Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 29(3): 1669 – 1690 (2025)
www.ejabf.journals.ekb.eg

Population Dynamic and Spawning Potential Ratio of Tiger Shrimp (*Penaeus Monodon*) Fisheries Using Double Rig Trawl in the Arafura Sea, Indonesia

Mustasim[1*], Tri Djoko Lelono[2], Daduk Setyohadi[2], Edi Susilo[2], Ady Jufri[3], Ananda Sekar Kinanti[4]

[1]Marine and Fisheries Polytechnic, Sorong 98414, Southwest Papua, Indonesia
[2]Faculty of Fisheries and Marine Sciences, Brawijaya University, Malang 65145, East Java, Indonesia
[3]Faculty of Animal Husbandry and Fishery, Sulawesi Barat University, Majene 91411, Indonesia
[4]Master Study Program, Department of Aquaculture, Faculty of Fisheries and Marine Science, Brawijaya University, Malang 65415, East Java, Indonesia

[*]Corresponding Author: mustasim@polikpsorong.ac.id

ARTICLE INFO

Article History:
Received: March 24, 2025
Accepted: May 26, 2025
Online: May 28, 2025

Keywords:
Tiger shrimp,
Arafura sea,
SPR,
Trawl

ABSTRACT

The population dynamics and spawning potential ratio (SPR) of the tiger shrimp (*Penaeus monodon*) in the Arafura Sea, Indonesia, were studied to support sustainable fisheries management. This research measured carapace length distribution, length at first capture (Lc), growth parameters, mortality, and SPR using the length-based spawning potential ratio (LB-SPR) method. Data were collected from shrimp trawl vessels operating in the Arafura Sea over one year. Results showed that the carapace length of captured tiger shrimp ranged from 30.2 to 99.8mm, with an average of 62.03mm. The estimated Lc was 52.43mm, indicating that most captured shrimp had reached gonadal maturity. Growth parameters based on the von Bertalanffy growth model indicated an asymptotic length ($L\infty$) of 102.82mm and a growth rate (K) of 1.10/year. Total mortality (Z) was estimated at 3.85, with natural mortality (M) at 1.37 and fishing mortality (F) at 0.33, resulting in an exploitation rate (E) of 19%. The SPR analysis yielded a value of 31%, which is below the sustainability threshold of 40% but has not yet reached a critical level. These findings indicate that the tiger shrimp stocks in the Arafura Sea are in a moderate condition but are at risk of overexploitation. Therefore, quota-based fisheries management and stricter fishing gear regulations should be reinforced to ensure the sustainability of tiger shrimp resources.

INTRODUCTION

The availability of employment sources and animal protein sources in the form of fish, including shrimp, can improve community welfare **(Ali, 2021; Teniwut *et al*., 2022)**. Therefore, utilizing resources in a particular region must apply a measured and sustainable system to ensure their benefits for future generations **(Huse *et al*., 2021)**. The Arafura Sea is recognized as an important area for commercial shrimp fisheries in Indonesia **(Abdul-Aziz *et al*., 2015; Simbolon, 2020; Tirtadanu *et al*., 2022; Aruri *et al*., 2024)**. The

Arafura sea, located within Fisheries Management Area of the Republic of Indonesia (WPPNRI) 718, are among the most fertile waters, contributing 21% of Indonesia's total fish potential **(Suman *et al*., 2017; Sari *et al*., 2018; Muawanah *et al*., 2021)**. The estimated shrimp resource potential in the Arafura Sea is approximately 45% of the national marine fish potential **(KKP, 2014)**, and based on Ministerial Decree No. 19 of 2022, the estimated potential of penaeid shrimp production in Indonesia is approximately 62,842 tons per year. However, actual production data over the past decade indicates a significant increase. In 2012, the aquaculture production volume was around 9.45 million metric tons, which rose to approximately 14.65 million metric tons by 2021. Specifically, shrimp production reached 1.09 million tons in 2022 **(Siahaan, 2024).**

Several studies based on production assessments, fishing efforts, and biological indicators from 1984 to 2014 indicate that shrimp fishing in the Arafura Sea has been overexploited **(Wijopriono *et al*., 2019; Sari *et al*., 2021)**. In response to this phenomenon, the Indonesian government issued Ministerial Regulation No. 56/PERMEN-KP/2014 concerning a moratorium on fishing business permits in WPPNRI. Subsequently, Ministerial Regulation No. 02/PERMEN/2015 **(KKP, 2015)**, was issued prohibiting the use of trawl nets and seine nets in Indonesia's fisheries management areas. However, in 2021 Ministerial Regulation No. 18/PERMEN-KP/2021 was enacted, regulating the placement of fishing gear and fish aggregating devices in Indonesian waters and the high seas, as well as the arrangement of fishing operations. This regulation was later amended by Ministerial Regulation No. 36/PERMEN-KP/2023 following the issuance of Government Regulation No. 11 of 2023 on measured fishing.

Tiger shrimp and other penaeid shrimp species have fast growth rates and short lifespans **(Suman *et al*., 2020; Günther *et al*., 2021; Salim *et al*., 2021)**. The natural mortality rate of the tiger shrimp is 1.7 per year (for both females and males), necessitating prudent management and utilization of these resources **(Tirtadanu & Chodrijah, 2019)**. This issue arises because management efforts have not been based on scientific assessments, leading to poor policy quality. If this situation persists without proper management actions, it will threaten the sustainability and long-term utilization of shrimp resources, ultimately affecting the viability of the national shrimp fishery industry **(Suman *et al*., 2017)**.

