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Inferring Stock Status of Painted Spiny Lobster (*Panulirus versicolor*) in Aru Islands Waters, Indonesia

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Abstract

Three of seven commercial spiny lobster species in Indonesian waters were found in Aru Islands waters which exploited continuously using drift gillnet and the catch was dominated by painted spiny lobster (*Panulirus versicolor*). To ensure the sustainability of the lobster stock, fisheries should be managed properly based on the best available science. In data-limited fisheries, length composition data are the most common form information available for researchers and managers because of its relatively cheap and simple to collect. In this study, we evaluate the stock status of *P. versicolor* in Aru Islands waters using three length-based method: 1) length-converted catch curve (LCCC), 2) length-based spawning potential ratio (LB-SPR) and 3) length-based Bayesian biomass (LBB). The result showed that the mean length at catch of *P. versicolor* was 80.9 mm in carapace length. Furthermore, the three methods agree that the current status of painted spiny lobster stock seems to be fully-exploited where the exploitation rate, the spawning potential ratio, and relative stock size (B/B_{MSY}) were 54%, 35%, and 85%, respectively. Thus, for sustainability of this stock, it is highly recommended to catch *P. versicolor* at size greater than 80 mm in carapace length.

Introduction

There are seven commercial lobster species of *Palinuridae* family exploited in Indonesian waters: scalloped spiny lobster (*Panulirus homarus*), ornate spiny lobster (*P. ornatus*), long-legged spiny lobster (*P. longipes*), stripe-leg spiny lobster (*P. femoristriga),* pronghorn spiny lobster (*P. penicillatus*), painted spiny lobster (*P. versicolor*) and mud spiny lobster (*P. polyphagus*) (Kembaren et al., 2021a). Three of them were found in Aru Islands waters where the painted spiny lobster (*P. versicolor*) was dominate in the catches reaching up to 63% of lobster landing in 2021. Meanwhile, ornate spiny lobster and long-legged spiny lobster compose the catch by 36% and 1%. These lobsters are harvested all year around in Aru Islands waters using drift gillnets with mesh size 5-6 inch (127-152.4 mm) by small-scale fishers (Kembaren et al., 2021b).

The simultaneous exploitation of lobster stock could be leading to the over-exploitation and depletion if there is no management on the utility of this resources. Thus, fisheries should be managed properly through applying the science-based fisheries management to ensure the sustainability of fisheries (Cooke et al., 2017; Su et al., 2021). On the other hand, lobster fishery is commonly small-scale and data-poor fishery where age data collection is often limited by lack of technical expertise and funds. In addition, length composition data are most common form information available for researchers and managers to formulate the management measures since its relatively cheap and simple to collect (Baldé et al., 2019; Hordyk et al., 2014a; Quinn & Deriso, 1999). There are a number of length-

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based methods that have been developed in relation to the availability of the data for many stocks. Those methods were applied to estimate the biological parameters to understand the dynamics of fish populations which starting from estimating the growth and mortality upon to assess fish stock status (Basson et al., 1988; Froese et al., 2018; Gulland & Rosenberg, 1992; Hordyk et al., 2014b; Mildenberger et al., 2017; Pauly, 1983; Pauly & Morgan, 1987).

In this paper, we applied three length-based methods: I) length converted catch curve (*LCCC*), II) length-based spawning potential ration (*LB-SPR*), and III) length-based Bayesian biomass (*LBB*) for assessing the stock status of *P. versicolor* in Aru Islands waters. Electronic length frequency analysis (*ELEFAN*) is widely used to fit von Bertalanffy growth function and estimate growth and mortality parameter for data-limited fisheries in tropical waters (Mildenberger et al., 2017; Pauly & David, 1981). In addition, for assessing the exploitation rate, total mortality is estimated using length-converted catch curve (Pauly, 1983; Sparre & Venema, 1998). This method was mostly used for fish stock in Indonesian waters, particularly for crustacean fisheries (Ernawati et al., 2014; Kembaren & Suman, 2013; Suman et al., 2017; Tirtadanu & Yusuf, 2018; Yusuf et al., 2018, 2019).

