ORIGINAL PAPER

Citizen Science-Based Coral Reef Monitoring in Trat Province, Eastern Gulf of Thailand

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Abstract. Coral reefs in Trat Province, eastern Gulf of Thailand, are ecologically and economically important but increasingly threatened by climate change, pollution, and human activities. This study employed a citizen science-based approach to assess reef condition, benthic invertebrates, and reef fish assemblages across seven sites around Koh Chang, Koh Mak, and Koh Kut. A total of 140 photographs and 7 underwater videos were collected by citizen scientists and verified by researchers. Results showed clear spatial variability: live coral cover was highest at Koh Phi (73.44%) and lowest at Koh Rayang Nok (10.12%). Macrobenthic invertebrate density peaked at Hin Luk Baht (6.96 ind./m²), dominated by *Junceella* sp. and *Diadema setosum*, while other sites supported lower densities. Reef fish density was highest at Hin Ao Salad, Koh Rad, and Hin Luk Baht (>1,600 ind./100 m²). Despite lower densities, Koh Kham maintained high species diversity. These findings demonstrate the value of citizen science in producing accurate and cost-effective datasets while enhancing community participation. Integrating public contributions with scientific verification provides a practical mechanism for monitoring, conservation, and adaptive management of coral reefs. This study highlights how citizen science can strengthen ecological knowledge, raise awareness, and promote sustainable marine resource management in regions with limited research capacity.

Keywords: Citizen science, Coral reefs, Reef monitoring, Trat Province, Gulf of Thailand

1. Introduction

Coral reefs are among the ecosystems with the highest biodiversity and economic value. They play vital roles in providing various ecosystem services, such as protecting coastlines, serving as habitats for fisheries resources, supporting marine tourism activities, and functioning as important carbon sinks (Yeemin et al., 2006; Bruno and Selig, 2007; Phongsuwan et al., 2013; Sutthacheep et al., 2013; Sutthacheep et al., 2019; Yeemin et al., 2024). However, coral reefs are currently facing severe pressures and threats from multiple factors, including climate change, marine pollution, and human activities, which have led to the degradation and destruction of coral reef ecosystems (Hoegh-Guldberg et al., 2018; Hughes et al., 2019).

In recent decades, coral reefs in both Thailand and around the world have undergone severe and continuous degradation. A clear and most recent piece of evidence is the fourth global coral bleaching event (2023–2024), which caused extensive damage to coral reefs worldwide and further increased their vulnerability to heat stress, diseases, and long-term degradation (Hughes et al., 2021; Sully et al., 2022; Pearce-Kelly et al., 2025). The establishment of appropriate conservation and management strategies is therefore essential for the recovery of coral reef ecosystems (Yeemin et al., 2006; Bruno and Selig, 2007; Phongsuwan et al., 2013; Sutthacheep et al., 2013; Sutthacheep et al., 2018). Collaboration among government agencies, the private sector, and local communities in monitoring, conserving, and restoring coral reefs thus plays a crucial role (Yeemin et al., 2012; Aswani et al., 2015; Obura et al., 2019; Licuanan et al., 2021). Citizen science initiatives for monitoring changes in coral reef ecosystems have become an important tool that enables scientists to obtain long-term and continuous data on reef health, such as coral bleaching, coral growth, and the diversity of associated organisms (Pocock et al., 2017).

Citizen science represents a collaborative approach between scientists and the public in collecting data for environmental conservation, particularly within coral reef ecosystems that are facing threats such as climate change, marine pollution, and unsustainable resource use (Bonney et al., 2014). Citizen science can contribute to the development of knowledge and localized solutions through long-term monitoring and data collection (Dickinson et al., 2012), while also providing opportunities for the public to engage in scientific research and data gathering, especially in areas that may be difficult for scientists to access comprehensively. Public participation in citizen science projects enhances awareness and understanding of coral reef ecosystems and can further support their conservation and restoration (Bonney et al., 2014; Crall et al., 2017; Dickinson et al., 2012; Great Barrier Reef Marine Park Authority, 2013; Kelly et al., 2020; McKinley et al., 2017).

The development of appropriate methods and procedures for citizen science participation in coral reef monitoring is an urgent necessity. Such approaches should be simple, cost-effective, provide accurate and reliable data, and foster interaction among managers, scientists, local communities, and the general public to maximize benefits for coral reef conservation (Turrini et al., 2018; Licuanan et al., 2021; Bird et al., 2014; Kosmala et al., 2016). Evidence shows that well-trained volunteers can generate reliable ecological data, detect long-term changes in reef condition, and contribute to global biodiversity assessments at scales comparable to professional monitoring programs (Forrester et al., 2015; Done et al., 2017; Edgar et al., 2014). Moreover, agencies are increasingly integrating citizen science into decision-making processes, such as the Eye on the Reef program by GBRMPA, which uses public submissions alongside professional monitoring to inform reef condition assessments and management actions (GBRMPA, n.d.).

Citizen science for coral reef monitoring has been widely developed across different geographic regions and for diverse objectives, particularly in monitoring coral bleaching, reef mapping, reef condition assessments, and reporting threats (Siebeck et al., 2006; Branchini et al., 2015;

Bauer-Civiello et al., 2018; Licuanan et al., 2021). Non-governmental organizations and citizen science initiatives can employ repeatable and cost-effective monitoring programs that address multiple conservation and management objectives (Dickinson et al., 2010; Marshall et al., 2012; Jambeck & Johnsen, 2015). Beyond ecological contributions, citizen science also builds social capital and fosters stewardship, with long-term evaluations showing that participants often retain ecological knowledge and adopt conservation-oriented behaviors (Hesley et al., 2023; McLeod et al., 2019; McLeod et al., 2021).

Coral reefs in Thailand play a vital role in generating income and sustaining the livelihoods of coastal communities through tourism, fisheries, and coastal protection (Sutthacheep et al., 2022). However, Thailand's coral reefs are facing continuous threats of increasing severity, particularly in the Gulf of Thailand. To address these challenges, it is essential to establish effective coral reef monitoring programs that integrate scientific knowledge with local participation. Citizen science networks represent an important opportunity to enhance monitoring efforts by engaging local communities in data collection, thereby supporting the sustainable management of coral reef ecosystems.

This research focuses on developing knowledge and innovations for coral reef monitoring by assessing the status and structure of biological communities in coral reefs in Trat Province. The findings will serve as a foundation for developing new methods suitable for coral reef monitoring, based on the concept of citizen science, which allows the public and local communities to participate actively in the research process. The study also aims to build and expand citizen science networks to strengthen stakeholder participation in continuously monitoring ecological changes in coral reefs. This will support the collection of scientific data and its application for sustainable resource management.

The objective of this research is to demonstrate the importance and potential of citizen science participation in monitoring and observing changes in coral reef ecosystems. It highlights how integrating scientific knowledge with local

community engagement can generate accurate, comprehensive, and continuous databases. Furthermore, this study emphasizes that citizen science networks not only enhance the effectiveness of ecological research but also serve as a crucial mechanism for fostering awareness and shared responsibility in marine conservation. In addition, they contribute to the development of new generations of researchers and drive sustainable marine resource management at both local and national levels.

2. Materials and Methods

2.1 Location of study sites

This study was conducted in three major island groups of Trat Province: Koh Chang, Koh Mak, and Koh Kut, located in the eastern Gulf of Thailand. The Department of Marine and Coastal Resources oversees these areas, recognizing their high ecological significance and biodiversity (Figure 1). Koh Chang, the largest group, supports diverse coral reefs and marine life, and while under pressure from tourism, it retains strong potential for conservation. Koh Mak, about 20 km southeast of Koh Kut, contains relatively intact reefs with branching, massive, and encrusting corals and abundant reef fishes, though its proximity to the mainland makes it vulnerable to pollution and overfishing. Koh Kut, Thailand's fourth-largest island, lies 25 km offshore and supports highly diverse reefs of rigid and soft corals as well as marine invertebrates. These sites were selected for their ecological importance, accessibility, and potential for community participation through citizen science, with their proximity enabling comparative analyses of reefs under varying human impacts and protection levels.

2.2 Data collection

Coral reef surveys using a citizen science-based monitoring approach were designed to examine reef conditions through standardized photographic and video methods. At each site, at least 20 top-down photographs of coral reefs were taken from a distance of approximately 2 meters, ensuring no overlap between images (Figure 2). For reef fish surveys, underwater video recordings

of at least three minutes were conducted from about 2 meters above the reef, with the camera positioned at an angle of approximately 60°. All photographic and video files were submitted to scientists for verification and analysis via the Facebook platform: MBRG Ramkhamhaeng University (Yeemin et al., 2021).

