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

MANAGEMENT PLAN FOR TIGER PRAWN REFUGIA AT KUALA BARAM, MIRI, SARAWAK

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INCEPTION REPORT

JULY 2022

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List of Abbreviations

MLS	Minimum Landing Size
SEA	South East Asia
ha	hectar
km	kilometre
m	metre
mm	milimetre
kg	kilogram
g	gram
NM	Nautical Mile
DOF	Department of Fisheries
FRI	Fisheries Research Institute
DID	Department of Irrigation & Drainage
Sg	Sungai
NREB	Natural Resources and Environment Board
SEAFDEC	Southeast Asian Fisheries Development Centre
UNEP	United Nations Environment Programme
GEF	Global Environment Facility
LRP	Limit Reference Points
PTF	Provincial Trust Fund
MPA	Marine Protected Area
CFA	Conservation Finance Area
PIPA	Phoenix Islands Protected Area

1.0 Introduction

1.1 General Biology and life cycle of *Penaeus monodon*

The morphology of *Penaeus monodon* generally is similar to other penaeid shrimp species such containing a cephalothorax, tail, five pairs of swimming legs (pleopods) and walking legs (pereopods). This species is then distinguished by their distinct black and white stripes on the backs and tail. *P. monodon* are large in which they can grow up to 330mm or greater in length with females are generally larger than male shrimp (Kiel, 2013).

1.1.1 Reproductive biology

The sexes of *P. monodon* are distinguished by the external morphology of their reproductive organs namely petasma and a pair of appendix masculine in male and thelycum in female. The petasma is situated between the 1st pleopods (Fig. 1) and the appendix masculine on the exopods at the 2nd pleopods (Fig. 2). The petasma functions as interlocking structure for spermatophore transfer, while the appendix masculine branched out of the second pair of pleopods and serve to separate the petasma into two component halves (Motoh, 1985).

Thelycum is presence between the 4th and 5th pereopods of female shrimp (Fig. 3) (Motoh, 1985). There are two types of thelycum which are open" or "closed" thelycum depending on the species. *P. monodon* has closed thelycum type. For a "closed" thelycum, the thelycum is enclosed by exoskeleton plate. In the case of mating, spermatophore are placed in the groove below these plates by a male when the female exoskeleton is soft right after molting took place. The spermatophore will be stored for some time before spawning. Therefore, female shrimp with spermatophore presence within the thelycum is an evidence of successful mating.

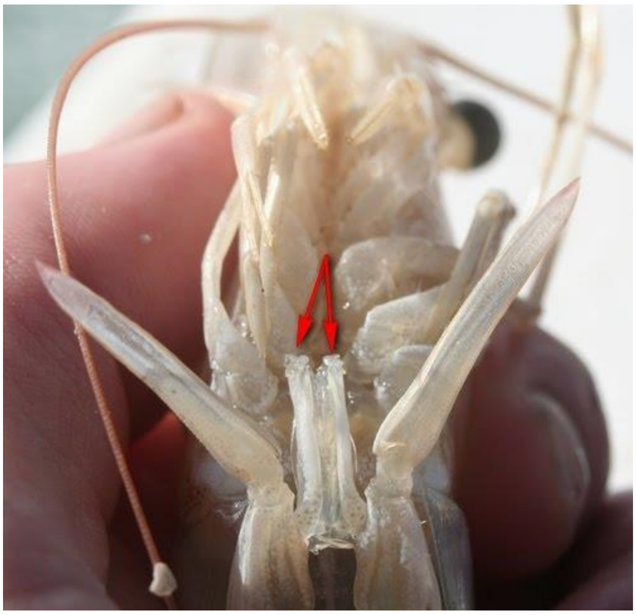

Fig. 1: Arrow showing petasma presence in male shrimp (Source: Lewis, 2010).

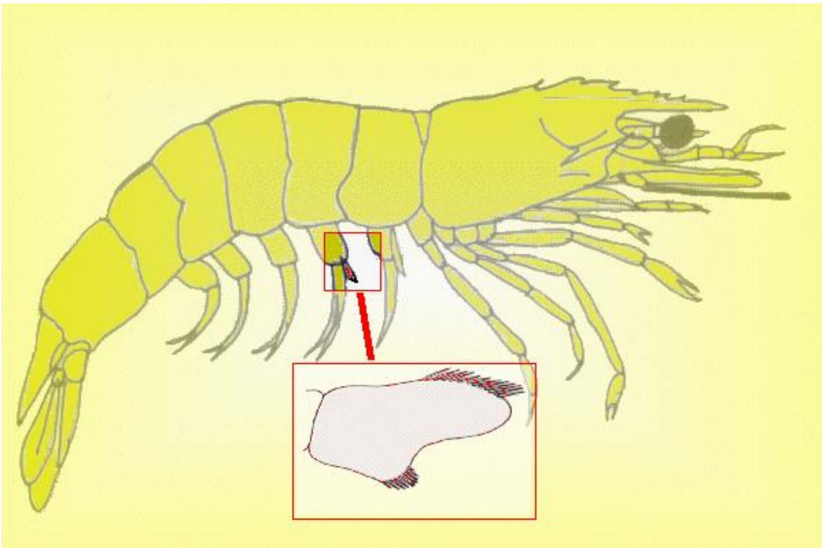

Fig. 2: Appendix masculine is located at the 2nd pleopods

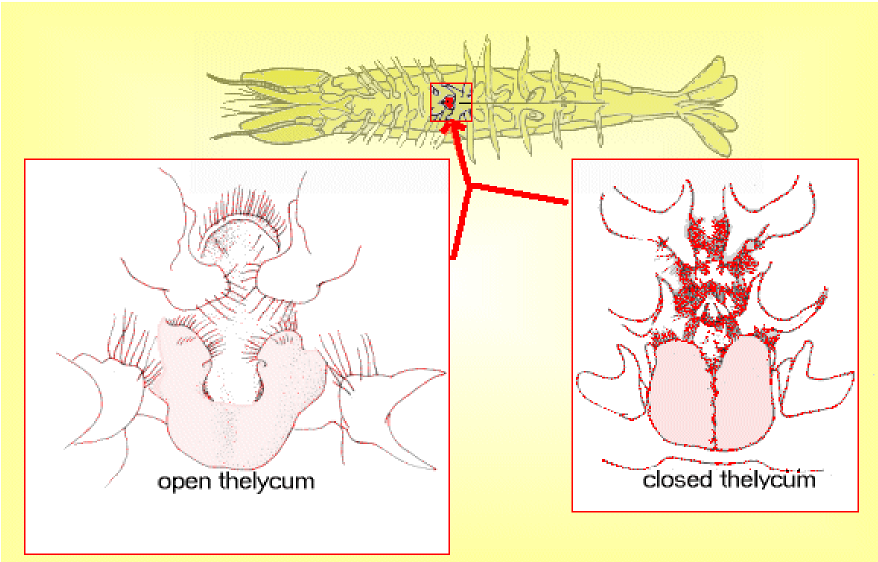

Fig. 3: Thelycum is situated between the 4th and 5th pereopods of female shrimps. There are two types of thelycum (open & closed) depending of the shrimp species.

1.1.2 Ovarian maturation

P. monodon are categorised as non-spawning or spawning based on their ovaries. There are four stages of ovarian maturation as followed (Kannan et al., 2014):

Stage 1 Immature: The ovaries are thin, translucent, unpigmented and confined to the abdomen. They contain oocytes and small spherical ova with clear cytoplasm and conspicuous nuclei.

Stage 2 Early mature: Ovary increases in size with light yellow and yellowish green in colour. Opaque yolk granules are formed in the cytoplasm and partly obscure the nuclei.

Stage 3 Late mature: The ovary is light green and is visible through exoskeleton. The anterior and middle lobes are fully developed. The accumulation of yolk resulted the maturating ova to appear opaque.

Stage 4 Mature: The ovary is dark green and clearly visible through exoskeleton. The ova are larger than in the previous stage and the peripheral region becomes transparent.

Stage 5 Spent recovering: After spawning has ended. The gonad reverts almost immediately to the immature condition. This stage is therefore, distinguishable from that found in the immature virgin females only from the size of the shrimp.

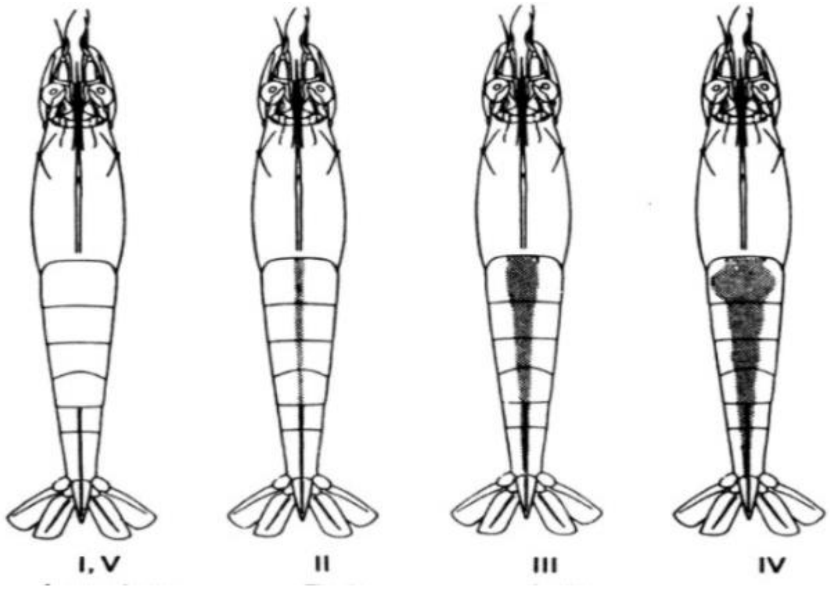

Fig. 4: Ovarian maturation stages of penaeid shrimp

1.1.3 Spawning behaviour

Spawning generally takes place at night. Female shrimp usually swims actively in the water column and slowed down when spawning take place. Eggs are extruded from the genital pores at the base of the 3rd pereopods and as the eggs are released, they passed through the spermatozoa being stored in the thelycum and the eggs are fertilised in the water column. Depends on the size and weights of the shrimp, a spawner usually produce between 250,000 to 1,000,000 eggs per spawning (Motoh, 1985).