The *LB-SPR* was developed by Hordyk et al., (2014a) which using length composition and life history parameter as an input to determine the stock status based on the proportion of reproductive population left in the exploited stock and was widely used to assess fish stock status in tropical waters (Ernawati et al., 2019; Kembaren & Ernawati, 2015; Prince et al., 2015; Satria & Sadiyah, 2017; Yonvitner et al., 2021). The LB-SPR method determines the stock status through the proportion of unfished reproductive population left after fishing activity based on the length composition and life history parameters and generally use to set target and limit reference point for fisheries management in data-limited fisheries (Hordyk et al., 2014a). Based on the definition of spawning potential ratio (SPR), unfished stocks have an SPR of 100% (SPR100%) and fishing mortality reduces the SPR from SPR the unfished level to $SPR_{X\%}$ (Prince et al., 2015).

Meanwhile, *LBB* is a length-based method which using Bayesian approach to assess the relative stock size and has been recently introduced for stock assessment in Chinese waters (Liang et al., 2020; Yue et al., 2021; Zhang et al., 2021a; Zhang et al., 2021b) but not implemented yet for stock assessment in Indonesian waters. The LBB method is method that requiring length frequency distribution that are representative of the fishery. It uses the Bayesian approach to estimate growth and relative mortality parameters, relative exploitation level and stock size (Froese et al., 2018). In addition, LBB produces important parameters for fishery management such as optimal length for first capture (L_{c_opt}) and length at maximum possible yield per recruit (L_{opt}). Furthermore, LBB allows to obtain relative biomass (B/B_0 and B/B_{MSY}).

The objective of this study was to provide information on stock status of *P. versicolor* in Aru Islands waters based on the three different length-based methods. The result may contribute to providing a scientific basis for sustainable utilization and management of fish stock in data-limited fisheries.

Materials and Methods

Data collection

The monthly length data were obtained from January to November 2021. The samples of lobsters were collected from the fishers catches at landing site in Dobo, Aru Islands, Indonesia. The lobsters were caught by drift gillnet fishery with 5-6 inches of mesh size from the fishing ground as presented in Figure 1. Lobsters caught from each vessel were measured in term of its carapace length (CL) – the length between middle part of supraorbital to middle part of carapace posterior (King, 2013; Sparre & Venema, 1998). The measurement of carapace length was conducted randomly approximately 150 individuals per month. For the analysis purposes, the length frequency distribution was created with 5 mm class interval.

Electronic Length Frequency Analysis (ELEFAN) and Length-converted Catch Curve (LCCC) Method

The growth of the lobster stock was modelled by the von Bertalanffy equation (von Bertalanffy, 1938):

$$L_t = L_{inf}(1 - \exp(-K(t - t_0))) \qquad (1)$$

where L_t is carapace length (mm) at age *t*, L_{inf} is the asymptotic length, K is the von Bertalanffy growth coefficient, and t_0 is the theoretical age at length zero. The electronic length frequency analysis with genetic algorithm (*ELEFAN-GA*) which provided in TrophFishR packages (Mildenberger et al., 2017) was used to fit growth curve to the restructured length frequency data since it provides the best fit estimate. The parameter t_0 was calculated following the empirical equation (Pauly, 1983):

$$\log(-t_0) = -0.3922 - 0.2752\log(L_{inf}) - 1.038\log(K) \qquad (2)$$

The calculation of maximum age (t_{max}) was defined as equation (Pauly, 1983):

$$t_{max} \approx \frac{3}{K} \qquad (3)$$

In fisheries science, it is known that there are three kinds of mortality that is total mortality (Z), natural mortality (M) and fishing mortality (F). Total mortality (Z) was estimated from linearized length-converted catch curve (*LCCC*) equation (Pauly, 1983; Sparre & Venema, 1998):

$$ln\frac{C(L1,L2)}{\Delta t(L1,L2)} = C - Z_t\left(\frac{L1+L2}{2}\right) \quad (4)$$

where Z is total mortality; C is frequency of carapace length class; Δt is the time takes for an average lobster to grow from L1 to L2; L1 is the carapace length at age t; L2 is the carapace length at age t+Δt. The *LCCC* method plots the natural log of catch vs relative age and estimating total mortality (Z) from the negative slope of the regression of the curve.