Uncontrolled exploitation can cause a drastic decline in tiger shrimp stocks, disrupting the marine ecosystem balance and reducing fishermen's catches. Additionally, the government must exercise caution in managing fishery resources to prevent stock depletion **(Wibisono *et al*., 2022)**. There is a need for research to explore alternative management strategies and regulations that optimize benefits while ensuring the sustainability of shrimp resources, particularly the tiger shrimp in the Arafura Sea. Based on these detailed data, a study on tiger shrimp is necessary, covering carapace length frequency distribution, the first capture length, growth rate, mortality, and the spawning potential ratio. Previous studies have investigated some of these parameters. For instance,

Anshary and Baxa (2018), analyzed the growth and mortality rates of *Penaeus monodon* in the coastal waters of South Sulawesi, while **Hapsari *et al*. (2023)** examined size frequency distribution and spawning potential ratio in the Java Sea. This research is intended to support the implementation of the 'Measured Fisheries' policy by generating scientific data on the biological characteristics of the tiger shrimp (*Penaeus monodon*), including carapace length frequency distribution, length at first capture, growth rate, mortality, and spawning potential ratio **(Luthfia, 2023)**. These data are fundamental for establishing biologically sound catch limits and formulating management strategies that ensure the sustainability of shrimp stocks. In this regard, the study contributes to the advancement of evidence-based fisheries governance and plays a strategic role in realizing the principles of the Blue Economy through sustainable and equitable resource utilization **Trenggono (2023)**.

MATERIALS AND METHODS

This study was conducted on trawl shrimp fishing vessels operating in the Arafura Sea, with a landing base in Sorong, Southwest Papua, as shown in Fig. (1). Data collection was carried out through direct surveys by observing the operation of trawl shrimp fishing over a full cycle (one year).

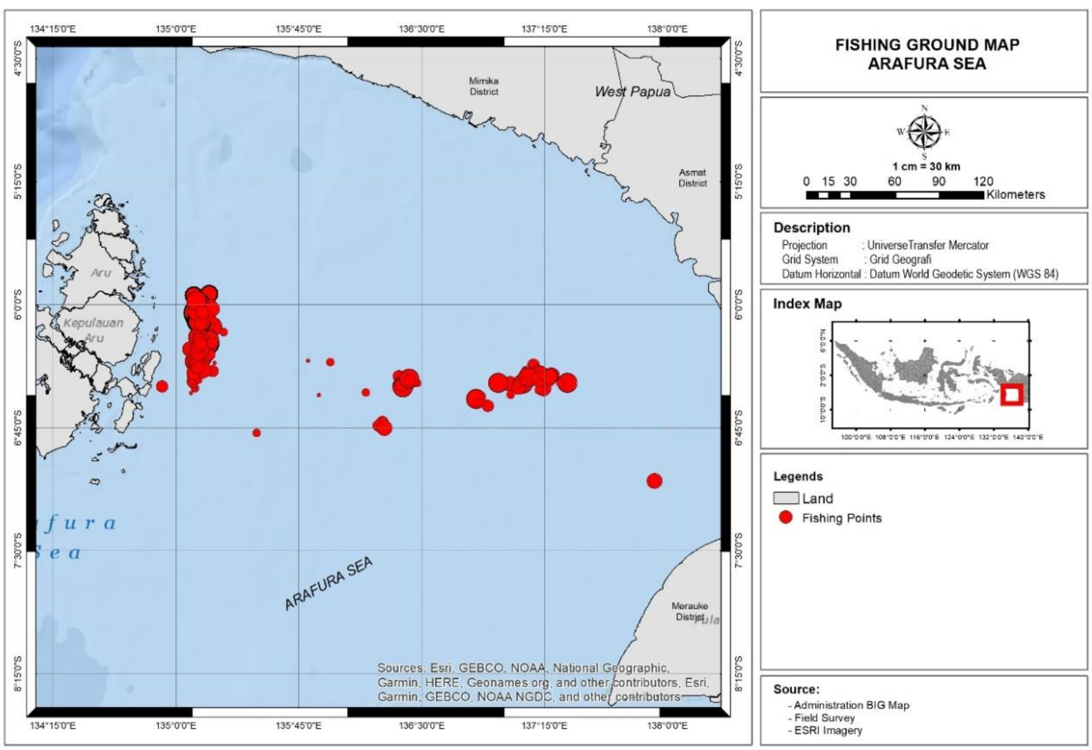

Fig 1. Research location map

Data collection was carried out by measuring the carapace length of tiger prawns using an electronic digital caliper of 8,004 individuals, referring to the research of **Chan *et al*. (2021)**, which explains the weight of tiger shrimp, the composition of catches (tiger shrimp) based on size, and gonad maturity. Tiger shrimp samples were measured daily and tabulated monthly in an Excel spreadsheet.

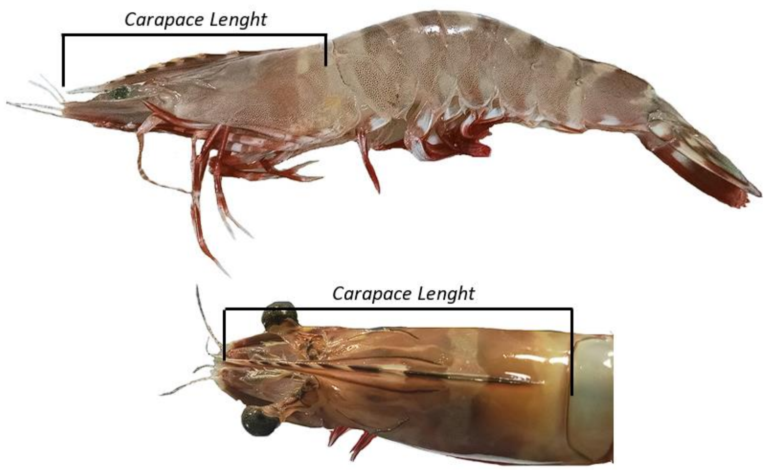

Fig. 2. Method of measuring tiger shrimp carapace length (CL) **(Mustasim *et al*., 2025)**

Length at first capture

Half of the retained fraction (the fish captured) corresponds to the length at first capture (Lc), which is determined by the fishing gear. The Lc value is derived from the length frequency distribution data, calculated using the formula provided by **Sparre and Venema (1999)**:

$SLest = 1/(1+\exp^{(S1-S2*L)})$ 1

$Lc=S1/S2$ 2

Where, SLest is a logistic curve, S_1 and S_2 are constant.

