Establishment and Operation of a Regional System of Fisheries *Refugia* in the South China Sea and Gulf of Thailand

DEVELOPMENT OF A REFUGIUM MANAGEMENT PLAN FOR THE MUD SPINY LOBSTER (*Panulirus polyphagus*)

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DEVELOPMENT OF A REFUGIUM MANAGEMENT PLAN FOR THE MUD SPINY LOBSTER (*Panulirus polyphagus*) AT TANJUNG LEMAN, JOHOR

INCEPTION REPORT

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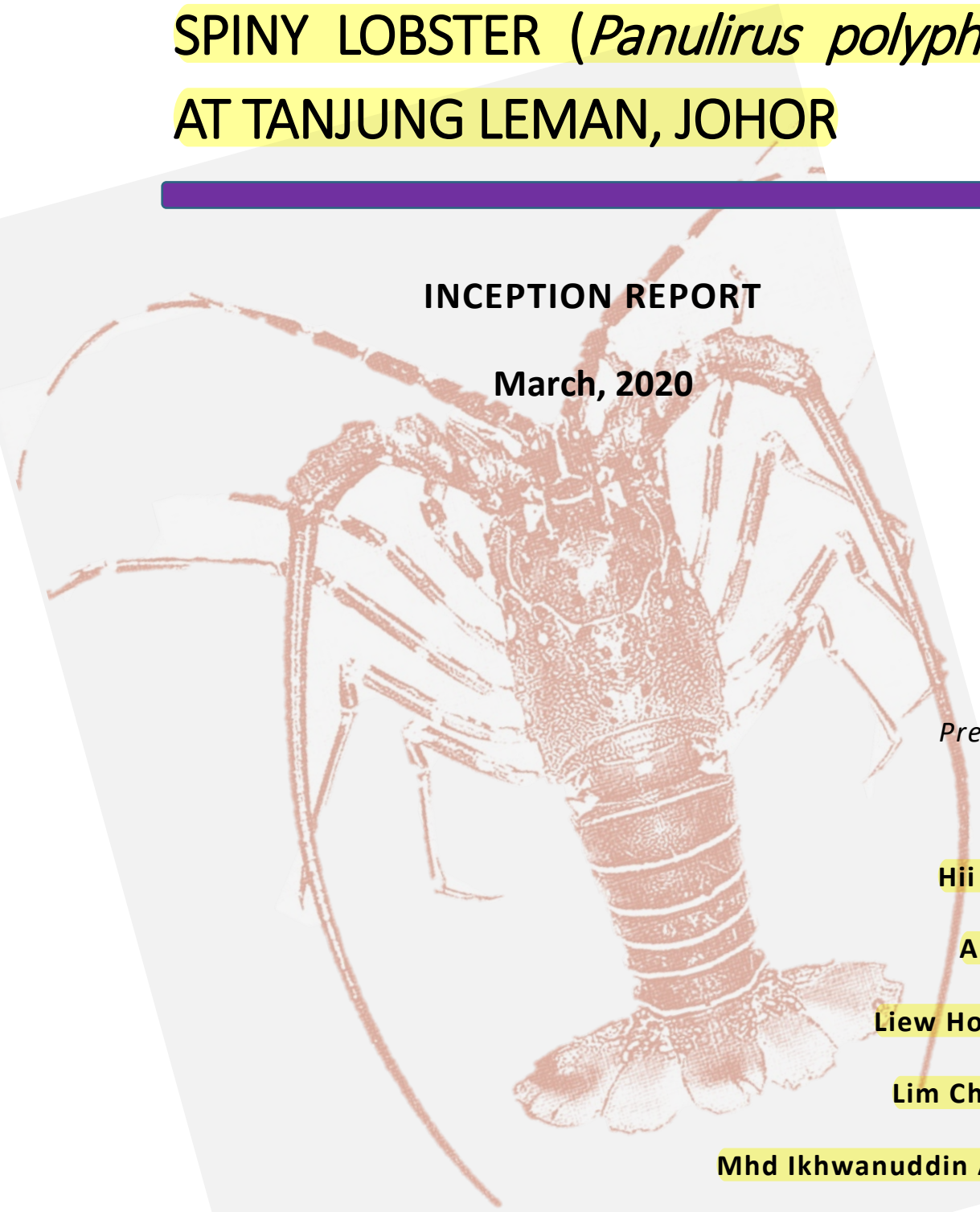

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LIST OF ABBREVIATION

AR	Artificial Reef
DOFM	Department of Fisheries Malaysia
MT	Metric tonnes
Tg.	Tanjung
FT	Federal Territorial
Kg.	Kampung
MPA	Marine Protected Area
SEAFDEC	Southeast Asian Fisheries Development Center
OTU	Operational Taxonomy Unit
i.e.	id est

PREAMBLE

The concept and term refugium (plural 'refugia') have been used in the conservation biology particularly in reference to refugium from predation as reported by (Elton, 1939) and other form of threats including glaciation, climate change, wildfire (Keppel et al., 2015; Kolden et al., 2017). The concept of fisheries refugia was widely review and practiced in ASEAN together with the Southeast Asian Fisheries Development Center (SEAFDEC). The fisheries refugia is deemed to be a workable solution for integrating fisheries and habitat management in the context of small-scale fisheries (Peterson et al., 2013). Information pertinent to the fisheries refugia in this region was systematically documented in https://fisheries-refugia.org/.

The fisheries refugia gained significant attention as it provides an alternative approach to the stringent no take zone in the Marine Protected Area (MPA). In 2016, Mohd Ghazali et al., reported the intension of the Department of Fisheries Malaysia (DOFM) to establish refugia for spiny lobster at Tanjung Leman, Johor and penaeid shrimp at Kuala Baram, Sarawak. Population of both the species have shown a declining trend since the last two decades as indicated in the DOFM fish landing database.

Selwood and Zimmer (2020) conducted a systematic review which provide a transparent, objective review on the implementation of refugia concept specifically at a temporal and spatial scale. The implementation of refugia in the protection of Operational Taxonomy Unit require the conservation manager to identify, prioritise, protect and enhance, or even create places that sustain the pervasive of the OTU. As a whole, to establish an efficient refugium program, there are three major components that needed to be taken into consideration i.e. the species, targeted area and the threats. Each component shall be addressed and prioritized for the establishment of refugium.

The mud spiny lobster (*Panulirus polyphagus*) is one of the favourites seafood exported from Malaysia. There are limited studies on the mud spiny lobster by the local scientific community as compared to the rock lobster (*Jasus edwardsii*) and common spiny lobster (*Panulirus vulgaris*). Although there are relatively less studies on the mud spiny lobster in this region, the *Panulirus polyphagus* is the predominant lobster reported in the east coast of the Peninsular Malaysia, from Kelantan in the North, down to Johor in the South (Alias et al., 2000). Noor Hanis and Siow (2019) reported the landing trend of this species begin showing a declining trend since early 2010s', probably associated with the harvesting pressure. The declining landing trend suggested the needs to protect this spiny lobster to be protected to sustain the species in the area.

Reproduction Cycle

The spiny lobster is a carnivorous predator feeding on sluggish and easily captured prey at relatively shallow water (Kanciruk, 1980; Chan, 1998). The lobster in general occurs in shallow waters that is less than 40 m depth. However, there are instances where the spiny lobster was also found in deeper waters at about 90m depth (Ikhwanuddin et al., 2014). To the best of our knowledge, there were no reports on the detailed life cycle of the mud spiny lobster, *Panulirus polyphagus*, nevertheless, there is a generic life cycle reported on the *Panulirus* spp. as given in **Figure 1**. The spiny lobster (*Panulirus* spp.) has adapted the reproductive strategy of having a high fecundity with low survival of the progeny in a highly variable environment. The *Panulirus* lobster exhibits sexual dimorphism and the reproductivity is different from species to species (Pollock 1997; Ikhwanuddin et al., 2014; Quackenbush, 1994). The size of the female brooder will affect the number of broods as well as the total number of eggs. During mating, the male deposits spermatophore, a capsule or mass spermatozoa on the female's belly, from which the eggs are externally fertilised (Cruz and Bertelson, 2009). In the *Panulirus cygnus*, they mate after the female moults because the fresh hair-like structures on the abdominal swimming legs after moulting, gears for egg attachment (Kittaka et al., 1994). After being extruded and fertilised from the ovary, the eggs are adhered to the filaments of the female's pleopods and carried until spawning. The lobster eggs hatches after 4 – 8 weeks into a planktonic phyllosoma. The body of the phyllosoma is dorso-ventrally compressed and has well-formed multispinose appendages. The phyllosoma will drift with the sea currents, and after several stages of moulting, the phyllosoma develops into a peuruli, a miniature and transparent lobster and starts to swim and settle in a benthic environment. The pueruli settlement behaviour can result from responding over a complex combination of stimuli such as salinity, turbidity, nutrients, tidal energy and currents. Habitat selection by puerulus is strongly influenced by the three-dimensional structure and architectural complexity of the seabed and they have often been found sheltering in rock crevices or holes on the reefs overgrown with macroalgae and seagrasses (Priyambodo et al., 2015; Siow et al., 2018). The spiny lobster has a prolonged planktonic stage. Matsuda et al., (2006) reported 244 days larval stages for *Panulirus penicillatus*, while Matsuda and Yamakawa (2000) reported 296 days planktonic stages for *Panulirus longipes* under captive conditions. Due to its long planktonic stage, distribution of the spiny lobster can be widely dispersed and predominantly regulated by the sea current circulation pattern.

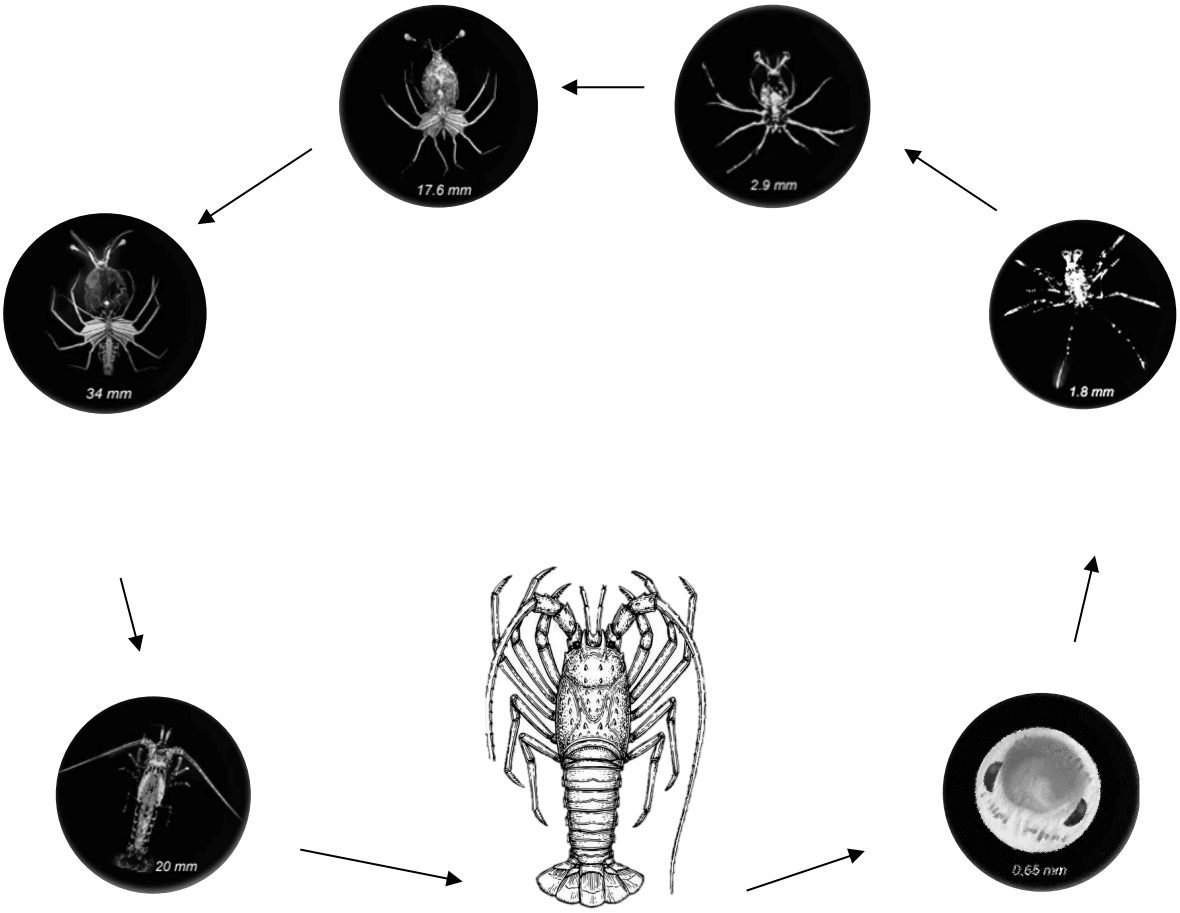

Figure 1: General life cycle of spiny lobster *Panulirus* spp. (Modified and adapted from marinewaters.fish.wa.gov.au)