Coral reef and macrobenthic invertebrate survey: Survey sites were selected to represent different reef zones and island orientations. Depth was recorded using a dive computer or depth gauge. At each site, a minimum of 20 photographs were taken from a distance of approximately 2 meters above the reef, ensuring no overlap between images. Photographs were captured either vertically or at a slight angle to provide an overall reefscape, and all image files were submitted to scientists for analysis. The density of macrobenthic invertebrates was calculated by counting the number of individuals of each species recorded within the total area represented by 20 photographs per site and expressed as individuals per square meter (ind./m²).

Reef Fish Survey: Surveys were conducted along reef slope zones or at underwater pinnacles, with depth recorded using a dive computer or depth gauge. At each site, an underwater camera was positioned at an angle of approximately 60° relative to the reef, and continuous video recordings of at least three minutes were taken while swimming slowly at a distance of about 2 meters above the reef. All video files were submitted to scientists for analysis. The density of reef fishes was then calculated by counting the number of individuals of each species recorded within the total area represented by a three-minute continuous underwater video per site and expressed as individuals per 100 square meters (ind./100 m²).

2.3 Data analysis

All survey data (corals, macrobenthic invertebrates, and reef fishes) were tested for differences among sites using one-way ANOVA, followed by Tukey's HSD post-hoc test ($p < 0.05$). Data are presented as mean ± standard deviation (SD), and bar charts illustrate the standard error of the mean (SEM).
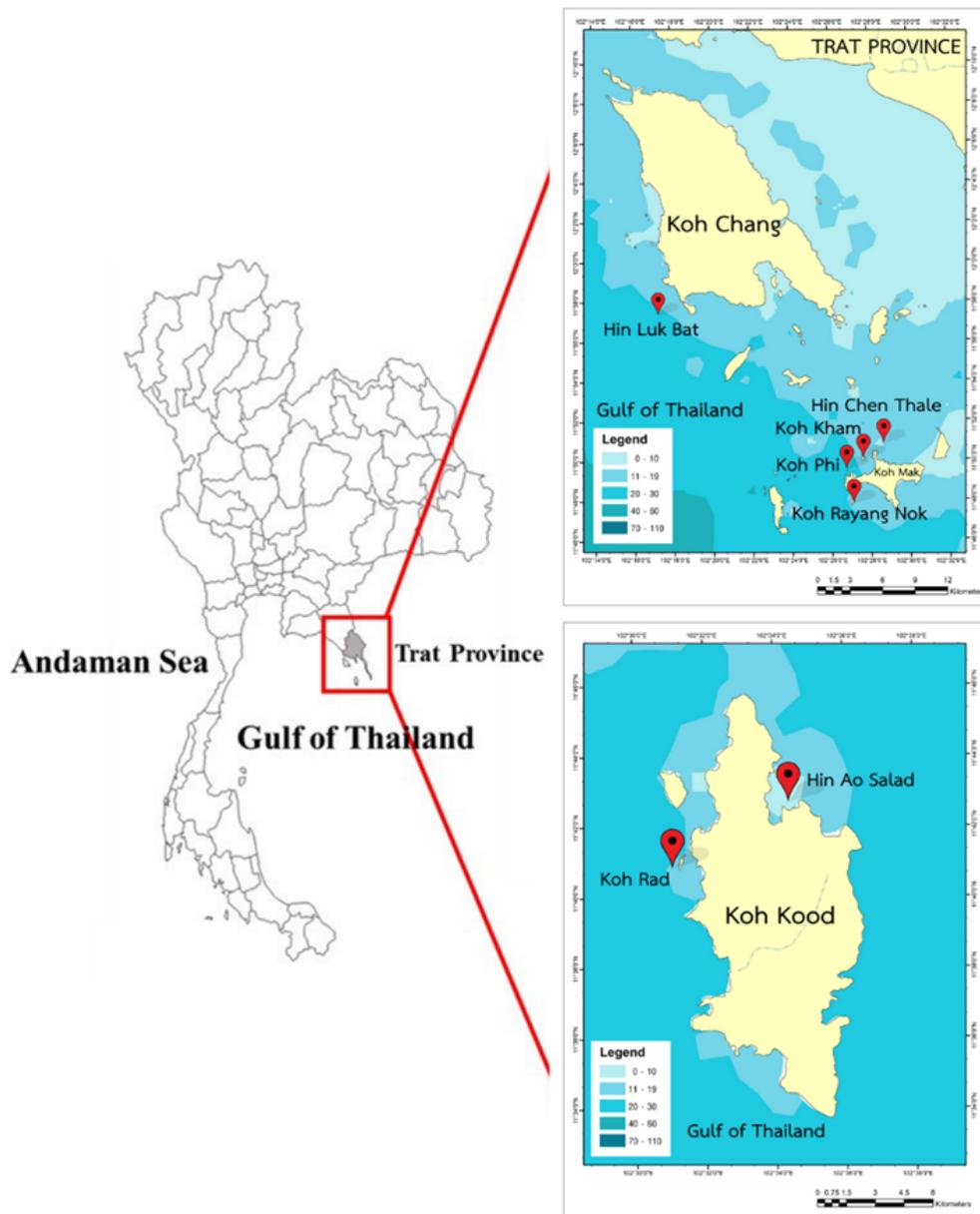
Figure 1. Study sites for coral reef monitoring through citizen science

Figure 2. Figure 2 shows examples of seabed conditions recorded during coral reef surveys using a citizen science-based monitoring approach.

Hierarchical clustering and heatmap analyses were performed using Ward's method and Euclidean distance to examine similarities in community composition among sites.

This study aims to generate valuable insights into the status of coral reefs in the Koh Chang, Koh Mak, and Koh Kut groups in Trat Province, while also emphasizing the potential of citizen science in monitoring and managing marine ecosystems

3. Results

Citizen scientists contributed a total of 140 photographs and 7 video files through the MBRG Ramkhamhaeng University Facebook platform, covering seven survey sites across three island groups (Koh Chang, Koh Mak, and Koh Kut). These contributions formed the complete dataset analyzed in this study, highlighting the crucial role of citizen science in coral reef monitoring in Trat Province.

3.1 Coral Reef Composition and Biodiversity

The survey of coral reef composition around Koh Chang, Koh Mak, and Koh Kut revealed that most areas were covered by live corals, although clear variations were observed among sites. The highest live coral cover was recorded at Koh Phi (73.44%), followed by Hin Chen Thale (63.56%) and Hin Luk Baht (58.75%). In contrast,

the lowest live coral cover was found at Koh Rayang Nok (10.12%). Regarding benthic substrate composition, the highest rock cover was observed at Koh Rayang Nok (59.34%) and Hin Ao Salad (30.61%), while sandy substrates were most dominant at Koh Rayang Nok (24.69%) and Koh Kham (13.68%). Dead corals and coral rubble were generally low across most sites (<10%), except at Hin Ao Salad (dead coral 10.65%) and Hin Chen Thale (dead coral 7.35%) (Figure 3).

The survey of live coral cover across the study sites (Figure 4) revealed statistically significant differences ($p < 0.05$, one-way ANOVA, Tukey's HSD). The highest mean live coral cover was recorded at Koh Phi, which was significantly greater than at all other sites. Hin Chen Thale and Hin Luk Baht also exhibited relatively high levels of live coral cover and were grouped separately from sites with lower cover values. In contrast, Koh Kham and Hin Ao Salad showed moderate levels of live coral cover. Koh Rayang Nok had the lowest live coral cover, which was significantly different from all other sites. These findings highlight spatial variability in coral reef health across the Koh Chang, Koh Mak, and Koh Kut groups, with some areas, such as Koh Phi, maintaining relatively healthy reef conditions, while others, such as Koh Rayang Nok, exhibited severe degradation potentially linked to recent bleaching events.
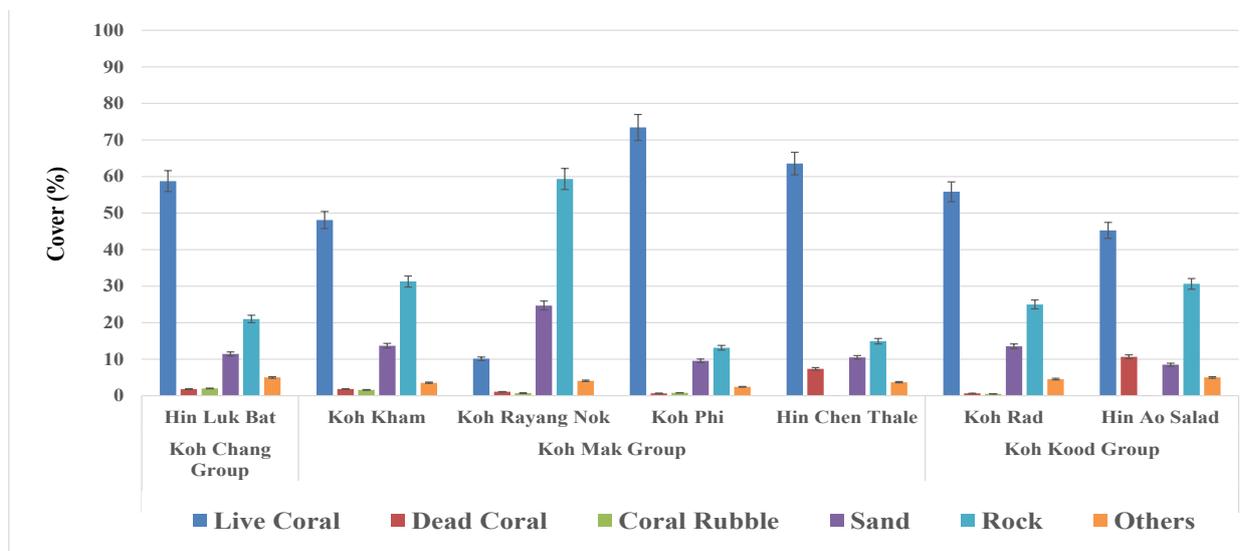

