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The Stock of *Panulirus homarus* in Kebumen Waters, Indonesia

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ABSTRACT

Kebumen Regency is a central lobster producing area in Indonesia, with a major catch of the *Panulirus homarus* which has high economic value. This research was performed to determine the level of exploitation of *P. homarus* in Kebumen waters. Data collection was conducted from October to December 2024 from 399 randomly-sampled lobsters to measure their carapace length. The growth rate, recruitment, mortality, and exploitation level were measured using FiSAT II. As a comparison, a surplus production examination was also conducted using the Schaefer model. The results showed that the initial size caught ($Lc_{50\%}$) was 6.51 cm CL, with a asymptotic carapace length ($L\infty$) of 12.8 cm CL. The highest recruitment is estimated to occur in May. Furthermore, the exploitation of *P. homarus* in Kebumen waters is regarded under-exploited at a value of 0.18. The results of the surplus production examination also show that the utilization of *P. homarus* is categorized underfishing.

INTRODUCTION

Panulirus homarus (Linnaeus, 1758), commonly known as scalloped spiny lobster is a high-value marine fishery commodity in Indonesia. Its high market price is primarily driven by strong global demand, since lobster species including *P. homarus* are widely regarded as premium seafood products **(Jones, 2015; Supriyono *et al.*, 2017; Damora *et al.*, 2018; Sudewi *et al.*, 2024)**. Scalloped spiny lobster in Indonesia is known locally as 'lobster pasir' or 'udang karang' **(Holthuis, 1991; Zairion *et al.*, 2017)**. Indonesia, particularly Kebumen Regency (located on the south coast of Java) is a major producer of *P. homarus* through capture fishery **(Saputra, 2009; Petersen *et al.*, 2020; Wahyuningrum *et al.*, 2022; Sudewi *et al.*, 2024)**.

Scalloped spiny lobster is widely distributed in coral waters, from the east coast of Africa, Japan, Australia, New Zealand, and Indonesia. It lives in shallow waters with depths ranging from 1 to 90 m and tends to be active at night **(Holthuis, 1991; Mulyanto *et al.*, 2022)**. Scalloped spiny lobster is an omnivore that eats detritus, macrophytes, and

mollusca **(Mulyanto *et al.*, 2022; Lubis *et al.*, 2023)**. According to **MMAF (2024)**, the export of lobster from Indonesia in 2018 reached 1,958 tons (USD 30 million) which declined in 2023 to 1,145 tons (USD 24 million). The decline is related to resource sustainability as many regions in Indonesia also experienced similar declines, including Bantul Regency and Kulon Progo Regency, located on the south coast of Java **(Larasati *et al.*, 2018)**.

To address sustainability concerns, the Indonesian government has implemented regulatory measures, including the Ministry of Marine Affairs and Fisheries Regulation Number 17 of 2021. This regulation prohibits the harvesting of berried (egg-bearing) lobsters and establishes minimum harvestable criteria of 6 cm Carapace Length (CL) or 150 grams in body weight. However, violations of these regulations are still frequently observed in the field, particularly the continued capture of undersized and berried lobsters. In line with this issue, **Wahyuningrum *et al.* (2022)** reported that some lobster catches in Kebumen consisted of small individuals and included egg-bearing females, indicating ongoing non-compliance. To address this gap, the present study analyzed the exploitation level of scalloped spiny lobster (*P. homarus*) in Kebumen waters by examining their growth characteristics, mortality rates, and size structure. The findings aim to support recommendations for the sustainable management of scalloped spiny lobster resources in the region.

MATERIALS AND METHODS

Research location and time

The research was conducted in Kebumen Regency at several fishing base locations: Logending Coastal Fishing Port (CFP), Karangduwur Fish Landing Place (FLP) and Pasir FLP. The fish were sold at a Fish Auction Place (FAP) at the CFPs (Fig. 1). Data collection was carried out from October to December 2024 through field surveys and interviews with fishermen and lobster traders. During this period, the carapace length of *P. homarus* specimens landed at these sites was measured to assess population structure.

Fig. 1. Kebumen Regency

Research materials

The object of research in this research was lobster species *P. homarus* caught by fishermen in Kebumen waters (Fig. 2). A systematic random sampling was performed to select the 10% of the captured lobsters **(King, 1995; Sparre & Venema 1998)**. There were 339 samples of lobsters used in this research.

