






# Distribution of EDGE Coral Species and Community Perceptions of Reef Conservation in Semporna, Sabah, Malaysia

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## Abstract

The Semporna Priority Conservation Area (PCA) in Sabah, Malaysia, is a Coral Triangle biodiversity hotspot increasingly threatened by destructive fishing, coastal development, and climate change. To address these challenges, this study assessed the distribution of Evolutionarily Distinct and Globally Endangered (EDGE) corals across ten islands alongside community conservation attitudes. Underwater surveys recorded six EDGE species, with *Heliofungia actiniformis* being the most abundant (n = 123 colonies), especially at Sebangkat, Larapan, and Sibuan. Conversely, *Nemenezophyllia turbida* and *Lithophyllon ranjithi* were entirely absent. Overall, EDGE corals were largely concentrated in the central PCA, an ecologically vital but heavily impacted zone. Concurrently, household surveys (n = 47) across four islands revealed significant variations in environmental awareness (p = 0.003), with Larapan scoring the lowest. While awareness of fish bombing was uniform across the sites, Bum Bum residents demonstrated a significantly higher willingness to combat the practice (p = 0.041). Synthesizing these results identifies Larapan as the most critical site for species-specific conservation, whereas Selakan and Bum Bum present strong opportunities for community-led engagement. These findings highlight the critical need to integrate ecological data with local social perceptions to prioritize conservation effectively. Establishing Locally Managed Marine Areas (LMMAs) in Semporna is recommended to safeguard threatened corals and empower local stewardship, directly contributing to Malaysia's biodiversity goals, the Global Biodiversity Framework's 30×30 target, and the Coral Triangle Initiative.

**Keywords:** Evolutionarily Distinct and Globally Endangered corals, community managed area, Coral Triangle, community awareness, coral reef conservation

## Introduction

Coral reefs are among the most diverse and productive ecosystems on Earth. They provide goods and services to humans, including fishery resources, coastal protection, recreational opportunities, cultural benefits, and potential medical applications (Good & Bahr, 2021). However, reefs are increasingly threatened by local pressures such as overfishing and sedimentation (Andrello et al., 2022; Burke et al., 2012; Hughes et al., 2007), destructive fishing (Pet-Soede, 1998), coastal development and live coral harvesting (Bruckner, 2000; Wabnitz et al., 2003). On a global scale, climate change threatens reef health by intensifying coral bleaching and disease events (Hughes et al., 2004). Collectively, these stressors are driving reefs into degraded states (Bellwood et al., 2004; Hughes et al., 2007; Bruno et al., 2009), reducing coral species richness and associated fauna such as fish, echinoderms, and crustaceans. Consequently, conservation of tropical reef systems is a global priority (Roberts et al., 2002). To set priorities and guide conservation responses to these escalating threats, global assessment tools such as the IUCN Red List and the Evolutionarily Distinct and Globally Endangered (EDGE) framework have become essential.

The IUCN Red List of Threatened Species remains the global standard for assessing species extinction risk and setting conservation priorities (Rodrigues et al., 2006). However, its reliance on threat-based criteria does not account for evolutionary distinctiveness (Possingham et al., 2002; Redding & Mooers, 2006). To address this, the Evolutionarily Distinct and Globally Endangered (EDGE) framework integrates extinction risk with evolutionary uniqueness to identify species of high conservation importance (Isaac et al., 2007). Among reef-building corals (Scleractinia), one-third of species were previously assessed as threatened (Carpenter et al., 2008) but the most recent global reassessment by the IUCN, announced at COP29 in Baku, Azerbaijan (November 2024) indicates that 44% are now at risk of extinction (IUCN, 2024). EDGE analyses further highlight coral lineages facing the highest risk (Huang, 2012; Curnick et al., 2015). However, translating these global priorities into effective local conservation remains a challenge. Fine-scale mapping of EDGE coral species is still scarce, particularly in Southeast Asia, limiting the ability to align global assessments with site-specific management.

Malaysia harbours some of the most biodiverse coral reefs in the world, concentrated in Sabah within the Sulu-Sulawesi Marine Ecoregion (SSME) and the Coral Triangle (Veron, 2009; WWF-SSME, 2004). The Semporna Priority Conservation Area (PCA) is a globally significant hotspot, hosting diverse reef types and exceptional species richness, including several EDGE coral taxa (Waheed & Hoeksema, 2013; Choo et al., 2021). The reefs generate an estimated RM 185 million in gross annual value (Yeo, 2011). Yet they are under intense anthropogenic

pressure (Choo et al., 2025). Destructive fishing practices such as blast and cyanide fishing threaten 85% of reefs nationally (Burke et al., 2012), while land-based pollution, sedimentation, overharvesting, and rapid tourism growth have reduced coral cover and reef resilience (Ho & Kassem, 2009; Choo & Sumampouw, 2014). Mean live coral cover in Semporna declined from 35.7% in 2008 to 30.4% in 2013, with low abundances of commercially valuable reef fish and invertebrates (Ho & Kassem, 2009; Choo & Sumampouw, 2014). In addition, the distribution and status of EDGE coral species remain poorly documented. These findings underscore the urgency of targeted conservation measures in this region.

Marine Protected Areas (MPAs) remain the most widely applied conservation tool, offering ecological benefits such as safeguarding threatened species, protecting habitats, reducing overfishing and enhancing fisheries through spillover effects (Ban et al., 2011; Zupan et al., 2018). Large-scale protection is ideal, but full protection of all areas is unrealistic where millions of people rely directly on marine resources for subsistence and livelihoods (Foale et al., 2013). Complementary approaches such as Other Effective Area-Based Conservation Measures (OECMs) and Locally Managed Marine Areas (LMMAs) are increasingly recognised for their emphasis on local governance, cultural values, and socio-economic needs, often achieving higher compliance and cost-effectiveness (Govan et al., 2008; 2009; Jupiter et al., 2014; Estradivari et al., 2022). While similar to MPAs, LMMAs typically operate on a smaller spatial and temporal scale (Mills et al., 2010). Although the small size of LMMAs has raised concerns about effectiveness, particularly for critical habitats such as grouper spawning areas (Waldie et al., 2016), networks of LMMAs have demonstrated fisheries benefits (Rocliffe et al., 2014) as well as social and economic benefits (Syakur et al., 2012).

The longevity of conservation efforts depends strongly on local community support. Their perceptions of ecological effectiveness, social impacts, and good governance are positively correlated with their support for conservation (Bennett et al., 2019). However, local perceptions of ecological conditions may be inaccurate, depending on their level of awareness and knowledge (Christie, 2005). For instance, in the Philippines, communities perceived higher fish abundance inside and outside MPAs, while fish censuses showed only moderate improvements in quantity, size, and diversity (Yasué et al., 2010). Understanding community willingness to engage in conservation is therefore crucial for the success of MPAs and LMMAs (Jupiter et al., 2014).

The study aims to 1) investigate the distribution and abundance of EDGE coral species, 2) evaluate knowledge levels among nearby island populations, and 3) identify islands that should be prioritised for future LMMA establishment in the Semporna PCA. Such locally governed measures could contribute to a wider network of LMMAs in Sabah.