Growth parameters

Several growth parameters were analyzed using the FiSAT II program. To determine the asymptotic length and growth rate, the ELEFAN I method was employed. ELEFAN I analyzes the forward movement of several modes, connecting mode to mode of monthly length frequency in a time series to form a growth curve. Growth analysis was performed using the formula proposed by von Bertalanffy **(Sparre & Venema, 1999)**:

$Lt = L\infty\ (1-e^{-K(t-t0)})$ 3

Where, Lt stands for length at age t; $L\infty$ denotes asymptotic length; K denotes growth rate; e stands for the exponential constant; and t_0 = theoretical age of the fish at zero length.

The formula used to estimate the theoretical age of the Indian mackerel when the fish's length is zero (t_0) **(Pauly, 1980)** is as follows:

$\text{Log}(-t_0) = -0.3922 - 0.2752 \text{ Log } L\infty - 1.038 \text{ Log } K$ 4

Pauly's (1980) empirical connection was used to estimate the natural mortality rate (M):

$\text{Log}(M) = -0{,}0066 - 0{,}279 \text{Log } L\infty + 0{,}654 \text{Log } K + 0{,}4634 \text{Log} T$ 5

Where, $L\infty$= asymptotic length; T= mean water temperature annually (˚C).

Mortality and exploitation rate

Using the length-converted catch curve technique in FiSAT II, the total mortality rate (Z) was estimated. The formula for calculating fishing mortality (F) is the total mortality (Z) minus natural mortality (M):

$F = Z - M$ 6

The exploitation rate (E) was determined using the following equation **(Sparre & Venema, 1999)**:

$E = F/Z$ or $E = F/(F+M))$ 7

Spawning potential ratio (SPR)

An SPR database that is based on length was utilized to determine the exploitation state using the spawning potential ratio (SPR) **(Hordyk *et al.*, 2015)**. Here, SPR makes use of **Hordyk *et al*. (2015b)** LB-SPR model. The LB-SPR model utilizes M/k, $L\infty$, and length at first maturity as inputs.

SPR analysis uses the following method, which was introduced by **Prince *et al.*, (2014)**:

$$SPR = \frac{\sum_{t=0}^{t} EPt}{\sum_{t=0}^{tmax} EPt} \quad \text{.......} \quad (8)$$

Where, SPRt is the proportion of reproductive potential at age t, EP_t is the reproduction output at age t, N_t is the number of individuals at time t, with N_0 being 1000, M is natural mortality, and f_t is the average fecundity.

However, since f_t's value is unavailable, EP_t was calculated using the following equation:

$EP = (N_{t-1}{}^{e} - M)ft$ .... (9)

Where, W_t is the weight of the fish at age t, and m_t is the average size of fish with mature gonads.

The reference threshold for the spawning potential ratio (SPR) is 40%. The spawning ratio of large fish can reach 40%, ensuring a new population and good recruitment **(Hordyk *et al*., 2015)**. This statement aligns with the findings of **Yonvitner *et al*. (2021)**, which indicate that an SPR value below 40% suggests low recruitment potential and weak stock resilience. Conversely, an SPR value above 40% signifies high recruitment potential, strong stock resilience, and a greater likelihood of stock sustainability.

RESULTS

The fisheries conditions in the Arafura Sea exhibit unique characteristics, making it one of Indonesia's most important fishing grounds—particularly for tiger prawns (*Penaeus monodon*). Despite its distance from the coastline (over 12 nautical miles), the area remains suitable for bottom trawling operations targeting the bagged shrimp. This is due to favorable oceanographic features: water depths ranging from 20 to 50 meters, a generally flat seabed, and a dominant substrate composed of muddy sand. In some areas, soft coral formations are still present.

According to reports from the Ministry of Marine Affairs and Fisheries (KKP) and the Arafura and Timor Seas Ecosystem Action Program (ATSEA), the Arafura Sea is rich in fisheries resources. However, the region also faces growing challenges, including overfishing and environmental changes that are increasingly affecting catch volumes and ecosystem health.

In 2023, the Indonesian government implemented a measured fisheries policy to regulate fishing activities in its waters, including the Arafura Sea **(President, 2023)**. The impact on tiger shrimp fisheries includes setting a catch quota of 50.3 thousand tons per year that is more structured and sustainable to prevent overfishing and to maintain the tiger shrimp population. According to **Trenggono (2023)**, this policy aims to enhance transparency and accountability in fishing practices, thereby supporting marine ecosystem sustainability while optimizing economic benefits for fishers. Following the introduction of the measured fisheries policy, KKP established new regulations regarding the placement of more sustainable fishing gear **(KKP, 2023)**. Fishing gear such as bottom trawls and danish seines are only permitted in specific areas under strict supervision to preserve the marine ecosystem.