Distribution of Lobster in Malaysia

In Malaysia, studies on spiny lobsters are fairly limited. Most of the reports on these lobsters were focused mainly on studies in the Johor Straits, east coast of Johor and Federal Territory of Labuan. There is a report on lobster resources in Sabah (Biusing and Chio, 2004), however there are not many follow up studies in Sabah. The most comprehensive reports on lobster in Malaysia are the studies conducted by DOFM – SEAFDEC, where the east coast of Johor was identified to be the area of concerns for lobsters. **Table 1** shows the list of studies on spiny lobster (*Panulirus* spp.) and the slipper lobster (*Thenus orientalis*) in Malaysia. Most of these studies were focused on reproduction and to elucidate reproductivity of the lobsters instead of population dynamics of the animals. All the studies were not established for long term monitoring. Hence, the available information on spiny lobsters in Malaysia were rather scattered. Nevertheless, all these studies have contributed to an important insight to the sustainable management of lobsters in Malaysian waters.

The *Panulirus* spp. is an important component of our commercial fisheries industry. Among the *Panulirus* spp, *Panulirus polyphagus* is the predominant species of commercial significance. **Figure 2** shows the locations where spiny lobster (*Panulirus* spp.) were reported. The mud lobster, *Thalassina* spp. are found in the mangrove area, and it is of little commercial interest.

Table 1: List of the key studies on the distribution and catch of Malaysian lobsters.

No.	Scientific names	Common names	Area found	Quantity captured	Reference
1.	*Panulirus polyphagus*	Mud spiny lobster	Southern part of east Johor coast • Teluk Ramunia • Sungai Rengit Johor Strait: • Kampung Jawa	300 individuals (Jul – Dec 2010)	Ikhwanuddin et al., 2014; Waiho et al., 2021
			Southern part of east Johor coast • Sungai Musuh	Main landing places of juvenile lobsters (102 - 220mm TL and	Alias et al., 2000

				body weight between 55 - 402g)	
			East Johor waters	7.26 kg/m^{-2} (average density)	Siow et al., 2018
			East Johor waters	0.95 kg/km^{-2} (average density)	DOFM, 2019
			Sedili, Johor	2830 individuals (Jul 2017 – Oct 2018)	Nur Hanis-& Siow, 2019
2.	*Panulirus ornatus*	Ornate spiny lobster	Labuan	2 individuals (8th & 14th Sept 2017)	Chen & Zakaria, 2018
			Sedili, Johor	1 individual (Jul 2017 – Oct 2018)	Nur Hanis-& Siow, 2019
3.	*Panulirus versicolor*	Painted spiny lobster	Labuan	2 individuals (8th & 14th Sept 2017)	Chen & Zakaria, 2018
4.	*Thenus orientalis*	Slipper lobster	East Johor waters	1.51 kg/m^{-2} (2016) 0.32 kg/m^{-2} (2017)	Siow et al., 2018
				1.29 ± 0.42 kg/km^{-2} (average density)	DOFM, 2019
5.	*Thalassina anomala*	Scorpion mud lobster	Sarawak coastal water: • Kuala Tatau • Kuala Balingian (Mukah) • Sarikei • Lingga (Sri Aman)	Not reported	Nur Nadiah et al., 2019

6.	*Thalassina* spp.	Scorpion mud lobster	Selangor • Klang-Langat Delta	Not reported	Moh et al., 2013

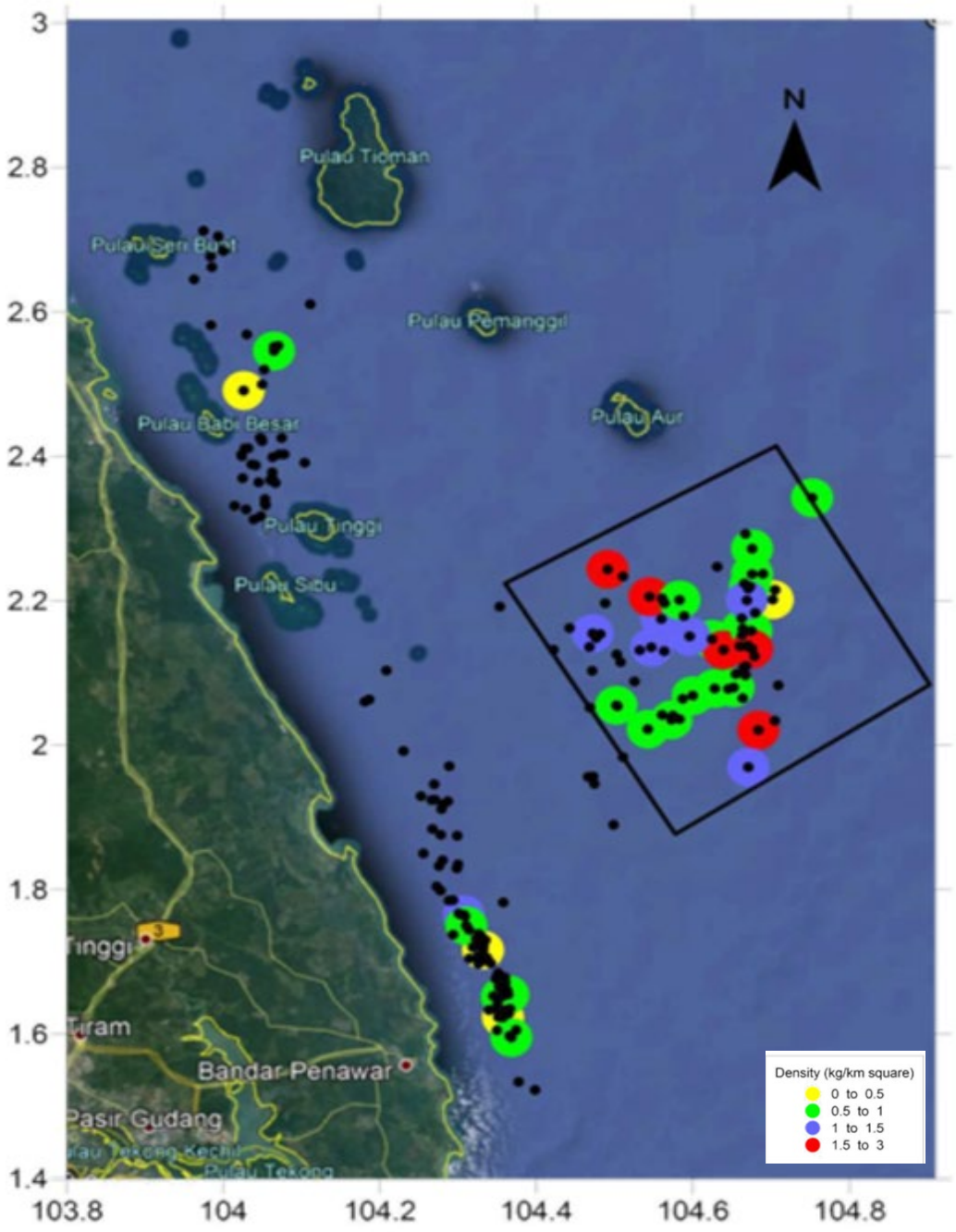

Fig 2a. Three areas *P. polyphagus* can be found in east Johor. Source: DOFM 2019

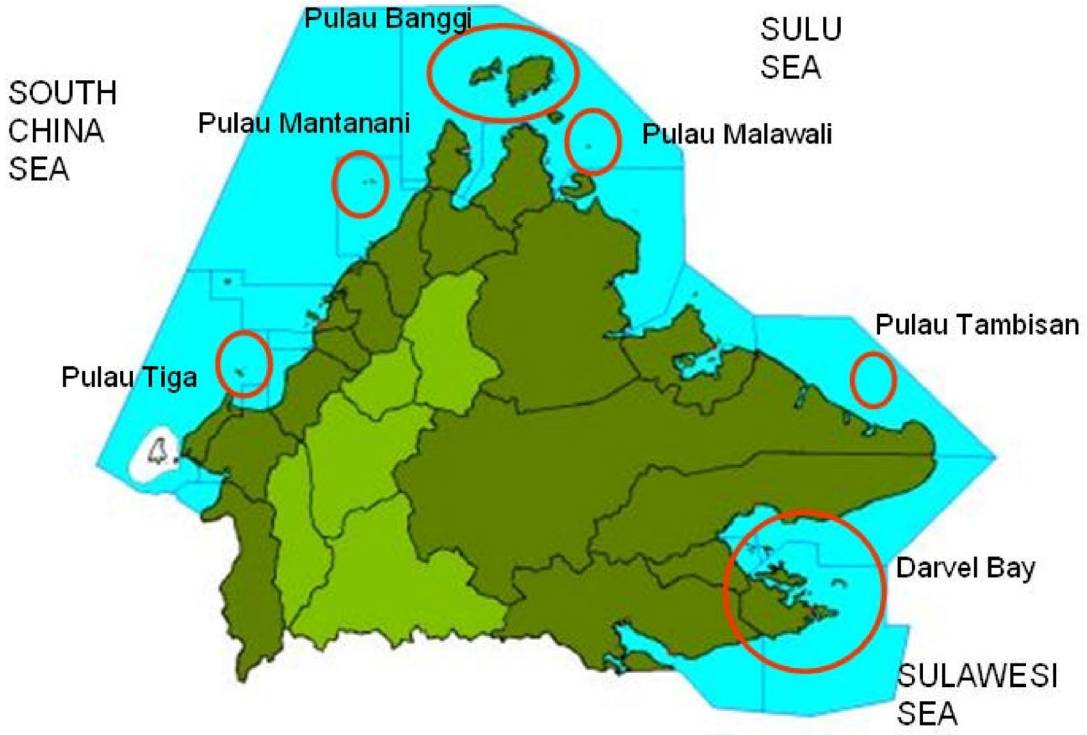

Fig 2b. Main spiny lobster fishing grounds in Sabah: Source: Biusing & Chio, 2004