## Materials and Methods

### *Study Site*

The Semporna PCA is located in Malaysia, northeast of Borneo Island, spanning 7,680 km<sup>2</sup>. The seascape encompasses diverse coral reef geomorphology (Kassem et al., 2011), including a barrier reef, fringing reefs, patch reefs, a pre-atoll, and an oceanic seamount (Sipadan Island). Semporna PCA harbours the highest concentration of coral reefs in Malaysia (Choo et al., 2021) and is recognised for its high biodiversity, with mushroom corals used as a proxy (Waheed & Hoeksema, 2013).

State jurisdiction covers Sabah's territorial waters (3 nautical miles), including the reefs of Semporna PCA. The Department of Fisheries Sabah regulates extraction, harvest, and export licences of corals (Section 43), while the Land Ordinance Sabah also governs coral extraction (Sections 23 and 23A). Two state parks exist within the Semporna PCA: Tun Sakaran Marine Park (340 km<sup>2</sup>) and Sipadan Island Park (168 km<sup>2</sup>), both managed under the Park Ordinance.

### *Target Species*

The Zoological Society of London (ZSL) developed the EDGE corals list of threatened scleractinian species (Curnick et al., 2015). Based on the Semporna Marine Ecological Expedition in 2010, which focused on three coral families (see Kassem et al., 2012; Waheed & Hoeksema, 2013), six EDGE coral species have been reported in Semporna's waters (Table 1): *Heliofungia actiniformis*, *Lithophyllon ranjithi*, *Nemenezophyllia turbida*, *Physogyra lichtensteini*, *Catalaphyllia jardinei* and *Pachyseris rugosa*.

### *Underwater Surveys*

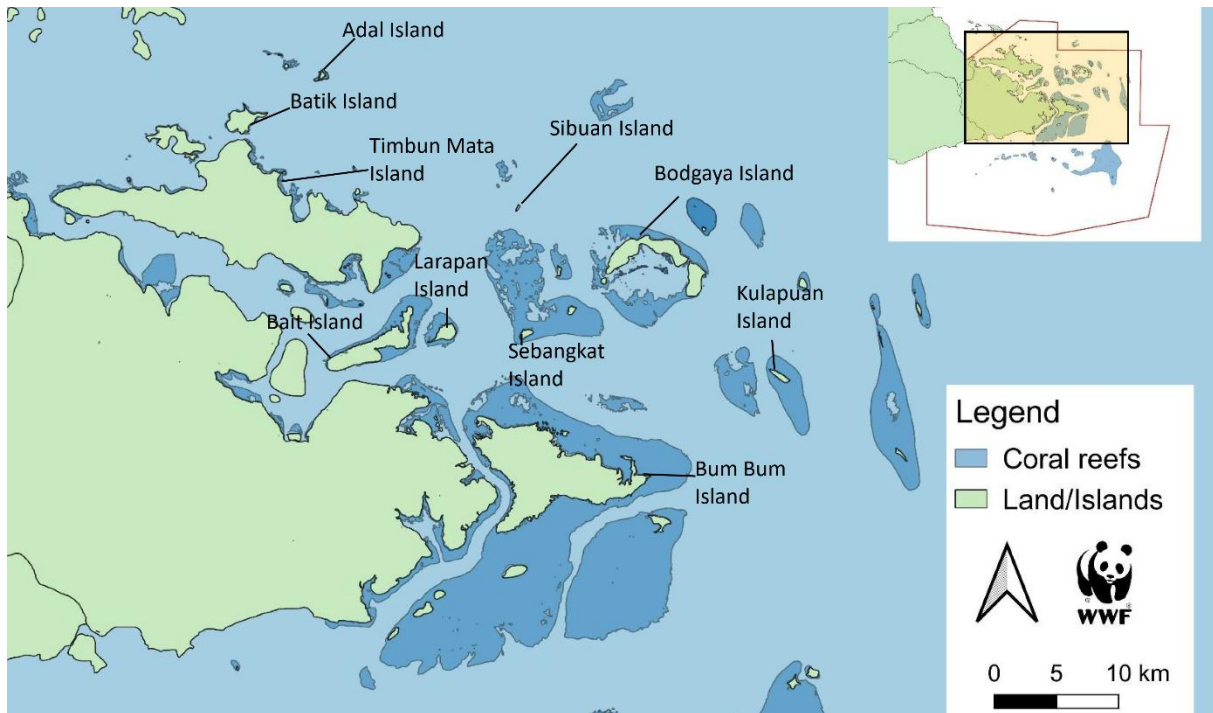
Field surveys were conducted in April–May and June–July 2017 at sites where threatened coral species were previously reported in the SMEE report (Kassem et al., 2012). Prior to data collection, dive operators received two training dives and assigned specific supporting roles, including laying transect lines with bearings provided, acting as safety divers, and deploying surface buoys. Ecological data were collected by trained biologists using non-destructive techniques. Belt transects (50 m x 1 m) were laid to assess the abundance and distribution of target corals (Hoeksema & Borel-Best, 1984). Transects were conducted at three depths, 6, 9 and 12 m (lagoon, crest, and outer slope) where possible, up to three sites per island, with sites separated by at least 500 m. Surveys covered 10 islands: Adal, Batik, Timbun Mata, Larapan, Sebangkat, Kulapuan, Sibuan, Bodgaya, Bait, and Bum Bum (Figure 1).

**Table 1.** IUCN categories and EDGE scores of coral species identified in Semporna (summarised from previous studies) with notes on coral population and habitat from IUCN (2025).

Family	Species	Previous records and distribution in Malaysia	IUCN Category	EDGE Score	Notes
Fungiidae	<i>Heliofungia actiniformis</i> Quoy and Gaimard, 1833	Wood & Tan (1987), Wood (1994), Ditlev <i>et al.</i> (1991), Waheed & Hoeksema (2013)  Found throughout Malaysia	Least Concern	3.81	<ul style="list-style-type: none"> <li>• Common species</li> <li>• Free-living single polyp</li> <li>• Widely found on reef flats and reef slopes</li> <li>• Prefers soft or rubble substrates, especially in lagoons or shallow turbid environments</li> <li>• Depth range: 1–40 m</li> <li>• Average generation length: 10 years</li> <li>• Mature polyps may grow up to 21 cm</li> </ul>
	<i>Lithophyllon ranjithi</i> Ditlev, 2003	Waheed & Hoeksema (2013)  Only documented in Sabah, not in Peninsular Malaysia	Data Deficient	4.07	<ul style="list-style-type: none"> <li>• Rare species</li> <li>• Very restricted range: northeast Borneo (Malaysia and Indonesia) and Spratly Islands</li> <li>• Found in nearshore coastal reefs and oceanic offshore reefs</li> <li>• In Darvel Bay: common below 10 m on steep hard substratum</li> <li>• Depth range: 10–20 m</li> <li>• Average generation length: 10 years</li> </ul>

Table 1. continued.