During the operation of trawl nets targeting tiger prawns in the Arafura Sea, *Penaeus monodon* was the most dominant catch, accounting for 81.4% of the total. The main target species included 12 shrimp types: the tiger prawn (*Penaeus monodon*), banana prawn (*P. merguiensis*), white prawn (*Parapenaeopsis sculptilis*), white and yellow prawn (*Parapenaeopsis australiensis*), king prawn (*Penaeus latisulcatus*), kiji shrimp (*Metapenaeus ebaracensis*), fan shrimp (*Thenus orientalis*), caterpillar shrimp (*Metapenaeopsis commensali*), red shrimp (*Metapenaeus ensis*), black tiger shrimp (*P. monodon fabricius*), pink dogol shrimp (*Metapenaeus ensis*), and blue dogol shrimp (*Metapenaeus endeavouri*). Bycatch species included the lobster shrimp (*Metanephrops sibogae*), mantis shrimp (*Harpiosquilla raphidea*), and rebon shrimp (*Mysis relicta*).

A study by **Prasetyo *et al*. (2014)** in the same waters identified only six shrimp species: the tiger prawn, Ende prawn, banana prawn, red shrimp, white prawn, and kiji shrimp. According to **Dahuri *et al*. (2001)**, Indonesia is estimated to have 11 species of marine shrimp (*Penaeidae*) and 7 species of rock shrimp. **Prasetyo *et al*. (2014)** also found that the tiger prawns were the dominant catch during their research. Similarly, a recent study by **Lelono *et al*. (2024)** confirmed that the tiger prawns remain the most dominant species caught in the Arafura Sea. Tiger prawns do not exhibit schooling behavior, meaning their catch patterns may be influenced by the distribution of individuals within their habitat.

Length-frequency distribution

A total of 8,004 tiger prawn (*Penaeus monodon*) samples were measured as part of the double rig trawl catch in the Arafura Sea (>12 nautical miles). The carapace length (CL) of the captured tiger prawns ranged from 30.2 to 99.8mm, with an average length of 62.03 ± 11.70mm CL. The mode of carapace length was 60mm CL, as shown in Fig. (3).

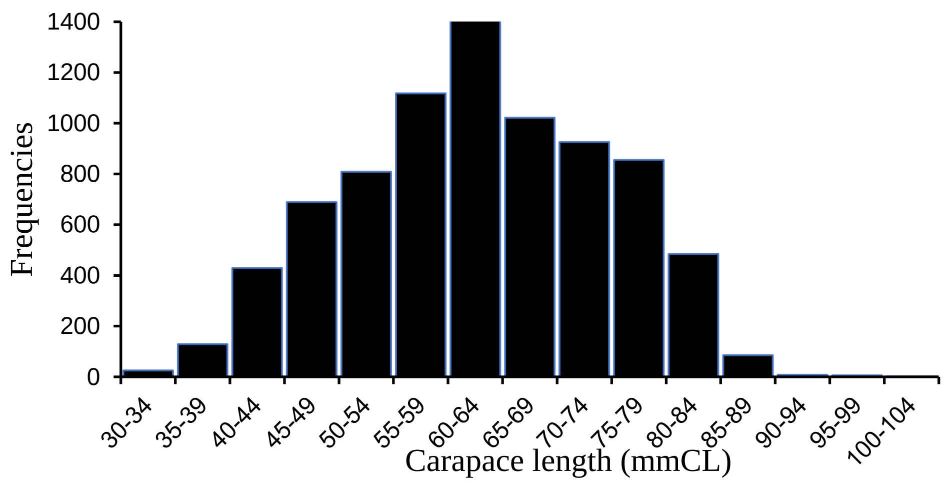

Fig. 3. Carapace length frequencies *Penaeus monodon* in the Arafura Sea

The carapace length distribution of tiger prawns (*Penaeus monodon*) in the Arafura Sea exhibits significant variation, reflecting the diversity of the captured population. These findings provide valuable insights into the population structure and growth patterns of tiger prawns in the region. Further analysis of this data can aid in fisheries resource management and the development of effective conservation strategies for this species in the Arafura Sea. Conservation strategies based on carapace length can be implemented by setting a minimum catch size. If many of the captured shrimp have not reached this size, it is recommended to limit the number of fishing vessels or temporarily close the fishery, especially in December and January, to protect spawning individuals. The carapace length distribution analysis also provides insight into the level of exploitation of tiger prawn resources. The presence of individuals with various carapace sizes indicates continuous recruitment within the population, which is essential for stock sustainability. Regular monitoring of this size distribution can help detect long-term changes in population structure and provide early indications of potential overfishing or environmental changes affecting the tiger prawn population.

The estimated length at first capture (Lc)

Knowledge of the first capture length (Lc) of the black tiger shrimp (*Penaeus monodon)* is essential for estimating the total mortality (Z) in a given fishery. A higher Lc value indicates a lower total mortality rate, meaning that more individuals can grow to larger sizes before being caught. The first capture length (Lc) is determined based on the modal class midpoint or the most frequently caught size class. This method enables the estimation of the exploitation rate within the black tiger shrimp population in Arafura Sea. Additionally, information on Lc can be used to develop more effective fisheries management strategies, such as establishing a minimum allowable catch size. This is crucial for ensuring the sustainability of black tiger shrimp populations and maintaining the balance of the marine ecosystem in the long term.

The carapace length of black tiger shrimp caught in the Arafura Sea (in fishing areas beyond 12 nautical miles from the coastline) ranged from 30.2 to 99.8mm CL, with weights between 6 and 143 grams. These values differ from those reported by **Rajkumar *et al.* (2023)**, who described the life cycle of black tiger shrimp as follows estuarine phase, including benthic postlarvae and juveniles for more than six months (33g), coastal sub-adult phase, lasting 5–6 months (60g), offshore adult and spawning phase, with weights ranging from 60 to 261g. The average first capture length (*Lc*) was 52.43mm CL (Fig. 4), as determined through FISAT II analysis. This Lc value indicates that the average captured shrimp had already reached adulthood or reproductive maturity. Thus, it can be inferred that current fishing practices in the Arafura Sea remain sustainable.