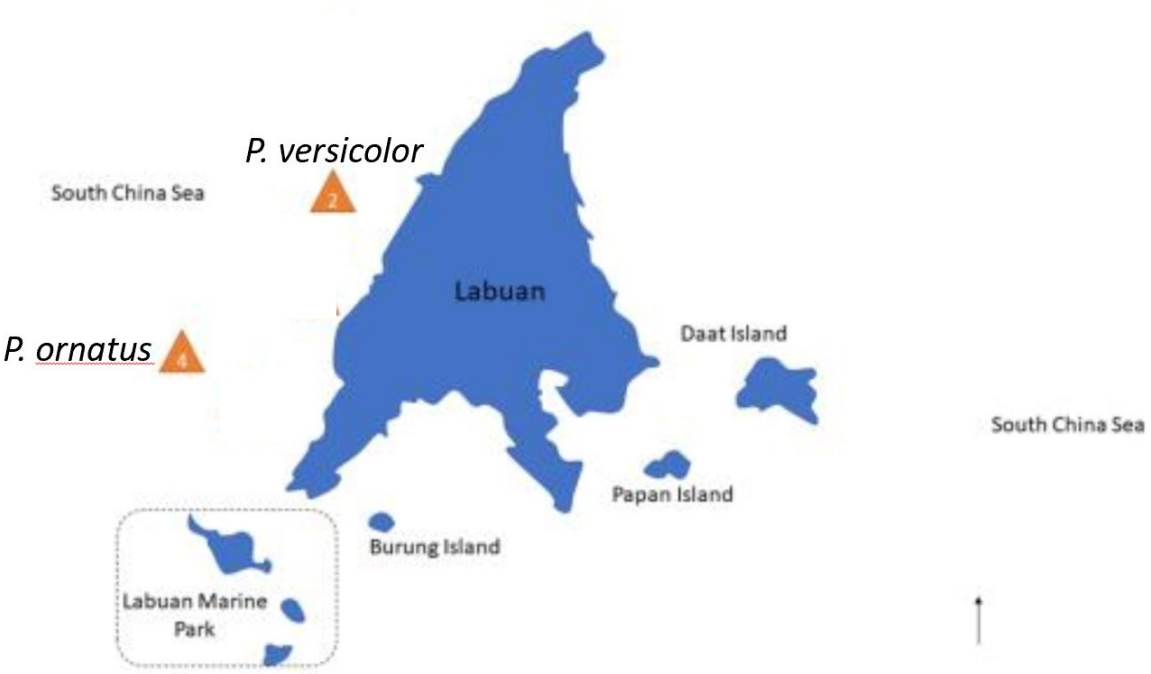

Fig 2c. Main spiny lobster fishing grounds in FT Labuan. Source: Chen & Zakaria, 2018

Figure 2: Locations of the spiny lobster (*Panulirus* spp.) reported in Malaysia

The distribution pattern of various life-stages of the mud spiny lobster in the area provides important insights on the migration route of the organisms. It is important to include area of concerns into the designated area for the fisheries refugium. In general, critical area, from the biological point of view comprises of the following criteria:

1. Organisms present in high density at a relatively small and confined area
2. Area that harbours a portion of the organisms life cycle
3. Area that served as the stop over points in the organisms' migration route

Threats to the Lobsters' Population

Based on the landing of the spiny lobster in Malaysia, the declining trend since early 2000's had triggered the push towards conserving the lobster population in Malaysia. **Figure 3** shows landing of the spiny lobster in the east coast of the Peninsular Malaysia. Habitat degradation, illegal fishing activities, and over-fishing are the key drivers that deteriorated the lobster population in the area. One of the key challenges in conserving the lobster population in the area is the overlapping of traditional fishing grounds and critical habitats of the lobster. The conflict of interest among the stake holders has presented a complicated scenario in the management effort for this fishery (Mohd Ghazali, 2016; Siow et al., 2020).

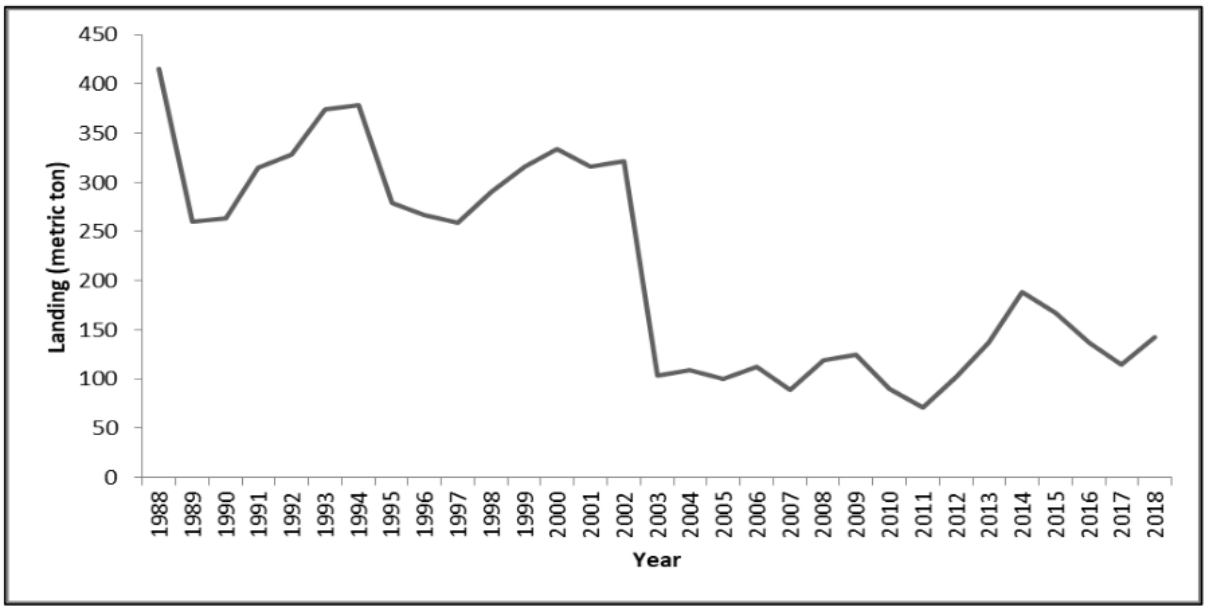

Figure 3: The landing trend of spiny lobsters in the east coast of Peninsular Malaysia during a thirty-year period (1988 – 2018) (Source: Siow et al., 2020)

The Establishment of Lobster Refugia in Malaysia

To deal with this declining resource, Zulkifli (2015) had suggested recommendations for the implementation of a lobster refugia in Malaysia. The four main components in establishing the refugia was further elaborated by Mohd Ghazali (2016). Based on the reports, the four components for establishment of refugia are:

1. Identification and management of fisheries and critical habitats
2. Improvement of the management of critical habitats for fish stocks of trans-boundary significance via national actions based on knowledge base management
3. Information management and dissemination in support of national level implementation of the concept of fisheries refugia
4. National coordination for integrated fish stocks and critical habitat management

In terms of the management structure, Zulkifli (2015), Mohd Ghazali (2016) and Siow et al., (2020), has reported the management steering framework as presented in **Figure 4**.

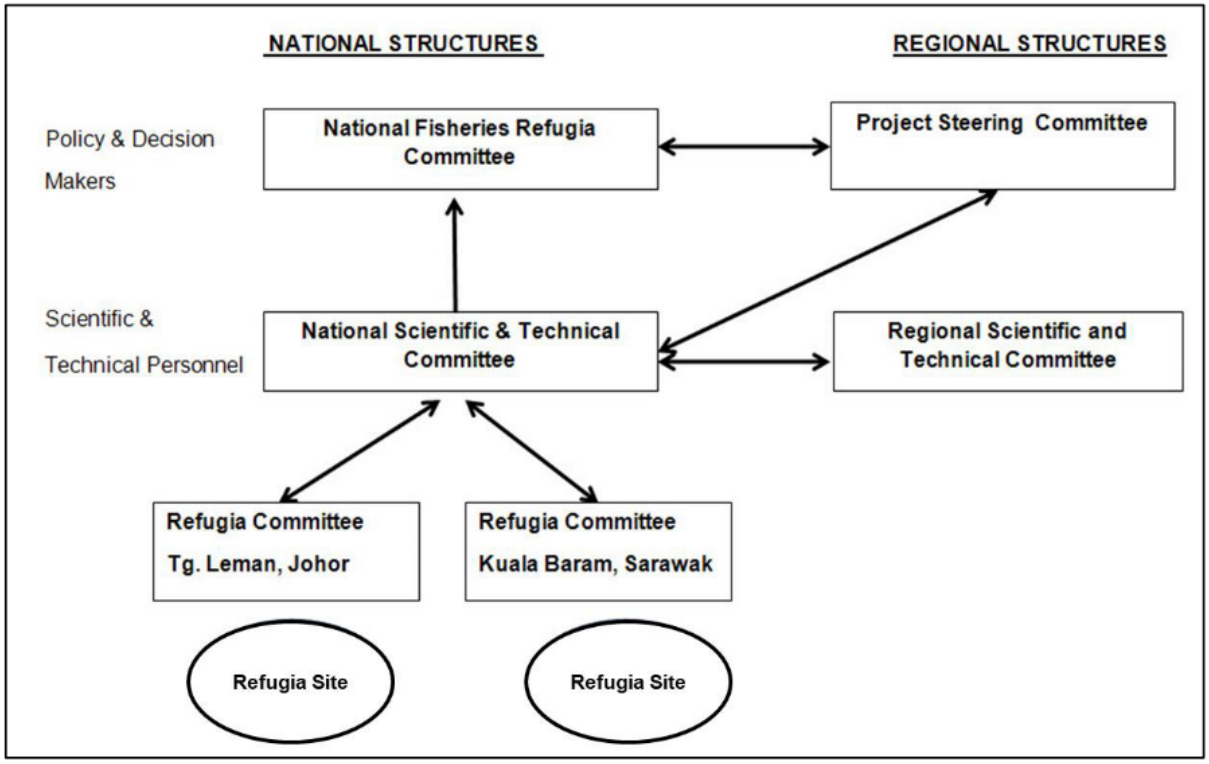

Figure 4: The national and regional coordination mechanism for the execution of Fisheries Refugia in Malaysia (Source: Siow et al., 2020)

Tanjung Leman area in Johor was identified to be the primary focus in protecting the spiny lobster via establishment of the fisheries refugia. Norhanida and Rozita (2018) then conducted a social economic survey to gauge the responses of fishers in the area. The survey covered eight fishing areas from Pahang to Johor. Based on the responses collected from 138 respondents that took part in this survey, 88.2% of the respondents agreed with the establishment of a fisheries refugia, while 85.3% of respondents agreed not to harvest lobster during its breeding season after the establishment of the refugia. More importantly, 97.1% of the respondents would like to have a role in the establishment of the fisheries refugia.

Siow et al. (2020) also pointed out the establishment of the refugia information centre to disseminate knowledge and information about the refugia and the spiny lobster, and at the same time to create awareness to the public.

All the studies pertinent to the Tanjung Leman Lobster refugia highlighted a few important points of concern summarised as below:

1. The establishment of the lobster refugia is not a repetition of a marine protected area, which is an area declared to be a no take zone at all times.
2. The lobster refugia could be declared closed during spawning seasons or any temporal time frame that is deemed to be critical for the reproduction and growth of the lobster populations.
3. The declaration of area closure should be based on scientific evidence taking into account temporal and spatial significance.
4. The fisheries refugia can be considered as a type of Ecosystem Approach to Fisheries Management (EAFM).
5. The refugia should be coordinated at the national level, participated by various agencies and stake holders.
6. The fisher's community shall have a role in the refugia management to avoid management disparity.

The current project aims to further elaborate the management plan to strategies the establishment of a lobster refugia at Tanjung Leman, Johor. All the baseline information collected via the various studies will be carefully analysed and assimilated into the design of the management plan.