Plerogyridae	<i>Nemanzophyllia turbida</i> Hodgson and Ross, 1982	Ditlev <i>et al.</i> (1991), Waheed & Hoeksema (2013)  Only documented in Sabah, not in P. Malaysia	Least Concern	3.91	<ul style="list-style-type: none"> <li>• Rare but conspicuous species</li> <li>• May form large carpets and can be locally abundant</li> <li>• Found in shallow, sheltered, turbid reefs</li> <li>• Depth range: 8–40 m</li> <li>• Average generation length: 10 years</li> </ul>
	<i>Physogyra lichtensteini</i> (Milne Edwards and Haime, 1851)	Wood & Tan (1987), Wood (1994), Ditlev <i>et al.</i> (1991), Waheed & Hoeksema (2013)  Found throughout Malaysia	Least Concern	3.98	<ul style="list-style-type: none"> <li>• Occurs in shallow tropical reefs, often in turbid environments</li> <li>• Can be found across most reef habitats</li> <li>• Depth range: 1–38 m</li> <li>• Average generation length: 10 years</li> <li>• Mature colonies may reach 3 m diameter</li> </ul>
Merulinidae	<i>Catalaphyllia jardinei</i> (Saville-Kent, 1893)	Ditlev <i>et al.</i> (1991), Waheed & Hoeksema (2013)  Only documented in Sabah, not in Peninsular Malaysia	Least Concern	4.23	<ul style="list-style-type: none"> <li>• Rare but widespread species</li> <li>• Found in shallow, sheltered, turbid reefs</li> <li>• Occurs in various reef types; prefers soft sandy substrates over dense coral growth</li> <li>• Depth range: 0–55 m</li> <li>• Average generation length: 10 years</li> <li>• Mature colonies may reach 100 cm diameter</li> </ul>
Scleractinia <i>incertae sedis</i>	<i>Pachyseris rugosa</i> (Lamarck, 1801)	Wood & Tan (1987), Wood (1994), Ditlev <i>et al.</i> (1991), Waheed & Hoeksema (2013)  Found throughout Malaysia	Least Concern	3.95	<ul style="list-style-type: none"> <li>• Widespread and common species</li> <li>• Found in shallow waters</li> <li>• May forms large mound-shaped colonies</li> <li>• Smaller colonies distributed across a wide range of habitats, including strong current areas</li> <li>• Depth range: 2–75 m (most common at 9–20 m)</li> <li>• Average generation length: 10 years</li> </ul>



**Figure 1.** EDGE coral survey sites in the Semporna Priority Conservation Area (PCA)

GPS location, bearings, sea condition and tide levels at each site were recorded. In total, 69 belt transects were completed (Appendix A). Colonies of targeted species were photographed with a reference scale, and data on size, associated organism and coral condition were collected to quantify the health, size structure, and ecological relationships of the targeted species, as well as to detect early signs of stress or disease. Coral identification followed guides in situ records (Hoeksema, 1989; Veron, 2000), and where necessary, ex situ using photographs to verify species that were difficult to identify underwater. At each site, different transects were surveyed by two biologists, and species identifications were subsequently cross-checked to minimise observer bias and ensure taxonomic accuracy.

Distributions of the targeted species were mapped using QGIS, producing heat maps of occurrence based on data from Kassem et al. (2012). Abundance mapping was possible for *H. actiniformis* and *P. rugosa* only as other species were either absent or encountered very few times ( $\leq 6$  individuals) to generate meaningful maps.

### ***Local Community Perception of Reefs***

Community surveys were conducted on four islands (Bum Bum, Denawan, Larapan, and Selakan-Sebangkat) with the permission and support of village heads. Site selection depended on village leaders' approval. Respondents were primarily household breadwinners, as they play a central role in livelihood decisions. Despite efforts to include women and youth, most declined participation.

Consequently, 46 respondents were adult men and one was an adult woman, all with primary responsibility for household support.

The interviews assessed local awareness of environmental condition of Semporna reefs, knowledge of fish bombing, and willingness to support efforts to curb fish bombing (Appendix B). Scoring matrix for the questionnaire is provided in Appendix C. Verbal consent was obtained from all participants and their respective village leaders.

### ***Socio-demographic Characteristics of Respondents***

Respondents belonged to Bajau, Bajau Sama, and Bajau Laut communities, groups often associated with illegal and destructive fishing practices such as blast and poison fishing (Clifton & Majors, 2012; Pet-Soede & Edrmann, 1998). Traditionally seafaring, some Bajau remain nomadic, travelling long distances across the Sulu-Celebes region to exploit remote reefs. Many now settle in permanent villages and abandon destructive practices once local reefs degrade.

Most respondents reported monthly incomes below RM500 (74.47%), similar to Yusah et al. (2018) but higher than values reported over a decade earlier Wood (2001). Fishing was the primary occupation (68.1%), with 23.4% combining fishing with other work such as house cleaning, woodworking, or security. A minority (8.5%) were homemakers, small business owners, 23.4% or government employees. The respondents were breadwinners for their families, with ages ranged from 21 to 72 years old, with men predominating. A copy of the questionnaire is provided in Appendix B.

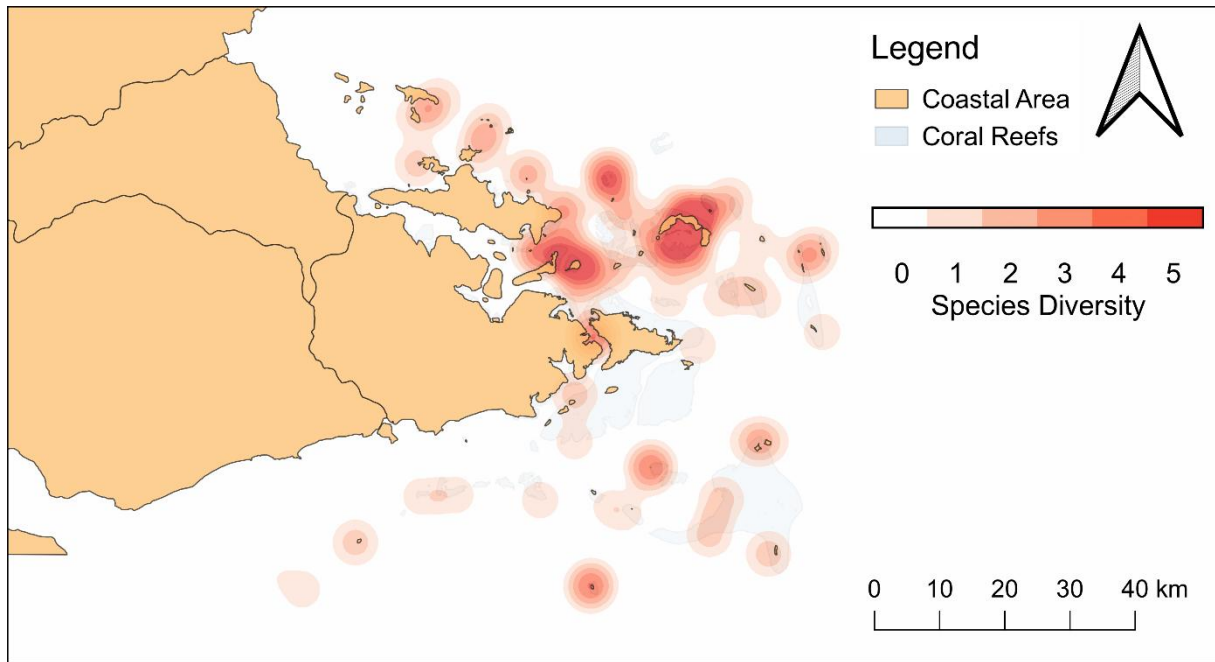
### ***Data Analysis***

Responses were analysed using Pearson's chi-square test to evaluate general awareness, awareness of fish bombing, and attitudes toward fish bombing and conservation. Likelihood ratio tests were applied to examine response tendencies and potential biases by island towards fish bombing. Results of ranking of the awareness and altitude levels are presented in comparison tables.