Fig. 2. *P. homarus*

Analysis method

The carapace length data analysis was conducted using the FiSAT II tool, while the growth function was estimated using the von Bertalanffy equation **(Sparre & Venema 1998)**. The estimated $L\infty$ and K values were measured using the ELEFAN (Electronic Length Frequency Analysis) I method, while the t_0 values were measured using the **Gulland (1983)** formula. Total mortality (Z) was estimated through FiSAT II, and natural

mortality (M) was determined using Pauly's empirical formula **(Pauly, 1980)**. To assess the Maximum Sustainable Yield (MSY), a surplus production model was employed using the Schaefer model approach. The analytical framework applied in this research incorporates a range of established models and formulas as referenced in previous studies **(Gayanilo *et al.*, 2005; Larasati *et al.*, 2018; Wijayanto *et al.*, 2019; Baskoro *et al.*, 2019; Samad *et al.*, 2023; Dutta, 2023; Bhakta *et al.*, 2024)**.

Growth coefficient

$$Lt = L_\infty (1-e^{-K(t-t0)}) \quad \text{..... (1)}$$

$$\text{Log}(-t_0) = -0.3922 - 0.2752 \text{ Log } L_\infty - 1.038 \text{ Log } K \quad \text{..... (2)}$$

Mortality rate and exploitation rate

$$\text{Log } (M) = -0.0066 - 0.279 \text{ Log } L_\infty + 0.6543 \text{ Log } K + 0.4634 \text{ Log } T \quad \text{..... (3)}$$

$$F = Z - M \quad \text{..... (4)}$$

$$E = F/Z \quad \text{..... (5)}$$

MSY estimation

$$CPUE = a - b.f \quad \text{..... (6)}$$

$$C_{MSY} = a^2/4b \quad \text{..... (7)}$$

$$f_{MSY} = a/2b \quad \text{..... (8)}$$

$$E_{MSY} = 0.5 \quad \text{..... (9)}$$

$$F_{MSY} = 0.5\ Z \quad \text{..... (10)}$$

$$C_{MSY} = (F_{MSY}/F).C \quad \text{..... (11)}$$

Where, Lt is the carapace length (CL) at age 't' (cm). L_∞ is the infinite carapace length of *P. homarus* (cm). K is the growth coefficient. The notation t is the age of *P. homarus* (years). The notation t_0 is the estimated theoretical age of *P. homarus* when it has a carapace length of 0 cm (years). T is the average water temperature (°C), estimated to be 30°C. F is the fishing mortality index. Z is the total mortality index. M is an index of natural mortality. E is the exploitation rate. CPUE is the catch per unit effort. The notation f is the fishing effort, while f_{MSY} is the fishing effort at maximum sustainable yield (MSY). The notations a and b are constants. E_{MSY} is the exploitation rate at MSY. F_{MSY} is the fishing mortality index at MSY. C_{MSY} is the production of *P. homarus* at MSY in tons. C is the existing production of *P. homarus* in tons.

RESULTS

The main fishing gear used by Kebumen fishermen to catch *P. homarus* is monofilament gillnet, a similar tool used by fishermen along the south coast of Java Island, including Gunung Kidul Regency and Cilacap Regency **(Baskoro *et al.*, 2019;**

Wahyuningrum *et al.*, 2022; Tirtadanu *et al.*, 2024). In catching lobsters, fishermen use a one-day fishing method, where the fishing gear is set in the afternoon and left to soak overnight **(Boesono *et al.*, 2011; Damora *et al.*, 2018; Suman *et al.*, 2019; Wahyuningrum *et al.*, 2022)**. Lobsters live in shallow tropical sea waters, around coral reefs and waters with rocky or sandy substrates. Scalloped spiny lobster is nocturnal and often gather in groups **(Saputra, 2009; Lubis *et al.*, 2023)**. Table (1) shows the size composition of *P. homarus* catches in Kebumen waters, ranging from 4.0-12.9 cm CL.

Table 1. Composition of *P. homarus* size caught in Kebumen waters

Carapace length interval (cm)	Median	Frequency	Percentage (%)	Cumulative percentage (%)
4.0-4.9	4.5	17	5.01	5.01
5.0-5.9	5.5	51	15.04	20.06
6.0-6.9	6.5	101	29.78	49.85
7.0-7.9	7.5	61	17.99	67.85
8.0-8.9	8.5	49	14.45	82.30
9.0-9.9	9.5	40	11.80	94.10
10.0-10.9	10.5	15	4.42	98.53
11.0-11.9	11.5	4	1.18	99.71
12.0-12.9	12.5	1	0.29	10.00

The largest size caught was within 6.0-6.9 cm CL, amounting to 29.7% of the total sample. The frequency of carapace length can be used to determine the growth parameters of marine biota resources, including *P. homarus* **(Sparre & Venema 1998)**. The first capture size ($Lc_{50\%}$), defined as the carapace length at which 50% of *P. homarus* individuals are retained by the fishing gear, was estimated by plotting the cumulative frequency distribution of carapace length (Fig. 3). The analysis yielded the $Lc_{50\%}$ value of 6.51 cm CL.