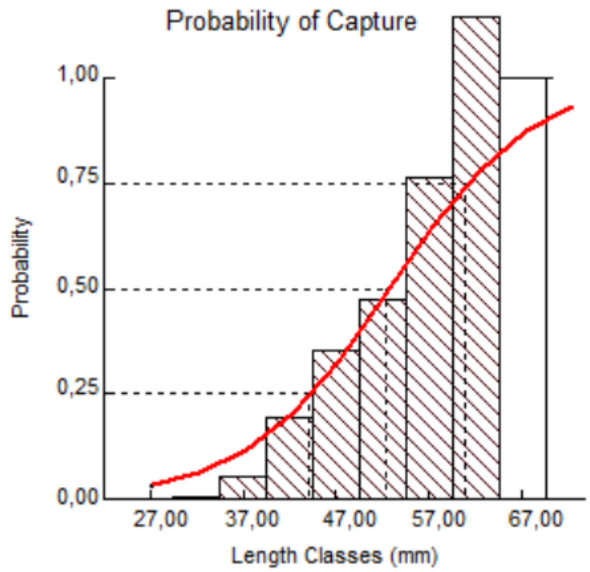

Fig. 4. Mean carapace length (*Lc*) of *Penaeus monodon* in the Arafura Sea

The estimated growth

The growth parameters of *Penaeus monodon* based on the von Bertalanffy Growth Function (L∞ and K) were obtained from the analysis of length frequency distribution data using FISAT II, yielding L∞ = 102.82 mmCL and K = 1.10/year. The t_0 value of *P. monodon* in the Arafura Sea was determined using **Pauly**'s **(1984)** equation: t_0 = -10^ (0.3922 - 0.2752) * log (L∞) - 1.038 * log (K), resulting in a t_0 value of -0.104. This value differs from that reported for the same waters by the **Ministry of National Development Planning/Bappenas (2021)**, which recorded a t_0 value of -1.

Once the L∞, K, and t_0 values were determined, the von Bertalanffy growth equation for *P. monodon* was formulated as follows: $L_t = 102{,}82*(1\text{-exp}^{(-1{,}10(t1\text{-}0{,}104)})$ (Fig. 5). The L∞ value of 102.82mm indicates that *Penaeus monodon* in the Arafura Sea has the potential to reach a carapace length of approximately 102.82mm during its life cycle. The growth coefficient (K) of 1.10/year suggests a relatively fast growth rate, meaning that the species approaches its maximum length in a relatively short period. A study by **Egna (2020)**, in the Philippines reported an L∞ value of 85.0mm and K = 0.95/year, indicating a faster growth rate but a smaller maximum size compared to the population in the Arafura Sea.

Fish and shrimp growth models are essential for stock population assessments and growth evaluations. These models describe how individuals within a population develop over time, serving as a fundamental basis for fisheries resource management. Although variations in these models may be minor, they can yield significant insights into population analysis. This is particularly important when assessing exploited stocks with different growth patterns. Such analyses also help establish reference points necessary for sustainable fisheries management. These reference points may include minimum population size, desired growth rates, or recommended catch limits, all of which aim to maintain ecosystem balance and ensure the long-term sustainability of fishery yields **(Idoko *et al*., 2024)**.

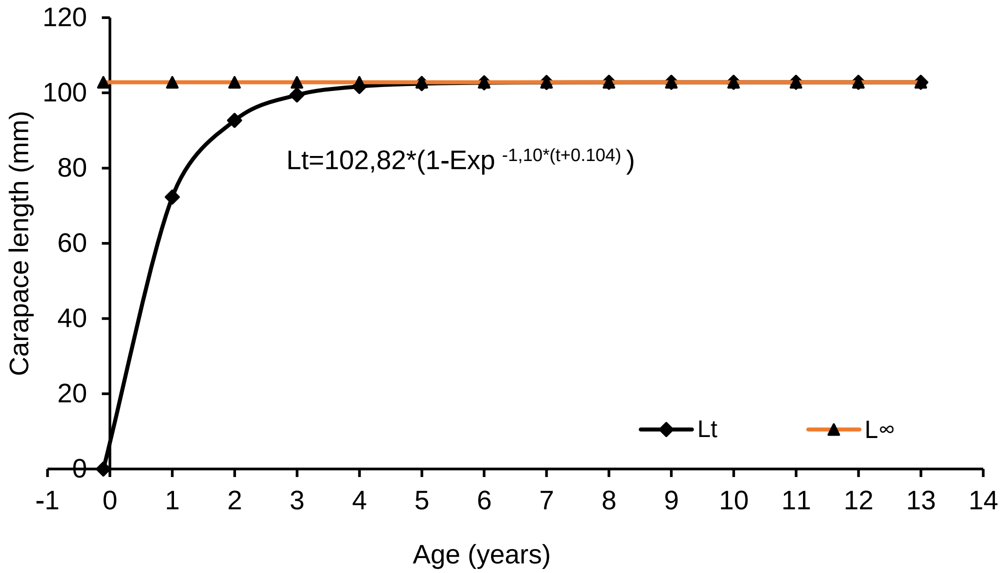

Fig. 5. Growth curve of *Penaeus monodon*

Mortality and exploitation rate

In the context of stock management for the giant tiger prawn (*Penaeus monodon*), factors influencing population dynamics are crucial elements in determining stock sustainability. Growth and recruitment play vital roles in increasing the stock, where growth refers to the increase in size or weight of individual shrimp, while recruitment indicates the addition of new individuals into the population, either through birth or migration of younger individuals into a particular water body **(Evania *et al*., 2018; Suryandari *et al*., 2018)**.