## **Results**

### ***Distribution of EDGE Corals***

The distribution and richness of the EDGE coral species were primarily concentrated in the centre region of the Semporna PCA (Figure 2, Appendix A). Diversity and abundance declined with increasing distance from the coastline, particularly the mushroom coral *H. actiniformis* (Figure 3).

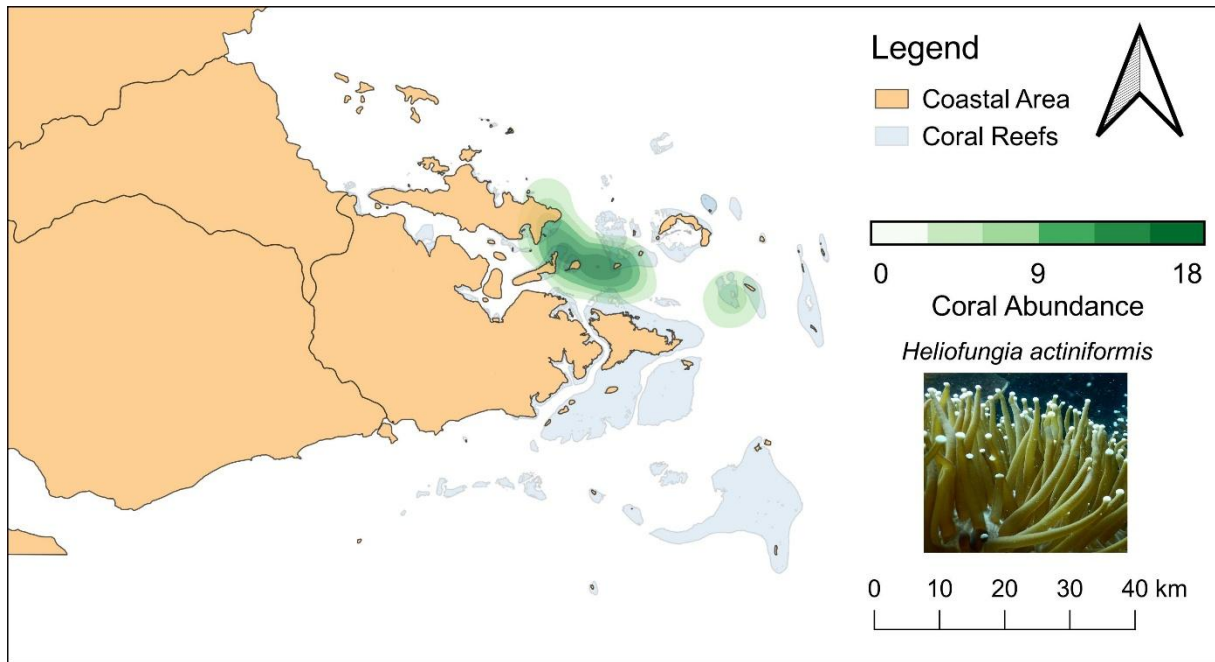


**Figure 2.** Heat map showing overall distribution of all six EDGE coral species in the Semporna PCA

### ***Abundance of EDGE corals***

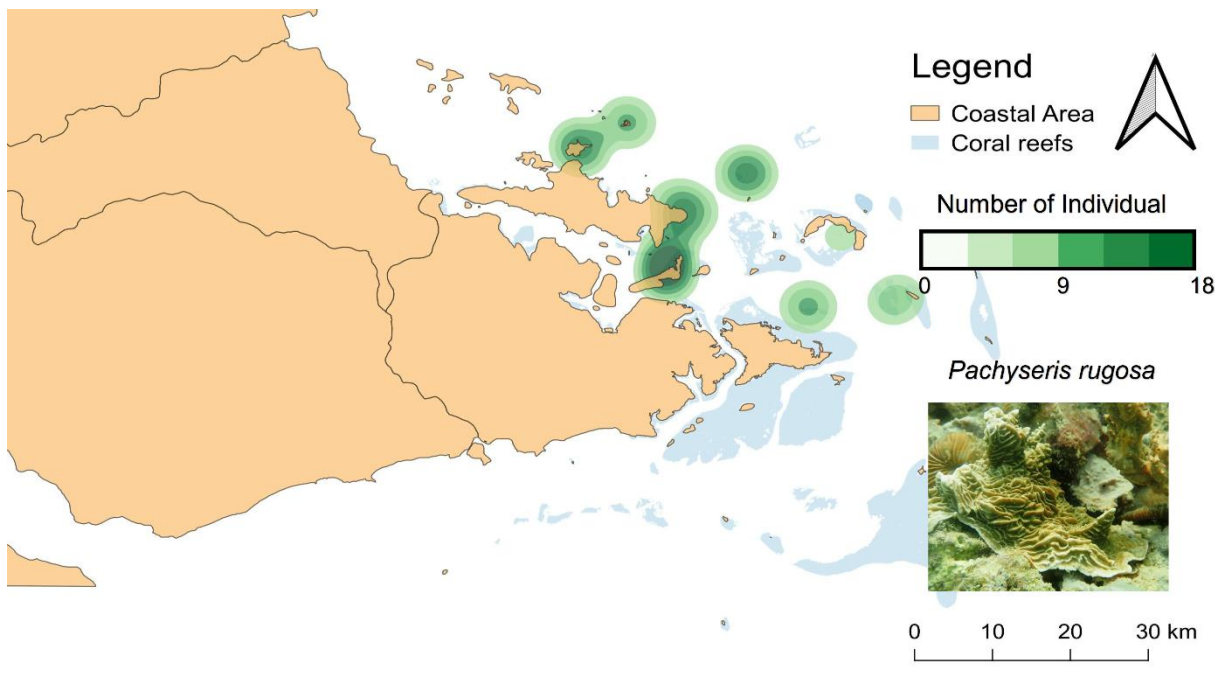
A total of 123 colonies of *H. actiniformis* were recorded. Sebangkat Island (26.8%), Larapan Island (20.3%), and Sibuan Island (20.3%) hosted the highest number of colonies (Figure 3). No colonies were found at Adal Island. Colony size ranged from 3.2 cm to 26.4 cm, with a median size of 9.8 cm. Approximately 15.5% of colonies supported associated fauna such as small fish, shrimps, and sea stars, most frequently observed at Timbun Mata Island. Most coral colonies were in healthy condition, with less than 1% showing signs of disease.