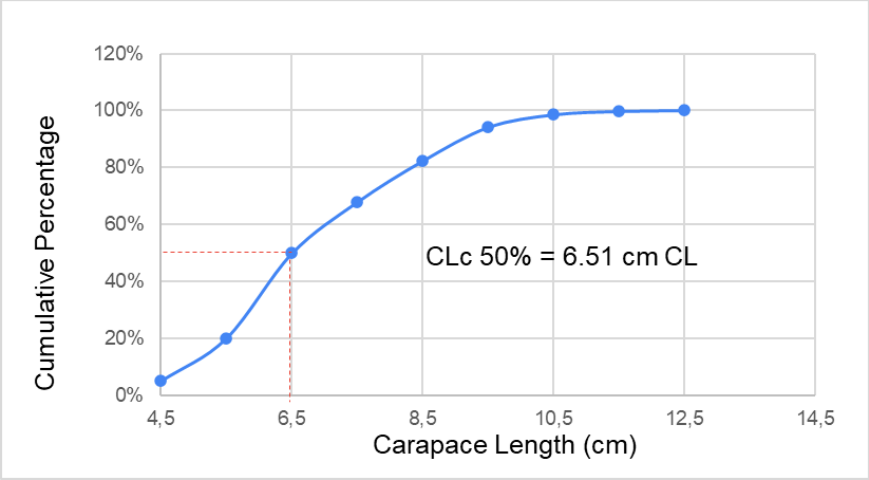


Fig. 3. $Lc_{50\%}$ analysis

The Lc value of 50% can be compared with the Lm value. Ideally, Lc value is greater than the Lm value, showing that the regeneration of *P. homarus* is sustainable. In principle, marine organisms targeted by fisheries should have spawned prior to capture. This research did not estimate Lm. Prior researchers reported variations in Lm of *P. homarus* across some parts: Ekas Bay (Lombok Island) of 7.74 cm CL **(Junaidi *et al.*, 2010)**, and West Aceh (Sumatra Island) of 7.68 cm CL **(Kembaren & Nurdin, 2015)**, Prigi (south coast of Java Island) of 6.15 cm CL **(Suryandari, 2017)**, Gunung Kidul (south coast of Java Island) of 5.85 cm CL **(Damora *et al.*, 2018)**, and Lampung (Sumatra Island) of 6.31 cm CL **(Zairion *et al.*, 2023)**. In this research, the smallest *P. homarus* specimen recorded had a carapace length of 4.0 cm, suggesting that some individuals were likely caught before reaching sexual maturity and prior to spawning, indicating that the catch in Kebumen waters consists of undersized and immature individuals.

The estimated growth rate (K) of *P. homarus* was 0.55 per year, with a total mortality (Z) of 1.93 and an exploitation rate (E) of 0.18 (Table 2). According to **Sparre and Venema (1998)**, an E value below 0.5 indicates that the resource is under-exploited. Thus, the exploitation level of *P. homarus* in Kebumen waters is currently categorized as under-utilized **(Samad *et al.*, 2023; Bhakta *et al.*, 2024)**. Further support for this assessment is provided by the results of the Schaefer model, as presented in Table (3) and Fig. (4). The number of fishing trips recorded in 2023 remains below the estimated effort corresponding to Maximum Sustainable Yield (MSY) conditions. This finding further confirms that the *P. homarus* fishery in Kebumen waters is currently operating under conditions of under-fishing.