Figure 3. Average percentage cover of live corals, dead corals, coral rubble, sand, rock, and other benthic components at the study sites around Koh Chang, Koh Mak, and Koh Kut. Error bars indicate standard error of the mean.

The diversity and evenness of coral communities also varied across the seven survey sites in Trat Province (Table 1). Koh Kham exhibited the highest species diversity, with a Shannon–Wiener index (H′) of 2.5942 and the highest evenness (J′ = 0.9580), indicating a diverse and well-balanced coral assemblage. Koh Phi also showed high diversity (H′ = 2.5136) with moderate evenness (J′ = 0.8017). Hin Ao Salad displayed moderate diversity (H′ = 2.1995) but relatively high evenness (J′ = 0.8575). In contrast, Koh Rayang Nok had the lowest species diversity (H′ = 1.8532), despite a moderate evenness value (J′ = 0.7728), suggesting limited species richness but a relatively balanced distribution among the taxa present. Koh Rad also showed low diversity (H′ = 1.9860, J′ = 0.7163), reflecting a reduced coral assemblage. Hin Luk Baht (H′ = 2.1869, J′ = 0.6563) and Hin Chen Thale (H′ = 2.2184, J′ = 0.7534) exhibited intermediate values, indicating

moderate diversity and community balance. The heatmap with hierarchical clustering revealed distinct patterns of live coral composition across the survey sites (Figure 5). *Porites lutea* and *Acropora muricata* were the dominant species, with the highest percentage cover particularly at Koh Phi, Hin Chen Thale, and Hin Luk Baht, which clustered together, indicating relatively healthy reef conditions. In contrast, Koh Rayang Nok formed a separate cluster due to consistently low coral cover across most species, reflecting a degraded reef state. Intermediate conditions were observed at Koh Kham, Hin Ao Salad, and Koh Rad, where coral cover was moderate but lacked clear species dominance. Overall, the clustering highlights site-specific variability, with some areas maintaining high coral cover and species dominance, while others exhibit signs of significant decline.
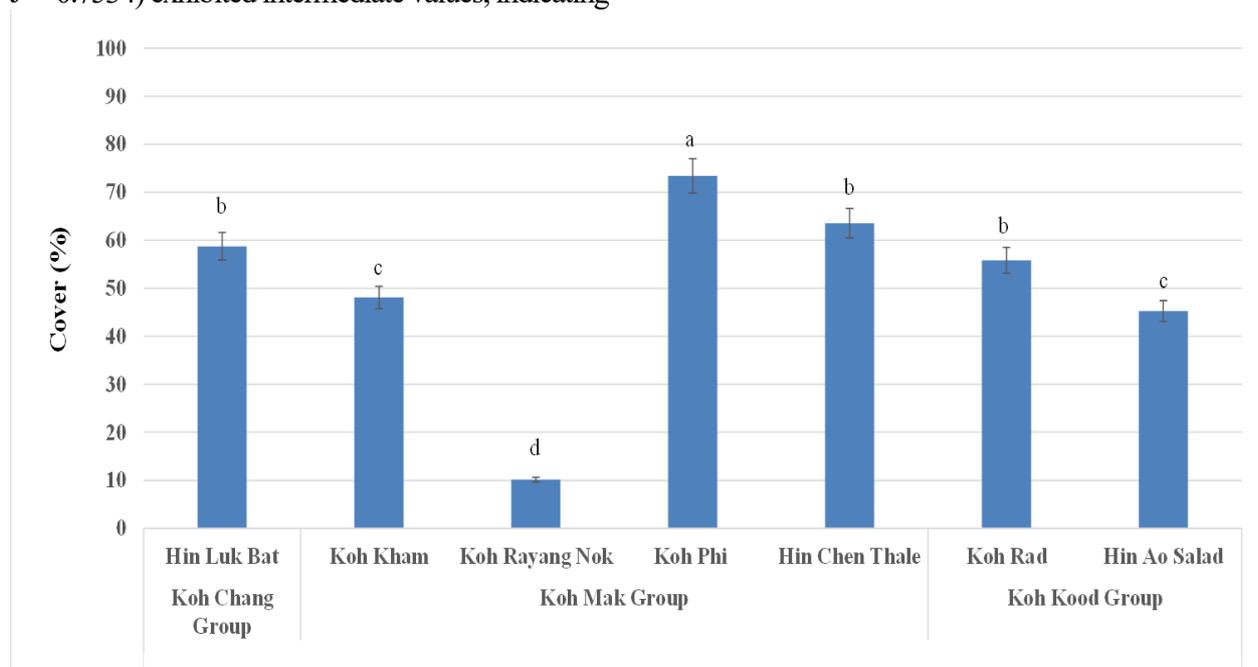

Figure 4. Live coral cover at the study sites in Trat Province, Thailand. Error bars represent the standard error of the mean. Different letters above the bars indicate statistical differences among sites (one-way ANOVA, $p < 0.05$), as determined by Tukey's HSD.

Table 1. Shannon diversity index (H′) and Pielou's evenness index (J′) of corals at study sites in Trat Province, Thailand.

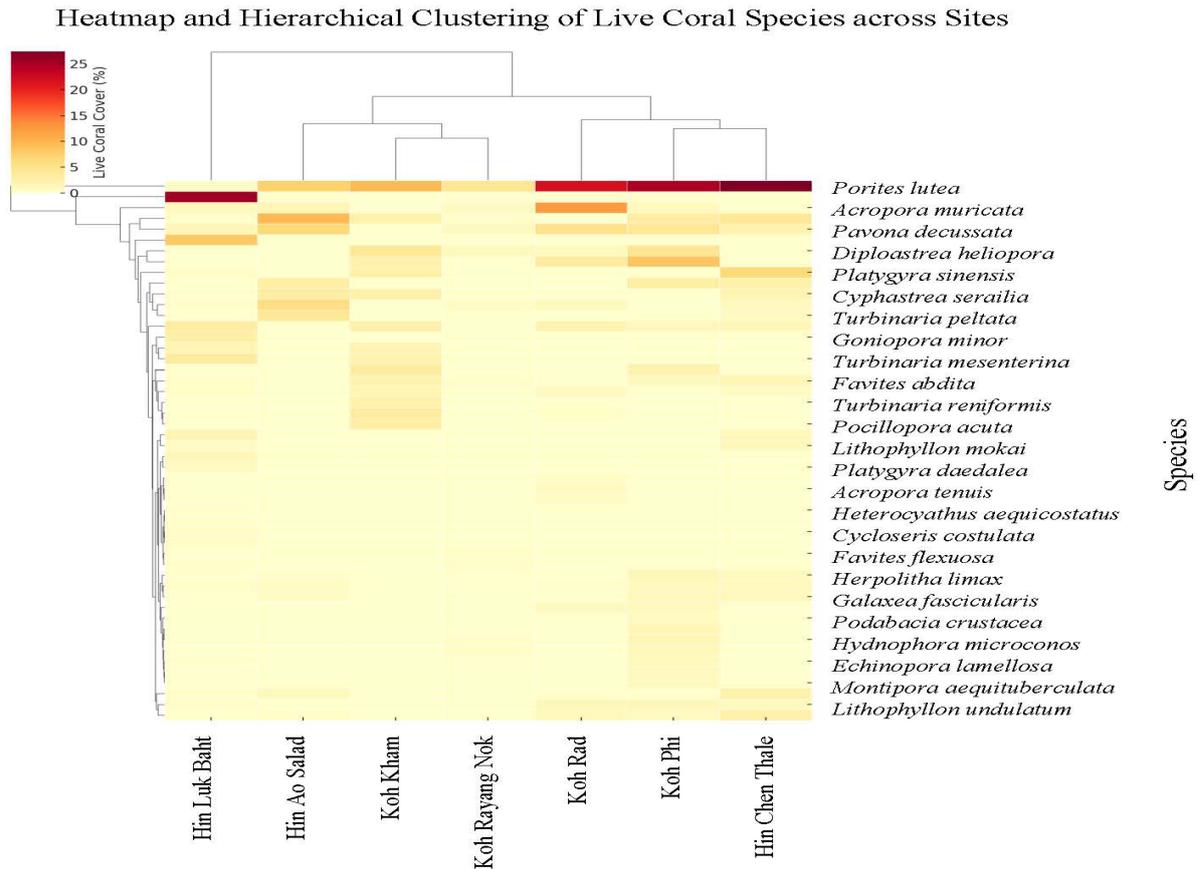|	Study site	Shannon index (H′)	Evenness index (J′)
Koh Chang	Hin Luk Baht	2.1869	0.6563
Koh Mak	Koh Kham	2.5942	0.9580
	Koh Rayang Nok	1.8532	0.7728
	Koh Phi	2.5136	0.8017
	Hin Chen Thale	2.2184	0.7534
Koh Kut	Koh Rad	1.9860	0.7163
	Hin Ao Salad	2.1995	0.8575

