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Research Article

Hotspot analysis and spatial distribution of sharks and rays: Implications for conservation and management strategies

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Abstract

Shark and ray populations are increasingly threatened, highlighting the need for effective management and conservation. This study aimed to identify hotspot areas for these species in the waters of Kuala Dungun, Malaysia. Monthly onboard observations were carried out on trawl, longline, and fish trap vessels from June 2023 to May 2024. Hotspot analysis was then performed using the Getis-Ord Gi* statistic in QGIS platform. Significant hotspots for *Carcharhinus sorrah, Chiloscyllium punctatum, C. hasseltii, Rhynchobatus australiae*, and *Maculabatis* spp. were primarily identified in coastal regions, as well as in proximity to Fish Aggregating Devices (FADs) and artificial reefs. The association between hotspots and FADs/artificial reefs suggests these structures may enhance abundance, benefiting both conservation and fisheries productivity. Bamboo shark egg cases were also reported on traps located near FADs. The findings emphasize the importance of habitat protection and the implementation of marine spatial planning to support sustainable management practices.

Introduction

Shark and rays belong to Chondrichthyes or also known as elasmobranchs, inhabit the top of the trophic in the aquatic ecosystem (Compagno, 1990; Dulvy *et al*., 2014). They are characterized by simple cartilaginous internal skeleton that are formed by tough and flexible cartilage and no bones present in the skeleton, fins, or scales and another characteristic is they have placoid scales and rows of teeth that continually replaced (Ebert *et al*., 2021).

Sharks and rays were once primarily regarded as bycatch, incidentally captured alongside commercially valuable species during fishing operations (Arai and Azri, 2019). However, they have increasingly become targeted species, particularly in longline fisheries, due to their rising commercial value. Braccini and Waltrick (2019) highlighted growing global demand for shark and ray fins, meat, and other body parts, leading to intensified fishing pressure and posing serious risks to population sustainability. Their inherently vulnerable life history traits such as slow growth, late sexual maturity, long lifespan, and low fecundity further exacerbate these threats (Hutchings *et al*., 2012; Doherty *et al*., 2023). In addition, several other factors including habitat degradation, pollution, and climate change further increase the pressure on the sustainability of shark and ray populations (Stobutzki *et al*., 2002; Blaber *et al*., 2009; Simpfendorfer *et al*., 2011; Haque *et al*., 2021). Environmental conditions may influence the sustainability of vulnerable taxa such as sharks and rays. Dehghani *et al*. (2024) showed that changes in seawater physical properties altered assemblage structure in the northeastern Persian Gulf, contributing to reduced taxonomic richness in sharks while highlighting species-specific depth and environmental preferences.

In Malaysia, sharks and rays account for less than 1% of total marine landings, with reported landings of 5,736 mt for sharks and 11,318 mt for rays. Over the past two decades, shark and ray landings have declined by approximately 35% to 40% according to in Department of Fisheries (DOF, 2023). A recent study by Sharikin *et al*. (2025) revealed that more than half of the shark and ray catches along the east coast of Peninsular Malaysia consist of species classified as endangered, with some showing a noticeable decline in individual numbers. Several studies on the population of sharks and rays in Malaysia have been conducted such as genetic analysis by Masstor *et al*. (2014), Lim *et al*. (2021), Fahmi *et al*. (2021) and Loh *et al*. (2023); trading of shark's fin by Seah *et al*. (2022) and feeding ecology by Abdullah *et al*. (2023). Additionally, the study on landings and species composition has been done by Booth *et al*. (2021) in Sarawak, Hilmi *et al*. (2017) in Perak and Yusof *et al*. (2021) in Pahang, Arai and Azri (2019) in the southern South China Sea and Sharikin *et al*. (2025) on the diversity and exploitation pattern of sharks and rays in the East Coast of Peninsular Malaysia.

Due to the importance of sharks and rays in the marine ecological systems and the threat to the population from various factors, it is crucial that the management and conservation plan of the population be adopted. Management strategies may include setting species-specific catch limits, enforcing gear restrictions, implementing time and area closures, promoting responsible fishing practices, and supporting research and monitoring initiatives (Sharikin *et al*., 2025). A comprehensive understanding of the population is essential for developing an effective management strategy.

Many aspects of shark and ray populations remain insufficiently studied, one of which is hotspot analysis. A hotspot is defined as an area within a broader region that exhibits a high concentration of individuals or species (Sussman *et al*., 2019). Identifying such areas is essential for understanding species abundance and distribution patterns. Hotspot analysis is a spatial statistical method used to detect clusters of significantly high or low values of a given phenomenon among neighbouring features compared to the overall dataset. This method typically employs the Getis-Ord Gi* statistic (Ord and Getis, 1995) to identify hot and cold spots based on the average computed test statistic across all features in a geographic information system (GIS) environment, such as Quantum Geographic Information System (QGIS) (Oxoli *et al*., 2018).

This analytical approach has been applied in various ecological studies. For instance, Bowser *et al*. (2023) utilized hotspot analysis for the early detection and monitoring of invasive species in Maumee Bay, western Lake Erie. Similarly, Ma *et al*. (2025) employed the method to identify fish diversity and composition hotspots in the Yangtze River, revealing key hotspot areas in the Dadu and Tongtian rivers. Mourato *et al*. (2011) also applied this approach to study longline fisheries along the southeastern coast of Brazil, identifying that fishing activities were more concentrated near the continental shelf break, corresponding with variations in catch per unit effort (CPUE) of major target species. Therefore, identifying shark and ray hotspots is valuable, as such information can assist management authorities in developing effective management plans (McAllister *et al*., 2024). This study aims to determine hotspot areas for shark and ray species, with a particular focus on identifying zones of species aggregation in the waters of Kuala Dungun. The findings will improve understanding of areas where sharks and rays are most heavily concentrated and exploited, providing crucial insights to support future management efforts especially within the framework of Marine Spatial Planning.

