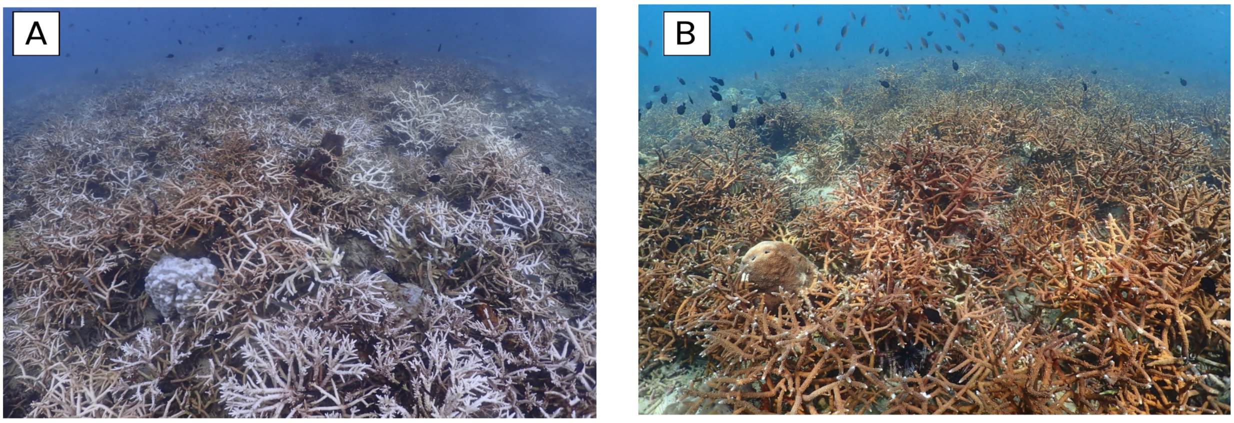

Figure 6. Coral bleaching and recovery at Mu Ko Chumphon showing severe bleaching during the May 2024 thermal anomaly (A) followed by noticeable partial recovery of coral communities in July 2024 (B).

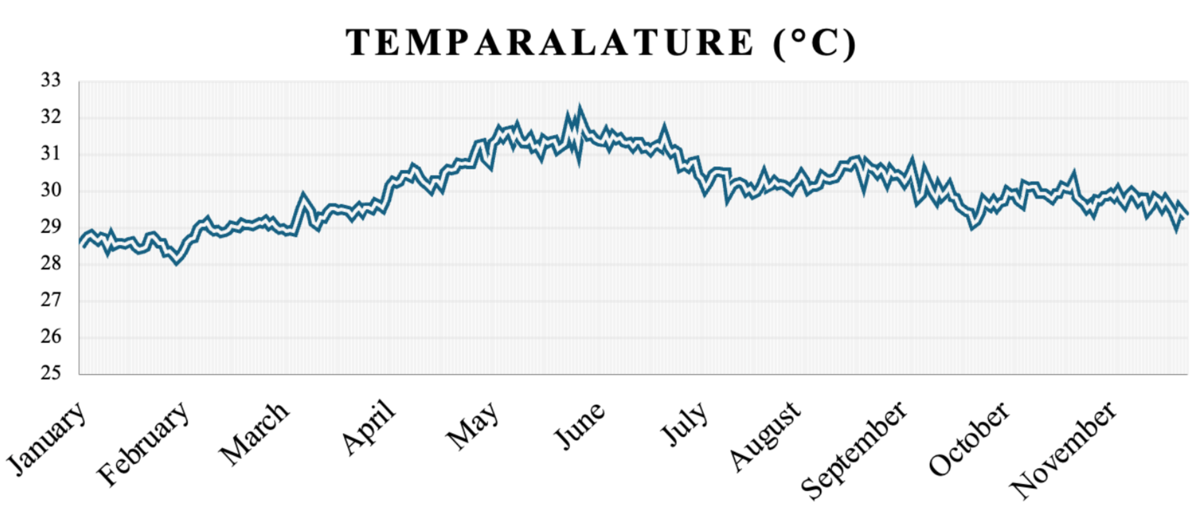

Figure 7. Sea surface temperature (SST) recorded throughout 2024 using autonomous temperature data loggers deployed at the study site.

The findings from Ko Ngam Noi provide critical, actionable guidance for local and regional reef management and align with long-standing recommendations from Thailand that emphasize resilience-based management, protection of recovery windows, and the reduction of local stressors following bleaching events (Yeemin et al., 2012; Sutthacheep et al., 2019). First, the clear distinction between relatively tolerant winner taxa, such as *Porites lutea* and *Echinopora lamellosa*, and more susceptible loser taxa offers an empirical basis for resilience-based mapping. Sites that support higher proportions of naturally tolerant species could be prioritised as candidate climate refugia within marine spatial planning frameworks and MPA zoning, thereby aligning conservation efforts with areas that are more likely to sustain coral cover under recurrent thermal stress (Bruno et al., 2018). Second, the results have direct implications for restoration and active intervention. Coral restoration programmes, particularly those based on nurseries and outplanting, should give priority to donor colonies and species that demonstrate strong recovery capacity, such as *Acropora muricata*, which bleached but subsequently regained normal pigmentation, rather than focusing predominantly on highly susceptible taxa. Approaches that incorporate assisted evolution and selective breeding can also be informed by traits expressed in resilient populations at Ko Ngam Noi, for example rapid recovery, partial bleaching rather than complete tissue loss, or high post bleaching survival (Humanes et al., 2024). Finally, the demonstrated capacity for natural recovery underscores the importance of minimising local stressors in order to maintain and enhance this resilience. Strengthening management to reduce water pollution, sedimentation and physical damage from tourism or fishing is essential to support physiological recovery and successful recruitment following bleaching events (Gopi et al., 2021). Together, these strategies can help translate species specific response data into practical, resilience-based management for Mu Ko Chumphon National Park and other reefs in the Gulf of Thailand.

In conclusion, the coral community at Ko Ngam Noi demonstrated substantial resilience to the 2024 marine heatwave, with widespread bleaching but limited immediate mortality and rapid pigmentation recovery in most taxa. At the same time, the observed species-specific mortality patterns point to the onset of a selective community shift. The future trajectory of this reef will depend on the frequency and intensity of subsequent thermal events, the capacity of sensitive species to recover through recruitment, and the effectiveness of management actions that maintain its inherent regenerative potential. Overall, this study reinforces that safeguarding coral reef resilience requires a dual strategy that combines rapid mitigation of global climate change with robust local management aimed at preserving the environmental conditions necessary for recovery and adaptation.

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