Figure 5. Heatmap showing live coral cover (%) across coral species and study sites in Trat Province, Thailand. Hierarchical clustering was performed using Euclidean distance and Ward's minimum variance method to illustrate similarities in coral community composition among sites.

3.2 Macrobenthic invertebrates

The survey of macrobenthic invertebrates across the study sites revealed clear differences in density among locations (Figure 6). The highest overall density was recorded at Hin Luk Baht (6.96 ind./m²), dominated by *Junceella* sp. (4.18 ind./m²) and *Melithaea* sp. (1.53 ind./m²), highlighting the ecological importance of these species at this site. In contrast, Koh Rayang Nok (0.45 ind./m²) exhibited the lowest density, with only a few species present in low numbers, including *Diadema setosum* and *Lamarcka ventricosa*.

Moderate densities were observed at Hin Chen Thale (3.29 ind./m²) and Koh Rad (3.19 ind./m²), where *Diadema setosum* (1.04 and 2.51 ind./m², respectively) and *Lamarcka ventricosa* were particularly abundant. Koh Phi (1.07 ind./m²) and Hin Ao Salad (1.85 ind./m²) showed relatively low to moderate densities, with scattered occurrences of species such as *Lamarcka*

ventricosa, *Diadema setosum*, and *Bequina semiorbiculata*. Koh Kham (2.96 ind./m²) also exhibited moderate density, characterized by the presence of *Diadema setosum* (1.41 ind./m²) and Bequina semiorbiculata.

A number of species, including *Phyllidia elegans*, *Tridacna squamosa*, and *Atrina vexillum*, were distributed across multiple sites but at relatively low densities (<0.5 ind./m²). These spatial differences in species composition and density reflect the heterogeneity of environmental conditions and reef structures across sites. While some species, such as *Junceella* sp. and *Diadema setosum*, showed localized dominance, others demonstrated broader adaptability but at low abundance. Overall, these findings emphasize the importance of surveying macrobenthic invertebrates in terms of both diversity and density to better understand the ecological dynamics of coral reef ecosystems in Trat Province.

The diversity and evenness of macrobenthic invertebrate communities also varied across the seven survey sites (Table 2). Koh Phi exhibited the highest species diversity with a Shannon–Wiener index (H′ = 1.7047) and relatively high evenness (J′ = 0.7759), indicating a diverse and well-balanced assemblage. Hin Chen Thale also showed high diversity (H′ = 1.6501) with the highest evenness value (J′ = 0.8480), suggesting a stable community structure. Koh Kham displayed moderate to high diversity (H′ = 1.4918) and high evenness (J′ = 0.7666), while Hin Ao Salad had lower diversity (H′ = 1.2134) but still maintained relatively high evenness (J′ = 0.7539). In contrast, Koh Rad exhibited the lowest species diversity (H′ = 0.8027) and the lowest evenness (J′ = 0.4987), reflecting a depauperate community dominated by a few taxa. Hin Luk Baht (H′ = 1.2812, J′ = 0.5343) also showed low values, indicating reduced diversity and uneven species distribution. Koh Rayang Nok presented intermediate values (H′ = 1.2173, J′ = 0.6794), suggesting limited species richness but a moderately balanced distribution of individuals among species.
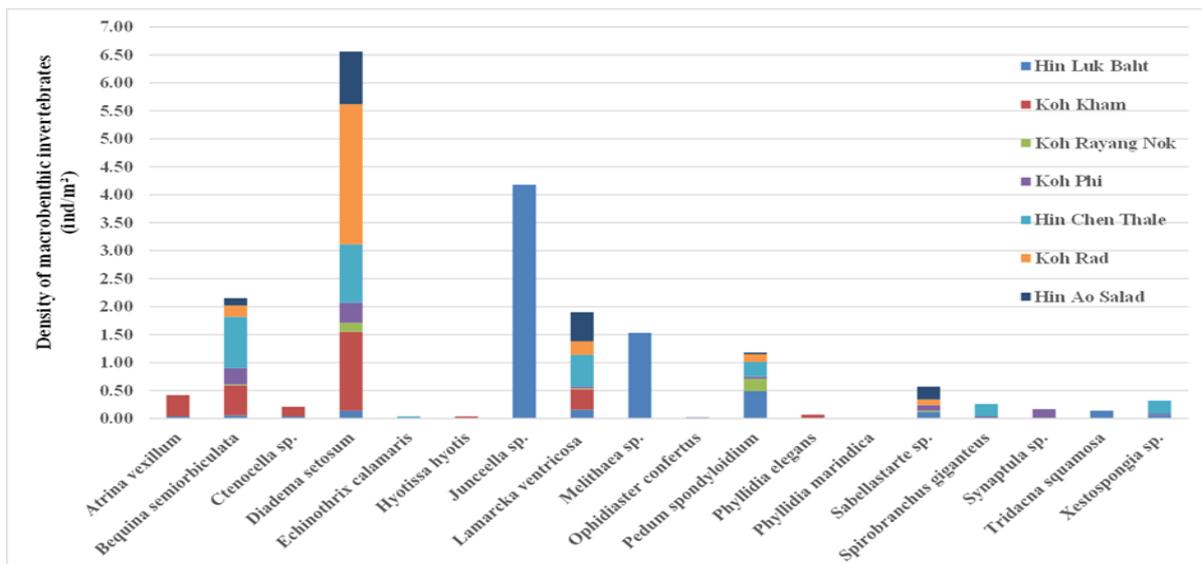

Figure 6. Density of macrobenthic invertebrates at the study sites.

Table 2. Shannon diversity index (H′) and Pielou's evenness index (J′) of corals at study sites in Trat Province, Thailand.

	Study site	Shannon index (H′)	Evenness index (J′)
Koh Chang	Hin Luk Baht	1.2812	0.5343
Koh Mak	Koh Kham	1.4918	0.7666
	Koh Rayang Nok	1.2173	0.6794
	Koh Phi	1.7047	0.7759
	Hin Chen Thale	1.6501	0.8480
Koh Kut	Koh Rad	0.8027	0.4987
	Hin Ao Salad	1.2134	0.7539