Materials and methods

Study area

This study was conducted in the waters of Kuala Dungun as shown in Figure 1. Kuala Dungun waters were selected after as proposed by the Department of Fisheries, Malaysia due to the high abundance of shark and rays observed during the department's long-term observation. Kuala Dungun waters, located in Terengganu on East Coast of Peninsular Malaysia region and facing the South China Sea discharged by Dungun River which the second largest river in Terengganu with the length of approximately 110 km and approximately 920 meters wide (Ishak *et al*., 2014).

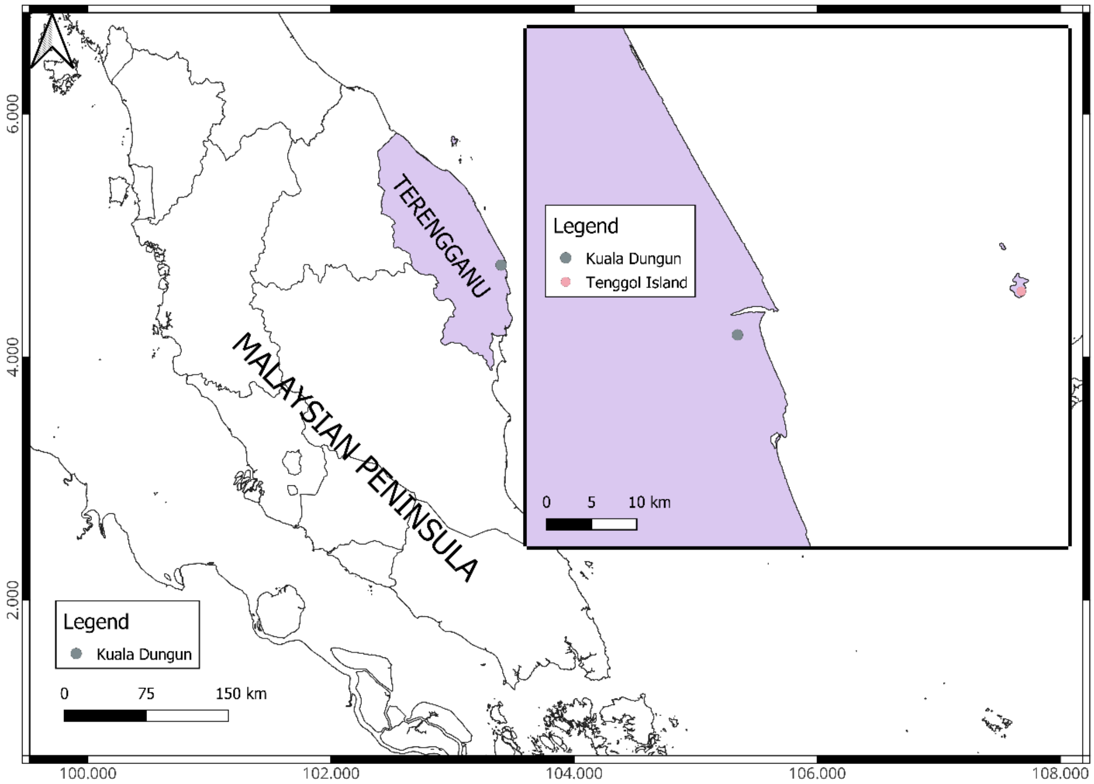

Figure 1: Location of Kuala Dungun waters in the Peninsular Malaysia.

The waters of Kuala Dungun range in depth from 10 to 60 m and include Tenggol Island, a well-known diving destination and a recognized site for whale shark (*Rhincodon typus*) sightings. The area also serves as an important fishing ground and a key source of livelihood for many artisanal and coastal fishers, as Kuala Dungun itself is a fishing village (Magson *et al*., 2022; Sanusi *et al*., 2024). Additionally, Rantau Abang is located within Kuala Dungun is a notable turtle nesting site and one of the designated prohibited fishing zones under the Fisheries Act of Malaysia 1985 (DOF, 2024).

Data collection

The permission to conduct this research was obtained from the Department of Fisheries Malaysia (Reference: Prk. ML. 11/02/37 Jld 15 (3). Monthly on-board observation was conducted from June 2023 to May 2024 on trawl, longline and fish trap vessels with the average of 6 days per month for each fishing vessels. Verbal fishermen consents were obtained before boarding their fishing vessels. During the onboard study, the enumerators observed the activities conducted such as the duration of fishing activities, number of fishing gears and baits used if applicable. If sharks or rays landed, species identification was conducted following the guidelines provided by Ali *et al*. (2019, 2020) and the sample was measured to the nearest 0.1 cm and 0.1 kg respectively for length and weight. The Geographic Information System (GIS) location of fishing operations was recorded by using Timestamp Camera application. In addition, the photos and videos of fishing operations were also recorded.

Fishing location and information

The location of fishing operation of all fishing vessels involved in this study is shown in Figure 2. Longline fishing operations in the waters of Kuala Dungun typically involve two sets of longlines, each equipped with 70 hooks. The fishing activity begins at around 3:30 a.m. and lasts for approximately five hours, including 30 minutes of travel time each way between the fishing ground and the landing site. Fishers use small boats powered by 15 hp outboard engines. Barracuda (*Sphyraena* spp.), a low-value species priced at around RM 1–2 per kg that is commonly used as bait. Fishing operations are conducted within a range of 0.3 to 4 nautical miles (nm) from shore, with the farthest sites extending up to 8 nm, at depths between 20 and 30 m. The primary targets are high-value demersal species such as groupers, snappers, croakers, and catfishes.