Conversely, stock depletion is influenced by natural mortality and fishing activities **(Amri *et al*., 2023)**. Natural mortality occurs due to ecological factors such as predation, disease, and unfavorable environmental conditions that affect survival. Human fishing activities also serve as a significant external factor, as excessive fishing or overfishing can lead to a drastic decline in stock if not properly managed.

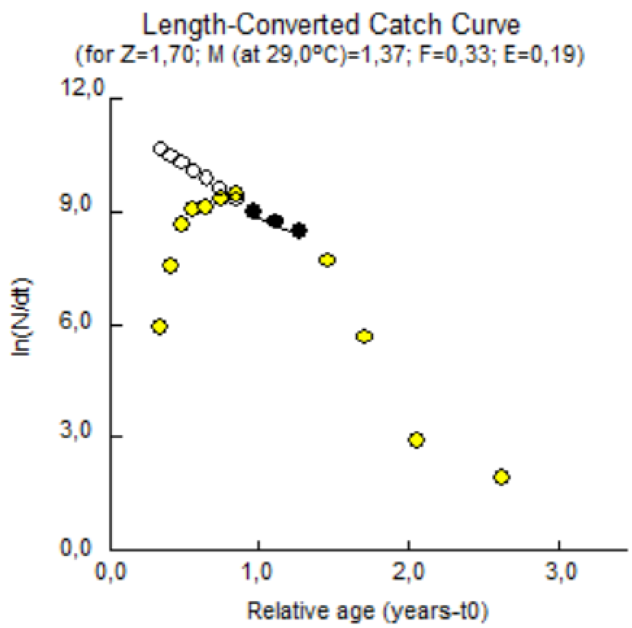

Fig. 6. Mortality curve of *Penaeus monodon*

Spawning potential ratio (SPR)

The length-based spawning potential ratio (LB-SPR) analysis is an effective method for estimating the spawning potential ratio of a species under fishing pressure **(Cousido-Rocha *et al*., 2022)**. Conceptually, the spawning potential ratio (SPR) represents the proportion of reproductive biomass remaining compared to an unexploited population **(Munyandorero, 2018)**.

According to **Prince *et al*. (2015)**, fisheries can be categorized into three exploitation statuses: under-exploited (SPR > 40%), fully-exploited (20% < SPR < 40%), and over-exploited (SPR < 20%). However, **Renjithkumar and Roshni (2024)** further classify SPR criteria as follows SPR below 30% is considered overfished, SPR between 30-50% is classified as fully-moderate fished and SPR above 50% indicates an underfished status, which is relatively safe for sustainability.

An SPR value of 0 signifies full exploitation to the point where the population no longer has reproductive potential, whereas an SPR of 100% represents an untouched natural state without fishing pressure **(Prince *et al*., 2015)**. SPR below 40% indicates low recruitment potential and low stock resilience, while SPR above 40% suggests high recruitment potential, strong stock resilience, and a high likelihood of sustainability **(Hordyk *et al*., 2015; Loneragan *et al*., 2021)**. In general, SPR decreases as fishing pressure increases **(Miller, 2022)**.

Additionally, the natural mortality rate (M) of 1.37 per year reflects mortality due to environmental factors, predation, and other natural causes, excluding fishing impacts. In the context of stock sustainability, the ratio of fishing mortality to natural mortality (F/M) serves as a key indicator for assessing the level of resource exploitation. From the gonadal maturation analysis, 50% of female individuals (Lm50) reach gonadal maturity at

49.74mm, while 95% (Lm95) mature at 54.71mm (Fig. 7). This indicates that most individuals are ready to reproduce within this size range. Comparing this to the selectivity size of the catch (50% captured at 52.43mm), it can be inferred that most of the captured individuals have already reached reproductive maturity, providing an opportunity to spawn before being caught. However, a high F/M ratio poses a threat to population sustainability if not balanced with effective management strategies.

As shown in Fig. (8), the size distribution of *P. monodon* is within the 70–80mm range, indicating that the majority of captured individuals fall within this size class. The size distribution follows an approximately normal pattern with slight right-skewness, suggesting that while some individuals have reached larger sizes, smaller individuals are still being caught.

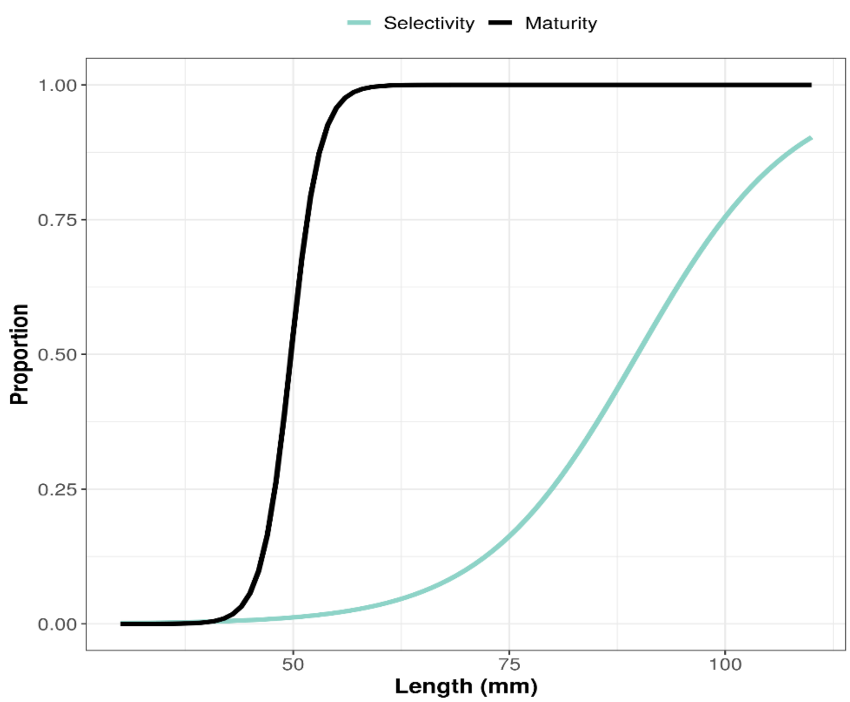

Fig. 7. Comparison of *Penaeus monodon* proportion at maturity (Lm50) and selectivity