The natural mortality (M) was estimated using modified Hoenig formula which based on the t_{max} by (Then et al., 2015):

$$M = 4.899 \times t_{max}^{0.916} \quad (5)$$

The fishing mortality (F) and exploitation rate (E) was estimated by the equation (Sparre & Venema, 1998):

$$F = Z - M; E = \frac{F}{Z} \quad (6)$$

Length-based Spawning Potential Ratio (LB-SPR) Method

The *LB-SPR* assessment method relies on the fact that size structure and spawning potential ratio in an exploited population are a function of the ratio of fishing mortality to natural mortality (F/M), and two life history ratio M/K and L_m/L_{inf} (Hordyk et al., 2014a; Hordyk et al., 2014b). The input parameter to *LB-SPR* model were the M/K ratio, asymptotic length (L_{inf}), variability of length at age (CV_{Linf}), and description of the size of maturity at 50% and 95% of a population mature ($L_{m50\%}$ and $L_{m95\%}$).

The growth parameters (L_{inf} and K) and natural mortality from the output of *ELEFAN* (Equation 1) and natural mortality (Equation 5) estimation were used as input parameters. Since the CV_{Linf} is difficult to estimate directly without reliable length and age data, it is normally assumed to be around 10%. Furthermore, size at maturity in this study refer to the work for the same species (Ernawati et al., 2019). Given the value for M/K and L_{inf} parameters and length composition data from an exploited stock, the *LB-SPR* model uses maximum likelihood method to simultaneously estimate the selectivity ogive, which is assumed to be a logistic curve defined by the selectivity at length parameters SL_{50} and SL_{95} and the relative fishing mortality (F/M), which are then used to calculate the SPR (Hordyk et al., 2014a; Hordyk et al., 2014b) as following formula:

$$SPR = \frac{\sum(1-\tilde{L}_x)^{(M/K[(F/M)+1])}\tilde{L}_x^b}{\sum(1-\tilde{L}_x)^{M/K}\tilde{L}_x^b} \; for \; x_m \le x \le 1 \quad (7)$$

where L_x is carapace length; x_m is standardized age that correspond to L_m; M/K is life history ratio; F/M is ratio of fishing mortality to natural mortality; b is exponent assumed close to 3. In this study, we analyzed the performance of *LB-SPR* using the web-based tools in http://barefootecologist.com.au.

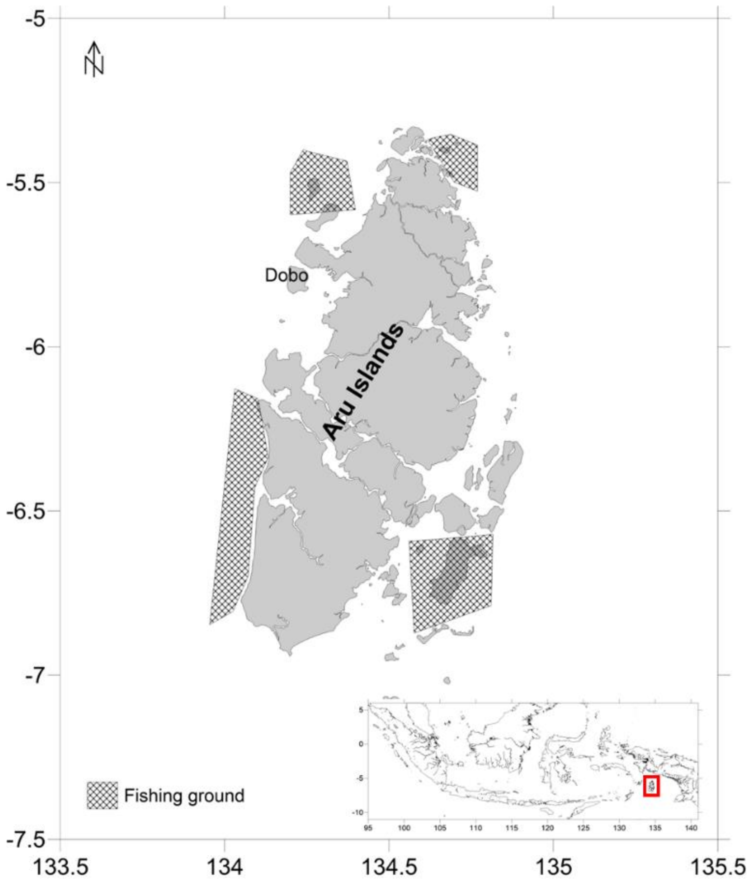

Figure 1. The lobster fishing ground in Aru Islands waters

Length-based Bayesian Biomass (LBB) Method

In the *LBB* method, growth in body length is also assumed to follow von Bertalanffy growth function (Froese et al., 2018). In the unfished state, the body size of exploited fish would approach the asymptotic length L_{inf} which can be expressed by:

$$P_{L/L_{inf}} = \left(1 - \frac{L}{L_{inf}}\right)^{M/K} \quad (8)$$

where $P_{L/Linf}$ is the probability to survive to length L/L_{inf}, which is solely a function of the *M/K* ratio.