1.1.4 Life cycle of *P. monodon*

The larval development stages of *P. monodon* consist of 6 nauplius, 3 protozoea and 3 mysis before they entered the juvenile and postlarvae stages (Fig. 5). The larval development of *P. monodon* takes place at the offshore for they are planktonic. At the end of the postlarvae stage, *P. monodon* move to the nursery ground at the estuaries which include wide brackish water rivers (mostly upstream and middle portion), mangrove swamps and interior portions of enclosed bays where they become mostly benthic. In this area, shrimps are exposed to wide physico-chemical fluctuations (especially temperature and salinity) (Motoh, 1985).

P. monodon at early juvenile stage has transparent body with dark brown streak on the ventral side (Fig. 6a) in which the body will then gradually turns blackish (Fig. 6b). The length of the carapace at this stage varies between 2.2 to 11.0mm. The sexes of the shrimp can be distinguished when they become adolescent through the presence of petasma in the male and thelycum in the female. The onset of sexual maturity happens during the subadult stage. At this stage female grows faster than male shrimp with spermatozoa present in the thelycum. Adult phase is when the shrimp has achieved sexual maturity. At this stage the ovary of the shrimp is at stage 4 and is ready to spawn (mostly at the offshore, some spawn in shallow water). Male shrimp on the other hand is not quite different from the subadult stage except from size increment and different habitat (offshore area of about 160m). The maximum adult shrimp size is about 270mm in body length and 260g in weight with the carapace length varies between 37 and 71mm in males and 47 and 81 mm in females (Motoh, 1985). The complete life cycle of *P. monodon* is shown in Fig. 5. The summary of *P. monodon* life cycle is as described in Table 1.

Table 1: Life cycle summary of *P. monodon* (Motoh, 1985).

Life Stages	Description	Mode	Carapace length
Larvae	Begins at hatching: Consist of 6 nauplii stages, 3 protozoea, 3 mysis and 3-4 megalopa.	Planktonic	-
Juvenile	Completion of gill system.	Benthic	2.2-11.0mm
Adolescent	Resembles adult shrimp. Sexes are distinguishable.	Benthic	11.0-30.0mm (male) 11.0-37.0mm (female)
Subadult	Onset of sexual maturity. First copulation. Presence	Benthic	30.0-37.0mm (male) 37.0-47.0mm (female)

	of spermatozoa in female thelycum.		
Adult	Completion of sexual maturity.	Benthic	37.0-71.0 (male) 47.0-81.0 (female)

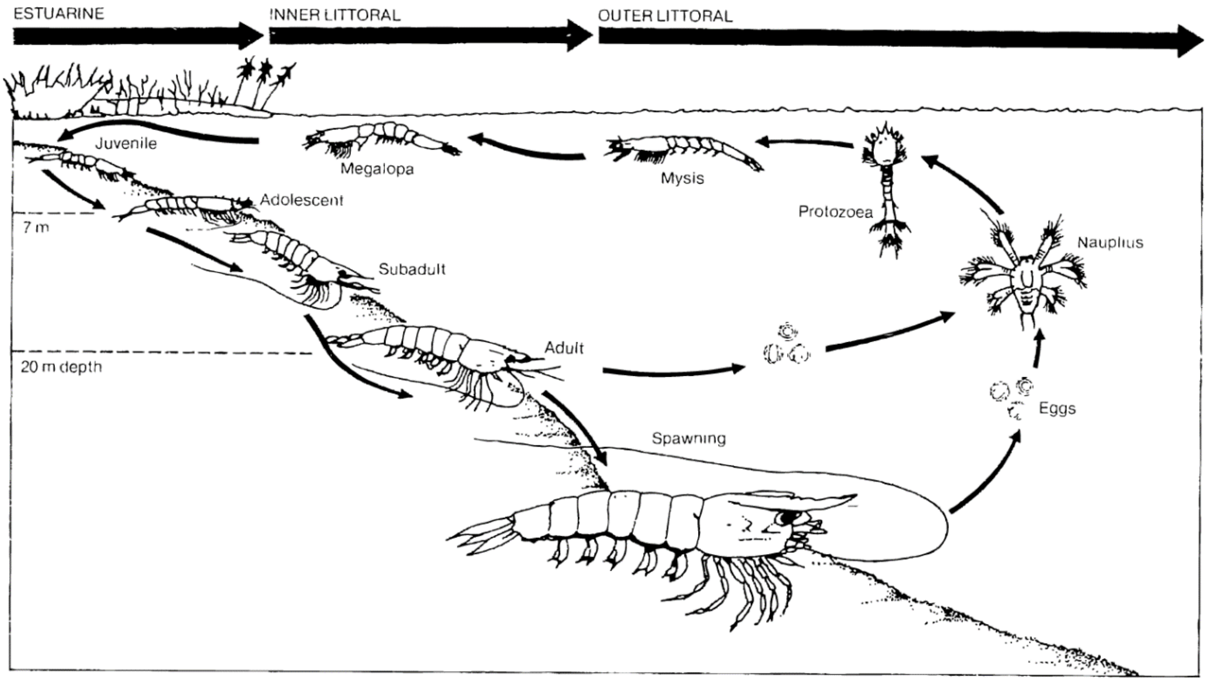

Fig. 5: Life cycle of *P. monodon* (Source: Motoh, 1985)

(a) (b)

Fig 6: (a) Lateral view of *P. monodon* juvenile (b) Juvenile gradually turn blackish as they grow

1.2 Distribution of *P. monodon*

Ecologically, penaeid shrimps have to go through two major ecosystems: the offshore and the coastal inshore environments in order to complete their life cycle. Mature penaeids breed in deep water while post-larval and juvenile sages inhabit inland marshes, estuaries, brackish water and mangrove areas, then they migrate back to the sea for maturation and breeding (Mosha & Gallardo, 2013).

P. monodon are widely distributed in the Indo-West Pacific area from Africa, to South East Asia and the Sea of Japan as well as Australia and Mediterranean Sea (Nahavandi et al., 2011) where generally at 30°C E to 155°E longitude and from 35°N to 35°S latitude (Motoh, 1985). Generally, *P. monodon* are found in waters of 18-34.5ºC and 5-45 ppt (Chen, 1990; Branford, 1981) The fishing activity of this shrimp species had been done mostly in tropical countries particularly Indonesia, Malaysia and Philippines (Motoh, 1985).

According to Rosle and Ibrahim (2017) *Penaeus monodon* was found to be one of the most abundant shrimp species found in the Kelantan delta covering approximately 38.67% of the total shrimp population. They were found abundant in the marine and brackish area with higher abundance of adult shrimp in brackish waters where the population was influenced by mangrove vegetation. In Sarawak, *P. monodon* is found to be one of the largest and most distributed commercially important shrimp species (Rajali et al., 2017) with 62.5% of its resources found in the area between 11m to 50m deep while the remaining percentage were reportedly caught in shallow waters (Hadil & Albert, 2001). *P. monodon* are mostly found in the waters of Kuala Baram and are not caught in large quantities (Rajali et al., 2017; Rajali, 2007). While *P. monodon* was not common along the Johor Straits, previous study reported that they were still found along the area (Upanoi, 2015).

1.3 Current harvest and fishery production

More than 50% of the global production of *P. monodon* are through intensive culture (Khedkar et al., 2013). Major producers of *P. monodon* are mostly of ASEAN countries including Thailand, Vietnam, Indonesia, Philippines, Malaysia and Myanmar. The total global production of this prawn were reported to be increased from 21,000 tonnes in 1981 to reaching 200,000 tonnes in 1988. The production then increased up to 500,000 in 1993 with the total value at USD 3.2 billion. The production had been unstable since due to disease outbreak as well as the introduction of *P. vannamei* in many shrimp farms. In 2009, the total production of *P. monodon* was at 770,000 tonnes, valued at approximately USD 3.7 billion (FAO, 2022).

In aquaculture farms, shrimps are harvested by two common methods that is by either draining the pond or by catching the shrimp using a net within the pond (AgriFarming, Year unknown). According to Alam et al. (2022) wild prawns (like other prawn species around the world), are captured using bottom trawl. Modern shrimp trawl nets (ranging from 20.5m to 44.5m) is currently used in Bangladesh's marine industrial fishing zone (40m depth in the EEZ). An assessment done by Rajali et al. (2017) on the shrimp catching in Sarawak reported that since the 1980s, prawns were captured in waters from 6 to 20 meters deep of Sarawak coastal water using commercial trawler SFI-88.

1.4 Current threats to tiger prawn population

While this shrimp species has been extensively farmed to meet increasing demand, they were also caught in the wild for production and spawners collection for seed production purposes. The high dependency of wild-caught spawners for seed production thus resulted in over-exploitation of the natural population, affecting the sustainability and biodiversity of fishery resources (Wong et al., 2021).

The study conducted by Rajali et al. (2017) revealed a negative allometric growth in shrimps in which the body length growth were not proportional to the body weight growth indicating an inconsistent growth among the shrimp within the population. Another possibility for such occurrence may be due to frequent catching activities at the same area, deforestation, and uses of inappropriate trawl type.