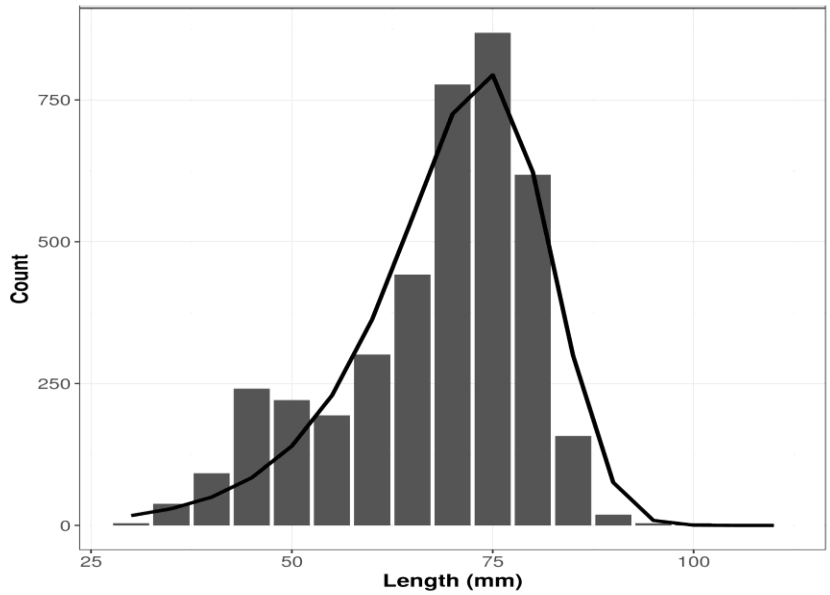

Fig. 8. Carapace length distribution of *Penaeus monodon*

LB-SPR estimation for the *Penaeus monodon* population in the Arafura Sea yielded a spawning potential ratio (SPR) of 0.31 (31%) (Fig. 9) and a yield per recruit (YPR) value of 0.032. This indicates that 31% of the *Penaeus monodon* population that is not caught still has the potential to spawn (classified as moderate). Although this value is below the >40% target for sustainable fisheries management, it has not yet reached a critical point. The relationship between SPR (0.31) and YPR (0.032) shows that the SPR value is higher than the YPR value, which suggests that a higher SPR means a larger remaining biomass of *Penaeus monodon* in the waters compared to those caught. This is the desired outcome, allowing *Penaeus monodon* to reproduce and eventually increase the YPR value. Therefore, it is essential to implement early fisheries management strategies, particularly for *Penaeus monodon* in Zones II and III of WPP 718, by regulating catch quotas (80% of the TAC) and restricting or even prohibiting fishing during peak spawning months. This approach ensures the sustainability and long-term viability of the stock.

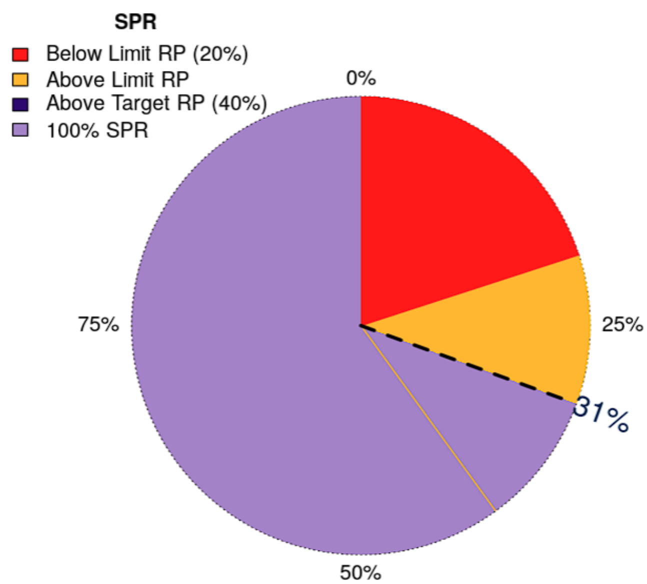

Fig. 9. Results of spawning potential ratio (SPR) analysis

DISCUSSION

The sizes found in the Arafura Sea are smaller than those reported by **Wakida-Kusunoki *et al*. (2016)** in the Yucatán Peninsula, eastern Mexico, where the tiger prawns reached 201–290mm TL with weights of 111.6–200 grams. This size difference is attributed to varying environmental factors between the Arafura Sea and the Yucatán Peninsula. Arafura sea are influenced by four seasons: the first transitional season (West to East), which occurs from March to May; the eastern season (June to August); the second transitional season (East to West), from September to November; and the western season (December to February). The sea surface temperature ranges from 23.03 to 34.00°C, and the water depth varies between 20 and 50 meters, with a sandy mud substrate, although coral areas are found in some locations. Habitat conditions, food availability, and predation pressure can influence growth rates and maximum attainable sizes in different locations. Additionally, genetic variations between populations in these regions may contribute to the observed size differences. However, the sizes of the tiger prawns found in the Arafura Sea fall within the range reported along the southern coast of Nigeria, which spans from 19 to 143.2mm **(Oketoki *et al.*, 2024)**. These sizes are notably larger than those recorded in Tarakan waters, where trawl nets captured specimens ranging from 21.9 to 63mm for carapace length (CL) **(Chodrijah & Faizah, 2018)**. Moreover, they exceed the sizes reported in Takalar waters, where trammel nets caught tiger prawns measuring 49–51mm CL **(Jamal, 2015)**.