For *P. rugosa*, 112 colonies were recorded, ranging from 7 cm to 128 cm in size (mean diameter 17.55 cm). Unlike *H. actiniformis*, this species was more evenly distributed across the surveyed islands (Figure 4). The highest proportion of colonies occurred at Timbun Mata (19.64%), followed by Sebangkat (16.07%), Batik (13.39%), and Sibuan (12.5%). As an encrusting coral, *P. rugosa* often occupies reef areas dominated by soft corals, which may explain its broader distribution and consistent presence across islands



**Figure 3.** Heat map showing the abundance of *Heliofungia actiniformis* in the Semporna PCA

For other species of EDGE corals, only six colonies of *Physogyra lichtensteini* (mean diameter 17.22 cm), and four colonies of *Catalaphyllia jardinei* (mean diameter 15.75 cm) were recorded. No colonies of *Nemanzophyllia turbida* or *Lithophyllon ranjithi* were found.



**Figure 4.** Heat map showing the abundance of *Pachyseris rugosa* in the Semporna PCA

## ***Community Surveys***

### Environmental and Fish Bombing Awareness

Survey results revealed variation in environmental awareness and attitudes among islands (Table 2, Appendix C). Denawan had the highest level of environmental awareness with mean score of 9.67 (SE  $\pm$  0.667), followed by Bum Bum (9.30  $\pm$  0.731), Selakan (9.00  $\pm$  0.572), and Larapan (7.07  $\pm$  0.579). These scores suggest that environmental changes might be more visible on Denawan Island compared to other islands. Conversely, Larapan scored highest for fish bombing awareness (16.07  $\pm$  0.57), followed by Denawan (15.75  $\pm$  0.63), Selakan (14.36  $\pm$  0.78), and Bum Bum (13.80  $\pm$  1.21).

Bum Bum respondents expressed the greatest willingness to cooperate against fish bombing (9.60  $\pm$  0.37), exceeding Larapan (7.43  $\pm$  0.80), Selakan (7.09  $\pm$  0.53), and Denawan (7.08  $\pm$  0.58). The higher mobility of the Bum Bum communities may make them more receptive to supporting new conservation initiatives.

**Table 2.** Summary of community survey scores for environmental awareness, fish bombing awareness, and attitudes

<b>Island</b>	<b>Environmental Awareness Score</b>	<b>Average</b>	<b>Fish Bombing Awareness Score</b>	<b>Average</b>	<b>Total Attitude Score</b>	<b>Average</b>
Denawan (n=12)	116	9.67	189	15.75	85	7.08
Larapan (n=14)	99	7.07	225	16.07	104	7.43
Selakan (n=11)	99	9.00	158	14.36	78	7.09
Bum Bum (n=10)	93	9.30	138	13.80	96	9.60

### Perceived Environmental Change and Causes

Overall, 68% of respondents identified reef degradation as the primary environmental change observed, followed by marine resource depletion (62%), pollution (45%), beach erosion (45%), seagrass degradation (28%), and groundwater salinisation (4%). Respondents from Bum Bum diverged from this trend, identifying pollution as the dominant concern.

All respondents attributed reef degradation primarily to destructive fishing practices (fish bombing and poison fishing). Additional causes cited included anchor damage (43%), crown-of-thorns outbreaks (36%), marine debris (34%), and hook-and-line/net fishing (32%). A few respondents (15%) also attributed reef health decline to tourist-related impacts, including diving and snorkelling.

### Fish Bombing Hotspots and Practices

Generally, island communities identified destructive fishing methods such as fish bombing (74%), poison fishing (57%), and gleaning (21%), as the main contributors to reef degradation on their respective islands. Fish bombing was reported widespread in the Semporna PCA. The central area of the PCA around Bum Bum and Sebangkat, as well as Ligitan reefs in the southeast recorded the highest reports of bombing (40% each), followed by the north around Larapan, Timbun Mata, Baik and Adal (26%).

Most respondents (91.5%) were aware that fish bombing is illegal. Incidents were most frequently reported in the morning (68%), evening (57%), and at noon (51%), with one respondent reporting night-time occurrences. Pump boats (81%) were the most commonly identified vessels, followed by engine boats (55%), sampans (34%), and outrigger canoes or 'bangka' (11%). Fish bombing was typically conducted in groups (74%) rather than individually (19%). More than 80% of respondents reported witnessing reef damage from fish bombing, with 32% hearing blasts almost daily, 21% monthly, 13% yearly, and 4% never.

### Attitude Towards Combating Fish Bombing

Community support for anti-fish-bombing initiatives was high. All respondents agreed that bombing should cease, and 95.7% were willing to support prevention efforts. Many expressed willingness to join patrols (89.4%), cooperate or participate in training on fish bombing issues (85.1%), discourage friends and family from purchasing bombed fish (72%), report incidents to enforcement agencies (68%), or support anti-fish bombing campaigns (66%). In addition, 62% favoured the establishment of patrolling and monitoring teams, while 47% were interested in training to become patrollers. Fewer respondents were willing to provide financial support (9%).

Regarding enforcement agencies' presence, 79% of respondents observed marine police patrols on their island, followed by the army at 68%, the Malaysian Maritime Enforcement Agency at 51%, and the Department of Fisheries and Sabah Parks, each observed by only one respondent. When asked about potential solutions, 85% of respondents perceived increased enforcement as crucial, followed closely by strengthened regulations at 81%. Additionally, 70% emphasized the importance of awareness-raising, while 64% highlighted the significance of information sharing in combating fish bombing.

### ***Priority Sites for Conservation***

Statistical analysis of awareness indicators across 47 respondents (Table 3) produced three main outcomes. First, environmental awareness differed significantly among islands ( $\chi^2 = 13.808$ ,  $df = 3$ ,  $p = 0.003$ ), with Larapan significantly lower than others. Second, fish bombing awareness showed no significant differences ( $\chi^2 = 3.245$ ,  $df = 3$ ,  $p = 0.355$ ), suggesting that awareness of fish bombing is similar across all islands. Third, attitudes towards combating fish bombing varied ( $\chi^2 = 8.254$ ,  $df$

= 3,  $p = 0.041$ ), with Bum Bum showing significantly more positive attitudes toward combating fish bombing. Overall, the findings suggest that while fish bombing awareness is fairly uniform across the islands, general environmental awareness and anti-fish-bombing attitudes differ, especially on Larapan and Bum Bum islands.

**Table 3.** Results of Pearson's chi-square tests comparing general environmental awareness, fish bombing awareness, and attitudes towards fish bombing

Awareness Score	N	Pearson Chi-Square	<i>df</i>	Asymptotic Significance (2-sided)	Remarks
General environmental awareness	47	13.808	3	0.003	Level of general awareness of Larapan community is significantly lower than other islands.
Awareness on fish bombing	47	3.245	3	0.355	Level of fish bombing awareness for all islands has no significantly differences.
Attitude toward combating fish bombing	47	8.254	3	0.041	Level of attitude towards fish bombing of Bum Bum island is significantly higher than other islands.