In the *LBB* method, a function of the selectivity of the gear assumed trawl-like and given by the ogive function as:

$$S_L = \frac{1}{1+e^{-\alpha(L-L_c)}} \quad (9)$$

where S_L is the fraction of individuals that are retained by the gear at length L, L_c is the length at 50% of the individuals are retained by the gear, and α represents the steepness of the ogive (Quinn & Deriso, 1999; Sparre & Venema, 1998). To minimize the required parameters for *LBB*, the analytical framework based on the ratio (*M/K* and *F/K*) instead of the absolute values of growth and mortality, with the goal of estimating mean relative fishing mortality (*F/M*) and current biomass relative to unfished biomass (B/B_0) (Froese et al., 2018).

The observed and predicted length distributions were then fitted by assuming Dirichlet multinomial distribution (Thorson et al., 2017), which was proposed for fitting size and age composition in stock assessment models using a Bayesian framework. Proportions-at-length assume Dirichlet-multinomial distribution with an effective sample size of 1,000, which was chosen based on desirable performance across various simulation-testing trial scenarios (Froese et al., 2018).

The following equations are used to approximate the population status through the estimated quantities L_{inf}, L_c, *M/K*, and *F/K*. First, the length L_{opt} representing the maximum biomass of unexploited cohort is obtained from:

$$L_{opt} = L_{inf}\left(\frac{3}{3+\frac{M}{K}}\right) \quad (10)$$

The length at first capture L_{c_opt} that maximizes catch and biomass for a given fishing pressure (F/M) and leads to L_{opt} as mean length in the catch (Froese et al., 2016) can be obtained from:

$$L_{c\_opt} = \frac{L_{inf}\left(2+3\frac{F}{M}\right)}{\left(1+\frac{F}{M}\right)\left(3+\frac{M}{K}\right)} \quad (11)$$

An index of catch per unit effort (CPUE’/R) is obtained through dividing relative yield-per-recruit (*Y’/R*) by *F/M*, if fishing mortality *F* directly proportional to fishing effort and expressed as:

$$\frac{CPUE'}{R} = \frac{\frac{Y'}{R}}{\frac{F}{M}} = \frac{1}{1+\frac{F}{M}}\left(1-\frac{L_c}{L_{inf}}\right)^{\frac{M}{K}}\left(1 - \frac{3\left(1-\frac{L_c}{L_{inf}}\right)}{1+\frac{1}{\frac{M}{K}+\frac{F}{K}}} + \frac{3\left(1-\frac{L_c}{L_{inf}}\right)^2}{1+\frac{2}{\frac{M}{K}+\frac{F}{K}}} - \frac{\left(1-\frac{L_c}{L_{inf}}\right)^3}{1+\frac{3}{\frac{M}{K}+\frac{F}{K}}}\right) \quad (12)$$

The relative biomass in the exploited phase of the population if no fishing takes place is given by:

$$\frac{B_0'>L_c}{R} = \left(1-\frac{L_c}{L_{inf}}\right)^{\frac{M}{K}}\left(1 - \frac{3\left(1-\frac{L_c}{L_{inf}}\right)}{1+\frac{1}{\frac{M}{K}}} + \frac{3\left(1-\frac{L_c}{L_{inf}}\right)^2}{1+\frac{2}{\frac{M}{K}}} - \frac{\left(1-\frac{L_c}{L_{inf}}\right)^3}{1+\frac{3}{\frac{M}{K}}}\right) \quad (13)$$

where $B_0' > L_c$ denotes the exploitable fraction ($>L_c$) of the unfished biomass (B_0). An index of relative biomass depletion for the exploited part of the population B/B_0 is then obtained from (Beverton & Holt, 1966):

$$\frac{B}{B_0} = \frac{\frac{CPUE'}{R}}{\frac{B_0'>L_c}{R}} \quad (14)$$

A proxy for the relative biomass that can produce B_{MSY}/B_0 was obtained by re-running Equations (12–14) with $F/M = 1$ and $L_c = L_{c\_opt}$ (Froese et al., 2018).