GENERAL METHODOLOGY

Based on DOFMs series of publications and taking into consideration the various challenges in sustaining the lobster fishing industry in the country, the management plan of the DOFM's lobster refugia aims to achieve the following objectives:

- To strategies and design a sustainable plan to provide a long-term protection for the lobster fisheries in the country
- To outline procedures and key activities that can contributed towards optimal utilization of the lobster resource
- To prepare plans and platforms to mitigate conflict and create awareness among stakeholders
- To design long-term research on the sustainable management of the lobster fisheries
- To plan key milestones that could maintain ecological integrity of the fisheries refugia

To achieve the refugium's objectives, the current management plan endorsed the following strategies to address they key concerns highlighted in the DOFM's publication. **Table 2** and **Figure 5** elaborated the key strategies that formed the framework for lobster refugium management plan at Tanjung Leman, Johor.

Table 2: Key components of refugia and its corresponding management strategies

Component for the establishment of lobster refugia	**Strategies**	**Related Outputs**	
OTU/ Targeted species	To elaborate lobsters' biology and reproduction cycle	To identify suitable harvesting technique for sustainable fisheries	Financial Sustainability
Establishment of refugium area	To outline potential migration patterns of the spiny lobster To identify area of potential settlement of the lobster's larvae	To delineate critical area to sustain lobster population in the area	
	To identify target groups for public awareness and dissemination of information	To collect information for public awareness program	

Off-season proposal for lobster refugium	To identify strategic period for closure of lobster fishing ground in the area	To identify critical period/ time/ spawning in a year for the lobster population	
Insufficient scientific data for decision support system	To identify information gaps and method for data collection	To involve fishers in the data collection of sustainable lobster fisheries	

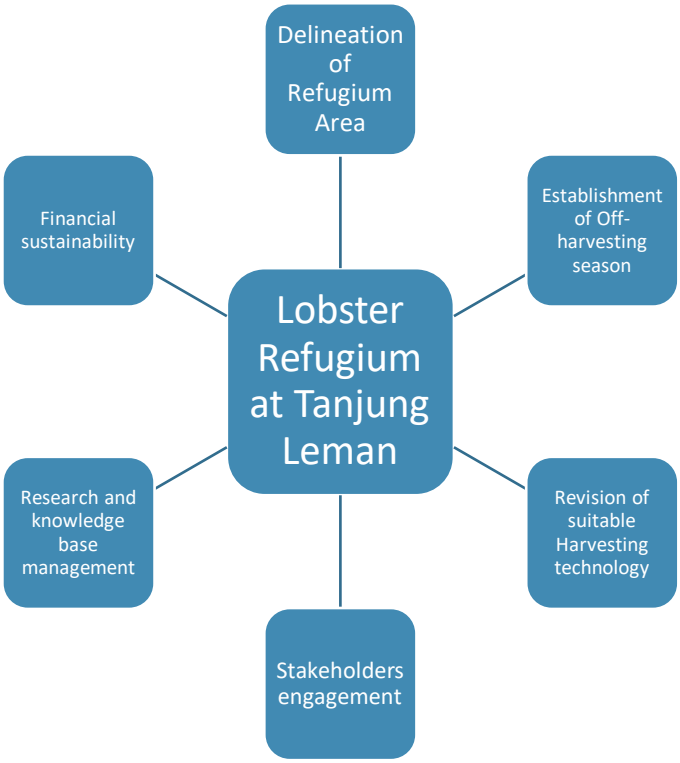

Figure 5: Components of the lobster refugium plan at Tanjung Leman, Johor

Delineation of Lobster Refugium at Tanjung Leman, Johor

Delineation of the lobster refugium at Tanjung Leman, Johor shall be based on the spatial representativeness in relation to the sustainability of lobster population. The criteria for establishing the area for lobster refugia shall include:

1. Existing lobster fishing ground
2. Critical habitats that harbour certain stage(s) of lobster's life cycle
3. Sea current circulation which plays an important role in the spread/ distribution of lobster
4. Area of ecological importance

Based on our preliminary assessment, there is a need to establish artificial reefs (ARs) to create new habitats that can act as the core of the lobster refugium. Location of spawning grounds were analysed based on studies conducted by several DOFM research including Alias and Rashidah (2000), Alias et al., (2000), Siow (2021), Siow et al., (2021a) and Siow et al., (2021b).

Alias and Rashidah (2000), reported that, juveniles of less than 200g/tail are mainly found on rocky bottoms in turbid water near river mouths at depths less than 10m, while the adults are found in deeper waters, usually about 50m deep. Mature adult, usually weight more than 400g/tail spawn in deep waters. Specific area of spawning grounds was not mentioned in this report. According to Alias et al., (2000), the mature lobsters mostly caught by trawlers. Endau is the main landing centre for the mature lobsters. Specific fishing grounds were not mentioned. The ranged sizes of mature lobsters sampled from Endau were between 218 - 310mm in total length, with the body weight between 370 - 1170g. Female lobsters carrying eggs (berried females) were also found in the catch. The composition of newly copulated female carrying sperm in their pouch or "tar spot "were high in July. Based on information, the breeding and migration season starts in July. The composition of berried females were high in August. On the other hand, the juvenile lobsters were caught mainly by the traditional fishers using drift nets and traps called 'bintoh'. Habitat, fishing ground and landing centres for juvenile lobsters are located mainly in the coastal areas of Pengerang. In the southern part of east Johor coast, Sungai Musuh is one of the main landing places of juvenile lobsters. Juvenile lobsters sampled from Sungai Musuh were measured between 102 - 220mm in total length and their body weight between 55 - 402g. No female lobsters with eggs were found in the juvenile catch.

Siow et al., (2021a), reported that during their survey in Zone B and Zone C off east Johor waters, several berried female mud spiny lobsters were caught within Zone C area at depth of more than 30m.

This survey was conducted in 2017. Locations of this survey are available. In 2019, an observer-on-board survey was conducted by the DOFM in Zone B and Zone C waters off east Johor using fishing vessels as reported by Siow (2021). The total number of mud spiny lobsters (*Panulirus polyphagus*) caught was 49 tails and 80% of total catch were from southern part of Pulau Aur within Zone C fishing area. Among the catches were berried female lobsters with ranged size between 7.5-11.7cm (Carapace Length) and weight between 470-810gm. The eggs were at the intermediate stage of development (based on the reddish color of the eggs). The density of lobster in this area were ranged between 0.87 - 1.17 kg/km^2 and the highest as compared to other areas during this survey. Details of survey areas are available.

Study on spiny lobster's landings in the east Johor-south Pahang waters by Siow et al., (2021b), recorded the differences size of spiny lobster landed at Sedili, Tanjung Leman and Endau. The size of spiny lobsters was highly related to the fishing areas and type of gears used. The fishers from Sedili and Tanjung Leman used traditional gears such as drift nets and traps and their fishing areas were in nearshore. These traditional fishers mainly caught the juvenile and young spiny lobsters which seek refuge among the rocks in the nearshore area. In contrast, the adult spiny lobsters landed at Endau were mainly bycatch from commercial trawlers operated in deeper waters within Zone B and Zone C fishing ground. Details of fishing ground of these trawlers are not available.

In general, all researchers agreed on area of spawning grounds in the east coast of Johor waters were in deeper waters or in Zone C fishing ground. Nursery grounds found to be scattered along nearshore areas from southern Pahang to Pengerang, Johor. Information on migration routes of adult females before and after spawning season is not available. Location of feeding grounds of adult lobsters also scattered along coastal areas of southern Pahang to Pengerang.

Since nursery area in Zone A are also a major fishing grounds for traditional fishers, at initial stage we propose DOFM to gazette only one spawning ground as refugia in Zone C. This strategy is to prevent social conflict with traditional fishers and at the same time the DOFM has more time for public awareness campaign activities to them. The most potential area to be gazetted was suggested by Siow (2021) in Zone C. This area was located in the southern part of Pulau Aur, in Johor waters and have a high concentration of mud spiny lobsters compared to other areas. This area also has a higher density of adult female lobsters including berried females which are ready to release its eggs. The coordinates of area suggested by Siow (2021) is shows in **Table 3**.

Table 3: Coordinates of the most potential area to be gazetted as refugia as suggested by Siow (2021) in Zone C

Position	Latitude	Longitude
Point 1	N 2° 14.670'	E 104° 21.753'
Point 2	N 2° 23.146'	E 104° 40.334'
Point 3	N 2° 04.972'	E 104° 48.686'
Point 4	N 1° 56.441'	E 104° 30.137'

In term of management and monitoring purposes during enforcement activity by the DOFM officers and for good memories for fishing vessel skippers, we will review all coordinates suggested by Siow (2021). Tentatively, we targeted the area as shows in **Figure 6**, coordinate as listed in **Table 4** which cover 500nm^2 of Zone C fishing area (25 nm X 20 nm). The targeted area covered most of the area proposed by Siow (2021).

Table 4: Coordinates of proposed refugia area in Zone C

Position	Latitude	Longitude
Point 1	N 1° 55.000’	E 104° 30.000’
Point 2	N 2° 20.000’	E 104° 30.000’
Point 3	N 1° 55.000’	E 104° 50.000’
Point 4	N 2° 20.000’	E 104° 50.000’

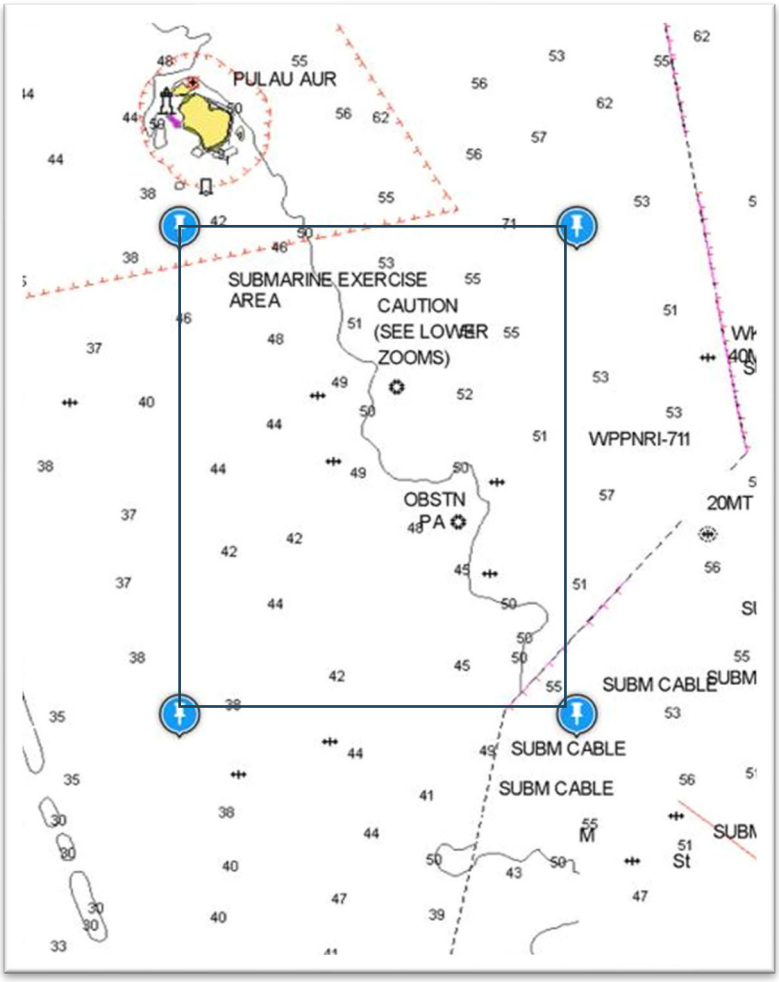

Figure 6: Proposed 500 nm2 area (25 nm X 20 nm) as refugia for adult and spawners in Zone C

The proposed delineation will be further studied based on the current circulation pattern, OTU habitats and critical area for the migration route as well as sensitive area for the lobster. One of the key concerns in the efforts to conserve the lobster population is the conflicting uses of the lobster fishing ground. Implementation of a no take zone will certainly jeopardize the incomes of the fishers in the area. Hence, one of the good alternatives to resolve the conflicting issue is to introduce artificial reefs into the refugium. The artificial reefs can serve two major roles:

1. Establish new habitats for the lobster in the area. These new “artificial” habitats can potentially be the no take zone within the refugium
2. To deter operation of bottom trawler within the refugium. Bottom trawling has long known to be destructive to the benthic ecosystem. This destructive method should be phased out in stages and replace with a less destructive fishing method.