The ranking (Table 4) further highlights Larapan as the most ecologically significant site, hosting all six EDGE coral species and high abundances of *H. actiniformis*. Selakan and Bum Bum also support diverse species, though at lower abundances, while Denawan ranked lowest. Overall, the findings indicate that Larapan is the most significant site for species conservation, while Selakan and Bum Bum provide additional ecological support that can aid in the connection and resilience of coral populations in Semporna.

**Table 4.** Rankings of the four study islands based on EDGE coral distribution and abundance, and community survey scores for environmental awareness, fish bombing awareness, and attitudes (with statistical results in Table 3). Y=Yes and N=No

Island	Denawan	Larapan	Selakan	Bum Bum
Distribution				
H. actiniformis	Y	Y	Y	Y
P. rugosa	N	Y	Y	Y
P. lichtensteini	Y	Y	Y	Y
C. jardinei	N	Y	N	N
N. turbida	N	Y	N	N
L. ranjithi	N	Y	N	N
Abundance				
H. actiniformis	N	Y	Y	N
P. rugosa	N	N	N	N
P. lichtensteini	N	N	N	N
C. jardinei	N	N	N	N
N. turbida	N	N	N	N
L. ranjithi	N	N	N	N
Level of awareness (General)	Average	Low	Average	Average
Level of awareness (Fish bombing)	Average	Average	Average	Average
Attitude (Fish bombing)	Average	Average	Average	High

## Discussion

This study identified areas of high EDGE coral diversity and abundance, revealing gaps in protection within the Semporna PCA. EDGE corals were concentrated in the central region, which lies partly outside Tun Sakaran Marine Park and is subject to intense pressures including fish bombing, marine debris, and coastal development (Choo et al., 2025). Strengthening conservation efforts in these areas, especially in the central region of Semporna PCA, is crucial to mitigating anthropogenic pressures and ensuring the effective preservation of coral biodiversity.

Fish bombing persists due to economic pressures, demand for rapid catches, limited enforcement, and lack of livelihood alternatives (Wood, 2006; Nina & Kassem, 2009; Kassem et al., 2012). Similarly, marine debris stems from inadequate waste management, population growth, and reliance on single-use plastics in tourism-heavy regions (MPMP, 2022; Tan et al., 2022). Both threats are exacerbated by gaps in education and awareness, limited community involvement in resource management, and the lack of effective enforcement mechanisms. Addressing these threats requires not only strengthening law enforcement but also fostering

community engagement, improving waste management systems, and exploring sustainable fishing practices to mitigate the pressures on marine ecosystems.

The relatively low prevalence of EDGE corals in surveys may reflect their natural rarity, specialised habitat preferences, occurrence outside the survey depth range (6–9 m), or anthropogenic pressures such as collection for the aquarium trade. For example, *C. jardinei* is often associated with sandy bottoms in high-light environments, whereas *L. ranjithi* is typically restricted to crevices in deeper or high-current areas. As limited baseline surveys exist in Semporna, further research is required to confirm long-term trends. *Lithophyllon ranjithi* illustrates this challenge. Previously assessed as Vulnerable under the Red List D2 criterion due to its highly restricted distribution, it is now listed as Data Deficient, reflecting uncertainty about its true status (Waheed et al., 2024). Knowledge of its population size, distribution and trends remains insufficient to make a definitive assessment. Species with limited ranges are particularly susceptible to localised impacts or unpredictable events (IUCN, 2001), and *L. ranjithi* may still face such risks. This highlights a broader challenge: limited population and distribution data for many coral species hampers systematic conservation planning and may mask the vulnerability of narrowly distributed taxa (Harvey et al., 2021). On the other hand, *H. actiniformis*, the most dominant EDGE species is a free-living coral and often abundant on reefs because it thrives on unconsolidated substrates such as rubble and sand, where many other corals cannot persist (Knittweis et al., 2009; Samimi-Namin et al., 2025). Its resilience in sediment-stressed habitats, combined with its capacity to support diverse associated fauna, further contributes to its ecological success and high local abundance (Hoeksema et al., 2019).

Community surveys indicated strong awareness of destructive fishing and willingness to support conservation through LMMAs in Semporna. Although these community initiatives may not always align perfectly with formal conservation objectives, they support the concept of sustainable resource management. Similar outcomes have been reported in Myanmar, where community support for LMMAs was high and dynamite fishing declined within managed areas (Thiha et al., 2023). Such findings highlight the value of community participation in conservation (Ferse et al., 2010). However, it should be noted that most respondents were men, which may have overlooked women's perspectives. In Bajau communities, gender roles shape environmental knowledge and management priorities, and women often contribute unique insights into resource use (Torell et al., 2020; Nessa et al., 2020). Future studies should therefore aim for a more gender-balanced approach to better reflect community-wide perceptions.

Larapan emerged as a priority site due to high coral diversity and community awareness. Its proximity to existing marine parks further enhances the feasibility of establishing an LMMA. Bum Bum, with its positive community attitudes, may also serve as a potential model site,

though it holds lower conservation priority than Larapan due to lower EDGE coral diversity. The development of LMMA networks requires strong local stewardship (Syakur et al., 2012; Jupiter et al., 2014), and Larapan could serve as a pilot for expanding community-based protection across Semporna.

International benchmarks such as the IUCN Red List can strengthen conservation by providing a standardised framework to guide national and local priorities. The case of *L. ranjithi* illustrates how global assessments can draw attention to species of concern, emphasising the need for complementary national protection measures. EDGE species with restricted ranges, in particular, should be formally recognised as threatened and afforded legal protection within Malaysia.

## **Conclusion**

This study documented the distribution and abundance of EDGE coral species and assessed community awareness in the Semporna PCA. EDGE corals, including *H. actiniformis* and *P. rugosa*, were concentrated in the central region, partly outside existing protected areas, highlighting conservation gaps and the need for deeper, habitat-specific surveys. Community surveys showed strong awareness of destructive fishing and widespread support for LMMAs, with Larapan emerging as the priority site due to its high coral diversity and readiness for community-based management. Bum Bum also demonstrated potential as a complementary model site.

These findings underscore the value of integrating ecological data with community perspectives to guide conservation priorities. Strengthening LMMAs and other locally governed measures can help conserve threatened coral species, address anthropogenic pressures, and enhance governance through both formal and traditional systems. By combining ecological monitoring with active community stewardship, conservation in Semporna can support Malaysia's biodiversity targets, the Global Biodiversity Framework's 30 × 30 goal, and regional commitments under the Coral Triangle Initiative.

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## Appendices

**Appendix A.** Survey sites across community islands in the Semporna PCA, Sabah, Malaysia, showing site name, geographic coordinates (latitude and longitude), abundance, and mean colony diameter (cm) of four EDGE coral species.