The exploitation of tiger shrimp in Sarawak had been going on since early 70s after the introduction of trawl gear. Since then the fishing activity had increased with annual catches of 19,000 tonnes until 1990s. The record were then fluctuated drastically with the lowest catch at 11,000 tonnes in 1998 (Rajali & Arshad, year unknown). According to Siow et al. (2020), declining number of tiger shrimp landing of tiger shrimp was reported between from 2008 to 2018 due to unrestricted coastal development (Fig. 7).

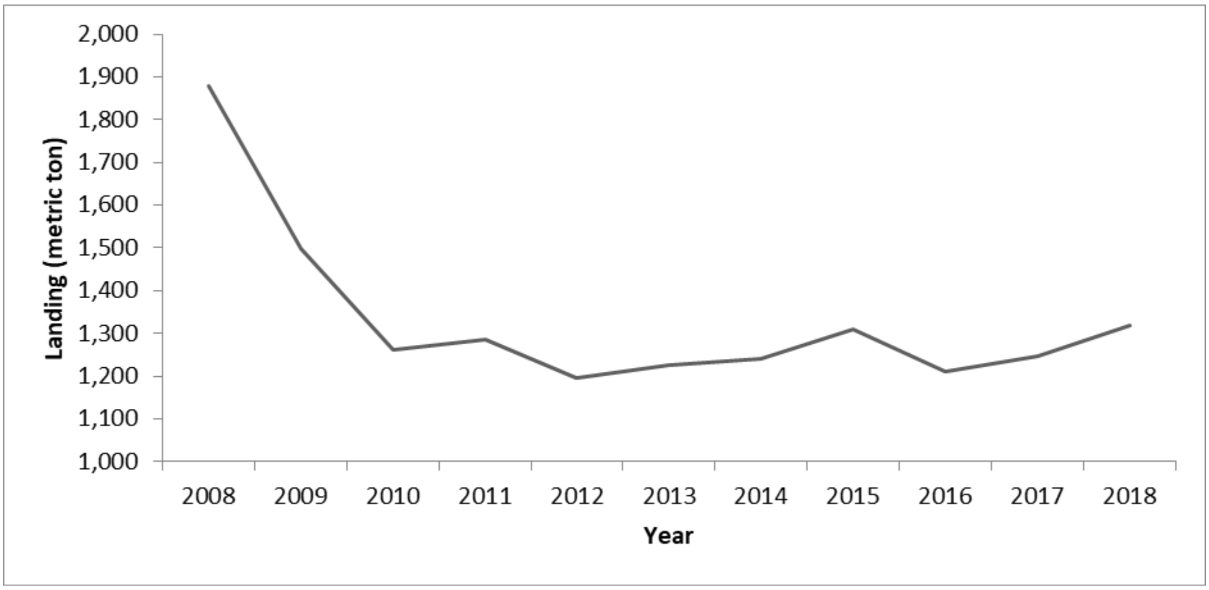

Fig. 7: Annual landing of *Penaeus monodon* recorded between year 2008 to 2018 (Source: Siow et al., 2020).

1.5 Refugia – The concept

According to Pauly (1997) limiting fishing activity may not be enough to achieve sustainable fishery exploitation due to a non-linear relationship between the animal size and egg production. However, catch restriction of animal of particular size and life stages may potentially maintain the population.

Refugia is defined as "spatially and geographically defined, marine or coastal areas in which specific management measures are applied to sustain important species (fisheries resources) during critical stages of their life cycle, for their sustainable use" (UNEP, 2005). The concept the fisheries refugia hence emphasised on the effort to protect the population of selected fishery species in a particular fishing area for sustainable fishery. This program was initiated by SEAFDEC-UNEP-GEF in the South East Asia Region involving six member countries including Malaysia, Cambodia, Thailand, Vietnam, Indonesia and the Philippines (Siow et al., 2020). This concept is different from marine parks as fisheries refugia program does not imply a permanently "no-take zones" on the area (Pernetta et al. (2010). Fishing restriction and closure are only temporary depending on season, life stages and life cycles of a selected species. According to Hillborn (2016), the establishment of refugia area not only to protect the population of selected species, but also to ensure that the ecosystem balance of the area is preserved. Pernetta et al. (2010) summarised the refugia concepts to:

a. Not be simply “no-take zones”.
b. Purposed for sustainable exploitation to benefit the present and future generations.
c. To succumb to the development of selected species during an important stage of their life cycle (e.g. spawning).

Some of the management measures being considered in a refugia program include fishing method such as restriction of fishing gears (e.g. nets, trawls, fishing gear size, etc), allowable vessel size or engine capacity into the area, seasonal closure (depending on the life cycles) and seasonal restriction (prohibition of certain fishing gear at particular seasons) (Pernetta et al., 2010).

1.6 Establishment of tiger prawn refugia

To date, there has not been scientific reports found on the establishment shrimp refugia. In Malaysia, refugia program had started for lobster (*Panulirus* spp. and *Thenus orientalis*) in Tanjung Leman, Johor and tiger shrimp (*P. monodon*) in Kuala Baram, Miri, Sarawak. Some of the important information for a successful *P. monodon* refugia taken into account include the landing data of the animal, maturation stage and life cycle of the prawn (Siow et al., 2020).

In the refugia program at Kuala Baram, Miri, two areas were identified and separated as nursing ground and spawning grown. The nursing grounds were identified along the rivers of Sungai Pasu, Sungai Lutong, Sungai Bakam and Sungai Sibuti while spawning grounds where the adults and spawners were found are located at deeper waters (10-60m) off Kuala Baram shore (Nurridan, 2021a; Hadil & Albert, 2001; Hadil, 1994). The proposed tiger prawn refugia area in Kuala Baram is as shown in Fig. 8 where it involved the demarcation of the mangrove area at least 20m of the lower water edge of 3 rivers including Sungai Pasu, Sungai Lutong and Sungai Bakam.

Fig. 8: Map showing the location of the proposed area for tiger prawn refugia program with the total area of approximately 852km^2 in Kuala Baram, Miri, Sarawak (Source: Nurridan, 2021a).

1.6.1 Catch limit policy

The purpose of refugia management is to limit the catch of the prawn in order to ensure sustainable fishing of both the prawns and other aquatic species. According to NOAA Fisheries (2020), the catch limit set (by size or seasonal closure) on shrimp is important because overfishing of shrimp could indirectly affect the population of other aquatic species. For example the population assessment of red snapper by the Gulf of Mexico in 2005 revealed that shrimp fishery as a primary factor affecting the recovery of Gulf Mexico red snapper. The limit zone 10-21 fathom water depth of shrimp fishing effectively end overfishing of red snapper alongside rebuilding the population (NOAA Fisheries, 2020). Under recreation shrimping regulation by Florida Fish and Wildlife Conservation Commission, allowable shrimp catching are set to total weight regardless of sized but limited to allowed area and season following the shrimp catching guidelines set by the association (Florida Fish and Wildlife Conservation Commission, 2019).

Some of the suggestion for refugia management of tiger prawns in Kuala Baram include spatial closure or a permanent legislated fishery closure of nursery grounds and prohibition of anthropology activities and development within the 200m radius from the river to protect the post-larvae and juveniles. Seasonal closure of spawning grounds was proposed during spawning season (August – October) to ensure high recruitment of juveniles as well as license restriction for prawn catching during off season.

1.7 Objectives of tiger prawn refugia management

The management tiger prawn refugia plan aims to achieve the following objectives:

1. To develop a sustainable plan for a long term protection of tiger prawn population at Kuala Baram fishing site.
2. To identify ways for optimal utilisation of tiger prawn resource.
3. To ensure ecological integrity of fisheries refugia is maintained.
4. To generate a plan and strategy to reduce conflict and create awareness among stakeholders.

2.0 Methodology for refugia establishment

Some of the important component for tiger prawn refugia management plant are as highlighted in Table 2.

Table 2: Key components and strategies of tiger prawn refugia establishment

Component for tiger prawn refugia establishment	Strategies	Related outputs
Focused area for refugia establishment.	To determine the migration pattern of tiger prawn from larvae to adulthood.	Identify potential area for tiger prawn fishing activity and protect vulnerable populations.
Protection of spawners and seasonal closure	To determine the ovarian maturation stages	Preserve spawners population to allow more natural larvae production.
	To determine the length of tiger prawn at maturity	To protect the harvested species and prevent overfishing.
	To propose off-season for tiger prawn	Yearly scheduled area closed for fishing.
Data acquirement for decision support system	To identify information gaps, insufficient data and method	To allow better data collection method and analysis for sustainable tiger prawn fishing plan.

Stakeholders engagement	To facilitate and validate the proposed management with stakeholders	Ensure an accurate representation of information regarding the program from relevant parties. For a smooth collaboration setting.
Developing refugia trust fund	Financial model for effective mix of finance solution	For financial sustainability: lower cost, increase capital flow.

2.1 Proposed site and focused area for tiger prawn refugia

The refugia site has been identified based on past and current research findings (Nurridan, 2021b; Hadil, 2007; Hadil & Albert, 2001) with the integration of knowledge between *P. monodon* life-cycle and its critical marine habitats. The proposed site encompasses the marine waters off Kuala Baram and the brackish riverine mangrove areas of the adjoining rivers: *Batang Baram, Sungei Pasu, Sungei Lutong, Sungei Miri, Sungei Bakam and Sungei Sibuti*.