Artificial Reefs for Lobsters

Recent concerns about habitat destruction and/or degradation through anthropogenic and natural occurrences, as well as previous interest in enhancement of local populations for exploitation purposes, has led to the investigation of providing additional sheltering opportunities for lobsters in shelter-limited habitats. Adult and juvenile lobsters are relatively large decapods that increase activity levels at dusk to forage and then decrease activity around dawn (Kanciruk and Herrnkind, 1973).

One possible solution for the population declines for lobsters is the construction of ARs. Various man-made structures such as shipwrecks, not originally designed or deployed to attract lobsters, have been known for decades to attract these crustaceans (Howard, 1980; Werz, 2007). Artificial reefs that were constructed for sessile organisms and designed to attract other taxa have also attracted lobsters, such as the Japanese "tsukiiso," (Sahoo and Ohno, 2000).

Despite the attractive nature of these structures, they are far from ideal man-made structures for lobsters and seldom imitate natural lobster dens or provide appropriate shelters for all benthic stages of lobsters (juvenile to adult). Hence, an efficient and effective design of ARs for lobsters needs to account for ontogenetic stages and their needs.

The DOFM has experienced in enhancing lobster resources using ARs (Ahmad et al., 2018). Two designs of concrete lobster reef were installed in Johor, Sabah and FT Labuan in 2008 and 2009 respectively to attract juvenile, sub-adult, adult and berried lobsters to aggregate, hide and spawning. The reefs were installed at 1 nm from Pulau Tinggi, Johor, 0.5 nm from Tg. Kabung and Kg. Layang-Layangan in FT Labuan and 3 nm from Kuala Penyu, in Sabah. These ARs were measured 1.65 X 1.65 X 1.65 m and 1.65 x 1.65 x 2.05 m, weighing 5 and 7 metric tons/module respectively. The construction protocols followed the British Standard 8110 with column and slab thickness of 15 cm, in which concrete was at least 50mm thick, column and beam rebar including four steel rods of Y12, links used R8 at 200 mm c/c and slab reinforcement used BRC A10. Ready-mix concrete grade 40 from a batch plant was used. Concrete cube test was conducted after 7 and 28 days of construction at government and private laboratories. Curing was allowed for at least 28 days before deployment. **Figure 7** shows a module of lobster ARs constructed in 2008 and installed at Tg. Kabung FT Labuan, Pulau Tinggi, Johor and Kuala Penyu, Sabah. **Figure 8** shows a module of lobster ARs constructed in 2009 and installed near Kg Layang-Layangan in FT Labuan.

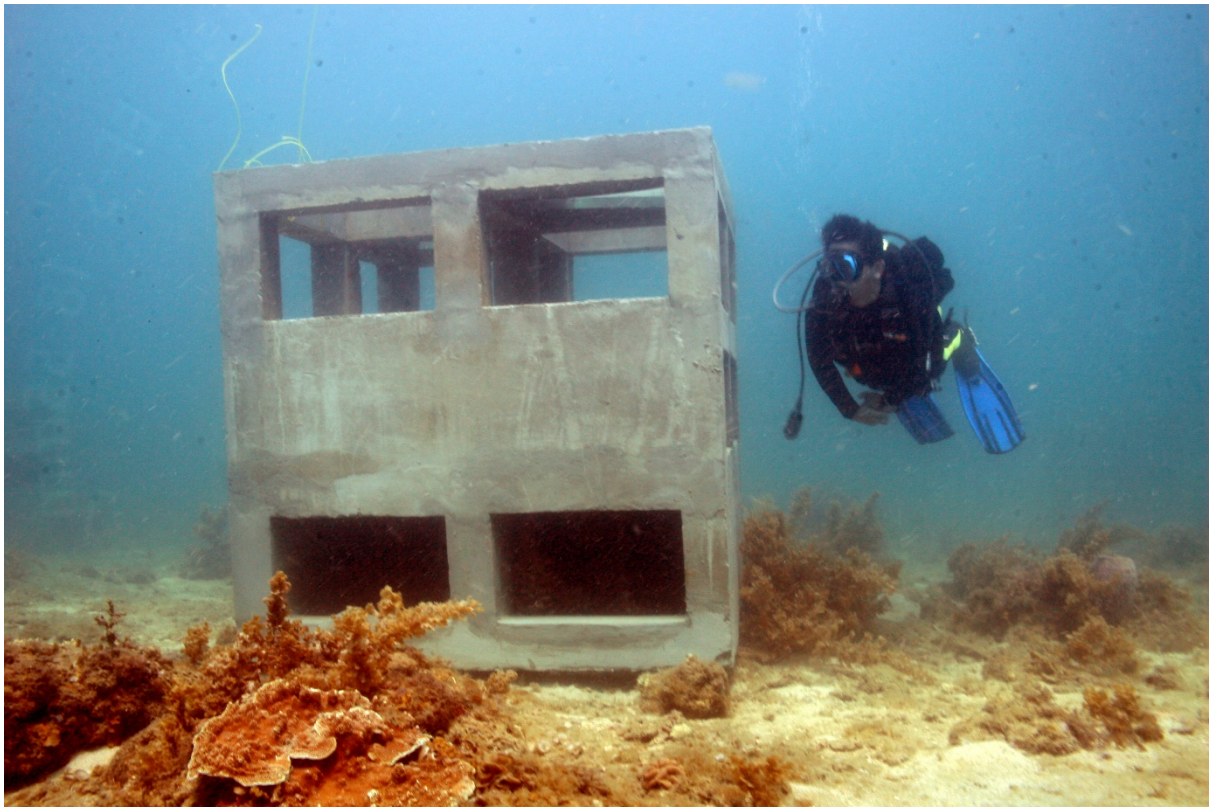

Figure 7: Lobster artificial reef designed in year 2008 and installed at Tg. Kabung FT Labuan, Pulau Tinggi, Johor and Kuala Penyu, Sabah

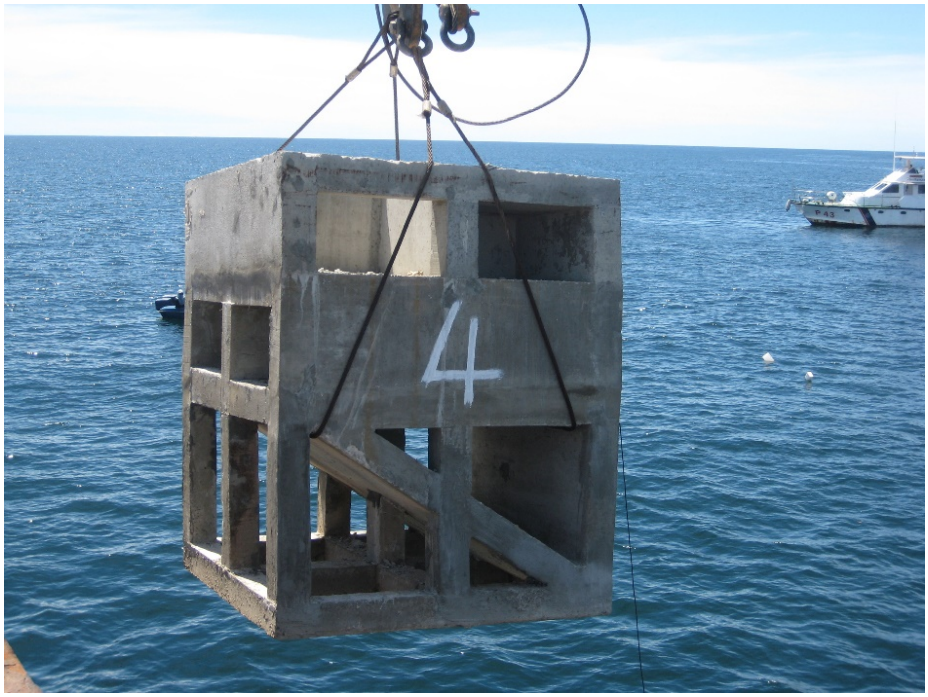

Figure 8: Lobster artificial reef designed in year 2009 and installed at near Kg. Layang-Layangan FT Labuan.

During installation, the free-fall deployment method was applied, using 50 mt crane and special mechanical-release device. Each module was placed on the seabed and spaced between 2 and 3 m from other modules. Soon after the deployment was complete, divers inspected the position of modules and video-recorded the reef for future references. Each site consisted of 20 modules. The success of these reefs to aggregate adult and berried lobsters were reported by Ahmad et al., (2013) and Ahmad et al., (2018).

In 2019, the DOFM produced a new design of lobster ARs proposed to be deployed near Pulau Lima, in Pengerang, Johor. This activity was under Corporate Social Responsibility (CSR) project by Pengerang Integrated Petroleum Complex (PIPC) but it was rescheduled due to covid-19 pandemic.

Artificial reefs for Post-larvae, Juvenile and Sub-adult Lobsters

Man-made structures for post larval stages (passive collectors) have been useful for evaluating patterns of settlement and recruitment of a variety of benthic decapod crustaceans including lobsters (Phillips and Booth, 1994). Materials that mimic the natural nursery habitat of the target species have been critical to the successful development of post larval collectors. Therefore, most of the research on ARs for post larvae has been conducted on commercial species of clawed and spiny lobsters whose natural nursing grounds are known and, for spiny lobsters, this represents a very small portion of the total species within the family.

Special ARs design has been used to capture post pueruli for grow out ("seed lobsters") in the aquaculture industry in Vietnam (primarily *P. ornatus*) (Hung and Tuan, 2009). The seed lobsters are collected from their settling grounds and kept in cages in the coastal waters where they are supplied with artificial shelters (wooden poles, pieces of corals, and other materials drilled with 5 to 10 mm holes) and fed with trash fish.

Most of juvenile and sub-adult lobsters were caught within Zone A along Tanjung Leman coastline. This area is also identified as a major fishing grounds for traditional fishers especially drift nets fishers. Installation of concrete reef lobster for juvenile and sub-adult lobsters within this area should be avoided to prevent social conflict because drift nets will entangle on ARs when they are fishing nearby AR modules. For better management and monitoring activity by the DOFM officers, the most suitable area to install ARs for post-larvae and juvenile lobsters to aggregate and hide are within Marine Park waters. Both ARs designed by the DOFM are suitable to be deployed within Marine Park area.

Artificial Reefs for Adult Lobsters

Spiny lobster reef design has a long history. Investigators in Japan began experimenting with bamboo-framed structures as ARs as early as the late 1700s (Tsumura et al., 1999). For more than 60 years, Cuban and Mexican fishers have increased their catch of lobsters using simple, inexpensive, durable, and easily harvested artificial shelters called a *pesquero* in Cuba (Cruz and Phillips, 2000) or a *casita* in Mexico (Briones-Fourzan et al., 2000).