In this study, we analyzed the performance of LBB method with prior information of parameters L_{inf} and *Z/K* from the output of ELEFAN and LCCC method. All the analysis was implemented using LBB_33a.R, and R-code algorithm (Froese et al., 2018, 2019). Fish stocks were classified to three exploitation statuses based on the estimates of B/B_{MSY}, over-exploited status was assigned where $B/B_{MSY} < 0.8$, fully-exploited status where $0.8 \le B/B_{MSY} \le 1.2$, and non-fully-exploited (under-developed and moderate) status where $B/_{BMSY} > 1.2$ (Amorim et al., 2019). Furthermore, the stocks are defined as suffering from growth overfishing when the estimated $L_c/L_{c\_opt} < 1$ (Liang et al., 2020; Zhang et al., 2021b).

Results

Size Structure and Length at Capture

Length data from 1.581 individual of *P. versicolor* which collected from drift gillnet catches in Aru Islands waters were analyzed. The carapace length (CL) of painted spiny lobster ranged from 42.1 to 148.7 mm and the length frequency (LF) distribution with the class interval of 5 mm showed that the modus found at 80 – 90 mm CL (Figure 2). The average CL of painted spiny lobster which caught on the period of this study was 80.9±15.7 mm (mean±sd).

ELEFAN and LCCC Method

Growth parameters of painted spiny lobster was estimated from monthly carapace length frequency by tracing the shifting mode of monthly size distribution. The fitting of von Bertalanffy growth model using *ELEFAN-GA* method presented in the Figure 3. The asymptotic carapace length (CL_{inf}) was estimated at 143 mm which could be reach by the instantaneous growth rate (K) of 0.38 year^{-1}. The theoretical age of *P. versicolor* at zero length (t_0) was -0.284 year. Thus, the von Bertalanffy growth formula for *P. versicolor* was L_t = 143 ($e^{-0.38(t+0.284)}$). From growth rate parameter, we estimate the maximum age (t_{max}) of this lobster species and found that its longevity up to 7.8 years.

Based on the length-converted catch curve analysis, the total mortality (Z) of *P. versicolor* in Aru Islands waters was 1.57 year^{-1} (Figure 4). Natural mortality based on t_{max} parameter which modified from Hoenig method (Then et al., 2015) was 0.73 year^{-1}. Furthermore, fishing mortality was estimated at 0.84. Thus, the exploitation rate of *P. versicolor* was 0.54, showing slightly higher than the optimal value of 0.50 and could be classified as fully-exploited.

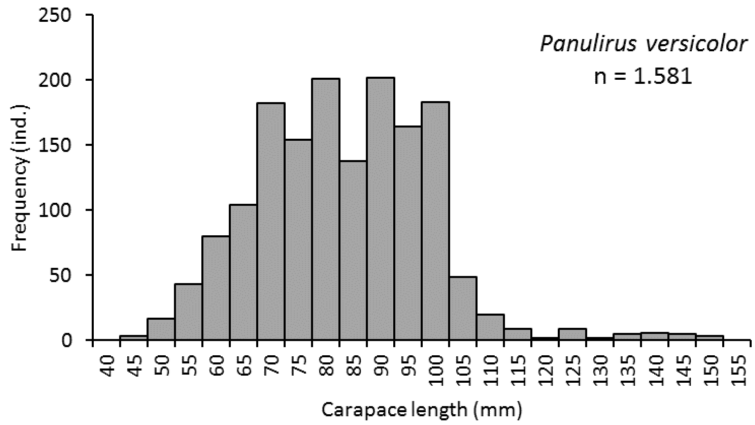

Figure 2. Carapace length distribution of *P. versicolor* in Aru Islands waters, 2021