The delineation of the tiger prawn refugia at Kuala Baram, Miri shall be based on the critical habitats in the tiger prawn life-cycle (see Chapter 1.1.4). The habitat of tiger prawns throughout their life cycle is divided into 2; the estuarine area (**Area A**) and the offshore (**Area B**). In general, the copulation of adult tiger prawn takes place in the deep water off Kuala Baram (**Area B**) before the larvae make their way back to the mangrove habitat of the adjoining rivers and where they grow into post-larvae and juveniles (**Area A**). Area A is a nursery ground for both post-larvae and juvenile prawns (Nurridan, 2021b) and they were found at the nearby rivers namely Sg. Pasu, Sg. Lutong, Sg. Bakam and Sg. Sibuti. (Fig. 9). Generally, tiger prawn preferred the muddy mangrove channels and often associated with marginal or floating vegetation (de Freitas, 1986).

According to previous studies, the offshore planktonic larval phase takes about 14 (Silas *et al*., 1978) to 20 days (Kenway and Hall, 2002) followed by benthic postlarvae and juvenile phase at the estuarines for 6 months (33 g). The sub-adult phase takes approximately 5 to 6 months at the coastal area (60 g) before they developed into adult and spawning phase (60 to 251g) in which they moved back to offshore for spawning (Kenway & Hall, 2002; Dall *et al.*, 1990).

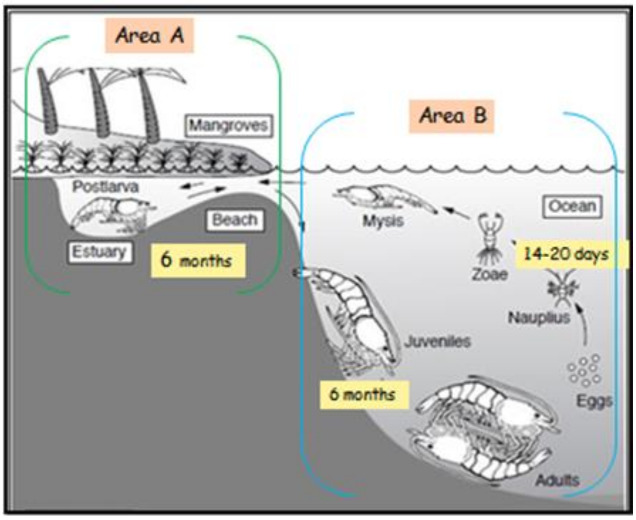

Fig. 9: *Penaeus monodon* life cycle (Rosenberry, 2009; Motoh 1981)

2.1.1 Tiger prawn sampling data

In 2020, a total of 79 juveniles (38 male and 41 female) tiger prawn (324.8 gm) were sampled (Fig. 10) from Sg. Pasu, Sg. Lutong and Sg. Bakam with the average density of 6.8 g/m^2, 1.66g/m^2 and 1.20 gm/m^2 respectively. Biomass estimation was directly proportional to the catch rate and the length of the river with the highest biomass at 31.94 kg contributed by Sg. Pasu, followed by Sg. Bakam (25.33 kg) and Sg. Lutong (4.80 kg) (Nurridan, 2021b).

Fig. 10: Post-larvae and juvenile prawn sampling using cast-net

According to FAO (1980), *P. monodon* are found at depth range between 0-110m inhabiting muddy and sandy bottom of the brackish (post-larvae & juveniles) and marine (adults and spawners) enviromment. Over 60% of the tiger prawn adults and spawners were found in **Area B** (deep water 10-60m) at 4-6NM offshore of Kuala Baram (Fig. 11) using small zone B trawler (Fig. 12a) and 70-tonnage twin outrigger trawler (Fig. 12b) (Nurridan, 2021b; Hadil & Albert, 2001; Hadil, 1994).

Figure 11: Tiger prawn adults and spawners collected from the offshore of Kuala Baram

(a) (b)

Fig. 12: Small (40-tonnage) zone B stern-trawler (a) and Big (70-tonnage) twin-outrigger trawler (b)

2.1.2 Designated area for refugia

From Fig. 9, **Area A** along the Kuala Baram involves the demarcation of the mangrove areas (at least 20m from the lower water edge) of the 5 rivers: Sg. Pasu, Sg. Lutong, Sg. Miri, Sg. Bakam and Sg. Sibuti. **Area B** on the other hand covers the waters off Kuala Baram to Miri Marina bay extending outwards to about 10 nautical miles from the beach with water depth up to 50m. The proposed Area B was based on the trawl stations having tiger prawn *adjusted mean catch rates* >1.0kg per hour or trawl stations having >5 tails male & >3 tails female tiger prawn caught (Nurridan 2021b; Hadil 2007; Hadil & Albert 2001) A*djusted mean catch rate, AMCr* was derived by normalizing the entire catch rates through log-transformation.

The map in Fig. 13 showed the location of the proposed tiger prawn refugia site off Kuala Baram (red-dash lines), covering an area of approximately 556 km^2. The 5 coordinates are as followed:

Table 3: Coordinates of proposed area of tiger prawn refugia site.

Point	Longitude	Latitude
A	N 04^o 35.000’	E 114^o 04.000’
B	N 4^o 39.000’	E 114^o 03.000’
C	N 4^o 46.000’	E 113^o 55.000’
D	N 4^o 43.000	E 113^o 49.000’
E	N 4^o 24.000’	E 113^o 59.000’

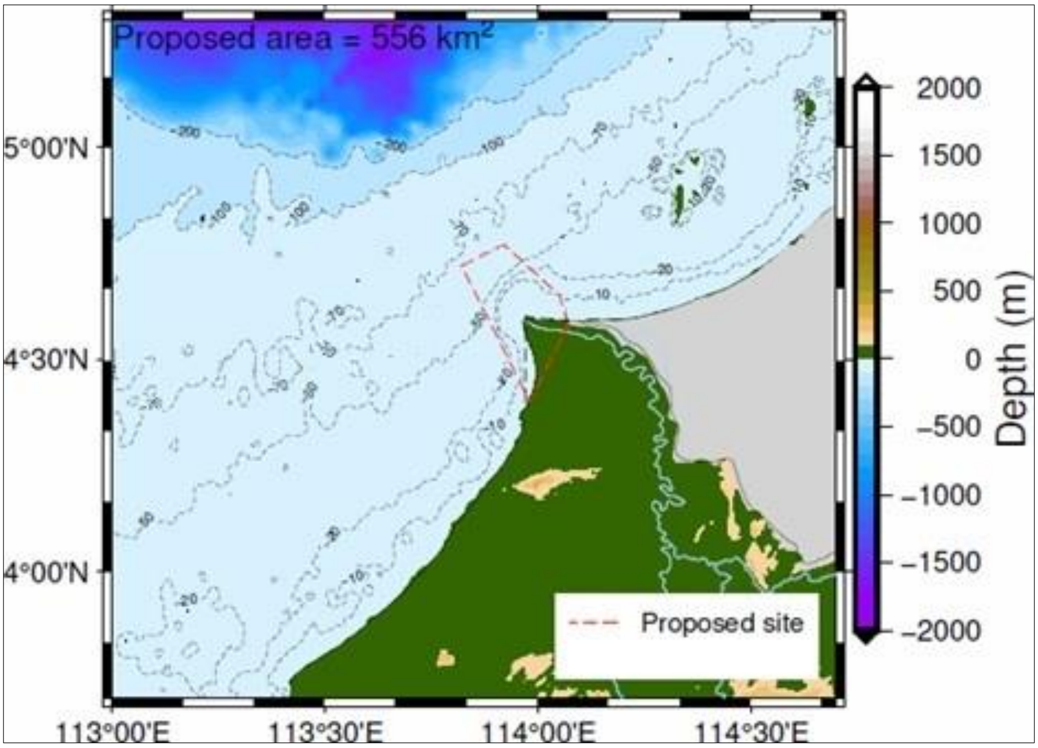

Fig. 13: Proposed tiger prawn refugia site off Kuala Baram

2.1.3 Population preservation and restoration effort

Mangrove buffer zones of 50 to 100 m facing open seas and 20 to 50 m along riverbanks should be preserved to protect the nursery area of the tiger prawn post larvae and juvenile. This regulation can be made administratively by the Forest Department or the Natural Resources and Environment Board, NREB in pursuant to section 5 of the Natural Resources and Environment Ordinance, 1993:-

"To provides rules, guidelines and directions for the protection and enhancement of environment relating to land use, protection of sources of water supply, exploitation of aquatic life & plants in rivers and foreshores, and any other matters over which the State exercise legislative authority or powers."

Effort to increase acreage of mangrove forest such as mangrove restoration should be carried out along the rivers of concerned. For example mangrove restoration done by the Forest Department along Sg. Pasu. However, a large part of this area has been subplots by Land & Survey Department and the development activities cause stress on the mangrove ecosystem.

Stock enhancement program whereby prawn fries produced from Kuala Baram spawners in the hatchery are release back into these rivers should be carried out at least twice a year. This is to increase prawn stock in the refugia area as well as the surrounding sea. Stock assessment and biological survey for post larvae and juveniles prawn in the area before and after the release program should also be carried out. Similarly, after each dredging and the clearing of mangrove fringes fries should be release in the area after 2 weeks. Dredging to deepen the river channel up to 10m was carried out once a year by the Department of Irrigation & Drainage, DID Sarawak to mitigate floods. The latest dredging was reported to be conducted on 12th May, 2022 at Sungei Lutong (Fig. 14).

Fig. 14: Dredging carried out by Department of Irrigation & Drainage, DID at Sungai Lutong to deepen the channel

Stock assessment for the tiger prawn resource in the refugia area is to be carried out once a year to ascertain the success of the demarcation of the area in preserving the stock.

Conservation policy regarding fishing and development activities at the refugia site can be formed under national policy such as Sarawak NATIONAL PARKS AND NATURE RESERVES ORDINANCE, 1998 (with amendments up to 2008) with management being assigned under Department of Fisheries Malaysia, DoF & Sarawak Forestry Department.