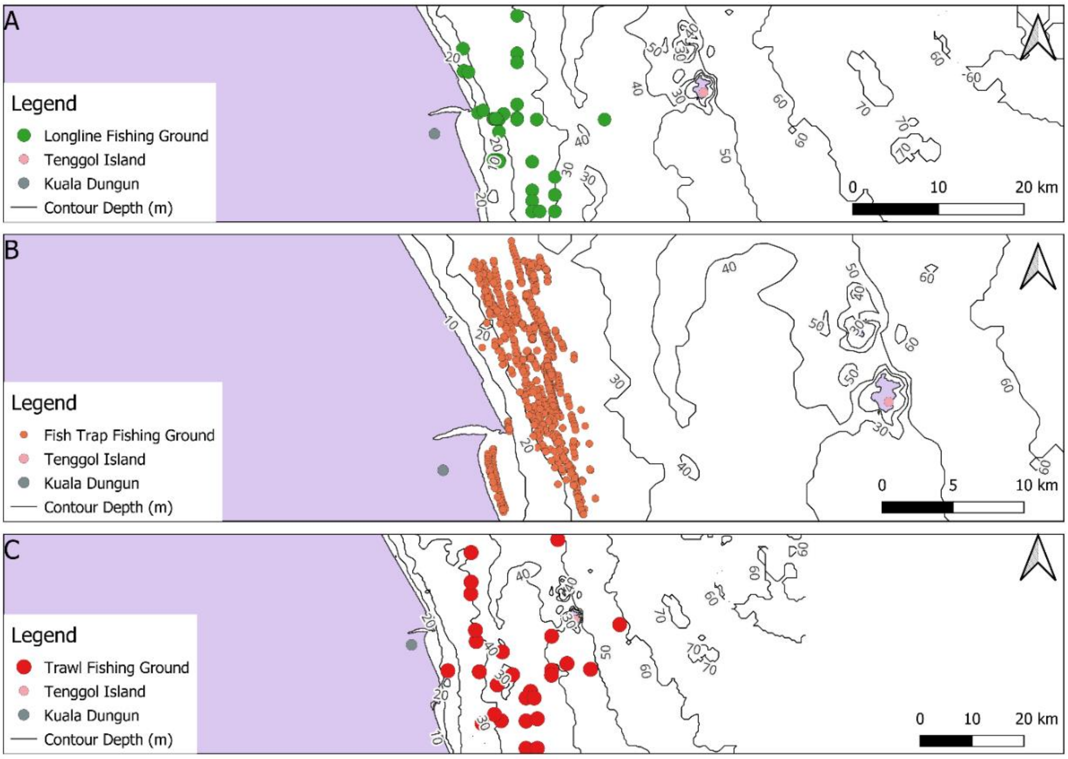

Figure 2: The location of fishing activity in Kuala Dungun waters, Fish trap (A), Longline (B), and Trawl (C).

Fish trap operations in the waters of Kuala Dungun typically involve an average of 40 traps. Each trap measures approximately 3 feet in width, and height, and 4 feet in length, and is fitted with eight bricks as sinkers and an empty bottle attached to the top to serve as a float. The target species vary seasonally: from June to August, fishers primarily target pharaoh cuttlefish (*Acanthosepion pharaonis*), while from September to November, the focus shifts to threadfin breams (*Nemipterus* spp.) and groupers (*Epinephelus* spp.), using baited traps. The operations are conducted using fiberglass vessels measuring about 7.14 meters in length, 2.14 m in width, and 0.35 m in depth, with a gross register tonnage (GRT) of 1.51 and powered by a 60-horsepower outboard engine. Fishing usually begins at 6:30 am. and concludes at 12:00 pm., within a range of 0.3 to 4 nm from shore, at depths between 10 and 30 m.

Trawl net operations in the waters of Dungun use nets measuring 5.5 m in length, with a 6-meter opening and a 1.5-inch cod end. The vessels employed are approximately 13.22 m long, 3.35 m wide, and 1.11 m deep, with a gross register tonnage (GRT) of 13.89 and powered by a 190 hp inboard engine. Each trawling haul lasts about three hours, conducted at a speed of around 4 knots, typically 5 nm from the coastline. The main target species are loliginid squids, prized for their high market value (RM 25–35 per kilogram).

Data analysis

In this study, the CPUE was calculated to observe the relative abundance of sharks and rays by fishing gear where:

$$CPUE= \frac{\text{Catch}}{\text{Effort}}$$

Where, Catch = Total Landing of Species A (individuals) and Effort = Total effort of fishing (Hours/Days/Haul).

The recorded coordinates, CPUE and the types of fishing gear then were sorted and converted into comma separated value files (CSV) for conversion into Quantum Geographic Information System (QGIS) version 3.28.11 software for Hotspot Analysis (Getis and Ord, 1992; Oxoli *et al*., 2016; Hurley *et al*., 2019; Sobri *et al*., 2022). The determination criteria of hotspot areas were based on Getis-ord GI* statistic where every fishing point were weighted based on CPUE/hour of sharks and rays caught by calculating the Z-score and P-value in the plot of 500 m^2 (Table 1).