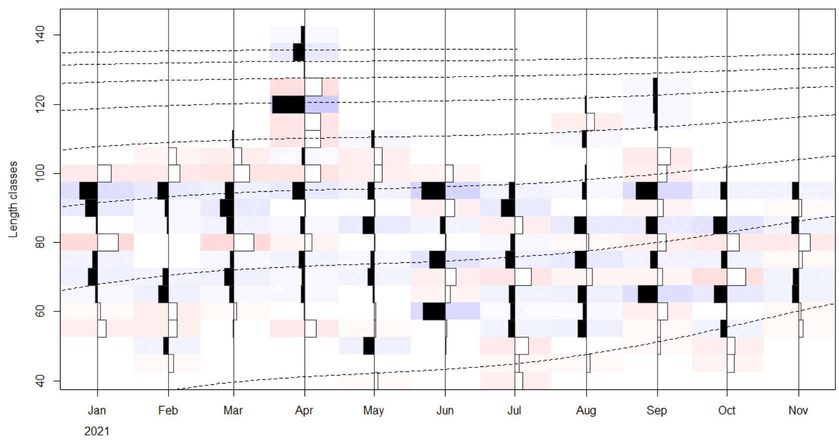

Figure 3. Fitting of ELEFAN-GA based on von Bertalanffy growth model of *P. versicolor* in Aru Islands waters, 2021

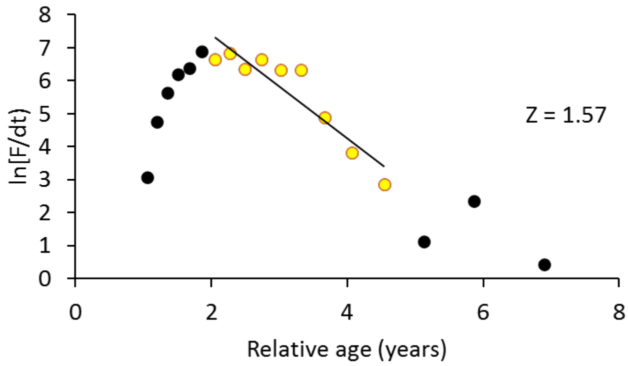

Figure 4. The length-converted catch curve for estimating the total mortality (Z) of *P. versicolor* in Aru Islands waters, 2021

LB-SPR Method

With the assumed parameters and size composition data (Figure 2), *LB-SPR* model estimated the 50% and 95% selectivity of painted spiny lobster were 71.65 mm CL and 93.45 mm CL with the relative fishing mortality (F/M) at 1.33 (Table 1). Thus, from all these parameters, SPR of painted spiny lobster from Aru Islands waters was calculated at 35%. Using the target reference point (TRP) of SPR at 40% and the limit reference point (LRP) at 20%, the SPR of painted spiny lobster rely on the between TRP and LRP which could be categorized as fully-exploited.

Length-based Bayesian Biomass (LBB) Method

The priors for the painted spiny lobster stock which is used as the initial information to run LBB model, including L_{inf}, Z/K, M/K, and F/K are using the value from ELEFAN, length-converted catch curve and natural mortality estimation as mentioned above and listed in the Table 2. The dominant length group were slightly

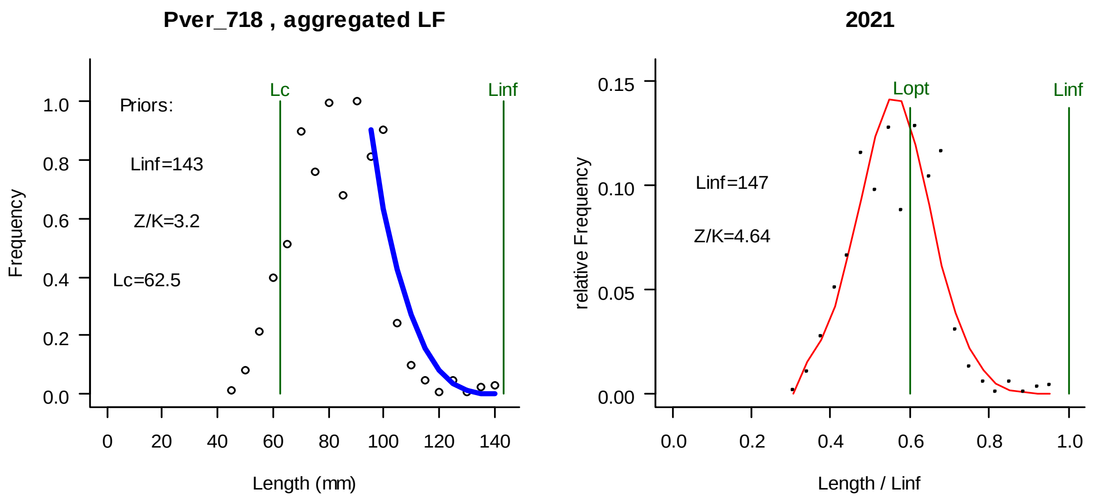

Figure 5. Length-based Bayesian analyses of painted spiny lobster in Aru Island waters. The left curve showed the fit of the model to the length data; the middle and the right curve are the prediction of the LBB analyses, L_c is the length of 50% individual capture by the gear, L_{inf} is the asymptotic length, and L_{opt} is the length where the maximum biomass of the unexploited stock is obtained.