The variation in tiger prawn sizes across different locations highlights the species' diverse growth patterns in various aquatic ecosystems. Factors such as water temperature, salinity, nutrient availability, and local food chain dynamics influence growth rates and maximum size attainment. Additionally, differences in fishing methods across locations can affect the size composition of captured samples, making it necessary to consider these factors when comparing data across regions. This is supported by **Chodrijah and Faizah (2018)**, who stated that size differences are influenced by environmental conditions, fishing gear, and fishing pressure. The relatively large maximum size recorded in this study (Arafura Sea) is likely due to the fishing grounds being located >12 NM (Nautical Miles) from the coastline, where bottom trawl nets are used. These nets are less selective, leading to the capture of both large and small prawns.

The capture of *Penaeus monodon* at sizes larger than the mean length at first maturity (*Lm*) (49.64±7.05 mmCL) indicates that harvesting practices have taken into account the sustainability of juvenile shrimp populations. This serves as an indicator of population regeneration for *P. monodon*. Therefore, it is crucial to maintain and reinforce responsible fisheries management by establishing a minimum catch size limit to ensure the sustainability of *P. monodon* stocks in the Arafura Sea in the future. The sizes observed in this study differ from those reported by **Komi and Francis (2017)**, who found that *P. monodon* was first captured at an average size of 12.44mm along the coast of Nigeria and 40.69 mmCL in the waters of Tarakan, Indonesia **(Chodrijah & Faizah, 2018)**.

According to **Kolody and Hoyle (2015)**, there are three primary sources of direct data that can be used to estimate growth equations: (1) Catch length (CL) frequency distribution, (2) Growth increments from tagging and recapture data, and (3) Age estimation from calcified structures (otoliths). However, length-based sampling methods may introduce bias in growth parameter estimation. This bias occurs because length-based sampling methods often fail to represent the entire population accurately, particularly when size distribution within the population is uneven or not properly accounted for **(Piner *et al*., 2016; Batts *et al*., 2019)**.

As black tiger shrimp (*Penaeus monodon*) grow with age, a growth model is developed as a key component of stock assessment models. Modeling shrimp growth, or understanding how shrimp increase in size over time, is a crucial element of most stock assessment models **(Francis, 2016)**. Additionally, other studies emphasize the importance of modeling process variations and sampling variability to obtain valid estimates in fishery stock assessments **(Fisch *et al*., 2023)**.

The total mortality rate (*Z*) of *Penaeus monodon* was estimated at 3.85, with a natural mortality rate (*M*) of 1.37 and a fishing mortality rate (*F*) of 0.33. These values yield an exploitation rate (*E*) of 0.19, or 19%. A study by **Tirtadanu and Chodrijah (2019)** reported that the natural mortality rate of *Penaeus monodon* is 1.7 per year for both males and females. This indicates that natural mortality is higher than fishing mortality, as the natural mortality rate (M) exceeds the fishing mortality rate (F) (M > F). This condition suggests that the *Penaeus monodon* population remains relatively stable and has not yet experienced excessive fishing pressure. However, management strategies must take into account that, although the current exploitation rate is low, changes in fishing practices or environmental factors could impact this balance. Therefore, continuous monitoring and policies aimed at ensuring the sustainability of *Penaeus monodon* populations and addressing factors influencing mortality are essential for maintaining this resource. According to **Edgar *et al*. (2024)**, to determine whether a stock is experiencing overfishing, the optimal exploitation ratio (Eopt) is assumed to be 0.5. The assumption behind using E = 0.5 for the exploitation ratio is that sustainable yield is achieved when F = M. This indicates that the *Penaeus monodon* fishery in the Arafura Sea is still far from overfishing conditions, especially after the eight-year fishing moratorium.

Gonadal maturation is a critical phase in the life cycle of the black tiger shrimp (*Penaeus monodon*), since it determines reproductive success, recruitment, and stock resilience in a given ecosystem. Based on the biological parameter analysis of female *P. monodon* in the Arafura Sea, the estimated asymptotic length ($L\infty$) is 102.82mm, indicating the maximum length an individual can reach in this population. The growth rate (K) of 1.10 per year suggests a relatively fast growth rate, which is common among shrimp species with short life cycles and high productivity. Ecologically, the utilization rate remains below the minimum conservation target (40%). Although it has not yet reached a critical point, it is approaching the overexploitation threshold (<20%), indicating that it is near a critical level. Therefore, these findings can serve as a reference for improving fisheries management to maintain fishing pressure at a controlled level, ensuring that the tiger shrimp population in the Arafura Sea continues to support sustainable fisheries and contribute to the well-being of key fisheries stakeholders.

CONCLUSION

The carapace length of captured male tiger shrimp (*Penaeus monodon*) ranged from 30.21 to 90 mmCL, with an average length of 56.34 mmCL and a mode length of 60 mmCL. Meanwhile, the carapace length of female shrimp ranged from 31 to 99.8 mmCL, with an average length of 67.78 mmCL and a mode length of 75 mmCL. Growth exhibited negative allometry, meaning that weight gain was slower than the increase in carapace length. The average first capture length (Lc) was 52.43 mmCL. The total mortality rate (Z) of tiger shrimp was 3.85, with a natural mortality rate (M) of 1.37 and a fishing mortality rate (F) of 0.33, resulting in an exploitation rate of 0.19 or 19%. The LB-SPR estimation for the tiger shrimp population in the Arafura Sea indicated a spawning potential ratio of 0.31 or 31%.

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