Results

Landing of sharks and rays

A total of 282 individuals of sharks and 92 individuals of rays from four species of sharks and five species of rays were recorded during onboard observation from three fishing gears (Table 2). The most caught sharks were *Carcharhinus sorrah*, which was caught from longline fisheries and *Chiloscyllium punctatum* and *Chiloscyllium hasseltii* that were caught by fish trap.

Table 1: The determination criteria of hotspot area based on the Getis-Ord Gi statistic.

	Not significant: Z-score >=1.65 & <=1.96, p-value => 0.1
	Hotspot 90% confidence level: Z-score >=1.65 & <=1.96, p-value <=0.1 & =>0.05
	Hotspot 95% confidence level: Z-score >=1.96 & <=2.58, p-value <=0.05 & =>0.01
	Hotspot 99% confidence level: Z-score >=2.58, p-value <= 0.01

On the other hand, the most caught rays were *Neotrygon varidens* and *Taeniura lymna* by fish trap, *Maculabatis* spp., by trawl net, and *Maculabatis* spp. from longline vessels. As for fish traps, the landings of sharks and ray were dominated by bamboo sharks (*C. punctatum* and C. *hasseltii*) and Mahogany maskray (*Neotrygon varidens*) along with Bluespotted lagoon ray (*Taeniura lymna*). Bamboo sharks were observed consistently throughout the year while *N. varidens* were observed from January to July. *T. lymna* landings were fluctuated along the study period.

Catch per unit effort of sharks and rays

The results on the catch per unit effort of sharks and rays for each fishing gear was presented in Table 3.

The highest catch per unit effort per hour by longline were *C. sorrah* with CPUE ranging from 0.83 individuals/hour in July 2023 to 14 individuals/hour in October 2023. *C. punctatum* only recorded in October 2023 with 0.5 individuals/hour while for *C. hasseltii* were 0.17 individuals/hour to 0.67 individuals/hour. As for rays, *Maculabatis* spp. CPUE were ranging from 0.17 individuals/hour to 0.83 individuals/hour while R. australiae and *H. uarnak* were both 0.17 individuals/ hour, respectively.

The CPUE of *C. punctatum* and *C. hasseltii* by trap ranged from 0.04 individuals/hour to 0.38 individuals/hour and 0.04 individuals/hour to 0.21 individuals/hour respectively. The highest CPUE observed in November 2023 for *C. punctatum* and in December 2023 and May 2024 for *C. hasseltii*. As for rays, *T. lymna* CPUE ranged from 0.04 individuals/hour to 0.29 individuals/hour with the highest in September 2023 while *N. varidens* ranged from 0.04 individuals/hour to 0.5 individuals/hour with the highest in January 2024. Lastly, the CPUE of *Maculabatis* spp. from trawl net ranged from 0.33 individuals/hour to 1.33 individuals/hour with the highest in May 2024.

Table 2: Landings of sharks and rays by fishing gear.

Fishing Gear	Species	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
Longline	*Carcharhinus sorrah*	-	5	9	48	84	27	2	-	17	-	-	-	192
	Carcharhinus spp.	-	-	-	-	1	-	-	-	-	-	-	-	1
	Chiloscyllium punctatum	-	-	-	-	3	-	-	-	-	-	-	-	3
	Chiloscyllium hasseltii	-	-	1	3	1	-	-	-	-	-	4	-	9
	Rhynchobatus australiae	-	-	1	-	1	-	-	-	-	-	-	-	2
	Maculabatis spp.	-	-	2	5	2	1	-	-	1	-	-	-	11
	Himantura uarnak	-	-	-	-	-	-	-	-	-	-	1	-	1
Fish Trap	*Chiloscyllium punctatum*	-	2	2	3	2	9	6	7	5	1	4	1	42
	Chiloscyllium hasseltii	1	2	1	4	2	4	5	2	3	2	4	5	35
	Taeniura lymna	-	-	-	7	2	-	-	-	2	-	1	-	12
	Neotrygon varidens	3	2	-	1	-	-	1	8	2	12	3	2	43
Trawl	*Maculabatis* spp.	-	-	1	-	1	-	-	6	-	-	2	4	14

Hotspot area of sharks and rays

During the study period, most of the sharks and rays were caught in coastal area of less than 4 nautical miles except for trawlers which operated up to 8 nm.

Figure 3 showsthe location of where all the dominant sharks and rays species were caught. Although *Maculabatis* spp. caught mostly at coastal area, it also caught further from shore by trawlers.

Table 3: Catch per unit effort of sharks and rays by fishing gear.

Fishing Gear	Species	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Longline	*Carcharhinus sorrah*	-	0.83	1.50	8.00	14.00	4.50	0.33	-	2.83	-	-	-
	Carcharhinus spp.	-	-	-	-	0.17	-	-	-	-	-	-	-
	Chiloscyllium punctatum	-	-	-	-	0.50	-	-	-	-	-	-	-
	Chiloscyllium hasseltii	-	-	0.17	0.50	0.17	-	-	-	-	-	0.67	-
	Rhynchobatus australiae	-	-	0.17	-	0.17	-	-	-	-	-	-	-
	Maculabatis spp.	-	-	0.34	0.83	0.34	0.17	-	-	0.17	-	-	-
	Himantura uarnak	-	-	-	-	-	-	-	-	-	-	0.17	-
Fish Trap	*Chiloscyllium punctatum*	-	0.08	0.08	0.13	0.08	0.38	0.25	0.29	0.21	0.04	0.17	0.04
	Chiloscyllium hasseltii	0.04	0.08	0.04	0.17	0.08	0.17	0.21	0.08	0.13	0.08	0.17	0.21
	Taeniura lymna	-	-	-	0.29	0.08	-	-	-	0.08	-	0.04	-
	Neotrygon varidens	0.13	0.08	-	0.04	-	-	0.04	0.33	0.08	0.50	0.13	0.08
Trawl	*Maculabatis* spp.	-	-	0.33	-	0.33	-	-	0.66	-	-	0.66	1.33