Spiny lobsters prefer dens that have shaded cover with multiple entrances and avenues of escape (Eggleston et al., 1990). Hence, for social spiny lobsters, AR designers must incorporate the ability of multiple individuals to co-den in crevices, something that is not necessary for clawed lobsters or solitary species of spiny lobsters. In order to enhance fisheries resources and to create new habitat for berried lobster, ARs should be deployed within this refugia area. Since water depth ranged from 38-55m within proposed area, durable materials such as reinforced concrete and steel are the most suitable materials for construction of ARs. The reinforced concrete ARs for lobsters constructed by the DOFM and PETRONAS ARs (Rig to Reef) are the most suitable designs to be deployed. The DOFM should share coordinates of each RTR module installed within refugia are with skippers and owners of Zone C trawl and purse seine nets. The DOFM also should officially inform all coordinates RTR modules to Marine Department. Marine Department will subsequently issue 'notice to mariners' as a navigation guidance to all sailors and fishers.

By identifying critical area and establishing artificial reefs within the refugium, the lobster refugium can further sub-classify into different zones. For examples, red zone is a strictly no take zone throughout the year, yellow zone permitted harvesting during certain windows in a year (off seasons) while green zone allowed to harvest throughout the years only by using certain types of fishing gear. The zonation must be made clear to all stake holders on do and don't in each zone, and there shall be a respective action plan in terms of enforcement activities.

Establishment of Off-Harvesting Seasons

The off-harvesting season for spiny lobster can be defined as the prohibition of any activity regarding fishing of spiny lobster within a certain period. During the closure, spiny lobster shall not be harvested, possessed, purchased, or sold. The aim of the off-harvesting seasons establishment is to protect this resource during the major spawning period. Implementation of the closed season has been demonstrated to improve the wild fish stocks. The off-harvesting seasons has been actively implemented in several places. In Florida and Gulf states, fishing seasons are closed from April to August due to the peak season for spiny lobster spawning (Fisheries Commission, 2020). In Puerto Rico, the harvesting of spiny lobsters is halted from August to October. In Florida, spiny lobster off-harvesting season is established from April to July (Plant, 2001). In the Caribbean, the close season for spiny lobster will be from March to June (Organization for central Fisheries and Aquaculture Sector (OSPESCA). In summary, the off-harvesting season for spiny lobster depends on its location as the peak period of spiny lobster has differed according to their habitat and such closed season is implemented from two to four months.

In Malaysia, the proposed off-harvesting season can be implemented during the breeding and spawning seasons of the spiny lobster. These breeding and spawning seasons will be enclosed for any catching and commercialization of spiny lobster. To establish the breeding and spawning seasons, several data and parameters are needed, such as data on berried females caught monthly, the sex ratio of spiny lobster caught monthly, and larval density caught monthly. Berried females are the main key indicator of spawning events in spiny lobster habitats. Also, the spawning event can be determined based on a smaller number of females caught (sex ratio) as these females reduced their feeding intensity and foraging movement due to their becoming a berried female. After several long periods, the berried spiny lobster released its egg, and the larval dispersal and density can be recorded to further confirmed the suitable season to be recognized as off-harvesting season.

Thorough literature related to berried females, sex ratio and larval density in Malaysian coastal waters areas will be accumulated, and a comprehensive literature review will be made to clarify the status of Malaysia spiny lobster. All information is collected from a wide variety of sources, mainly from web-based research such as Scopus, Web of Science and technical reports. Data collected will be consolidated analysed, and findings will be used to determine the possibility of spawning and breeding season of spiny lobster in Malaysia. Other than the desk study, interview with fishers and middleman is necessary to review the knowledge and experiences throughout their career to obtain any information regarding the berried females caught and the sex ratio of spiny lobster. An online meeting

will be conducted to gather local fishers at Tanjung Leman, Johor. Any information discussed between stakeholders and local fishers could contribute to the gap information during desk reviews. Besides, a field trip will be undertaken at Tanjung Leman, Johor, to gather data required, if necessary, to establish off-season spiny lobster. The workshop aims to gather opinions and concerns from the DOFM officers in relation to the concept, importance and regulation regarding this closed season and offers effective two-way communication between the local fishers and stakeholders on the lobster refugium.

Siow et al. (2020) revealed monthly data of sex ratio at Tanjung Leman. The data stated that the lowest percentage of females occurred during January and February (<20%) and the highest female obtained from March to July (>90%). Hence, the off-harvesting season probably could be suggested from Jan and February due to fewer percentage of females indicating a higher percentage of berried females. These berried females reduced their feeding intensity, which the researchers tended to catch males during both months. However, there is no monthly data of berried female caught and larval density in Malaysia. Thus, comprehensive research should be carried out to obtain a complete data set.

A survey at the fishing landing centre and fishing port can be performed to attain data on berried females caught. Meanwhile, larvae net sampling probably can be used to obtain data on lobster larval density at Tanjung Leman coastal areas. Collaboration of Non-Government Organizations (NGOs) and the government is essential to promote more eco-friendly harvesting methods and regulations regarding spiny lobster trading. These well fishing practices can be disseminated through mass media and social media. Previously, A 30-minute documentary about the lobster refugium was shown in Simfoni Alam programme in December 2018 with a collaborative effort between DOFM and Radio Televisyen Malaysia (RTM). Through the public education effort, this will improve the local fisher knowledge on the long-term sustainability of lobster exploitation.

Data on berried female caught, sex ratio and larval density with reliable statistical information on spiny lobster catches are essential to implement off-harvesting seasons of spiny lobster. The paucity of information on these data is one of the main reasons that fishery management purposes could not be established smoothly.

Revision of Harvesting Size and Technology

The main problems that affect the sustainability of spiny lobster resources are the capture of undersized lobster. Undersized lobster is captured and accepted for trading to increase profitability. The tendency of small lobster caught is higher by trapping with a small net mesh size. Rising mesh size net or providing a hole for juvenile spiny lobster to flee the trap should be considered as management measures. Concomitantly, the government is necessary to enforce a law on minimum legal size for spiny lobster trading. The minimum legal size for spiny lobster caught has been implemented in several places, such as Antigua/Barbuda (*P. argus* > 95 mm) and New Caledonia, French (*P. penicillatus* > 75 mm) (Tirtadanu et al., 2021). In Gunung Kidul, Indonesia, the optimal size for capturing *P. penicillatus, P. homarus* and *P. longipes* was 74 mm, 68 mm and 64 mm respectively (Tirtadanu et al., 2021). In Mauritania, the regulations state that the minimum landing size is 83 mm (Meissa et al., 2021). Through the regulation on trapping and enforcing minimum carapace length, these measures will offer sustainability of spiny lobster natural stock in Malaysia.

In Malaysia, spiny lobster is threatened with intensive fishing pressure due to the high market price. A wide variety of methods are utilized to catch the lobster either through freediving, gill nets, lobster traps, harpoons and trawling devices. A rebuilding program is vital to steer spiny lobster exploitation into sustainability. To rebuild the spiny lobster natural stock, several management tools could be taken into account, such as prohibition undersized harvesting and enforcing regulation related to fishing gear method. To establish the spiny lobster harvesting size, several data and parameters are needed, such as data on total length and body weight to calculate the size at sexual maturity. To enforce fishing gear regulation, several data and parameters are needed, such as data on fishing gear type and efficiency of the fishing gear.

In order to establish guideline for harvesting size and technology, thorough literature related to the size at sexual maturity of spiny lobster and fishing gear in Malaysian coastal waters areas will be accumulated, and a comprehensive literature review will be made to clarify the status of Malaysia spiny lobster and the technical aspect capturing the lobster. This information is collected from a wide variety of sources, mainly from web-based research such as Scopus, Web of Science and technical reports. Data collected will be consolidated analysed, and findings will be used to determine the size at sexual maturity and fishing gear utilized to capture spiny lobster in Malaysia. An online meeting will be conducted to gather local fishers at Tanjung Leman, Johor. The discussion between the stakeholder and the fishers will fulfil the gap information during desk reviews. Besides, a field trip will be undertaken at Tanjung Leman, Johor, to gather data for establishing harvesting size and method or

gear used to capture spiny lobster. An online workshop will be conducted to introduce and communicate to the local fishers regarding the implementation of harvesting size and technology used during spiny lobster catching. The workshop reveals and conveys the concept, importance and regulation on harvesting size and fishing gear, and offers effective two-way communication between the local fishers and other stakeholders.

Spiny lobsters of the genus *Panulirus* are economically important and support local fishing communities. However, mud spiny lobster, *Panulirus polyphagus* is among the least known species within this genus in terms of their biological information. Recent published paper on *P. polyphagus* by Waiho et al., (2021) studied on the size distribution, length-weight relationship, and size at morphometric maturity of *P. polyphagus* in the Johor Strait. Within the year 2010, 300 specimens were collected off the coast of Johor Strait, Malaysia. There was no significant difference in body size (Cephalothorax Length, CL) and Body Weight (BW) between sexes. CL and BW were highly correlated and males of *P. polyphagus* displayed positive growth allometry, whereas the opposite was observed in females. Based on the Merus Length (ML) and Carpus Length (CPL) of the third right walking leg, the piecewise linear regression analysis estimated that the size at maturity for male was 6.58 cm CL (based on ML) and 7.58 cm CL (based on CPL), whereas it was 8.18 cm CL (based on ML) and 6.75 cm (based on CPL) for females. Two discriminant functions of high classification and revalidation rates (> 98.6% in males and > 98.7% in females) that can discern maturation status in males and females of *P. polyphagus* were derived using the discriminant function analysis. Biological information derived from this study serves as an essential baseline for future fishery management primarily regarding the harvesting size of *P. polyphagus*.

Since no specific research has been carried out for fishing gear, thus, no data is available to summarize the technology or methods used to catch the spiny lobster in Malaysia. However, Siow et al., (2021a) conducted lobster resource surveys using trawl nets in east Johor waters in Zone B and Zone C in year 2016 and 2017. A study of spiny lobster landing was also conducted at Sedili, Tanjung Leman and Endau from July 2017 until March 2020 (Siow et al., 2021b). Based on the current state of arts (Ikhwanuddin et al., 2014), the estimated size at maturity for males was 6.58 cm CL (based on ML) or 8.18 cm CL (based on ML) meanwhile, the estimated size at maturity for females was 7.58 cm CL (based on CPL) or 6.75 cm (based on CPL). This size could be suggested as minimum CL to catch the spiny lobster at the proposed refugia site in Tanjung Leman, Johor. Nevertheless, all these information will be further analyzed and used as a basis for the subsequent recommendation in the lobster refugium management plan.

Stakeholders Engagement

The United Nations Conference on Environment and Development (UNCED) in 1992 recognised the critical role of education and public awareness in achieving sustainable development. Communication, education, and public awareness in fisheries management will be one of the key strategies to successfully implementing the Management Plan for Fishery Refugium of Spiny Lobster *Panulirus polyphagus* at Tanjung Leman, Johor. Public participation and community involvement are crucial to ensure success in the implementation of any management plan's measures. Effective communication processes and mechanisms to address conflict will encourage better community involvement in the lobster refugium program at Tanjung Leman, Johor. To maintain community support for management, it will be necessary to raise community understanding of refugium's management measures, rules, and regulations. Transparency in enforcement will be essential in gaining the trust of fishers and community members in the enforcement process. The long-term success of enforcement is expected to be aided by increased compliance from the fishers. To secure support from the fishers and community, focused education and awareness trainings on management rules, laws, and benefits will be carried out and will continue to be supplied when needed. Dissemination of knowledge about the efforts made to secure the future of lobster fishery is important to foster participatory management and self-governance (Yandle, 2008).