Table 2. Estimation of L∞, K, mortality, and exploitation rate

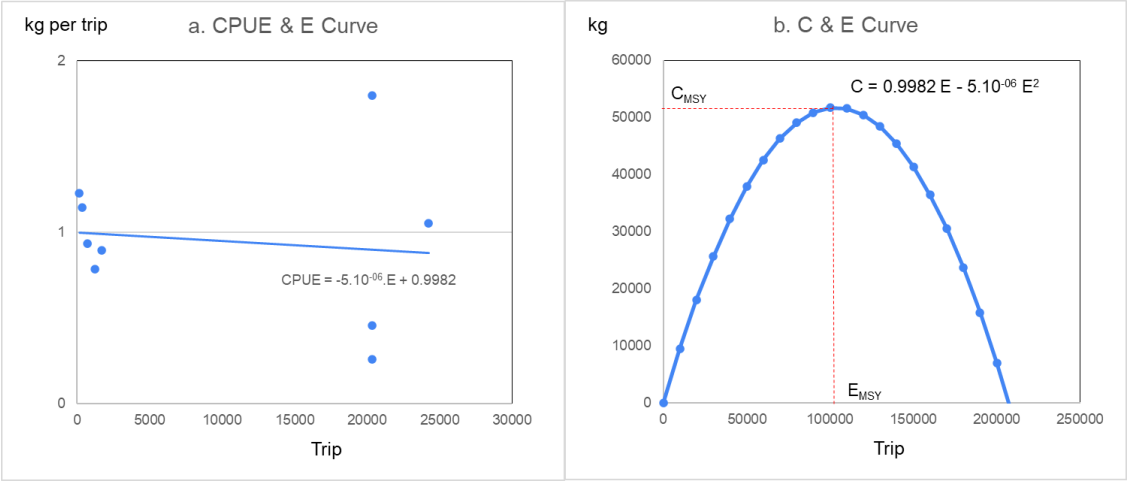
Parameter	Value
L_∞	12.8 cm CL
K	0.55
Total mortality (Z)	1.93
Fishing mortality (F)	0.35
Natural mortality (M)	1.58
Exploitation rate (E)	0.18 (under-exploited)
Assumption of fishing mortality*	27.4 tons
Estimated maximum sustainable yield (MSY) production**	75.7 tons
Estimated economic value of MSY production	IDR. 22.72 billion

*using 2020 production data (75% of lobster production is *P. homarus*); and

** using the assumption of *P. homarus* price at the fisherman level of IDR 300,000 per kg.

Table 3. Estimation of C_{MSY} dan f_{MSY} using Model Schaefer

Parameter	Value
C_{MSY}	51.7 tons
f_{MSY}	207,304 trip
f in 2023	20,368 trip (under-fishing)



Data source: **Saputra (2009)** and **MFD of Kebumen (2024)**

Fig. 4. Schaefer model

The estimated MSY level in Tables (2 and 3) show different values of 75.0 tons (population dynamics approach) and 51.7 tons (surplus production approach (Fig. 4)). Based on the population dynamics and surplus production approaches, *P. homarus* production in Kebumen Regency can be increased with greater concern on environmentally friendly fishing principles, including minimum size, selective fishing gear and proper fishing season. The estimated recruitment pattern is presented in Fig. (5), where April to July is the recruitment season.

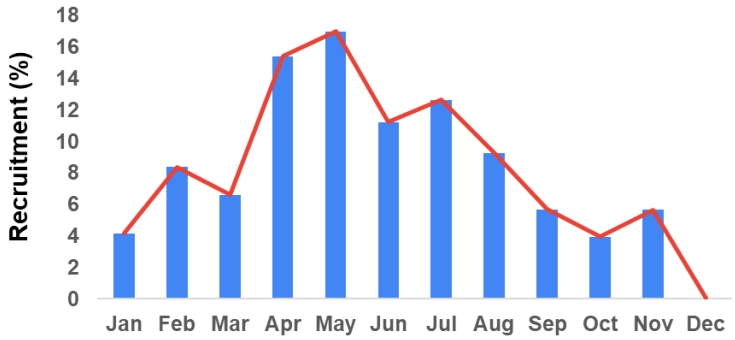


Fig. 5. Estimated recruitment time

In May, the recruitment is estimated to reach its peak at 17.0%. Based on the von Bertalanffy equation, the peak spawning occurrs in June, assuming that the lobster reaches 6.5 cm CL at 11 months of age. **Boesono *et al.* (2011)** stated that the *P. homarus*

fishing season can be year-round, despite the peak season that can occur in certain months. Therefore, it is necessary to regulate the fishing season, in order to allow for spawning during the peak spawning season.

DISCUSSION

Kebumen Regency is located on the southern coast of Java Island, between 109°33' - 109°50' EL and 7°27' - 7°50' SL. Kebumen Regency is administratively a part of Central Java Province **(BPS-Statistics of Kebumen Regency, 2024)**. There are eight Fish Auction Places (FAP) in the regency, where fishermen's catches are traded, with main landings for lobster catches at Logending FAP, Pasir FAP and Karang Duwur FAP **(Wahyuningrum *et al.*, 2022; MFAD of Kebumen, 2024)**. Fishermen usually sprinkle wet sand around the lobster's gills, allowing the lobsters to breathe for longer life on land.