The results of the heatmap analysis and hierarchical clustering of macrobenthic invertebrates revealed clear differences in both species composition and density among survey sites (Figure 7). Hin Luk Baht exhibited the highest density of macrobenthic invertebrates (6.96 ind./m²), particularly *Junceella* sp. and *Diadema setosum*, which were more abundant than at other sites. Consequently, Hin Luk Baht was distinctly separated into its cluster compared to the other areas. In contrast, Koh Rad and Hin Chen Thale showed similar species compositions, with comparatively high densities of *Diadema setosum*, *Lamarcka ventricosa*, and *Bequina semiorbiculata*. Koh Rayang Nok, Koh Phi, and Hin Ao Salad displayed moderate densities of several species with overlapping distributions, resulting in these sites being grouped together. On the other hand, Koh Kham had the lowest overall density (1.85 ind./m²) compared to all other sites, with most values close to zero, reflecting potential habitat degradation or unsuitable reef structures.
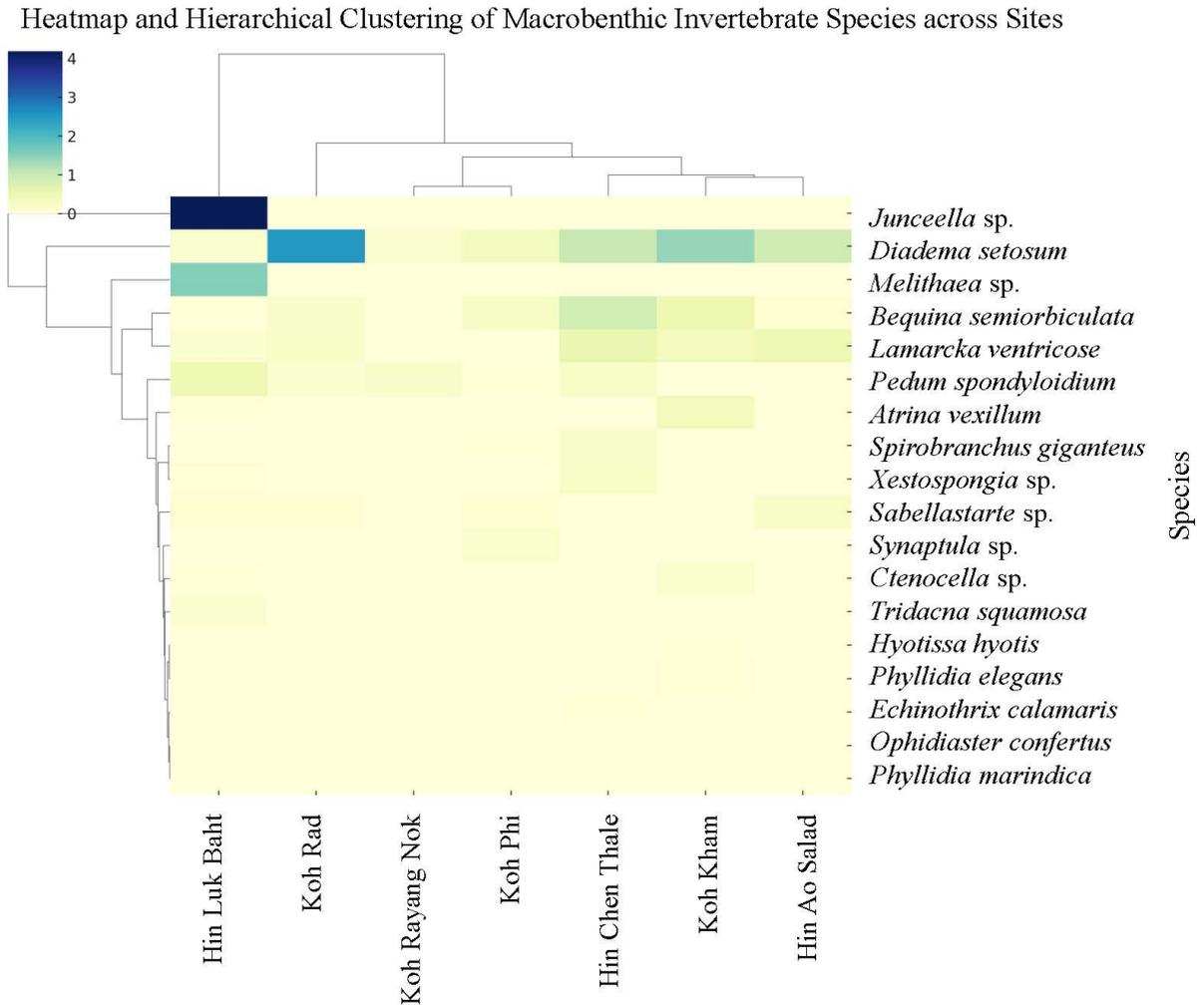
Figure 7. Heatmap showing density of macrobenthic invertebrates across the study sites in Trat Province, Thailand. Hierarchical clustering was performed using Euclidean distance and Ward's minimum variance method to illustrate similarities and differences in species composition and density among sites.

3.3 Reef fish

The survey of total reef fish density across the study sites (Figure 8) revealed statistically significant differences ($p < 0.05$, one-way ANOVA, Tukey's HSD). The highest mean fish densities were recorded at Hin Ao Salad (1,745.10 ind./100 m²) and Koh Rad (1,685.71 ind./100 m²) in the Koh Kood group, as well as at Hin Luk Baht (1,611.22 ind./100 m²) in the Koh Chang group. These sites were significantly different from all others and supported the most abundant fish assemblages. Moderate densities were observed at Hin Chen Thale (849.80 ind./100 m²) and Koh Phi (818.37 ind./100 m²) in the Koh Mak group. In contrast, Koh Kham (611.22 ind./100 m²) and Koh Rayang Nok (530.61 ind./100 m²) exhibited the lowest densities, which were significantly different from the other sites. These findings highlight spatial variability in reef fish abundance across the Koh Chang, Koh Mak, and Koh Kood groups, with the Koh Kood group, in particular, supporting more favorable conditions for sustaining reef fish communities compared to the Koh Mak group.

The Shannon diversity index (H′) and Pielou's evenness index (J′) of reef fishes also varied considerably among the seven survey sites in Trat Province, Thailand (Table 3). The highest species diversity was observed at Koh Kham (H′ = 1.961), which also recorded the highest evenness value (J′ = 0.561), indicating a well-balanced and diverse fish community despite its relatively low density. Hin Ao Salad also

exhibited relatively high diversity (H′ = 1.574) and evenness (J′ = 0.443), suggesting favorable habitat conditions that support a wide range of reef fishes. Moderate levels of diversity were recorded at Koh Phi (H′ = 1.156, J′ = 0.347) and Koh Rad (H′ = 1.140, J′ = 0.374), where the community structure was less evenly distributed and more influenced by dominant species. In contrast, the lowest diversity and evenness values were found at Hin Luk Baht (H′ = 0.896, J′ = 0.264), Koh Rayang Nok (H′ = 0.795, J′ = 0.310), and Hin Chen Thale (H′ = 0.776, J′ = 0.280). These results suggest that fish assemblages in these areas were characterized by low species richness and strong dominance by a few taxa. The results of the heatmap analysis and hierarchical clustering of reef fish species across the survey sites revealed distinct differences in both species composition and abundance (Figure 9). Koh Rad,

Hin Luk Baht, and Hin Ao Salad exhibited the highest densities of reef fishes (ind./100 m²), particularly species such as *Neopomacentrus anabatoides*, *Chromis flavipectoralis*, and *Scolopsis margaritifer*, which were more prominent at these sites compared to others. This resulted in these locations forming separate clusters, indicating distinct community structures. In contrast, Koh Phi and Hin Chen Thale showed moderate levels of fish density with overlapping species distributions, including *Pomacentrus pavo*, *Chaetodon octofasciatus*, and *Siganus guttatus*, leading to their clustering together. Meanwhile, Koh Kham and Koh Rayang Nok exhibited the lowest overall fish densities (ind./100 m²), with many species nearly absent, causing them to be grouped into a separate cluster and reflecting potentially less favorable habitat conditions.
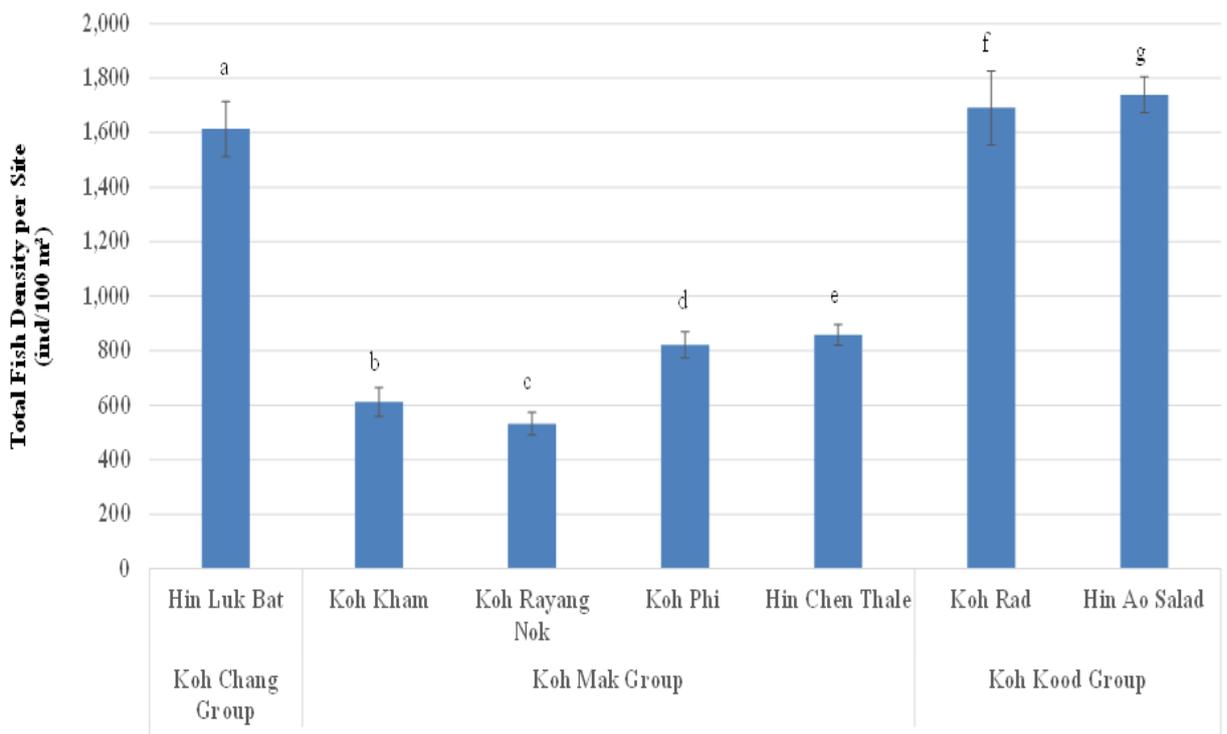

Figure 8. Total fish density at the study sites in Trat Province, Thailand. Error bars represent the standard error of the mean. Different letters above the bars indicate statistical differences among sites (one-way ANOVA, p < 0.05), as determined by Tukey's HSD.