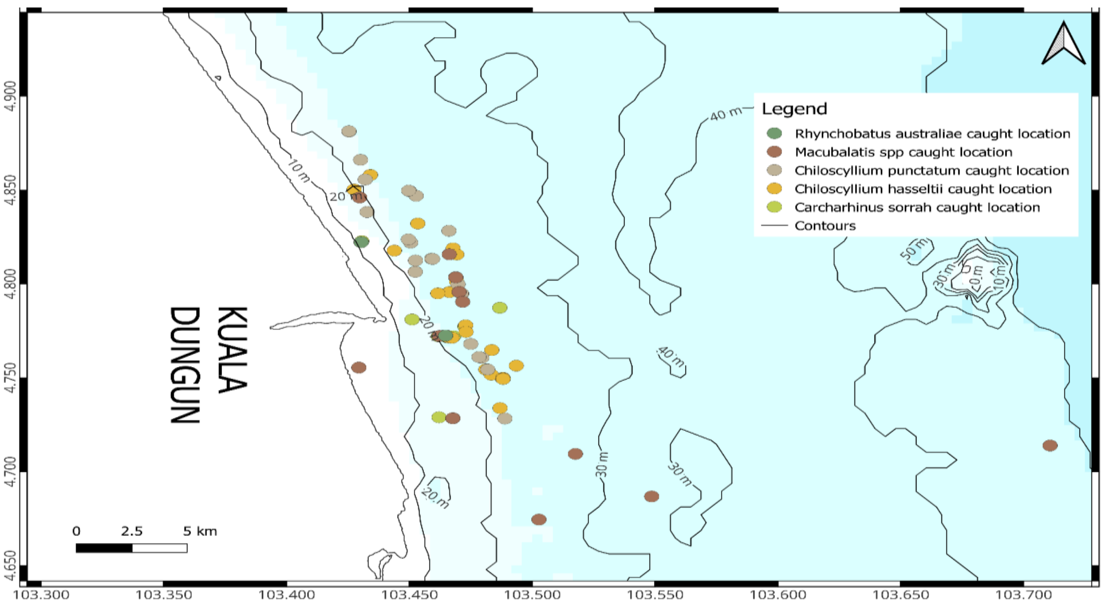

Figure 3: Location of the occurrence of the dominant sharks and rays caught during the study period.

The analysis of hotspot areas of the most dominant shark and rays species was presented in Figs. 4 to 8.

Spot-tail shark (*Carcharhinus sorrah*) hotspot shows that there are nineteen 99% confidence level hotspot area plot and two 95% confidence level hotspot area plot with each box represent 100m X 100m grids. The Spot-tail shark (*C.sorrah*) caught mostly in the areas where FADs are located (Fig. 4). The difference between 99%, 95% and 90% confidence level are based on the calculated Z-score and p-value.

Brownbanded Bambooshark (*Chiloscyllium punctatum*) hotspot shows that there are four 99% confidence level hotspot area plot with each box represent 100m X 100m grids. Brownbanded Bambooshark (*C. punctatum*) caught mostly in the areas where bottom type was sandy and muddy (Fig. 5).

Hasselt's Bambooshark (*Chiloscyllium hasseltii*) hotspot shows that there are six 99% confidence level hotspot area plot with each box represent 100m X 100m grids. Hasselt's Bambooshark (*C. hasseltii*) caught mostly in the areas where bottom type was sandy and muddy (Fig. 6).

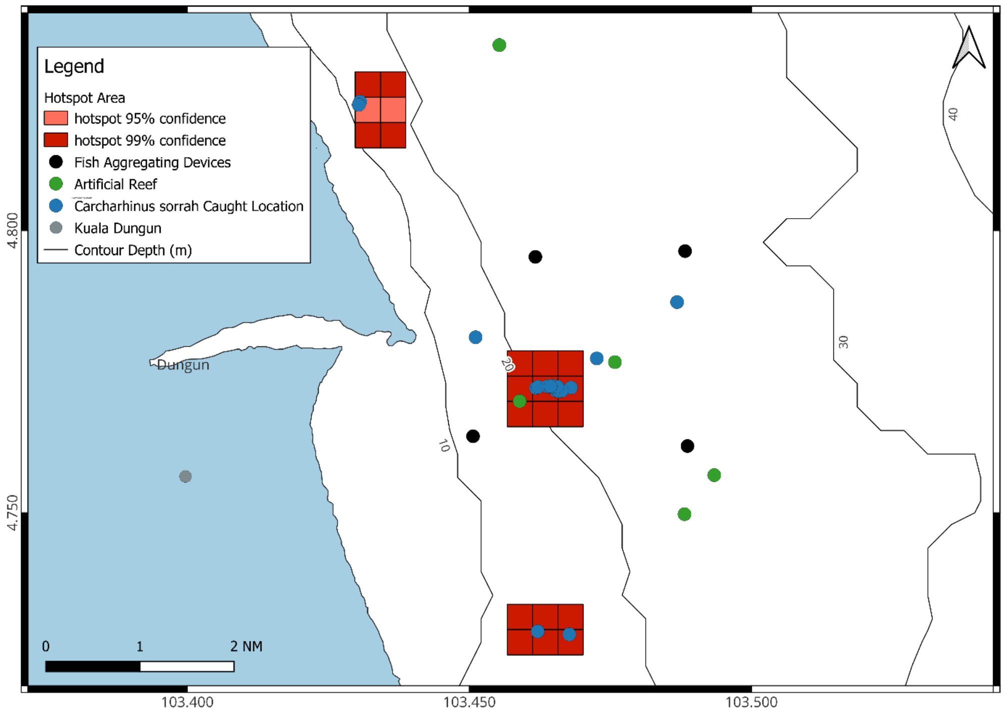

Figure 4: Hotspot area of *Carcharhinus sorrah* in the waters of Kuala Dungun.