Lobsters are the main target due to their high economic value. **Petersen *et al*. (2020)** reported the price of *P. homarus* is around USD 22 per kg or equivalent to IDR 352,000 per kg (USD 1 = IDR 16,000). Meanwhile, **Wahyuningrum *et al.* (2022)** explained that the selling price of lobster ranges from IDR 400,000 to IDR 700,000 per kg, depending on the type of lobster, size, and quality of the lobster. Currently, lobster production in Indonesia is predominantly reliant on wild capture fisheries, as aquaculture development faces several challenges, including inefficiencies in feed provision, low survival rates, cannibalism, molting failures, and limited technological mastery **(Baskoro *et al.*, 2019; Petersen *et al.*, 2020; Mulyanto *et al.*, 2022; Sudewi *et al.*, 2024)**. The estimation of lobster resource potential and Total Allowable Catch (TAC) is governed by the **Decree of the Ministry of Marine Affairs and Fisheries** (**MMAF**) **Number 19 of 2022**. This regulation includes provisions for Fisheries Management Area (FMA) 573, which encompasses Kebumen waters. Overall, lobster exploitation in FMA 573 is considered to be in an overexploited state, with the TAC set at 782 tons per year.

The first size caught ($Lc_{50\%}$) in this research was 6.51 cm CL. According to the **Decree of MMAF Number 17 of 2021**, the minimum size of *P. homarus* to harvest is 6 cm CL or more than 150 grams. The $Lc_{50\%}$ value is in accordance with the regulations set by the Indonesian government. However, in the sampling, 20.06% were under-sized (Table 1). Theoretically, the Lc value should be higher than the Lm value. Therefore, the government of Kebumen Regency is expected to enhance the monitoring, guidance, and enforcement of regulations related to the fishing. The Lm size of *P. homarus* varies in several waters in Indonesia, ranging between 5.85 cm CL to 7.74 cm CL **(Junaidi *et al.*, 2010; Damora *et al.*, 2018)**. Variations in the $Lc_{50\%}$ can be influenced by the characteristics of the fishing ground, including the depth of the water **(Suman *et al.*, 2019)**. Shallow waters often produce small lobsters **(Subani, 1981)**.

Variations in the Lc and Lm of *P. homarus* are affected by several ecological factors, including the availability of natural food, temperature, salinity, pH, and other

environmental conditions. Variations in lobster size might relate to food supply in the water area. This difference in size can affect the growth coefficient (K) value, in addition to biological factors: sex, gonad development, growth phase and feeding habits **(Kemp & Britz, 2008; Damora *et al.*, 2018)**. Lobsters have a relatively wide tolerance range for salinity. *P ornatus* can tolerate a salinity of 15 ppt. However, lobsters can be physiologically and growth-impaired at a salinity of 40 ppt **(Spencer *et al.*, 2025)**. Water temperature is one of the most important environmental factors in determining the growth rate of crustaceans, including lobsters **(Hartnoll, 1982; Kemp & Britz, 2008)**. Stress causes reduced growth energy allocation for homeostasis **(Supriyono *et al.*, 2017)**.

In this research, the K value of scalloped spiny lobster was found at 0.55, while L infinity was 12.8 cm CL. As proposed by **Sparre and Venema** (**1998**), lower growth coefficient (K) requires longer period for a fish species to reach its asymptotic length (L∞). Fish with a growth coefficient of more than one (K>1) can be categorized to have a relatively fast growth rate **(Gulland, 1983)**. The K value of scalloped spiny lobster in West Aceh is 0.39 **(Kembaren & Nurdin, 2015)**, in Prigi (south coast of Java Island) is 0.3 **(Suryandari, 2017)**, in Gunung Kidul (south coast of Java Island) is 0.46 for females and 0.49 for males **(Damora *et al.*, 2018)**, and in Cilacap (south coast of Java Island) is 0.78 **(Baskoro *et al.*, 2019)**.The L∞ (asymptotic carapace length) of *P. homarus* has been reported to vary across different regions in Indonesia. In Gunung Kidul, the L∞ value was estimated at 10.48 cm CL for females and 10.13 cm CL for males **(Damora *et al.*, 2018)**, while inn Cilacap, the L∞ value was found to be 9.37 cm CL **(Baskoro *et al.*, 2019)**. On the other hand, in West Aceh, it reached 11.95 cm CL **(Kembaren & Nurdin, 2015)** and in Prigi, it was 10.6 cm CL **(Suryandari, 2017)**. The *P. homarus* in Oman showed a K value of 0.75, an L∞ value of 14.4 cm CL for males, and a K value of 0.81 and an L∞ value of 13.5 cm CL for females **(Mehanna *et al.*, 2021)**. Meanwhile, **Holthuis (1991)** found that scalloped spiny lobster has a maximum total body length of 31 cm and a maximum carapace length of 12 cm. In this research, the maximum carapace length found was 12.6 cm with a total body length of 36.0 cm.