Table 3. Shannon diversity index (H′) and Pielou's evenness index (J′) of reef fishes at study sites in Trat Province, Thailand.

	Study site	Shannon index (H′)	Evenness index (J′)
Koh Chang	Hin Luk Baht	0.896	0.264
Koh Mak	Koh Kham	1.961	0.561
	Koh Rayang Nok	0.795	0.310
	Koh Phi	1.156	0.347
	Hin Chen Thale	0.776	0.280
Koh Kut	Koh Rad	1.140	0.374
	Hin Ao Salad	1.574	0.443

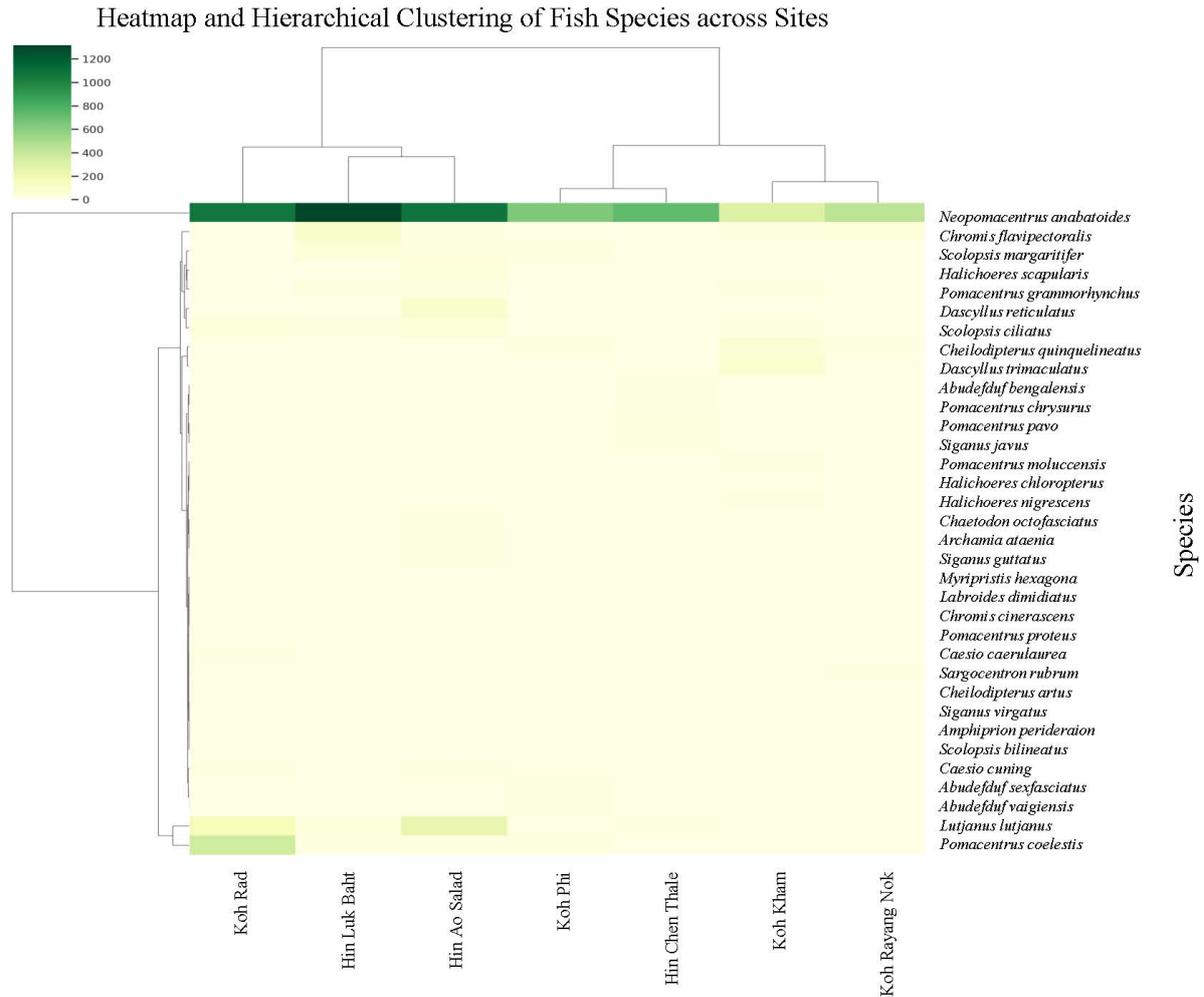Heatmap and Hierarchical Clustering of Fish Species across Sites

Figure 9. Heatmap showing the density of reef fish species (ind./100 m²) across the seven survey sites in Trat Province, Thailand. Hierarchical clustering was performed using Euclidean distance and Ward's minimum variance method to illustrate similarities and differences in species composition and abundance among sites.

4. Discussion

The findings of this study demonstrate that coral reef ecosystems in Trat Province exhibit substantial spatial variability in coral cover, macrobenthic invertebrate density, and reef fish assemblages. Such heterogeneity reflects both natural environmental variability and anthropogenic pressures, and aligns with broader regional and global patterns of reef change. Previous national assessments in Thailand have similarly reported declining coral cover in some locations and resilience in others (Phongsuwan et al., 2013; Yeemin et al., 2013; Sutthacheep et al., 2019), while global syntheses emphasize the accelerating risks facing coral reefs worldwide (Burke et al., 2011; Hoegh-Guldberg et al., 2018; Hughes et al., 2017).

The survey of coral reef cover showed clear differences among sites, with Koh Phi, Hin Chen Thale, and Hin Luk Baht maintaining relatively high levels of live coral cover, while Koh Rayang Nok exhibited severely degraded conditions. These findings are consistent with studies documenting localized stress from sedimentation, thermal stress, and coastal development in the Gulf of Thailand (Pengsakun et al., 2019; Tanaka et al., 2013), as well as comparative research showing that disturbance history strongly shapes reef community trajectories (Graham et al., 2014; Gouezo et al., 2019). The use of diversity indices (H′ and J′) highlighted the balance and dominance of coral taxa, echoing previous work that linked community evenness to ecosystem stability and recovery potential (McLeod et al., 2019; Schoepf et al., 2023).

The density of macrobenthic invertebrates also varied significantly across sites, with Hin Luk Baht showing dominance of *Junceella* sp. and *Diadema setosum*, while Koh Rayang Nok had very low densities overall. These spatial patterns indicate that certain taxa play disproportionately important ecological roles, particularly herbivory and bioerosion by sea urchins (Aunkhongthong et al., 2020; Pengsakun et al., 2020; Glynn & Enochs, 2010). Comparable results have been reported in Bangladesh, Egypt, and the Philippines, where benthic invertebrate assemblages shift dramatically under degraded conditions or environmental stress (Abdel-Gawad & Mola, 2014; Asadujjaman et al., 2012; Quimpo et al., 2018). Moreover, recent evidence from the Mediterranean highlights the vulnerability of *Diadema setosum* populations to mass mortality events, underscoring the importance of continuous monitoring (Zirler et al., 2023).

Reef fish densities were highest at Hin Ao Salad, Koh Rad, and Hin Luk Baht, suggesting that these sites provide more suitable habitat conditions. In contrast, Koh Kham and Koh Rayang Nok exhibited lower densities, though Koh Kham maintained high species diversity despite low abundance. Such findings mirror regional studies that emphasize the role of coral habitat quality and structural complexity in shaping reef fish communities (Nugraha et al., 2020; Mattos et al., 2023). Comparative research on submerged pinnacles has shown that fish assemblages at these habitats can be distinct from those at shallow emergent reefs, reinforcing the ecological significance of underwater pinnacles in biodiversity conservation (Galbraith et al., 2021; Yeemin & Pengsakun, 2020; Yeemin et al., 2023). Globally, functional trait studies highlight how fish diversity underpins ecosystem resilience, particularly through herbivory and trophic interactions (Hadj-Hammou et al., 2021; Schiettekatte et al., 2022).