2.2 Protection of spawners and seasonal closure

Like any commercial prawn fisheries, each tiger prawn in Kuala Baram can only be caught once in their lifetime. Although larger prawn can always fetch a higher price, it is critical to find a balance between the timing of harvesting (i.e., at which life stage) to ensure a sustainable tiger prawn fishery in Kuala Baram that protect spawner stocks and optimise profit at the same time.

Since tiger prawns inhabit in different habitats during the different stages of their life cycle, they are subjected to a wide range of environmental variables (Chen, 1990; Branford, 1981). Numerous studies have shown that environmental factors can directly and indirectly affect prawn's life cycles in many ways (Manson et al., 2005; Vance et al., 2003; Hill, 2000; Salini et al., 1990). In the worst-case scenario, a change in the environment can cause the recruitment of prawn to collapse (Dambacher et al., 2015). For example, early wet season rainfall has shown to increase food supply for larvae, juvenile and adult of prawn (Vance et al., 2003). The emigration of juvenile prawns can be triggered and even accelerated by rainfall through the effects on river flow and a reduction in salinity, which triggered the emigration of smaller prawns (Loneragan and Bunn, 1999; Vance et al., 1998). Meanwhile, late wet season can reduce inshore salinities, causing adult prawns to move offshore and increased their chances to be harvested (Vance et al., 2003). Furthermore, an increase in turbidity due to rainfall can make it difficult for predator to prey on juvenile prawn in estuary (Vance et al., 2003). In terms of habitat, mangroves provide ecosystem services such as retaining nutrients that enrich juveniles' food supply and providing refuge from predators, and cover for juveniles in estuary (Manson et al., 2005).

Therefore, to ensure a sustainable tiger prawn fishery in Kuala Baram, an in-depth understanding on the environmental conditions in each habitat hosting different stages of tiger prawn is required. Specifically, it is essential (1) to identify key environmental parameters influencing tiger prawn stocks in Kuala Baram, (2) to identify different types of habitats in Kuala Baram, (3) to identify spawning-sensitive areas in Kuala Baram, and (4) to determine critical timing of spawning season in relation to environmental factors.

2.2.1 Methods of data collection and analysis

Among the environmental variables, water temperature, salinity, dissolved oxygen, chlorophyll-a (proxy of food source), turbidity, rainfall, nutrients, and water currents have identified for analysis. In situ environmental data will be obtained from DOF e.g. data published by Nurridan (2021a) and via desktop review. Alternatively, similar environmental data will be obtained from satellite data. There is a caveat in using satellite data as resolution is usually more than 1 km, which might be too coarse to distinguish environment conditions at each habitat (Fig. 15).

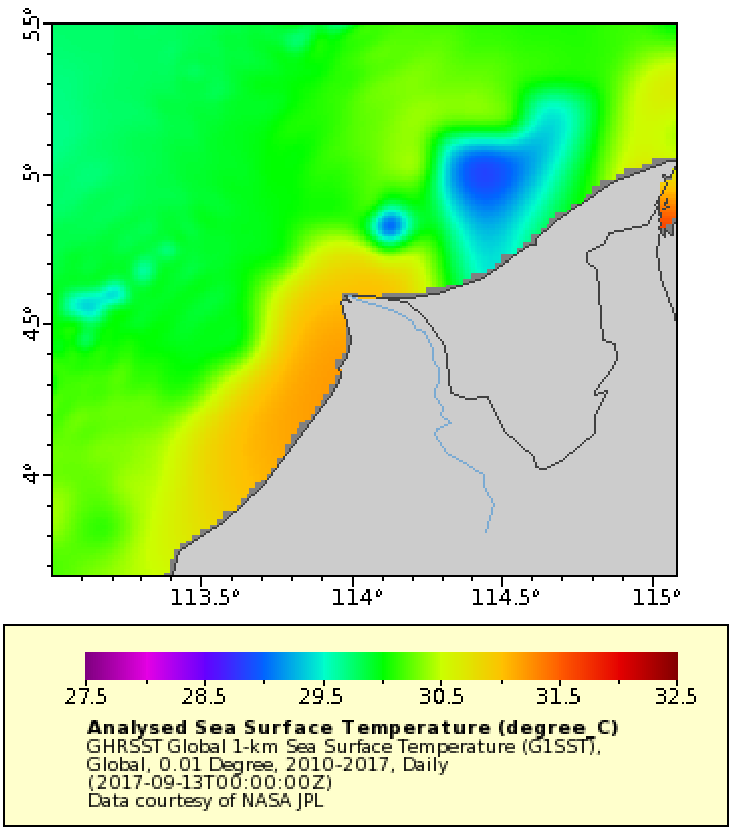

Fig. 15: Example of satellite-derived sea surface temperature at 1 km spatial resolution.

Spatial and temporal distribution of environmental parameters in each habitat will be analysed and the correlation between tiger prawn stocks and hydrological parameters will be investigated. Multivariate analysis e.g., principal component analysis and canonical cross correlation will be employed in R programming language to identify key environmental variables. The findings from the statistical analyses will be used in decision making of spawners protection and seasonal closure.

2.2.2 Preliminary findings from desktop review

In Miri, mangrove forest can be found around the coastal area, which 678ha of the mangrove forests are 45km west away from Miri town and had been declared as wildlife sanctuary in 2000, commonly known as Sibuti mangrove forest (Shah et al., 2016). From all the documents collected in the desktop review, there is no study that combine the economically importance fishery resources such as shrimp, and environmental parameters to study the effect of ecological stress on their temporal and seasonal abundance. It is rather crucial as there are increasing ecological stress such as sedimentation or effluent discharge in the Miri estuary, which can potentially alter the ecological landscape as well as the regional community structure, affecting the fisheries production in this region.

The industrial activities along the Baram bank and Miri rivers such as timber processing plant, palm oil estate and petroleum industry have raised the concern of pollutant or effluent discharge causing harm to the coastal ecosystem (Anandkumar et al., 2017; Billah et al., 2017) including tiger prawn's habitats. Among the rivers, Baram River was then reported to contribute higher sediment input into the Miri coast compared to the Miri and Sibuti River due to the deforested agricultural lands (Anandkumar et al., 2019; Nagarajan et al., 2015).

In situ environmental data for Kuala Baram are very limited as there are not many published reports or articles. This might affect the quantitative quality of the findings.

2.3 Size-based fishery (prevent the capture of immature individuals)

Body size is a common structuring variable in aquatic species, including fish stock and other economically important species. The reason behind the usage of body size instead of age is because body size is directly related to food consumption, mortality, maturation, fecundity, fish gear selectivity, and population variation. In addition, the measurement of body size is feasible and relatively easy to be conducted, making body size data largely availably (Andersen, 2020). Size-based fishery (minimum catch size) is often used in marine species, including shrimps (Larsen et al., 2018). For example, the overall shrimp (*Pandalus borealis*) catch can only contain less than 10% by weight of undersized shrimps in Norway.

Length-weight relationship of *P. monodon* is known to be negatively allometric, which means weight tends to increase at a faster rate than length as length increases. Length at first capture was 12.44 cm in Nigeria (Wilson & Amiye, 2017). However, data on *P. monodon* in SEA is limited.

2.3.1 Introduction of Minimum Landing Size

The availability of the length of maturity is crucial to setting and imposing Minimum Landing Size (MLS) and other regulatory measures to protect the harvested species and prevent overfishing. For example, Turkey has successfully introduced MLS to eleven taxa based on the length of maturity of these species (Yildiz & Ulman, 2020). The introduction of such a policy to prevent the capture of immature individuals is important as overfishing is known to be a plausible factor in the reduction of mean maturity sizes for many taxa, including economically important crustaceans (Waiho et al., 2016). However, it is also important to note that MLS measures can only be successful if they are accompanied by controls and implementation at the specific landing sites (Yildiz & Ulman, 2020). The implementation of MLS will ensure a more balanced and sustainable harvest of *P. monodon* (Fig. 16).