The mortality of scalloped spiny lobster in nature is influenced by natural mortality (M) and capture by fishermen (F). Sustainable exploitation level is shown by F value lower than 50% of the total mortality (Z) or the E value ≤ 0.5 **(Pauly *et al.*, 1984; Sparre & Venema, 1998)**. Meanwhile, the results of this research showed an E value of 0.18. Although classified as underexploited, the potential for increasing scalloped spiny lobster production still consider other factors, including the protection of lobster broodstock that will spawn and the minimum size that can be caught. In line with **Wahyuningrum *et al.* (2022)**, some of the lobster catches in Kebumen were in small sizes, and the catch included the eggs as well. Furthermore, the coastal ecosystem should be preserved and protected, since destructive anthropogenic activities can degrade the marine biological resource stocks, including *P. homarus* **(Makwinja *et al.*, 2021; Gernez *et al.*, 2023)**.

Mulyanto *et al*. (2022) explained that in general the lobster life cycle consists of several stages: eggs, nauplisoma, phyllosoma, puerulus, young lobsters (juveniles), and adult lobsters. Scalloped spiny lobster reaches gonad maturity around 12 months after puerulus when its size is around 300 to 500 g. Based on the von Bertalanffy growth model, a carapace length (CL) of 6.5 cm representative of the average size of lobsters caught corresponds to an estimated age of 11 months, suggesting that peak spawning likely occurred around June of the previous year. On the other hand, **Suman *et al*. (2019)** reported that lobster spawning frequently takes place during the rainy season (October to December), a period characterized by reduced seawater salinity, which may serve as a spawning trigger. Understanding recruitment patterns is essential for effective management of the fishing season. Supporting this, **Suryandari (2017)** found that peak recruitment along the south coast of East Java (Prigi) occurred in April and August. Protecting broodstock during their spawning period, particularly within known spawning habitats, is critical for sustaining lobster populations. Unfortunately, information on lobster spawning areas is not widely available.

The CPUE (Catch Per Unit Effort) of lobster fishing in Kebumen in 2023 was 1.8, indicating that each gillnet trip caught 1.8 kg of lobster. CPUE can be an indicator of resource biomass. Lower CPUE indicates decreased biomass and productivity of lobster fishing **(Tirtadanu *et al.*, 2024)**. There was a decrease in lobster CPUE in the period 2012-2016 in the Cilacap waters bordering the Kebumen waters **(Baskoro *et al.*, 2019)**. To address this issue, lobster resource management needs to be carried out with a comprehensive approach through fishing quota policies, restrictions on minimum catch sizes, prohibitions on the use of environmentally unfriendly fishing gear, protection of spawning areas, and the release of egg-laying lobster broodstock. These policies can be aligned with local wisdom since conservation efforts are prone to failure without strong support from the local community **(Johannesen, 2007; Priyambodo *et al.*, 2020; Islam *et al.*, 2024; Wijayanto *et al.*, 2025)**. This study is limited by its short duration of three months, which may not reflect seasonal variations in lobster dynamics or fishing intensity. Future research should include longer-term monitoring and explore aspects such as spawning grounds and bioeconomic to support more comprehensive fisheries management.

CONCLUSION

The results of this research showed the initial size ($Lc_{50\%}$) of *P. homarus* of 6.51 cm CL and $L\infty$ value of 12.8 cm CL with the peak recruitment in May. The scalloped spiny lobster exploitation is categorized under-exploited with E value of 0.18. This category shows that the exploitation of scalloped spiny lobster in the waters of Kebumen can still be increased. However, its exploitation should adhere to the minimum size of the catch and the protection of broodstock that will spawn in the Kebumen waters, in order to maintain the sustainability of its stock resources and protect the livelihoods of fishermen.

Further research should be conducted throughout the year, with inclusion of the level of gonad maturity in the analysis in order to provide more comprehensive policy recommendations.

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