Island	Site Name	Latitude	Longitude	Total abundance				Mean Diameter (cm)			
				<i>H. actiniformis</i>	<i>P. rugosa</i>	<i>P. lichtensteini</i>	<i>C. Jardinei</i>	<i>H. actiniformis</i>	<i>P. rugosa</i>	<i>P. lichtensteini</i>	<i>C. Jardinei</i>
Adal	Adal 1	N 4.748417	E 118.520167	0	3	1	0	0	11.333	32	0
Adal	Adal 2	N 4.744444	E 118.520389	0	3	0	0	0	23.333	0	0
Adal	Adal 3	N 4.747306	E 118.513667	0	4	0	0	0	45.05	0	0
Batik	Batik 1	N 4.723861	E 118.463500	1	6	0	0	5	32.2	0	0
Batik	Batik 2	N 4.720750	E 118.450694	2	1	0	0	19	42	0	0
Batik	Batik 3	N 4.708889	E 118.465306	0	8	2	1	0	37.286	18	21
Timbun Mata	Timbun 1	N 4.621250	E 118.587472	0	5	0	0	0	55.58	0	0
Timbun Mata	Timbun 2	N 4.597194	E 118.568194	15	5	0	0	10.6	31.8	0	0
Timbun Mata	Timbun 3	N 4.640167	E 118.589056	2	8	0	0	8.4	44.5	0	0
Timbun Mata	Timbun 4	N 4.649806	E 118.563472	8	4	0	1	8.714	25.25	0	11
Larapan	Larapan 1	N 4.547528	E 118.608694	9	0	0	0	10.333	0	0	0
Larapan	Larapan 2	N 4.574306	E 118.604167	16	3	0	0	10.32	16.333	0	0
Larapan	Silawa, Bait	N 4.574944	E 118.566556	4	5	0	0	6.625	50.4	0	0
Sebangkat	Sebangkat 1	N 4.554225	E 118.667600	17	11	0	0	12.176	69.073	0	0
Sebangkat	Sebangkat 2	N 4.553144	E 118.655369	10	4	0	1	10.53	32.625	0	22.5
Sebangkat	Sebangkat 3	N 4.555528	E 118.654806	6	3	0	0	9.81	37.267	0	0
Sibuan	Church reef 1	N 4.681917	E 118.657889	6	11	0	0	17.567	41.545	0	0
Sibuan	Church reef 2	N 4.686250	E 118.649028	4	3	0	0	18.2	31.833	0	0
Bodgaya	Ribbon reef	N 4.602778	E 118.764889	2	4	0	0	9.85	57.9	0	0
Kulapuan	Batuara 1	N 4.513500	E 118.808667	5	0	0	0	13.94	0	0	0
Kulapuan	Batuara 2	N 4.525500	E 118.831917	5	7	0	0	9.9	70.214	0	0
Kulapuan	Batuara 3	N 4.510500	E 118.811167	4	2	0	0	15.825	37.433	0	0
Bum Bum	Pasalat Reef 1	N 4.514213	E 118.727238	1	4	2	0	4	17.35	24.6	0
Bum Bum	Pasalat Reef 2	N 4.514217	E 118.727092	4	6	1	1	7.625	32.017	28.7	8.5
Bum Bum	Palang - palang	N 4.446167	E 118.769317	2	2	0	0	12.95	42.6	0	0
Bum Bum	Channel	N 4.461306	E 118.635861	0	0	0	0	0	0	0	0
				123	112	6	4				

**Appendix B.** Questionnaire on coral reefs in Semporna. The survey was designed to assess local community perceptions of coral reefs, destructive fishing practices, environmental changes, and willingness to participate in conservation initiatives. Responses were voluntary and confidential.



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#### Borang Kaji Selidik Tentang Terumbu Karang di Semporna

Tujuan soal selidik ini adalah untuk mengetahui persepsi orang tempatan terhadap batu karang dan ancaman terumbu karang yang berada di kawasan masing-masing. Jawab soalan ini adalah secara sukarela dan informasi personal adalah terpelihara. Sila jawab soalan secara jujur dan ikhlas dan sila menambah sebarang maklumat yang tuan/puan rasa berkaitan

- 1) Apakah pendapat anda tentang terumbu karang berbanding dengan 10 tahun yang lepas?
  - a) Bertambah baik
  - b) Tidak berubah
  - c) Berkurang dan rosak
- 2) Apakah cara menangkap ikan yang merosakkan berleluasa di kawasan ini?
  - a) Tidak
  - b) Ya
  - c) Di kawasan: \_\_\_\_\_
- 3) Apakah pandangan anda tentang cara memancing secara merosakkan dalam jangka masa 10 tahun ini?
  - a) Bertambah
  - b) Tidak berubah
  - c) Berkurang
- 4) Apakah perubahan persekitaran yang anda dapat melihat di kawasan anda?
  - a) Hakisan pantai
  - b) Kerosakan terumbu karang
  - c) Air tawar menjadi masin
  - d) Air laut tercemar
  - e) Kekurangan kawasan rumput laut
  - f) Sumber laut semakin berkurang
  - g) Lain-lain: \_\_\_\_\_
- 5) Apakah cara penangkapan ikan yang merosakkan sering dilakukan di kawasan anda?
  - a) Bom ikan
  - b) Sujum
  - c) Memecahkan batu karang
  - d) Lain-lain: \_\_\_\_\_
- 6) Mengebom ikan adalah salah di sisi undang-undang. ( )  
Kenyataan atas adalah betul atau salah?
- 7) Pada pendapat anda, apakah aktiviti yang merosakkan batu karang?
  - a) Bom ikan dan Sujum
  - b) Memancing dan memukat
  - c) Sentuhan pelancong
  - d) Sampah sarap
  - e) Jangka dari boat
  - f) Mahkota laut/haiwan lain
  - g) Lain-lain: \_\_\_\_\_
- 8) Di manakah selalu menjadi kawasan bom ikan?
  - a) Pulau: \_\_\_\_\_
- 9) Bilakah masa yang selalu berlaku pengeboman ikan?
  - a) Pagi
  - b) Petang
  - c) Malam
- 10) Apakah jenis bot yang biasa dipakai oleh nelayan yang menjalankan aktiviti mengebom ikan?
  - a) Pam bot
  - b) Sampan (boggo')
  - c) Bot dengan enjin
  - d) Bangkero/Bangka/Katig
- 11) Aktiviti mengebom ikan yang pernah dilihat dijalankan secara individu atau berkumpulan?
  - a) Individu
  - b) Berkumpulan: Berapa bot?  
Berapa orang ?
- 12) Pernahkah anda melihat terumbu karang yang telah dirosakkan akibat pengeboman ikan?
  - a) Tidak
  - b) Ya. di kawasan: \_\_\_\_\_