Table 1. The output of LB-SPR model of painted spiny lobster in Aru Islands waters

Species	SPR (%)	SL50 (mm)	SL95 (mm)	F/M
P. versicolor	35 (32 - 39)	71.65 (69.05 - 74.25)	92.45 (88.41 - 96.49)	1.33 (1.08 - 1.58)

Table 2. The prior parameter of *P. versicolor* for further LBB stock assessment analysis

Species	L_{inf}_mm	Z/K	M/K	F/K
P. versicolor	143	3.2	1.9	1.33

Table 3. Summary of LBB output and stock status of painted spiny lobster in Aru Islands waters

Species	$L_c/L_{c\text{-}opt}$	B/B_0	B/B_{MSY}
P. versicolor	1.0	0.30 (0.22-0.45)	0.85 (0.63-1.30)

Table 4. Growth parameters of *P. versicolor* in different areas

Locations	CL_{inf} (mm)	K ($year^{-1}$)	Reference
Great Barrier Reef, Australia	144.7	0.27	Frisch, 2007
Northern Flores, Sikka, Indonesia	146.7	0.44	Ernawati et al. 2014
Northern Java, Karimunjawa, Indonesia	131	0.34	Ernawati et al. 2019
Simeuleu, Western Sumatra, Indonesia	149.1	0.32	Yusuf et al. 2017
Aru Island, Indonesia	143	0.38	This study

smaller than optimum length (L_{opt}) where the maximum biomass of unexploited cohort would be obtained (Figure 5). The L_{opt} and L_{c_opt} were estimated at 88 mm CL and 75 mm CL.

The value of the stock parameter of LBB output were presented in the Table 3. The estimate of $L_c/L_{c\text{-}opt}$ was equal to 1, the current biomass was 30% from the virgin stock and 85% of biomass at MSY level.

Discussion

The average carapace length of *P. versicolor* in this area was 80.9 mm and this size was greater than found in the Northern Flores waters (73.67 mm; Ernawati et al., 2014), Pangandaran waters (50 mm; Nuraini & Sumiono, 2008), and Northern Java waters (58.9 mm; Ernawati et al., 2019) while smaller than found in Simeuleu, Western Sumatera waters (86 mm; Yusuf et al., 2018). The different in mean size of lobster catch could be affected by biotic and abiotic environmental variable, such as temperature, population density, food availability as well as fishing pressure (Chang et al., 2007; Chittleborough, 1975; DeMartini et al., 2003; Ernawati et al., 2014; Polovina, 1989).

The asymptotic carapace length (CL_{inf}) and growth rate (K) of *P. versicolor* was varied among locations with the range of 131-149.1 mm and 0.32-0.44 year^{-1} (Table 4). The growth rate of *P. versicolor* in Great Barrier Reef were lower than some areas in Indonesia (Frisch, 2007). The main factors that affecting this difference could be the environmental factors, particularly the water temperature where lobster in tropical waters mainly have the higher growth rate than those in subtropical waters (Green et al., 2014; Raper & Schneider, 2013).

This study is the first attempt to apply three kinds of length-based methods, namely length-converted catch curve method (*LCCC*; Pauly, 1983), length-based spawning potential ratio (*LB-SPR*; Hordyk et al., 2014b; Hordyk et al., 2014a) and the length-based Bayesian biomass (*LBB*; (Froese et al., 2018) method, to the exploited lobster stock particularly in Aru Islands waters. This study shows that across three kinds of length-based method, the current status of painted spiny lobster stock seems to be fully-exploited. The exploitation rate of *P. versicolor* in Aru Island water was 0.54 which slightly higher than optimal level (E=0.5; Gulland, 1983). The exploitation rate as stock status indicator was common used in assessing spiny lobster stock in tropical water (Damora et al., 2018; Ernawati et al., 2014; Kembaren & Nurdin, 2015b; Suman et al., 2019; Tirtadanu et al., 2021; Tirtadanu & Yusuf, 2018; Yusuf et al., 2018).