The main strength of this study is the use of citizen science data obtained from surveys of seven coral reef sites in Trat Province. Citizen science has been increasingly recognized as an effective approach to extend spatial and temporal monitoring, enhance public engagement, and support adaptive management of marine ecosystems (Kelly et al., 2020; McKinley et al., 2017).

Peer-reviewed studies indicate that trained volunteers can detect long-term changes on coral reefs comparable to professional programs, and that Reef Check's point-intercept survey protocols achieve high inherent accuracy (approximately ±7% absolute error for 1–50% cover), underscoring the reliability of community-generated data (Forrester et al., 2015; Done et al., 2017). Furthermore, networks such as Reef Life Survey have demonstrated that standardized volunteer methods, coupled with appropriate statistical treatment of error and bias, can generate biodiversity datasets of significant value for management at global scales (Bird et al., 2014; Edgar et al., 2014). Importantly, management agencies have already integrated citizen contributions into decision-making processes. For example, the Great Barrier Reef Marine Park Authority's Eye on the Reef program uses public submissions alongside other monitoring streams to assess reef condition and inform management actions (GBRMPA, n.d.). Beyond cost-effectiveness, the implementation of best-practice QA/QC protocols and workflow design ensures that data are fit-for-purpose (Kosmala et al., 2016), while also fostering stewardship and community participation. These characteristics align with resilience-based management (RBM), in which managers prioritize actions that enhance resistance, recovery, and adaptation; citizen-generated indicators and local knowledge can improve resilience assessments and implementation pathways (McLeod et al., 2019; McLeod et al., 2021).

Social evaluations also support these advantages. For instance, the Rescue a Reef (RAR) program in Florida found that volunteers not only contributed reliable ecological data but also retained higher levels of knowledge about reef ecology, threats, and conservation tools compared with control groups, even years after participation. Moreover, more than 70% of participants reported positive changes in perceptions, and over 60% reported behavioral shifts, such as advocacy, environmentally friendly lifestyle choices, and participation in volunteer or support activities (Hesley et al., 2023). These findings highlight that citizen science does not merely generate data but also serves as a crucial mechanism for fostering social learning, raising awareness, and promoting long-term community engagement.

5. Conclusion

Overall, these results reinforce the necessity of targeted conservation and adaptive management in Trat Province, guided by both ecological evidence and stakeholder participation. Ensuring the persistence of coral reef ecosystems will require coordinated strategies addressing reef resilience, benthic invertebrate roles, fish community integrity, and community-based monitoring, consistent with regional and global calls for securing the future of coral reefs in the Anthropocene (Hughes et al., 2017; Hoegh-Guldberg et al., 2018; Pengsakun et al., 2022; Sutthacheep et al., 2022).

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References

Abdel-Gawad SS, Mola HR (2014) Macrobenthic invertebrates in the main channel of Lake Nasser, Egypt. *Egyptian Journal of Aquatic Research* 40(4): 405–414.

Asadujjaman M, Hossain MB, Shamsuddin M, Amin MA, Azam AKM (2012) Occurrence and abundance of macrobenthos of Hatiya and Nijhum Dweep Islands, Bangladesh. *Middle-East Journal of Scientific Research* 11(2): 184–188.

Aunkhongthong W, Phoaduang S, Wongnutpranont A, Sutthacheep M, Sangmanee K, Yeemin T (2020) Population densities of a sea urchin *Diadema setosum* on shallow reef flats in the Gulf of Thailand. *Ramkhamhaeng International Journal of Science and Technology* 3(3): 13–20.

Bauer-Civiello A, Loder J, Hamann M (2018) Using citizen science data to assess the difference in marine debris loads on reefs in Queensland, Australia. *Marine Pollution Bulletin* 135: 458–465.

Bird TJ, Bates AE, Lefcheck JS, Hill NA, Thomson RJ, Edgar GJ, Stuart-Smith RD (2014) Statistical solutions for error and bias in global citizen science datasets. *Biological Conservation* 173: 144–154. https://doi.org/10.1016/j.biocon.2013.07.037

Bonney R, Shirk JL, Phillips TB, Wiggins A, Ballard HL, Miller-Rushing AJ, Parrish JK (2014) Next steps for citizen science. *Science* 343(6178): 1436–1437.

Branchini S, Meschini M, Covi C, Piccinetti C, Zaccanti F, Goffredo S (2015) Participating in a citizen science monitoring program: implications for environmental education. *PLoS One* 10(7): e0131812.

Bruno JF, Selig ER (2007) Regional decline of coral cover in the Indo-Pacific: timing, extent, and subregional comparisons. *PLoS One* 2(8): e711.

Burke L, Reytar K, Spalding M, Perry A (2011) Reefs at risk revisited. World Resources Institute (WRI), Washington, DC.

Dickinson JL, Shirk J, Bonter D, Bonney R, Crain RL, Martin J, Purcell K (2012) The current state of citizen science as a tool for ecological research and public engagement. *Frontiers in Ecology and the Environment* 10(6): 291–297.

Dickinson JL, Zuckerberg B, Bonter DN (2010) Citizen science as an ecological research tool: challenges and benefits. *Annual Review of Ecology, Evolution, and Systematics* 41(1): 149–172.

Done T, Roelfsema C, Harvey A, Schuller L, Hill J, Schläppy M, Pomeroy R (2017) Reliability and utility of citizen science reef monitoring data collected by Reef Check Australia, 2002–2015. *Marine Pollution Bulletin* 117(1–2): 148–155. https://doi.org/10.1016/j.marpolbul.2017.01.054

Edgar GJ, Stuart-Smith RD, Willis TJ, Kininmonth S, Baker SC, Banks S, Thomson RJ (2014) Global conservation outcomes depend on marine protected areas with five key features. *Nature* 506(7487): 216–220. https://doi.org/10.1038/nature13022

Forrester GE, Baily P, Conetta D, Forrester LM, Kintzing E, Jarecki L (2015) Comparing monitoring data collected by volunteers and professionals shows that citizen scientists can detect long-term change on coral reefs. *Journal for Nature Conservation* 24: 1–9. https://doi.org/10.1016/j.jnc.2015.01.002

Galbraith GF, Cresswell BJ, McCormick MI, Bridge TC, Jones GP (2021) High diversity abundance and distinct fish assemblages on submerged coral reef pinnacles compared to shallow emergent reefs. *Coral Reefs* 40: 335–354.

GBRMPA (n.d.) *Eye on the Reef: Monitoring and assessment program*. Great Barrier Reef Marine Park Authority. Retrieved from https://www.gbrmpa.gov.au

Glynn PW, Enochs IC (2010) Invertebrates and their roles in coral reef ecosystems. In: *Coral reefs: an ecosystem in transition*. Springer, pp. 273–325.

Gouezo M, Golbuu Y, Fabricius K, Olsudong D, Mereb G, Nestor V, Doropoulos C (2019) Drivers of recovery and reassembly of coral reef communities. *Proceedings of the Royal Society B* 286(1897): 20182908.

Graham NA, Chong-Seng KM, Huchery C, Januchowski-Hartley FA, Nash KL (2014) Coral reef community composition in the context of disturbance history on the Great Barrier Reef, Australia. *PLoS One* 9(7): e101204.

Hadj-Hammou J, Mouillot D, Graham NA (2021) Response and effect traits of coral reef fish. *Frontiers in Marine Science* 8: 640619.

Hesley CE, Shaver EC, Lu J, Ware M, Nedimyer K, Kaufman L (2023) Citizen science benefits coral reefs and community members alike. *Frontiers in Environmental Science* 11: 1199196. https://doi.org/10.3389/fenvs.2023.1250464

Hoegh-Guldberg O, Kennedy EV, Beyer HL, McClennen C, Possingham HP (2018) Securing a long-term future for coral reefs. *Trends in Ecology & Evolution* 33(12): 936–944.

Hughes TP, Kerry JT, Álvarez-Noriega M, Álvarez-Romero JG, Anderson KD, Baird AH, Wilson SK (2017) Global warming and recurrent mass bleaching of corals. *Nature* 543(7645): 373–377.

Hughes TP, Kerry JT, Baird AH, Connolly SR, Chase TJ, Dietzel A, Woods RM (2019) Global warming impairs stock–recruitment dynamics of corals. *Nature* 568(7752): 387–390.