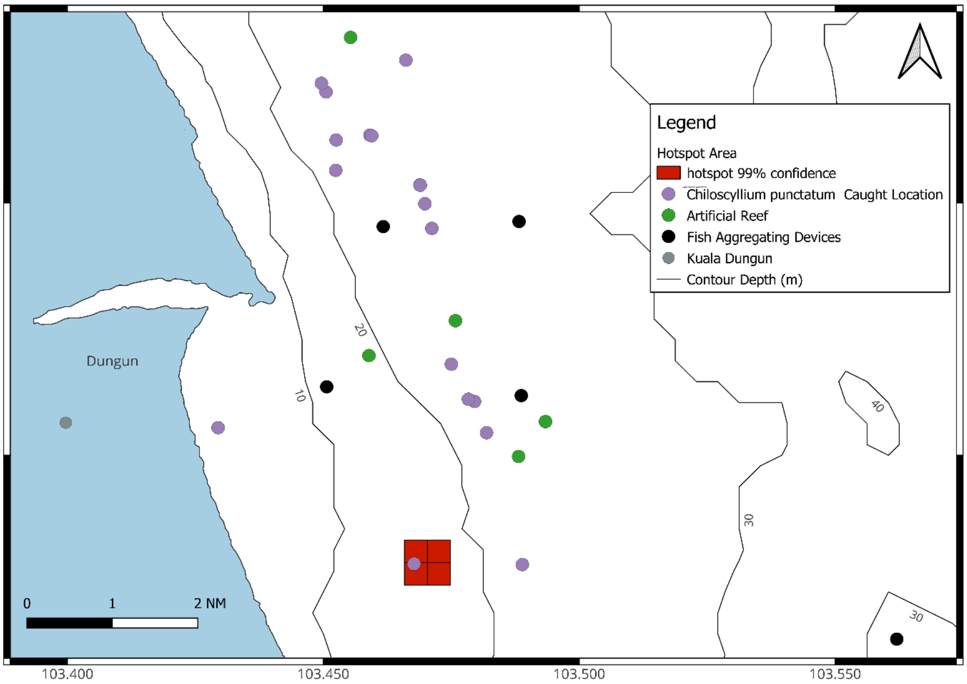

Figure 5: Hotspot area of *Chiloscyllium punctatum* in the waters of Kuala Dungun.

Whitespotted Wedgefish (*Rhynchobatus australiae*) hotspot shows that there are four 99% confidence level hotspot area plot with each box represent 100m X 100m grids. Whitespotted Wedgefish (*R. australiae*) caught mostly in the areas where FADs are located (Fig. 7).

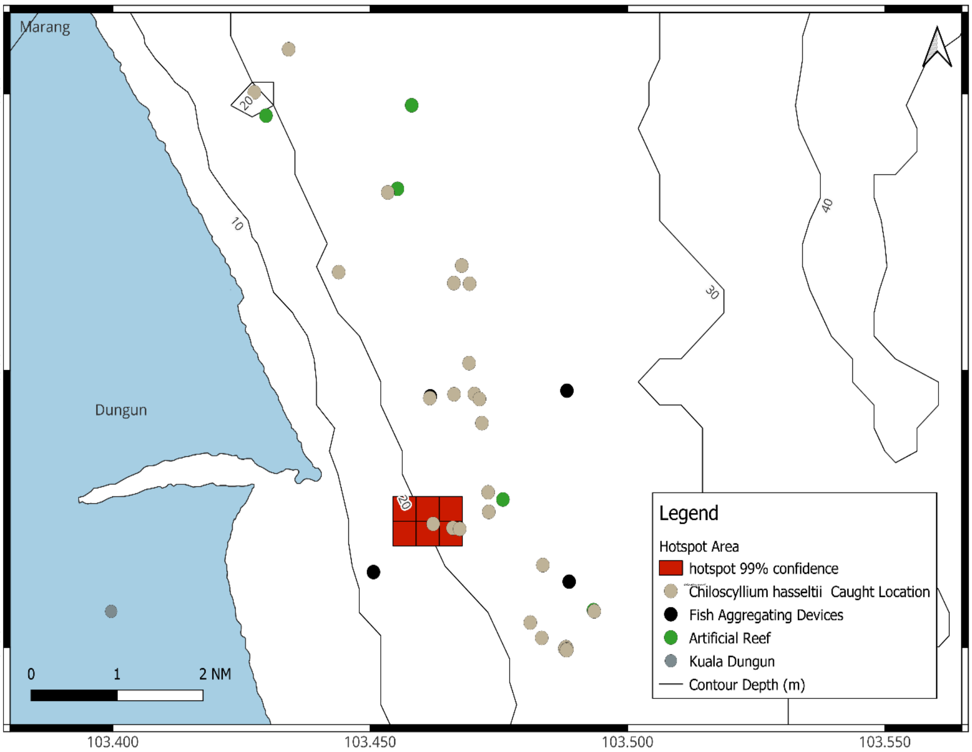

Figure 6: Hotspot area of *Chiloscyllium hasseltii* in the waters of Kuala Dungun.