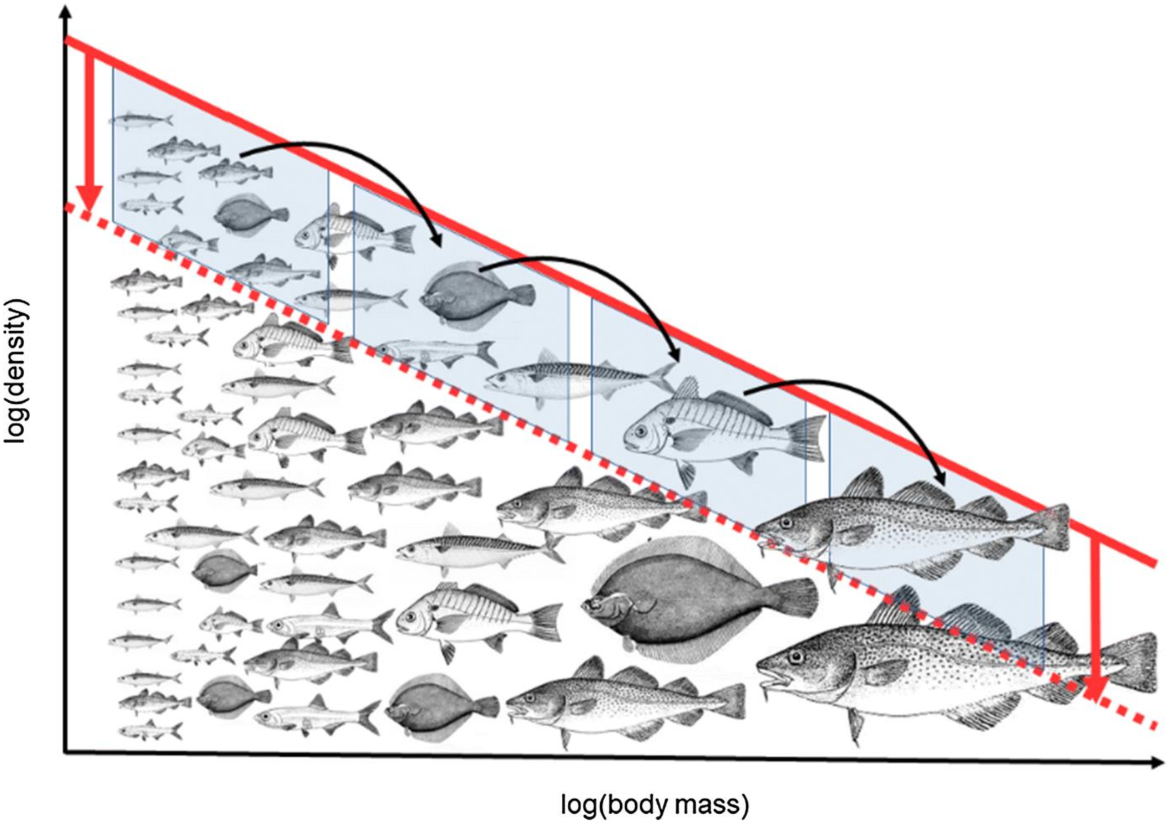

Fig. 16: The ideal equilibrium community size spectrum, with increasing body mass and decreasing density in an unexploited fish community (solid red line). Balanced harvest removes (harvests) a cross-section of this size-structured community, eventually reduces the overall density, but has little impact on the slope (dashed red).

2.3.2 Preliminary data of size-based fisheries of tiger prawn in Kuala Baram

In regards to the *P. monodon* population in Kuala Baram, there is currently no knowledge on the size at maturity and thus, no limit of catch based on their body sizes has been proposed. All sizes of *P. monodon* and all maturation stages, from immature juveniles to mature adults and berried females, are harvested. This scenario is especially dangerous because it will cause the collapse of a population in near future.

The current data available on *P. monodon* was provided by the research of Nurridan (2020a, 2020b) as an effort to establish a regional system of fisheries refugia in the South China Sea and Gulf of Thailand. Based on the 95 individuals caught and measured, the length-weight relationship of *P. monodon* from Kuala Baram is as in Fig. 17. In general, at the same length, females exhibited higher body length compared to males after the cut-off value of approximately more than 5.5 cm. The higher body weight of females is attributed to the development of gonads for reproduction purposes. However, due to the limited number of specimens and the lack of knowledge on the maturation status of both sexes in the specific area, the exact size at maturity of *P. monodon* from Kuala Baram is still undetermined. Nonetheless, the data of Nurridan (2020a) shows that the size range of females at gonad stage 0 was 5.5 to 6.7 cm. Therefore, based on this, we can preliminarily predict that the MLS of females should be slightly above this size range to enable sufficient time for females of *P. monodon* from Kuala Baram to reproduce at least once before being caught by fishermen. This will ensure the sustainability of *P. monodon* populations in the proposed refugia zone of Kuala Baram.

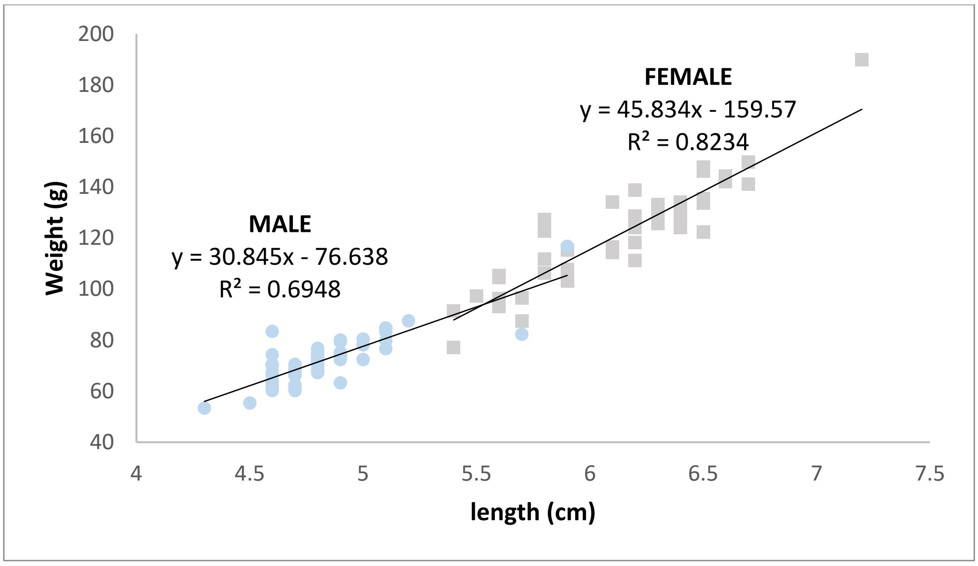

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Fig. 17: The length-weight relationship of P. monodon in Kuala Baram (n = 95) sampled in August 2019 by Nurridan (2020a).

In addition, based on the results of Nurridan (2020b), the maturation stages of female *P. monodon* at Kuala Baram is similar to other crustaceans and can be divided into five stages. Out of the six survey trips conducted from June to November, females with stage 4 ovarian maturation stage dominated in the month of August, and the highest concentration of stage 4 and 5 ovarian maturation stages can be found between August to October (Fig. 18). Therefore, we agree with the suggestion of Nurridan (2020b) to implement closure or other protective measures to ensure that females are protected during such a high reproductive output period. It is, however, important to note that, future studies that incorporate at least a one-year period with a higher number of individuals and more concrete data should be conducted to provide a solid foundation and support for the identification of the high fecundity period of *P. monodon* in Kuala Baram.

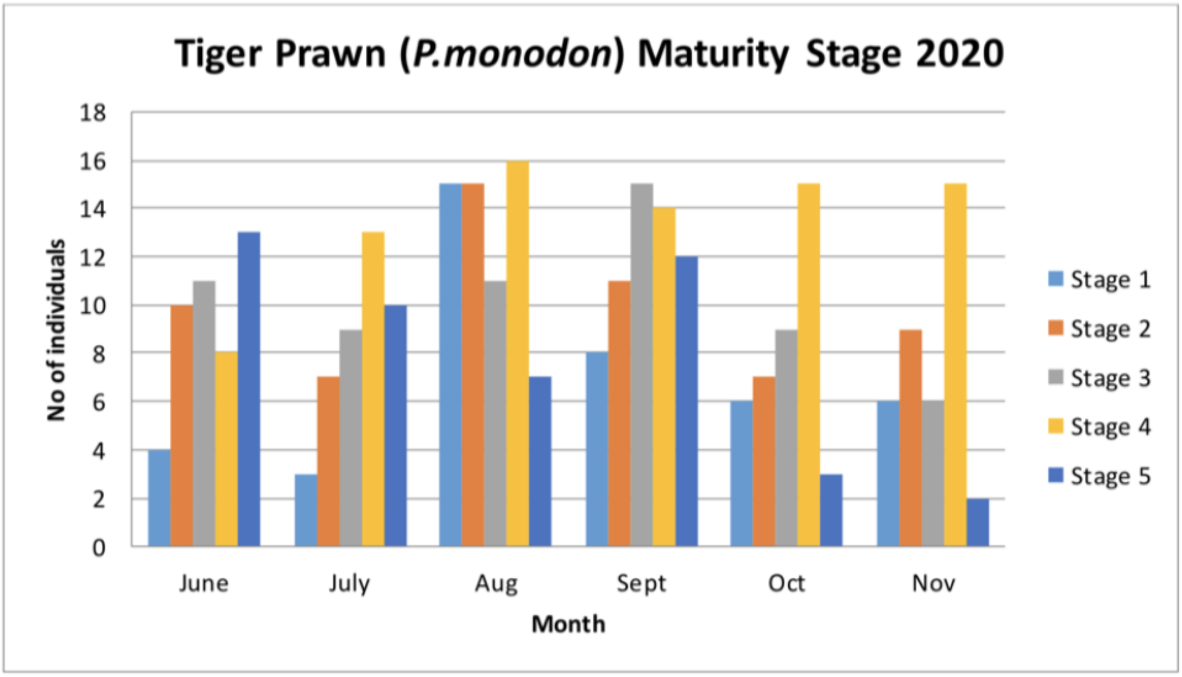

Fig. 18: The distribution of maturation stages of female *P. monodon* from June to November 2019 (Nurridan, 2020b).

2.4 Revision of harvest methods and gears

2.4.1 Fishing gears and trawling areas

According to a survey conducted at *Kampung Kuala Baram, Kampung Pengkalan Lutong, Kampung Pulau Melayu, Kampung Piasau Utara, Kampung Kuala Bakam* and Miri town, a total of 112 fishers operating drift net, hook & line, trammel net and trawl net (twin out-rigger) are being used at the coastal waters up to 15NM offshore in Miri. The number of licenses by zone: C12-30; C10-1; C7-24 and the rest (57 boats) are traditional operators from zone B and A. Local fishermen claimed that the sea off Kuala Baram contributed 70-80% to their income. According to the survey conducted in 2016 (*Anon.* 2016) on local fishermen, 44% of them has landed tiger prawn within 3NM; 32% (3-5NM); 13% (5-7NM) and 11% (7-12NM) (Fig. 19).