Jambeck JR, Johnsen K (2015) Citizen-based litter and marine debris data collection and mapping. *Computing in Science & Engineering* 17(4): 20–26.

Kelly R, Fleming A, Pecl GT, Richter A, Bonn A (2020) Citizen science and marine conservation: a global review. *Philosophical Transactions of the Royal Society B: Biological Sciences* 375(1814): 20190461. https://doi.org/10.1098/rstb.2019.0461

Kosmala M, Wiggins A, Swanson A, Simmons B (2016) Assessing data quality in citizen science. *Frontiers in Ecology and the Environment* 14(10): 551–560. https://doi.org/10.1002/fee.1436

Licuanan WY, Mordeno PZB (2021) Citizen science reveals the prevalence of the 2020 mass coral bleaching in one town. *Philippine Journal of Science* 150(3): 945–949.

Marshall NA, Park SE, Adger WN, Brown K, Howden SM (2012) Transformational capacity and the influence of place and identity. *Environmental Research Letters* 7(3): 034022.

Mattos FM, Yeemin T, Sutthacheep M, Feitosa JL (2023) Biogeographic and environmental drivers of reef fish diversity in coastal islands of the Gulf of Thailand. *Marine Ecology Progress Series* 724: 33–46.

McKinley DC, Miller-Rushing AJ, Ballard HL, Bonney R, Brown H, Cook-Patton SC, Soukup MA (2017) Citizen science can improve conservation science, natural resource management, and environmental protection. *Biological Conservation* 208: 15–28. https://doi.org/10.1016/j.biocon.2016.05.015

McLeod E, Anthony KRN, Mumby PJ, Maynard J, Beeden R, Graham NAJ, Tamelander J (2019) The future of resilience-based management in coral reef ecosystems. *Journal of Environmental Management* 233: 291–301. https://doi.org/10.1016/j.jenvman.2018.11.034

McLeod E, Shaver EC, Beger M, Koss J, Grimsditch G (2021) Using resilience assessments to inform the management and conservation of coral reef ecosystems. *Journal of Environmental Management* 277: 111384. https://doi.org/10.1016/j.jenvman.2020.111384

Nugraha WA, Mubarak F, Husaini E, Evendi H (2020) The correlation of coral reef cover and rugosity with coral reef fish density in East Java Waters. *Jurnal Ilmiah Perikanan dan Kelautan* 12(1): 131–139.

Pearce-Kelly P, Altieri AH, Bruno JF, Cornwall CE, McField M, Muñiz-Castillo AI, Yesson C (2025) Considerations for determining warm-water coral reef tipping points. *Earth System Dynamics* 16(1): 275–292.

Pengsakun S, Hamanee S, Saengthongsuk O, Avirutha A, Rakklin P, Klinthong W, Sutthacheep M (2022) High resilience of coral communities at Hin Ang Wang, Surat Thani Province and a proposed management strategy.

Pengsakun S, Klomjit A, Sutthacheep M, Yeemin T, Chamchoy C, Phantewee W (2020) Impacts of natural disturbances on the population dynamics of the sea urchin *Diadema setosum* at Khang Khao Island, the Upper Gulf of Thailand. *Ramkhamhaeng International Journal of Science and Technology* 3(2): 44–49.

Pengsakun S, Yeemin T, Sutthacheep M, Samsuvan W, Klinthong W, Chamchoy C (2019) Monitoring of coral communities in the inner Gulf of Thailand influenced by the elevated seawater temperature and flooding. *Acta Oceanologica Sinica* 38: 102–111.

Phongsuwan N, Chankong A, Yamarunpatthana C, Chansang H, Boonprakob R, Petchkumnerd P, Bundit OA (2013) Status and changing patterns on coral reefs in Thailand during the last two decades. *Deep Sea Research Part II* 96: 19–24.

Pocock MJ, Tweddle JC, Savage J, Robinson LD, Roy HE (2017) The diversity and evolution of ecological and environmental citizen science. *PLoS One* 12(4): e0172579.

Quimpo TJR, Cabaitan PC, Olavides RD, Dumalagan Jr EE, Munar J, Siringan FP (2018) Preliminary observations of macrobenthic invertebrates and megafauna communities in the upper mesophotic coral ecosystems in Apo Reef Natural Park, Philippines. *Raffles Bulletin of Zoology* 66: 1–12.

Schiettekatte NM, Brandl SJ, Casey JM, Graham NA, Barneche DR, Burkepile DE, Parravicini V (2022) Biological trade-offs underpin coral reef ecosystem functioning. *Nature Ecology & Evolution* 6(6): 701–708.

Schoepf V, Baumann JH, Barshis DJ, Browne NK, Camp EF, Comeau S, Sommer B (2023) Corals at the edge of environmental limits: a new conceptual framework to re-define marginal and extreme coral communities. *Science of the Total Environment* 884: 163688.

Siebeck UE, Marshall NJ, Klüter A, Hoegh-Guldberg O (2006) Monitoring coral bleaching using a colour reference card. *Coral Reefs* 25(3): 453–460.

Sully S, Hodgson G, van Woesik R (2022) Present and future bright and dark spots for coral reefs through climate change. *Global Change Biology* 28(15): 4509–4522.

Sutthacheep M, Chamchoy C, Pengsakun S, Klinthong W, Yeemin T (2019) Assessing the resilience potential of inshore and offshore coral communities in the Western Gulf of Thailand. *Journal of Marine Science and Engineering* 7(11): 408.

Sutthacheep M, Saenghaisuk C, Pengsakun S, Donsomjit W, Yeemin T (2013) Quantitative studies on the 2010 mass coral bleaching event in Thai waters. *Galaxea, Journal of Coral Reef Studies* 15(Supplement): 379–390.

Sutthacheep M, Yeemin T, Aliño PM (2022) Reef ecology in the Western Pacific for adaptation to global change. In: *Coral Reefs of the Western Pacific Ocean in a Changing Anthropocene*. Springer, Cham, pp. 55–98.

Tanaka K, Ohde S, Cohen MD, Snidvongs A, Ganmanee M, McLeod CW (2013) Metal contents of *Porites* corals from Khang Khao Island, Gulf of Thailand: Anthropogenic input of river runoff into a coral reef from urbanized areas, Bangkok. *Applied Geochemistry* 37: 79–86.

Whomersley P, Bell J, Clingham E, Collins MA, Feary DA, Stockill J, Bamford K (2022) Working towards a blue future: promoting sustainability, environmental protection and marine management: examples from the UK Government Blue Belt Programme and current international initiatives. *Frontiers in Marine Science* 9: 861632.

Yeemin T, Mantachitra V, Plathong S, Nuclear P, Klinthong W, Sutthacheep M (2012) Impacts of coral bleaching, recovery and management in Thailand. In: *Proceedings of the 12th International Coral Reef Symposium*, Cairns, Australia, pp. 9–13.

Yeemin T, Pengsakun S, Rangseethampanya P, Yossundara N, Yossundara S, Sutthacheep M (2021) A new method for citizen science to monitor coral reefs in Thai waters. *Ramkhamhaeng International Journal of Science and Technology* 4(3): 11–20.

Yeemin T, Pengsakun S, Yucharoen M, Klinthong W, Sangmanee K, Sutthacheep M (2013) Long-term changes in coral communities under stress from sediment. *Deep Sea Research Part II* 96: 32–40.

Yeemin T, Pengsakun SP (2020) First quantitative ecological study of the Hin Pae pinnacle, Mu Ko Chumphon, Thailand. *Ramkhamhaeng International Journal of Science and Technology* 3(3): 37–45.

Yeemin T, Sutthacheep M, Aunkhongthong W, Chamchoy C, Jungrak L, Chaithanavisut N, et al. (2024) Community structure of underwater pinnacles in Mu Ko Si Chang, the Upper Gulf of Thailand. *Ramkhamhaeng International Journal of Science and Technology* 7(2): 15–35.

Yeemin T, Sutthacheep M, Pengsakun S, Klinthong W, Aunkhongthong W, Limpichat J, Jowantha M (2023) Diversity of scleractinian corals, microbenthic invertebrates and reef fish on underwater pinnacles in Surat Thani Province, Thailand. *Ramkhamhaeng International Journal of Science and Technology* 6(2): 71–85.

Yeemin T, Sutthacheep M, Pettongma R (2006) Coral reef restoration projects in Thailand. *Ocean & Coastal Management* 49(9–10): 562–575.

Zirler R, Schmidt LM, Roth L, Corsini-Foka M, Kalaentzis K, Kondylatos G, Bronstein O (2023) Mass mortality of the invasive alien echinoid *Diadema setosum* (Echinoidea: Diadematidae) in the Mediterranean Sea. *Royal Society Open Science* 10(5): 230251.