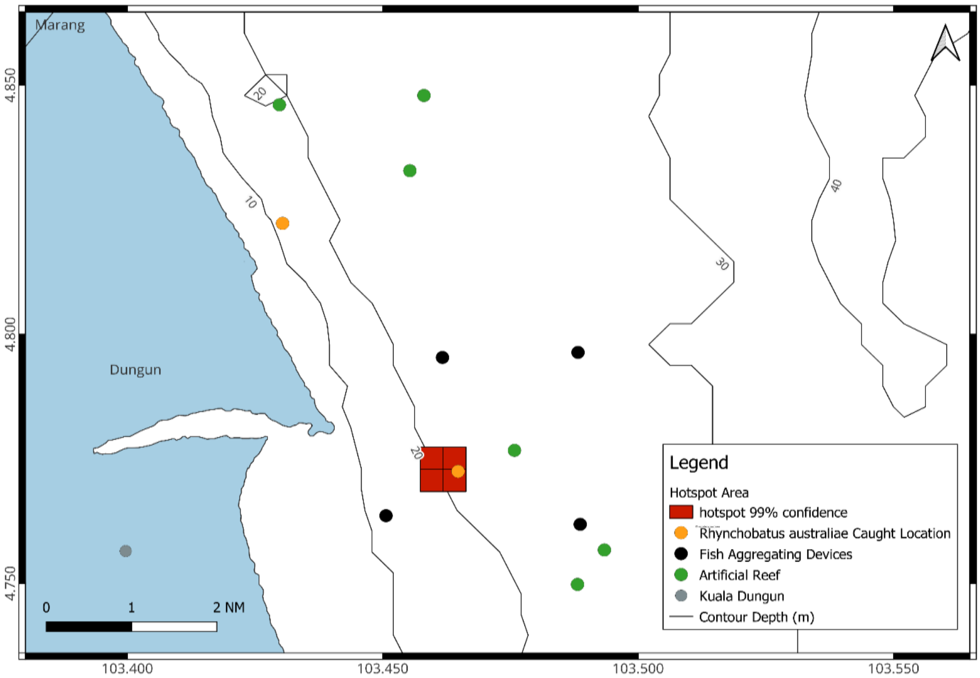

Figure 7: Hotspot area of *Rhynchobatus australiae* in the waters of Kuala Dungun.

Whitespotted Whipray (*Maculabatis* spp.) hotspot shows that there are thirty-one 99% confidence level hotspot area plot, five 95% confidence level hotspot area plot, and one 90% confidence level hotspot area plot with each box represent 100m X 100m grids. Whitespotted Whipray (*Maculabatis* spp.) caught mostly in the areas where FADs are located (Fig. 8).

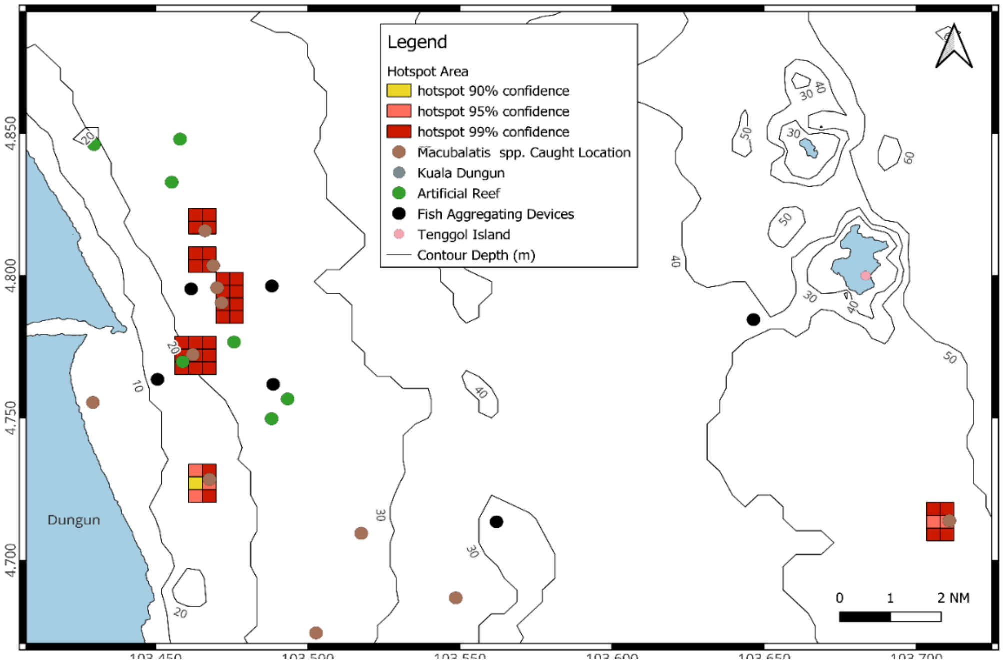

Figure 8: Hotspot area of *Maculabatis* spp. in the waters of Kuala Dungun.

Discussion

Hotspot analysis in fisheries can be defined as fish aggregation on a specific area (Wilen, 2004; Giacomo *et al*., 2018). Identifying hotspot areas are crucial to propose effective management and conservation measures as the location and fishing pressure to be identified (Hall and Close, 2007; Lewison *et al*., 2009; Jalali *et al*., 2015; Giacomo *et al*., 2018).