The SPR value of 20–40% is generally considered as limit and target reference point (Berger et al., 2009; Bunnell & Miller, 2005; Hordyk et al., 2014a). The output of *LB-SPR* method showed the stock status of *P. versicolor* in this study resulted in mean SPR value of 35%. This result indicates that the stock status of *P. versicolor* in Aru Island waters was fully-exploited based on the criteria developed by Amorim et al., (2019) since the SPR value was in the range of limit and target reference point. Based on the *LB-SPR* method, stock status of *P. versicolor* in this study was better than found in Karimunjawa waters where its SPR was only 19% and indicating over-exploited (Ernawati et al., 2019). The main factor that affects this situation was the difference in size of *P. versicolor* which represented by parameter of asymptotic length (CL_{inf}) and size selectivity (SL_{50}). The CL_{inf} and SL_{50} of *P. versicolor* from Karimunjawa waters (131 mm and 48.2 mm) were lower than in Aru Islands (143 mm and 71.65 mm). This condition also confirmed to the statement of Hordyk et al., (2014b) whose stated that this model most sensitive to the under-estimation of asymptotic length and large rapid change in recruitment rate.

The output of *LBB* method showed the $L_c/L_{c\text{-}opt}$ were in the unity (=1.0), suggesting that large lobster was still present, but it would be potentially to be suffering from growth overfishing if not well managed. Growth overfishing occurs when fish (lobsters) are harvested before they reach their optimal size thus leading to reduce fishery yields (Nadon et al., 2015). Moreover, based on the criteria from Amorim et al., (2019), the biomass status of *P. versicolor* (0.85) in the category of fully-exploited since the current biomass is in about target reference point ($0.8 \leq B/B_{MSY} \leq 1.2$).

The implementation of *LBB* method to assess data-limited fisheries was mostly used in Chinese waters for various stocks such as *Portunus trituberculatus* in Yangtze estuary (Yue et al., 2021), 14 exploited fish and invertebrate in Chinese waters (Liang et al., 2020), eight fish species in Bohai and Yellow seas (Yue et al., 2021), jointly exploited fish stock between China and Vietnam (Zhang et al., 2021a) , and coral reef fish in Nansa Island (Zhang et al., 2021b). The LBB method assumes fluctuation of mortality, growth, and recruitment around mean value over the range of ages in the length frequency data, thus it should not be used if these assumptions are violated. Furthermore, LBB method will results in biased estimates if length frequency data does not reflect the nature of size composition which is affected by different selectivity or catchability or in areas where only juveniles or adults occur. However, when LF data are meet these assumptions, the LBB method can be a good option to infer the stock status, especially in data-poor situations (Froese et al., 2018; Liang et al., 2020) if the assumption are met.

Three length-based models which were applied to infer the stock status of *P. versicolor* in this study came out with the same conclusion that is the stock status is in fully-exploited condition. However, LBB method was resulting in the lower value which indicated by closer value to the lower limit of the fully-exploited criteria which perhaps affected by the violation to the assumption of dome-shape selectivity. Therefore, we remind that the model assumptions must be fulfilled as much as possible to get the best result.

Conclusion

In conclusion, stock status of small-scale data-limited fisheries could be inferred from length frequency data through kinds of length-based assessment methods such as length-converted catch curve which resulted in exploitation rate, length-based spawning potential ratio and length-based Bayesian biomass methods. This study reveals that the stock status of *P. versicolor* in Aru Island waters were in the fully-exploited situation based on the exploitation rate, reproductive biomass indicator, size structure and biomass indicator. It should be noted that the result of our study applied only to the specific study area and only one year data. Thus, further research will be needed to complement our study and improve our understanding of this stock. Moreover, for sustainability of this stock, it is highly recommended to catch *P. versicolor* at size greater than 80 mm in carapace length as well as stated in the Marine Affairs and Fisheries Ministerial Decree Number 17 of 2021

Ethical Statement

Not applicable

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Author Contribution

First Author: Conceptualization, data handling and analysis, Visualization, Writing – original draft, review dan editing; Second Author: Supervision, Writing – reviewing and editing

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflict that have appeared to influence the work reported in this paper.

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