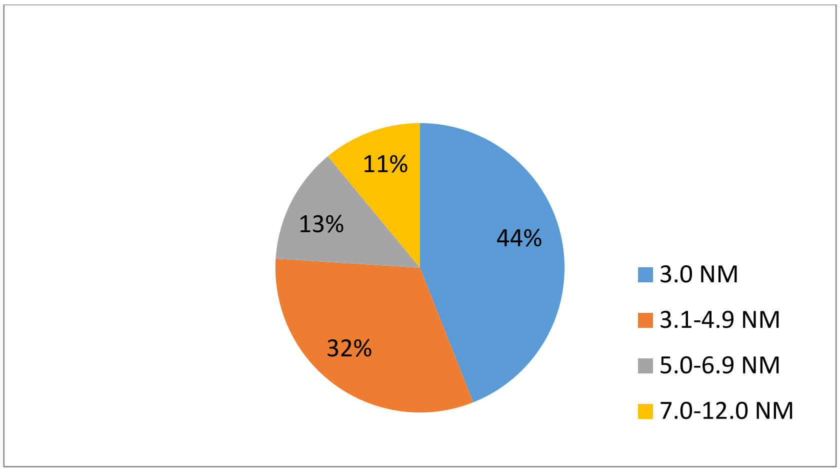

Fig. 19: Distant in NM from the coast where local fishermen landed tiger prawn in their catch

With the new regulation of shifting the trawling area to 8NM and above, the areas of less than 5 NM are considered protected from trawling activities where the stations of high concentration of tiger shrimp spawners are in the range of 4.47 – 5.76 NM (Nurridan, 2021b). But, the lucrative nature of the business (Hadil, 2004) encourages encroachment of trawlers to the coastal zone to catch spawners (Fig. 20).

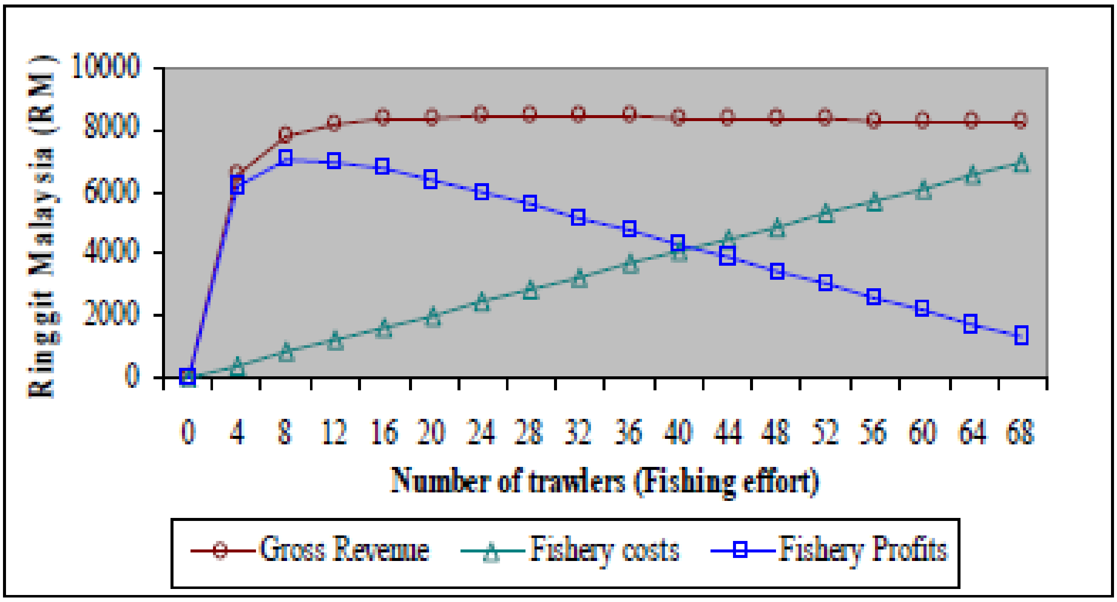

Fig. 20: Fishery profit and revenue versus fishing effort (Hadil, 2004)

The problem of over-exploitation of the tiger prawn resource is aggravated by the deployment of destructive fishing gears such as beam-trawl and mechanized push net in the coastal prawn nursery areas. Prawn nursery area in the riverine ecosystem is also affected by deforestation of mangrove area for development and housing.

2.4.2 Harvest strategy

The harvest strategy is required to be responsive to the state of the stock and should be designed to achieve the stock management objectives reflected in the Limit Reference Points, LRPs. The Limit Reference Points, LRP are maximum values of fishing mortality or minimum values of the biomass. Exceeding the LRP may endanger the capacity of self-renewal of the stock (Cadima, 2003). The primary strategy would be to introduce measures that would reduce fishing capacity by 50% through limited access and the use of rights-based approaches in small-scale fisheries.

2.5 Identification and engagement with stakeholders

Most of the fishermen involved in the harvest of *P. monodon* are small-scale fishers that operate along the coastal zones and utilize traditional gears, although there are also some fishermen that operate trawlers and purse seine in deeper off coastal zones of more than 5 nautical miles.

The establishment of a refugia requires the combined effort from various stakeholders. Public participation and the active involvement of community players are critical to ensure the successful implementation and sustainability of any refugia management plan. Therefore, the main stakeholders will be the fishermen community, a critical player that will play a vital role in ensuring the success of this refugia project. In Malaysia, fishermen are being registered and monitored under the Fishermen Association (Persatuan Nelayan). It is a multi-purpose cooperative that provides a much-needed platform for fishermen to voice their opinions, in addition to handling various administrative and commercial-related activities such as marketing, input supply, insurance, educational activities etc.

In addition to the fishing communities, another important player in the establishment of the Kuala Baram Tiger Prawn Refugia would be the government sector, specifically the Department of Fisheries Malaysia and its subsidiary Fisheries Research Institute. The

Department of Fisheries Malaysia is a core stakeholder of this project as it holds vital monitoring, regulatory and advisory role in the *P. monodon* fishery and harvest activities.

To gain trust and support from the community for the management of tiger prawn refugia, transparency in the regulation and enforcement, and awareness on the importance of refugia should be conducted. These aspects include management regulations, importance of enforcement, general biology and life cycle of tiger prawns, the long-term benefit of refugia, and the responsibility of all stakeholders to safeguard its population. Such strategies would ensure voluntary participation from all stakeholders and self-governance of the refugia program in the long run.

2.5.1 Stakeholders' engagement

Under the joint effort with Southeast Asian Fisheries Development Center (SEAFDEC), United Nations Environment Programme (UNEP), and Global Environment Facility (GEF), the Department of Fisheries Malaysia initiated the establishment of tiger prawn refugia in Kuala Baram, Miri, Sarawak. A stakeholders' engagement with other relevant stakeholders, including Miri Port Authority, Sarawak Fishing Vessel Association, Department of Marine Fisheries, Sarawak, Sarawak Forestry Corporation, Miri Fishermen Association, Department of Irrigation and Drainage Branch Miri, and Sarawak Rivers Board was held on 23rd September 2021 and 21st October 2021, chaired by the Director of Sarawak Marine Fisheries Department. The full report of the engagement session can be found in the report of Department of Fisheries, Malaysia (2021).

Based on the report, all stakeholders understand the importance of the establishment of *P. monodon* refugia to safeguard the wild *P. monodon* populations at Kuala Baram, Miri, Sarawak. The details of the proposed refugia monitoring and management plan is outlined in section 2.6.

To facilitate and revalidate the proposed management plan, a direct consultation/engagement with all stakeholders, including the Department of Fisheries and Persatuan Nelayan Miri was conducted on 11-13 May 2022. A direct consultation/engagement method was selected as this will ensure an accurate representation of information from all relevant authorities and parties, and also owing to the scarce data available in the public domain. In addition, stakeholders, particularly fishermen, will feel more comfortable and more ready to collaborate in a relaxed setting and face to face nature. Moreover, this allowed all parties, especially the consultancy group members a chance to visualize the site location and the local communities in person. Such engagement opportunity will be critical for the upcoming workshop and future engagement activities.

2.6 Proposed monitoring and management plan for refugia

The refugia consultancy project was initiated by the Department of Fisheries, Malaysia to propose a monitoring and management plan for tiger prawn refugia at Kuala Baram, Miri, Sarawak. The four components for refugia establishment identified by Mohd Fhazali (2016) was used, which includes (1) the 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 based management; (3) information management and dissemination in support of national level implementation of the concept of fisheries refugia; and (4) national coordination for integrated fish stocks and critical habitat management.

In short, it can be divided into two main sections; a baseline scientific and technical personnel level for data verification and suggestion, and the subsequent policy and decision makers level, where suggestions from the various scientific and technical communities will be incorporated into policy (Fig. 21). Similar coordination mechanism is used in the establishment of refugia of *P. monodon* in Kuala Baram, Miri, Sarawak, and mud spiny lobster in Tanjung Leman, Johor.