Informed users are valuable resources that can boost public knowledge and promote personal stewardship of the lobster fisheries in the region. The development and dissemination of instructional materials will be vital to win public support for refugium's management activities. A range of topics focusing on the target species (*P. polyphagus*) such as its biology, life history, the existing lobster fisheries at Tanjung Leman, concept of fisheries refugia etc. should be addressed to promote public awareness and understanding. These topics among others, will be supported by scientific data and highlight the impacts of overfishing and illegal fishing gears/methods on the lobster population at Tanjung Leman, as well as the advantages of establishing a lobster refugium program in the area.

Hence, the following actions have been identified to implement the key strategy of 'Communication, Education, and Public Awareness' for the spiny lobster refugium management plan at Tanjung Leman, Johor:

- Convey the scientific and technical efforts of lobster/fishery refugia in a manner that is understandable to a wide range of people;
- Incorporate lobster/fishery refugia into educational and awareness programs;

- Investigate options to increase public awareness of the importance of sustainable lobster fishery as well as its inherent value.

As DOFM has conducted a comprehensive socioeconomic survey on lobster fishermen at Tanjung Leman and its surrounding areas (Norhanida & Rozita, 2018). Among others, this study will be used as one of the primary references for determining applicable criteria and measures for 'Communication, Education, and Public Awareness.' The following methodology will be employed to gather the relevant information:

Desk Review: A detailed review of all related documents pertaining to lobster fishery generally and in Malaysia in particular, will be conducted. This will include documents within the public domain, such as fishery policies, scientific papers, technical reports, etc. to gain insight on the current perception of stakeholders towards the establishment of a lobster refugium at Tanjung Leman, Johor.

Apart from scientific papers published by the scholarly community, DOFM will be the principal source of any significant documents relative to the local environment. The management of lobster fisheries in other countries (e.g., the United States, India, Australia, and others) will be examined, and applicable strategies will be incorporated into our management plan where appropriate. These data will be acquired mostly through online-based research, such as official government web portals, academic literature databases such as Scopus, and fishing community webpages or social media.

All secondary data collected will be consolidated, analysed, and a reference list will be created so that all documents are organized and easily accessible to all team members and DOFM. Findings relevant to our management needs will be used as educational and promotional materials to boost awareness and participation in the program. The information obtained through desk research can also be used to support other initiatives in the management strategy.

Direct Observations/Informal Interviews: As DOFM has carried out several stakeholder engagements/consultations prior to this project (see section – *Preliminary Findings*), necessary follow-up (during data gathering fieldtrip) will be undertaken in cases where information is not provided, data is incomplete, or the information is incomprehensible. If clarifications are required on any aspects about the lobster fisheries at Tanjung Leman and its neighbouring areas, major stakeholders such as DOFM officers and fishers actively involved in the industry will be consulted.

The consultation or stakeholder engagement activities outlined here refers to either informal conversations or observations of lobster fisher's actions. Stakeholders will feel more at ease in a relaxed setting, increasing their readiness to collaborate and share local lobster fishing knowledge.

Moreover, observing the process of lobster catch on site and the subsequent journey from net to plate may provide significant insights to the researchers on how to advocate responsible fishing in our management initiatives.

Data Gathering: An online meeting will be organised between the project researchers and DOFM officers who were involved in the preliminary surveys at Tanjung Leman, Johor. Researchers who have previously worked on a resource survey of lobster fisheries in the east coast Johor region will be contacted for further explanations or to fill in any gaps in the data. The purpose of this meeting is to gain better understanding of the existing lobster fisheries at Tanjung Leman. A fieldtrip will be conducted to gather additional information about lobster resources at Tanjung Leman, Johor. During this fieldtrip, observations and informal interviews will be carried out to supplement any data gaps discovered during desk review (see previous section). In addition, photos and video footage of the lobster fishery activities will be taken to be used as educational/promotional materials (i.e., infographics, documentary clips, pamphlets, product brochures, guides etc.). Utilizing local representations rather than general materials acquired from online resources will build social inclusion and develop sense of belonging at the local level. In turn, this sentiment will enhance community participation in the lobster refugium program.

Workshop: An online induction seminar will be conducted for DOFM officers to introduce the concept and mechanisms of lobster refugium management. The goal of this induction training is to prepare these officers, especially those who work directly in the Tanjung Leman lobster fisheries, to effectively enforce new refugium regulations and implement specified management strategies in their everyday operations. An effective induction program will enable DOFM to understand more about the refugium program, their role and responsibilities of managing a lobster refugium, as well as to address issues that may arise from the transition into their new role.

In collaboration with DOFM, a workshop will also be organized for local lobster fishers and other key players in the lobster industry to communicate important findings and the value of participatory management of the lobster refugium. The researchers will explain the key strategies that have been identified to establish the lobster refugium. Current and future efforts to boost the lobster fisheries in line with the strategies proposed for the lobster refugium program at Tanjung Leman will be highlighted to the community. Both seminar and workshop will provide an opportunity to respond to questions from main stakeholders regarding the lobster refugium program.

Preliminary Findings

Socio-economic Survey: In 2018, as part of a socio-economic survey, a questionnaire study that consisted of 22 questions about perceptions and issues of a prospective lobster refugium was conducted (Norhanida & Rozita, 2018). A total of 138 respondents had participated in the survey. A favorable response was received from the local fishing community regarding the establishment of a lobster refugium (Appendix A). The positive feedback was measured using Cronbach's Alpha Reliability Test to assess the reliability, or internal consistency, of the set of 22 test variables (questions). **Table 5** shows the rating system of Cronbach's Alpha. All responses were scored at more than 0.7 (**Table 6**). The overall Cronbach's Alpha score was at 0.819, which indicated good internal consistency of responses collected (**Table 7**). This suggests that the local fishing community is receptive towards the establishment of a lobster refugium at Tanjung Leman, Johor, and amenable to a closed lobster fishing season during breeding period. A large majority of respondents also agreed that DOFM should consult with the local fishing community about any plan to develop a lobster refugium (Norhanida & Rozita, 2018).

Table 5: Cronbach's Alpha score guide (Norhanida & Rozita, 2018)

Cronbach's Alpha	Internal consistency
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable
$0.6 > \alpha \geq 0.5$	Poor
$0.5 > \alpha$	Unacceptable

Table 6: Reliability statistics for 22 test variables (Norhanida & Rozita, 2018)

Variable		Scale Mean If Item Deleted	Scale Variance If Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha
Keyword	Item				
Concept	Fig.i	50.04	69.431	-0.001	**0.826**
Site	Fig.ii	51.75	68.898	0.063	**0.823**
Agree site	Fig.iii	51.27	64.907	0.330	**0.814**
Prohibit	Fig.iv	51.25	61.020	0.456	**0.808**
Maintan	Fig.v	51.15	62.410	0.428	**0.809**
No_fishing	Fig.vi	51.15	61.418	0.492	**0.806**
Discuss	Fig.vii	51.52	63.385	0.467	**0.808**
Income	Fig.viii	51.32	61.024	0.669	**0.799**
Benefit	Fig.ix	51.24	60.401	0.743	**0.796**
Knowledge	Fig.x	51.20	62.271	0.599	**0.803**
Increase	Fig.xi	51.15	59.710	0.703	**0.795**
Quality	Fig.xii	51.19	58.434	0.793	**0.790**
More_refugia	Fig.xiii	51.16	58.792	0.703	**0.796**
Human_rights	Fig.xiv	51.19	58.434	0.793	**0.790**
Social_conflict	Fig.xv	51.15	59.710	-0.703	**0.795**
Change	Fig.xvi	51.16	58.792	-0.658	**0.796**
Relocate	Fig.xvii	49.87	70.421	-0.093	**0.834**
Lose_jobs	Fig.xviii	50.05	71.620	-0.172	**0.838**
Eco_tourism	Fig.xix	49.95	70.601	0.106	**0.833**
Livelihood	Fig.xx	49.79	70.469	-0.097	**0.831**
Impact	Fig.xxi	49.59	69.305	0.011	**0.826**
Culture	Fig.xxii	49.59	70.194	-0.073	**0.829**

Table 7: Overall result of Reliability Test Cronbach's Alpha (Norhanida & Rozita, 2018)

Cronbach's Alpha	Cronbach's Alpha based on Standardized Item	No of Item
0.819	0.799	22

Stakeholder Engagements: As shown in **Table 8**, a succession of stakeholder discussions was held at potential fisheries refugia locations in east Johor-south Pahang. The participants were given briefings on the fisheries refugia concept, results from associated scientific investigations, and management methods for the targeted fisheries during the discussions. Following the briefing, participants (both fishers and local agencies) were given the opportunity to ask questions and provide input, which was included into the creation of the fisheries refugia (Siow et al., 2019).

Table 8: List of stakeholder consultation sessions conducted in Malaysia for the Fisheries Refugia (Siow et al., 2019)

No.	Type of stakeholder consultation	Location	No. of participants	Date
1.	Fishers Consultation Session	Miri, Sarawak	55	18th July 2017
2.	Fishers (Artisanal) Consultation Session	Sedili, Johor	130	20th Aug 2017
3.	Local Agencies and Fishers Consultation Session	Kuala Rompin, Pahang	41	10th Oct 2017
4.	Fishers (Trawlers) Consultation Session	Endau, Johor	30	30th July 2018
5.	Fishers (Trawlers) Consultation Session	Sedili, Johor	18	31st July 2018
6.	Fishers Consultation Session	Kuala Rompin, Pahang	75	29th Aug 2018

Information Center: DOFM has established Refugia Information Center (RIC) at Tanjung Leman Ferry Jetty in November 2017 to promote the concept of fisheries refugia to the public. The purpose of these Refugia Information Centers is to create public awareness and spread information about the fisheries refugia concept to the public. The RIC has a wide range of information about the targeted fisheries on display, and employees on duty may provide more information about the refugia project if required (Siow et al., 2019).

DOFM's concerted efforts in engaging stakeholders and developing public knowledge regarding fisheries refugia, notably to protect lobster resources at Tanjung Leman, Johor, have laid the groundwork for Strategy - Communication, Education, and Public Awareness, as mentioned above. Moving forward, the course of setting up a community-based management system and developing a sustainable management plan will involve assessment of all available educational/promotional options. By utilising various outreach and communication tools, the values, attitudes, and trust required for the local fishing community to comply voluntarily with the regulatory requirements of the lobster refugium can be nurtured and strengthened over time.

Research and Knowledge Base Management

The collection of pertinent data through monitoring and research initiatives should be continued to improve our knowledge base on the biology, ecology and population dynamics of this lobster. All these information would help provide the science behind successful management of this important resource. Some of the important research and monitoring initiatives pertinent for successful implementation of the refugia includes the following

The lobster fisheries landing statistics have to be continuously monitored to track changes in population trends and impact of the fisheries in order to implement mitigation measures where necessary. This would require all fishers that harvest these lobsters from this region to report their catches to the DOFM. Information to be collected should include locations caught, no. of tails, size, weight, and reproductive condition.

Undersized lobsters (juveniles) should not be taken and should be released to the sea. This can help protect the population and reduce the impact of overfishing. Similarly, berried females should also be released immediately after making the necessary measurements to ensure good recruitment into the population.

Though information is available on their reproductive biology as implied from other *Panulirus* spp. life cycle, information about when and where they go to spawn is still scanty and uncertain. Identifying these spawning locations and period of spawning is crucial in the establishment of successfully protected refugia sites for these critical habitats. There are a number of ways to get this information which includes: -

Noting the reproductive state of the berried females from fisheries catch information with location and time data. Of importance would be the stage of the eggs being carried and released. Obtaining such information from adult berried females can give some insight into possible location of spawning grounds and period of spawning.