During the study period, *Carcharhinus sorrah* was extensively caught by longline fisherman with the average weight of 3- 4 kg per individual and the total length ranged from 66.4 to 91.3 cm. This suggest that *C. sorrah* caught were ranged from juveniles (60-89cm) and nearing mature stage (90-118cm) (Ebert *et al*., 2021). Although rays were fewer in numbers, but their size is larger such as *Maculabatis* spp. and *R.australiae* which weights around 12 to 24 kg with the disc length ranged from 55 to 77 cm and total length ranged from 112 to 122 cm, respectively.

In this study, *C. sorrah* hotspot were identified near the artificial reef and nearshore area which supported by findings from other studies, where *C. sorrah* important habitat includes bay areas and coral reef (Knip *et al*., 2012a; Samusamu *et al*., 2021). For *Chiloscyllium punctatum* and *C. hasseltii*, same pattern of hotspot was also observed near artificial reef and nearshore waters. According to Arai and Azri, (2019) and Fahmi *et al*. (2021), *C. punctatum* and *C. hasseltii* prefers sandy and muddy bottom as they are inshore bottom dweller supporting the findings of this study. *Rhynchobatus australiae* and *Maculabatis* spp. hotspots were observed nearshore and artificial reef. *R. australiae* favours shallow warm coastal water, mud bottom and coral reefs (Last *et al*., 2016; Kyne *et al*., 2020: Then *et al*., 2025). *Maculabatis* spp. also dwells at the sandy and muddy bottom of shallow coastal waters (Last *et al*., 2016; Shabani *et al*., 2024).

Trawl net vessel that involved in this study surprisingly have very little bycatch of sharks and rays which contradict with previous studies such as by Hilmi *et al*. (2017); Arai and Azri (2019); and Yusof *et al*. (2021) which all mentioned that trawlers landed high volume of sharks and ray as bycatch. The reason for the low numbers of sharks and rays landed by trawl nets probably due to the main target of the trawl net are squids and operated along the pipeline ridge in the Dungun Waters. The trawling method during this period which operated slightly midwater to avoid the pipeline may contributed to the low number of sharks and rays caught. Midwater trawling has been known to be effective in minimizing bycatch as suggested by Reed *et al*. (2017) and Azeez *et al*. (2021). Further study onboard trawl vessels should be conducted in the future to further understand the relationship between the method of operation with the volume of bycatch especially for sharks and rays.

The findings from this study suggested that the hotspot of *C. sorrah, C. punctatum, C. hasseltii, R. australiae*, and *Maculabatis* spp. positively correlated with the distribution of FADs and artificial reefs. Most of the sharks and ray caught and their hotspot are in the vicinity of either FADs and artificial reef. Interestingly, during this study, a few egg cases of bamboo shark (*Chiloscyllium* spp.) were observed attached to fish trap (Fig. 9). Usually, bamboo shark deposited their egg cases on the sea bed whether sheltered or deserted and also attached it to bottom marine plants with maximum 3 months incubation period (Compagno, 2001; Lim *et al*., 2021). Paxton *et al*. (2020) suggested that artificial reef tends to aggregate large predator such as sharks and ray but it is unknown whether the sharks and ray simply aggregating or spawning at the area. Additionally, Becker *et al*. (2024) suggested that there was no evidence of any shark become resident at the artificial reef. Hence, further observation should be conducted in the future to confirm the residency of shark and rays at the artificial reef.

Figure 9: Bamboo shark (*Chiloscyllium* spp.) egg case attached to a fish trap (circled).

The hotspot areas of *Carcharhinus sorrah, Chiloscyllium punctatum, Chiloscyllium hasseltii, Rhynchobatus australiae* and *Maculabatis* spp. were inshore waters and artificial reefs. Based on this finding, a few management measures should be considered such as size limits, closed seasons, and also implementing hotspot areas in marine spatial planning such as no take zones or introduction of marine protected area (Knip *et al*., 2012b; Estradivari *et al*., 2022; Chin *et al*., 2023). The findings of this study also may suggest that Kuala Dungun waters is a potential preliminary area of interest for Important Sharks and Rays Area under category C1 (Reproductive Areas) for bamboo sharks and C2 (Feeding Areas) for spot-tail sharks (Hyde *et al*., 2022; Boyd *et al*., 2025) but more information are needed to confirm.

This study presenting interesting findings related to the area of sharks and rays's aggregation on a specific area which helps in formulation Marine Spatial Planning as one of management measures for shark and rays' population.

Conclusion

This study successfully identifies the hotspots for shark and ray species in Kuala Dungun waters, with dominant species such as *Carcharhinus sorrah*, *Chiloscyllium punctatum*, *Chiloscyllium hasseltii*, *Rhynchobatus australiae*, and *Maculabatis* spp. concentrated in coastal areas and near Fish Aggregating Devices (FADs) and artificial reefs. Additionally, bamboo shark egg cases were observed attached to fish traps near FADs in the area. Given the high fishing pressure on shark and ray populations, particularly along the east coast of Peninsular Malaysia, there is an urgent need for conservation management measures. Habitat protection strategies should be prioritized based on the findings of this study. Since most sharks and rays were caught in coastal regions, the data gathered here provides essential insights for the future development of Marine Spatial Planning initiatives. The positive correlation between hotspot areas and the location of FADs and artificial reefs suggests that these structures can effectively enhance shark and ray populations. Consequently, incorporating additional FADs and artificial reefs into future fisheries management plans could benefit not only sharks and rays but also other commercially important species. Future research should focus on expanding the study area and including a broader range of fishing vessels and gears to gain a more comprehensive understanding of the distribution and critical habitats of sharks and rays.

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Conflicts of interest

The authors have no conflicts of interest to disclose

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