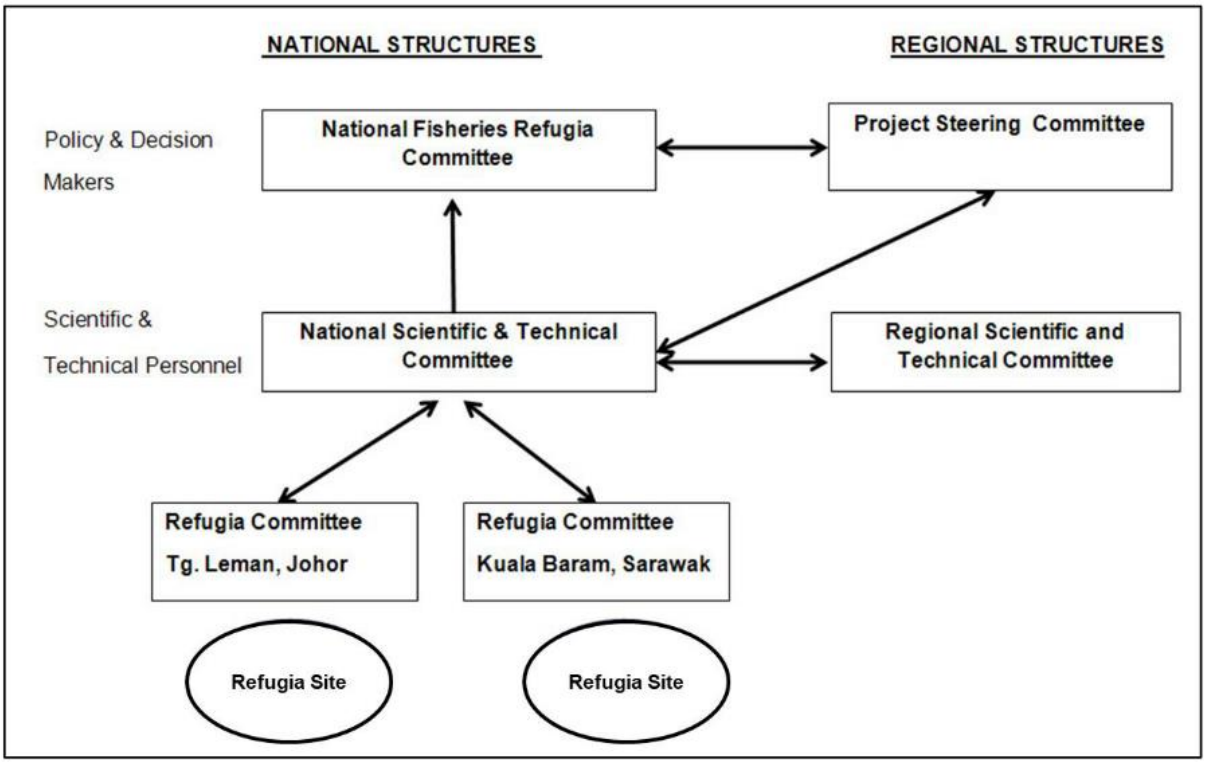

Fig. 21: The coordination mechanism for the establishment of fisheries refugia in Malaysia (Siow et al., 2020)

Based on the previous engagement session (Department of Fisheries, Malaysia, 2021),

1. All stakeholders agreed with the proposal of the tiger prawn refugia establishment.
2. August to October will be regulated as the closed season for tiger prawns.
3. This regulation is applicable for all trawlers at Zone C7. All fishing activities by the trawlers must operate at 12 nautical miles from the shoreline.
4. 2021 will be the first year of the implementation of this regulation
5. The department also encourages the fishermen to comply with this regulation voluntarily for this year. In the year 2023, the department will fully enforce these regulations.
6. For tiger prawn, specifically for Kuala Baram, the Close season from August to October will be included as an additional clause in the Vessel License and Fishing Equipment for fishermen's Zone C7.
7. FRI Bintawa will appoint a Technical Committee for the management of Sungai Bakam.

The above summary will serve as the initial guidelines for the proposal of *P. monodon* refugia in Kuala Baram, Miri, Sarawak. After the first engagement session by the consultancy group on 11-13 May 2022, the above suggestions for the refugia management plan are confirmed by all stakeholders.

2.7 Financial sustainability

Oceans are a natural resource that, along with soils and forests, contribute to the global stock of natural capital. These natural resources produce essential ecosystem goods and services including food, climate regulation, coastal protection, and cultural value that ensure human existence and well-being on a global scale (Sumaila et al., 2021). Diverse renewable and non-renewable resources (such as fisheries, oil, and gas reserves) can be found in the oceans, and these resources supply intermediate inputs like waves and fish stocks to enable ocean-based industries like seafood production and renewable energy (Sumaila et al., 2021). However, a lot of things about how we now use ocean resources make it unsustainable. Damage to habitats and widespread biodiversity loss are effects of human-induced changes to marine ecosystems (Sumaila et al., 2021). Therefore, it is compulsory to sustain the marine resources, and the government also oversees a variety of initiatives, one of which is the sustainable financing of marine resources. Even though the sustainable financing of marine protected areas is still an important issue on the conservation agenda. We will discuss about the financial sustainability of marine resources using the seven articles we previously chose.

2.7.1 Willing-to-pay approaches

The research of Getzner et al. (2017) identify financial sustainability through which options for funding are based on visitors' willingness-to-pay to conserve marine biodiversity in the Lastovo Archipelago Marine Park in Croatia. Based on the depiction of three possible scenarios, the authors examine the willingness-to-pay (WTP) among tourist for the conservation of distinctive habitats and species and discovered that a major WTP might help with the long-term management and financing of the site. They also co-finance the work of public institutions paying an "entrance fee" to enter the area. A portion of the protected area's income comes from access and use (e.g., fishing concession licenses, sailors' entrance fees, recreational fishing licences, souvenirs and merchandise), as well as through contributions from various organizations, charities, and ministries.

2.7.2 Provincial Trust Fund

Moreover, Ison et al. (2018) evaluate the willingness of stakeholders to pay (WTP) and/or volunteer their time (WtCT) to manage the Qoliqoli (area) in the MPA area in Fiji as a potential financing mechanism for inshore MPA. The extent to which bottom-up governance systems offer a possible financing mechanism for an MPA network was investigated using the Willingness to Pay (WTP) and Willingness to Contribute Time (WtCT) techniques. The WTP and WtCT of stakeholders to manage an MPA were significantly influenced by factors such proximity to a fishing market, dependence on marine resources, food security, income, and international commitments. A Provincial Trust Fund (PTF) is considered as a financing instrument for inshore MPAs using WTP and WtCT data. A PTF is a source of sustainable financing for the management of protected areas and long-term biodiversity protection. A PTF also supports sustainable management of traditional fishing societies through its polycentric and decentralized governance model. The PTF will act as a tool for managing finances and as a middleman between people who use resources and those who protect them. For instance, the Phoenix Islands Protected Area in Kiribati uses PTFs as a system of financial inducement. It serves as a middleman to gather donations and direct them to organizations that provide ecosystem services (Govan, 2015).

2.8 Financial model - Refugia trust fund

Generally, there were a variety of sustainable financing models in financing the identified potential marine areas. A study by Millage et al. (2021) researched about self-financed marine protected areas. They propose a new institution to improve MPA design: a Conservation Finance Area (CFA), that utilises leased fishing zones inside MPAs, fed by spill over, to fund monitoring and enforcement and achieve greater conservation success. The purpose of the Conservation Finance Area (CFA) is to help overcome the challenges of adequate enforcement by providing an economically sustainable financing pathway. Therefore, the size of the conservation financing area is one of the key elements that helps to calculate and measure conservation finance in this study.

McGowan et al. (2020) conducted a study about prioritizing debt conversion opportunities for marine conservation. Investment based debt conversion mechanism helps to calculate and measure conservation finance in this study. Incentivized debt conversion is a financing mechanism that can help debt-burdened countries boost long-term domestic investment in nature conservation. They demonstrate how environmental organisations, private entities, and investment banks can use structured prioritisation frameworks to make conservation finance investment decisions, such as debt conversions.

Bos et al. (2015) provide a high-level overview of the various financing mechanisms being used or considered for marine conservation, as well as the typical investors and investees involved (refer figure below).

Most common type of financing for marine conservation that used in this study was:

Marine Financing Conservation Mechanisms	**Author**
Grant	Lennox (2012)
Market-Based Instruments create economic incentives (rewards or punishments)	Fujita et al. (2013).

Grants are funds that are not required to be repaid. Governments, high-net-worth philanthropists, foundations, multi-lateral institutions (government conglomerates), and private companies are all sources of funding for marine conservation. Grants are required, but insufficient, to achieve marine conservation objectives.

While for market-based instruments, the environmental economists developed many market-based instruments to reduce the negative environmental impacts associated with the production of goods and services (hereafter 'environmental damages') and the uncompensated costs associated with those environmental damages (the damages and costs together are referred to as 'environmental externalities').

Fitzgerald et al., (2020) study used conservation investment as the key elements that helps to calculate and measure conservation finance. Conservation investments, a subset of impact investments, aim to return principal or make profits while also benefiting natural resources and ecosystems. They have stated that investors can accelerate the global transition to sustainable fisheries by seeking conservation investments that have a positive ecosystem impact while also producing financial returns.

2.8.1 Marine resource financing research

Perera-Valderrama et al. (2020) conduct research on marine resource sustainability financing through a project proposal grant "Southern Archipelagos," led by the National Centre of Protected Areas of Cuba and funded by the GEF. Through the establishment of 12 new marine protected areas, the project improved Cuba's efforts to preserve its marine biodiversity (MPAs). The financial planning of protected areas is addressed based on the identification of the conservation objects and the dangers they face, which serves as a starting point for determining the necessary tasks to carry out their monetary quantification.

Mallin et al. (2019) paper demonstrated that they studied the financing of marine resource sustainability using funds from philanthropic foundations based in the US. These funds are intended to support the operation and management of the LMPA and eventually make up for lost fishing license revenue by the government through the establishment of a trust fund. To empirically trace the political, legal, and financial evolution of Phoenix Islands Protected Area (PIPA), content analysis of important documents is undertaken.

3.0 Inception Summary

The establishment tiger prawn refugia requires careful and detailed representation of important aspects such as their life-cycle followed the determination of their weight-length relationship, environmental conditions and their harvesting methods and gears. The involvements of specific parties; the stakeholders and the government bodies are important for management and financial sustainability throughout the entire refugia plan. According to acquired preliminary data and observable anthropogenic impact, more conservation efforts are required to ensure that the population of tiger prawn at the refugia area are not affected. Furthermore, financial sustainability research is necessary for a long term establishment of tiger prawn refugia.

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