Larval fish surveys have been used successfully to determine spawning locations and spawning periods of numerous fishes and the same can be applied to these lobsters. It should be noted here that the larval phyllosoma stage can persist for 2 years or more hence can disperse far and wide. It is hence important to note the stage of the phyllosoma and consider only the early stages for identifying spawning locations and spawning time. However, larval fish surveys using 1-m ring nets or bongo nets can be quite costly to run as samples will have to be collected at regular intervals (monthly) with grid transect stations over a large area to cover possible locations. It would be ideal if this was done as a

large larval fish survey program to cover other species of commercially important fishes like tuna, marlin, mackerel, etc that may also spawn in the area.

After a prolonged planktonic larval stage drifting in offshore waters which may last up to two years or more, the phyllosoma larvae, aided by currents, will make their way from oceanic pelagic habitats to coastal waters. They will also moult and transform into transparent early puerulus stage where they become nektonic and actively swim towards the coast in search of suitable habitats to settle. This early recruitment phase may be significant in determining whether you will get a strong recruitment cohort, hence a better understanding of factors influencing this recruitment phase may have importance. It will be useful to monitor recruitment trends, protecting recruitment habitats, and also enhancing using artificial structures to encourage and safeguard the new recruits. Ways to achieve this includes:

Regular sampling for puerulus juveniles to determine relative recruitment cohort strengths and trends. In Western Australia, they were able to predict four years in advance the strength of their spiny lobster fisheries from their puerulus postlarval surveys. There is no clear ideal method for doing this but the use of light to attract the nektonic puerulus juveniles into traps can be implemented. Some of these methods are being used to harvest lobster puerulus juveniles for aquaculture grow out. By setting such traps at various prospective coastal habitat locations and monitoring puerulus juvenile abundance, some useful information on their favoured locations. cohort strength and seasonality can be inferred.

Due to logistic, manpower and financial constraints, it would be prudent to conduct the above research requirements in phases. We could initially continue with current gathering of lobster catch data with modifications of the content to include more information as outlined above. The second phase involving offshore zooplankton survey for phyllosoma would have to be conducted as a separate larval fish survey program using 1m ring nets or large bongo nets. Funding for this will have to be sourced separately and expanded to include larvae of other commercially important fishes like tuna, marlin, mackerel, coral fishes, etc. The third phase looking at puelurus recruitment to nearshore habitats will also need to be a separate program as puerulus collection is not currently conducted at a large scale in the Peninsular Malaysia.

Financial Sustainability for the Lobster Refugium

People benefit from the world's oceans because they provide marine ecosystem services such as food, income, cultural services, recreation, carbon storage, and storm protection (Borger et al., 2014; Werner et al., 2014). Climate change, fishing pressures, coastal development, land-based pollution, and recreation all put the oceans' ability to continue providing these essential ecosystem services in jeopardy (Halpern et al., 2012). There is a scarcity of funding to protect and manage marine biodiversity and ecosystem services, and the funding is too short-term and vulnerable as a result of a lack of diversity in funding portfolios (Bos et al., 2015).

To address these challenges, a variety of approaches and tools are being used, including but not limited to marine protected areas (MPAs), marine and climate policy, sustainable or green development, and fisheries management (Ray and McCormick-Ray, 2014). Marine conservation initiatives are widespread throughout the world, involving nearly every country, but conservation finance offers promising new sources of funding for this critical endeavour. Conservation finance is a type of financial structuring that seeks to realign incentives to increase the pay-off for preservation over consumption. It usually involves using a variety of financial tools to help protect and restore ecosystems, and it can be done by governments, charities, or private investors (Bose et al., 2019).

Millage et al., (2021) investigated self-funded marine protected areas. They propose a new institution to improve MPA design: the Conservation Finance Area (CFA), which would fund monitoring and enforcement using leased fishing zones within MPAs fed by spill over. The Conservation Finance Area (CFA) was established to assist in overcoming the challenges of adequate enforcement by providing a financially viable financing pathway. The size of the area where the money was spent was one of the main factors in this study to make it easier to figure out and measure how much money was spent on conservation.

Furthermore, McGowan et al., (2020) investigated the significance of debt conversion opportunities for marine conservation. In this study, an investment-based debt conversion mechanism is used to aid in the calculation and measurement of conservation finance. Debt conversion incentives are a type of financing mechanism that can help debt-burdened countries increase long-term domestic conservation investment. They show, for example, how environmental organisations can use structured prioritisation frameworks to make conservation finance investments such as debt conversions.

According to Bos et al. (2015), while market-based instruments can reduce (formally, "internalise") environmental externalities, they cannot eliminate all environmental damage. Market-based instruments in particular provide economic incentives (rewards or penalties) for positive outcomes in marine conservation. Right now, there aren't enough resources being used to make things more sustainable, but conservation finance could be a good way to raise more funds for this important project.

As a result, Fitzgerald et al. (2020) included conservation investment as a key component in calculating and measuring conservation finance. Conservation investments, a type of impact investment, seek to return capital while also benefiting natural resources and ecosystems. Investors, they argue, can help accelerate the world's transition to more sustainable fisheries by seeking out investments that have a positive environmental impact while also making money.

Model for Conservation Finance

The bioeconomic model was used in Millage et al., (2021) research study. Their main system is split into two parts: an open access patch (F) and a multi-use MPA patch (M). They employ a two-patch stock-dynamic model in which the fish stocks in each patch grow independently, such that the discrete-time population growth for the stock in patch i at time t is equal to the discrete-time population growth for the stock in patch i at time t as:

$$\boldsymbol{g}\left(\boldsymbol{X_{i,t}}\right) = \boldsymbol{X_{i,t}} + \boldsymbol{r}\boldsymbol{X_{i,t}}(\mathbf{1} - \frac{\boldsymbol{X_{i,t}}}{\boldsymbol{K}} - \boldsymbol{H_{i,t}}$$

where Xi,t is the fish biomass in patch i at time t, r is the intrinsic growth rate of the stock, K is the carrying capacity, and Hi,t is the harvest from all fleets in patch i at time t. A fraction of the stock in each patch is then redistributed to the other patch, while a fraction remains in the origin patch. A dispersal matrix describes movement between the two patches:

$$\boldsymbol{D} = \begin{bmatrix} \boldsymbol{d_{F,F}} & \boldsymbol{d_{M,F}} \\ \boldsymbol{d_{F,M}} & \boldsymbol{d_{M,M}} \end{bmatrix}$$

where dF,F is the fraction of the stock from patch F that remains in patch F, dM,F is the fraction of the stock from patch M that redistributes to patch F, and so on. Therefore, the biomasses in patches F and M at time t + 1 are given by:

$$\boldsymbol{X_{F,t+1}} = \boldsymbol{g}(\boldsymbol{X_{F,t}})\boldsymbol{d_{F,F}} + \boldsymbol{g}\left(\boldsymbol{X_{M,t}}\right)\boldsymbol{d_{M,F}}$$

$$\boldsymbol{X_{M,t+1} = g(X_{M,t})d_{M,M} + g\left(X_{F,t}\right)d_{F,M}}$$

This stock biomass model allows biomass to accumulate inside of M, but it does not take into account age structure or within-time-step dynamics, and it assumes that the stock is uniformly distributed within each patch.

Descriptions of each fleet are below, but in general, harvest from fleet j at time t is:

$$\boldsymbol{H_{j,t} = qE_{j,t}[f(X_t, L, D)]}$$

where q is catchability, Ej,t is fishing effort (days) from fleet j at time t, and f (Xt,L,D) is the fraction of total biomass available to be fished by fleet j, which is a function of Xt (total biomass across both patches at time t), L (size of the Conservation Finance Area (CFA)), and D (the dispersal matrix).

They track two legal fishing fleets. The first legal fleet comprises all fishing effort in patch F (denoted by EF,t). The second legal fleet comprises the portion of fishing effort in the CFA (denoted by EL,t) which is subject to the per-unit-effort access fee. They also track one illegal fishing fleet, which comprises both the portion of fishing effort in the CFA not subject to the per-unit-effort access fee and all fishing effort in the no-take zone (together denoted as EI,t). They assume the illegal fishing fleet is subject to a per-unit effort expected fine for fishing illegally, defined as the product of the probability of being apprehended (θ) and the fine (ψ). System of equation below describes time-t expected profit for each fleet:

$$\boldsymbol{\prod_{F,t} = pqE_{F,t}X_{F,t} - cE_{F,t}^{\beta}}$$

$$\boldsymbol{\prod_{L,t} = pqE_{L,t}X_{M,t}L - cE_{L,t}^{\beta} - \chi E_{L,t}}$$

$$\boldsymbol{\prod_{I,t} = pqE_{I,t}(X_{M,t} - H_{L,t}) - cE_{I,t}^{\beta} - \theta\psi E_{I,t}}$$

Here,

p is the price of fish,

c is a fishing cost parameter,

β is a coefficient that determines the shape of the cost curve (values of β > 1 imply increasing marginal cost of fishing effort),

χ is the per-unit-effort access fee levied for fishing in the CFA,

θ is the probability of detecting illegal fishing activity, and

ψ is the fine.

Furthermore, McGowan et al., (2020) conducted cost-effectiveness analyses. They developed guidelines for doing so by utilising a decision-support approach based on a novel threat-based adaptation of cost-effectiveness analysis. They created scenarios by varying the approach's parameters, such as enabling conditions, expected benefits, and threat classifications. The inclusion of both abatable and unabatable threats influenced priorities across planning scenarios. This type of cost-effectiveness analysis is frequently used to prioritise conservation actions for threatened species recovery and invasive species management. This analytic approach is advantageous in the case of debt conversions because it allows nonmonetary values to be quantified as benefits, and variations in parameters aid in the development of a variety of informative scenarios.

They embed cost-effectiveness into a three-step prioritisation framework for their purposes: first, a screening step in which enabling conditions for filtering eligible candidates are identified and compiled; second, a scenario construction step in which the variables of the cost-effectiveness analysis are defined; and third, a prioritisation step in which a ranked order of priorities for a given scenario is produced and analysed.

As a result, they considered a biodiversity benefit (B) that is affected by threats that are abatable (I_a) and unabatable (I_u), depending on the action being implemented, the probability that the action will succeed (P), and the total cost (C) of taking the action according to cost effectiveness.

$$\text{Cost - effectiveness} = \frac{B I_a (1 - \alpha I_u) P}{C}$$

Where α is a multiplier that ensures the effect of unavoidable threats does not result in a negative value in the overall net benefit function. That is why α must be chosen to ensure $(1 - \alpha I_u)$ is never negative.

FORMULATION OF REFUGIA MANAGEMENT PLAN

In preparation of the refugium management for lobster at Tanjung Leman, Johor, the outputs of the six key components as presented in **Figure 5** and **Table 2** will be used as the fundamental for the Lobster Refugium Management Plan in Tanjung Leman, Johor. The lobster refugium plan, as any other management plans is a dynamic document which should be updated regularly to stay relevant. The management plan will provide guides and key performance indicator for the efficiency of the management in the respective aspect of importance. The key performance indicator will be used as a benchmark for the efficiency of the management plan, which will be review from time to time. The frequency of review shall be based on the efficiency of the plan, as well as changes in the government policy.

It is important to note that there may be information gaps and lacking scientific data of the mud spiny lobster in the area for the development of the management plan, the limitation shall not be limiting the development of a management plan. It just needs to be improved and keep improving.

"A bad plan is better than no plan, and the most important quality of any plan is the flexibility to change."

- Judson L Moore

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