- 13) Apakah kekerapan anda mendengar bom ikan di kawasan anda?
- Sangat jarang (setahun sekali)
  - Kadang-kala (sebulan sekali)
  - Selalu (seminggu sekali)
  - Sangat kerap (>5 kali seminggu)
- 14) Pernahkah anda melihat bot peronda pihak berkuasa meronda kawasan ini?
- Tidak
  - Ya. Jika ya, sila pilih,
    - Tentera
    - Polis marin
    - APMM
    - Lain-lain: \_\_\_\_\_
- 15) Adakah anda setuju untuk menghentikan aktiviti pengeboman ikan di Semporna?
- Setuju
  - Tidak setuju Sebab : \_\_\_\_\_
- 16) Adakah anda sudi membantu dalam usaha menghentikan aktiviti pengeboman ikan di Semporna?
- Ya
  - Tidak. Sebab: \_\_\_\_\_
- 17) Adakah anda pernah mengikuti latihan, meronda atau memantau?
- Tidak pernah
  - Pernah. Agensi : \_\_\_\_\_
- 18) Adakah anda bersetuju untuk mengikuti latihan, pasukan meronda dan memantau bagi menghentikan bom ikan?
- Ya
  - Tidak
  - Tidak Pasti
- 19) Adakah anda bersetuju untuk menubuhkan pasukan pengawal-pengawal laut bertujuan memantau dan menghalang aktiviti pengeboman ikan di Semporna?
- Ya
  - Tidak setuju Sebab : \_\_\_\_\_
- 20) Pada pendapat anda, manakah yang lebih penting dari segi pendidikan, perkongsian maklumat, undang-undang dan penguatkuasaan dalam
- 22) Adakah anda sudi memberikan kerjasama memberikan maklumat untuk dihubungi pada masa hadapan tentang latihan-latihan yang berkaitan usaha menghentikan bom ikan?
- menangani masalah bom ikan? (Boleh pilih lebih dari satu).
- Pendidikan:
    - Poster
    - Risalah
    - Bahan pembelajaran di sekolah
    - Tayangan video
    - Lain-lain: \_\_\_\_\_
  - Perkongsian maklumat:
    - Kajian tentang kesan bom ikan kepada terumbu karang
    - Garis panduan untuk mengenalpasti kawasan bom dan sujum
    - Lain-lain : \_\_\_\_\_
  - Undang-undang:
    - Denda setimpal terhadap orang yang melakukan kesalahan di sisi undang-undang
    - Undang-undang perlu diketatkan terhadap penggunaan bom ikan dan sujum
    - Lain-lain : \_\_\_\_\_
  - Penguatkuasaan:
    - Lebih ramai pegawai penguatkuasa
    - Lebih banyak bot untuk rondaan
    - Memberikan latihan
    - Lain-lain : \_\_\_\_\_
- 21) Saya boleh memainkan peranan penting dalam usaha menghentikan pengeboman ikan melalui :
- Mengikuti latihan sebagai pengawal untuk meronda dan memantau
  - Menyokong menubuhkan pasukan pengawal untuk meronda dan memantau
  - Memberikan maklumat lokasi dan masa pengeboman ikan berlaku
  - Memberitahu kepada kawan-kawan, ahli keluarga dan saudara mara supaya jangan membeli ikan yang telah dibom
  - Menyumbang kepada pasukan meronda dan memantau (kos operasi)
  - Menyertai dan menyokong Kempen Anti Bom Ikan
  - Lain-lain : \_\_\_\_\_

- a) Tidak
- b) Ya. Nombor telefon dihubungi : \_\_\_\_\_

23) Nama : \_\_\_\_\_

Jantina :                      Lelaki                      Perempuan

Umur : \_\_\_\_\_

Bangsa : Bajau              Bajau Laut              Suluk              Lain – lain : \_\_\_\_\_

Pulau : \_\_\_\_\_

24) Pekerjaan

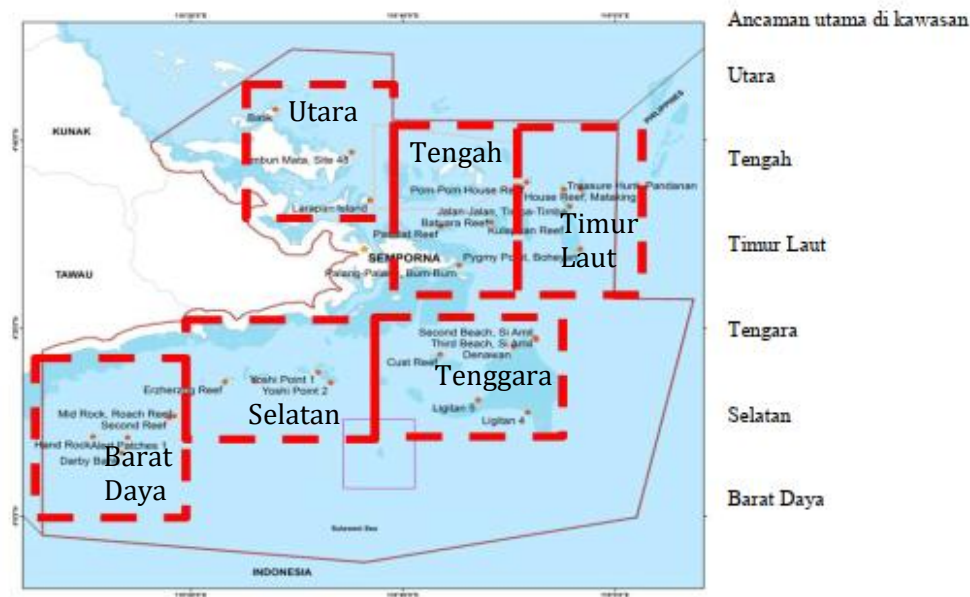
- a) Surirumah
- b) Penternak ikan
- c) Pengusaha rumpai laut
- d) Peniaga
- e) Sektor kerajaan
- f) Sektor pelancongan
- g) Lain-lain: \_\_\_\_\_
- h) Nelayan
  - (a) Memancing
  - (b) Memukat

- (c) Menyelam
- (d) Menohor/Mengarang
- (e) Lain – lain : \_\_\_\_\_

25) Jumlah pendapatan bulanan :

- a) RM 200 ke bawah
- b) RM 250 – RM 500
- c) RM 500 – RM 1000
- d) RM 1000 – RM 1500
- e) RM 1500 – RM 2000
- f) RM 2500 ke atas

26) Di manakah kawasan anda melakukan aktiviti perikanan? Sila nyatakan dalam peta di bawah



**Appendix C.** Scoring matrix for community survey responses in Semporna, showing component questions and maximum possible points for Environmental Awareness, Fish Bombing Awareness, and Fish Bombing Attitude scores.

<b>Environmental Awareness Score</b>									
Q1	Q2	Q3	Q4	Q5	Q6	Q7			Total
0/1	0/1	0-4	0/1	0-5	0/1	0-6			19
<b>Fish Bombing Awareness Score</b>									
Q6	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q20	Total
0/1	0-5	0/1	0/1	0/1	0/1	0-4	0/1	0-4	19
<b>Fish Bombing Attitude Score</b>									
Q15	Q16	Q18	Q19	Q21	Q22				Total
0/1	0/1	0/1	0/1	0-7	0/1				12