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REFERENCE POINT AND EXPLOITATION STATUS OF MUD SPINY LOBSTER (*Panulirus polyphagus* Herbst, 1793) IN SEBATIK WATERS, INDONESIA

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ABSTRACT

Mud spiny lobster (*Panulirus polyphagus* Herbst, 1793) was one of the most important species in Sebatik waters where the resource has been intensively exploited because of its high economic values. The harvest strategy was needed for the sustainability of its stock. The basis studies needed to develop its harvest strategy are the exploitation status and its reference point. The aims of this research were to study the reference point and the exploitation status of *P. polyphagus*. This research was conducted from March 2016 to December 2018 and the total samples of 1.261 female lobsters had been collected monthly from the traditional gillnet fishers in Sebatik. Reference point was determined from the Beverton and Holt yield per recruit and the exploitation status was estimated from the length-based spawning potential ratio (LB-SPR). The results showed that a lot of *P. polyphagus* catched by gillnets were still immature. Annual spawning potential ratios (SPR) of *P. Polyphagus* from 2016 to 2018 ranged from 19% to 22%. The limit reference point was suggested as 21% SPR while 40% SPR as the target reference point. The 2018 spawning potential ratio was higher than the limit reference point but it was still lower than the target reference point of 40% SPR so the fully-exploited condition had occurred for *P. polyphagus* in Sebatik waters. The minimum legal size of 87 mmCL or the minimum weights of 500 grams and not increasing the quota vessels followed by the monitoring study of its stock for the next several years were some recommendations for the sustainable *P. polyphagus* management in Sebatik Waters.

Keywords: Fully-exploited; P. polyphagus; Spawning Potential Ratio; Yield per Recruit

INTRODUCTION

Indonesian coastal waters was one of the important habitats for varied economical lobsters especially from *Palinuridae* family with the five main species fishing targets in Indonesia including *P. ornatus*, *P. polyphagus*, *P. longipes*, *P. penicillatus,* and *P. versicolor*. The distribution of lobsters was limited only in some locations with the different species abundance from each site. *Panulirus ornatus* was captured in Sorong-West Papua and Bulukumba-South Sulawesi (Tirtadanu & Yusuf, 2018; Musbir *et al*., 2018). Panulirus *homarus* was captured in Tabanan-Bali and Gunungkidul while *P. polyphagus* was captured in Sebatik Waters, North Kalimantan (Damora *et al*., 2018; Kembaren *et al*., 2015; Chodrijah *et al*., 2018).

According to the intensive fishing and the limited habitat of lobsters, the Indonesian government had built the regulations related to the minimum legal size of 8 cm and minimum legal weights of 200 gram and also the ban on fishing of berried lobsters. This regulation was in the ministerial decree of Ministry of Marine Affairs and Fisheries No. 56/PERMEN-KP/2016. One of the areas affected by this regulation was in Sebatik Waters where the most dominant lobster species was mud spiny lobster (*P. polyphagus* Herbst, 1793).

Sebatik Waters was part of the Fisheries Management Area (FMA) 716 and the exploitation status of lobsters according to the Ministerial Decree No. 47/PERMEN-KP/2016 was fully-exploited. Chodrijah *et al*. (2018) also reported the exploitation rate of *P. polyphagus* has led to the overfishing status. The intensive fishing for a long time without the management strategy could cause the depletion of its stock and threat its sustainability.

The important information that was needed for formulating the effective management were the reference point and the current exploitation status. This information could be determined by some

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methods, such as surplus production and analytical methods (Sparre & Venema, 1992). The surplus production method needs the time-series of production catch and catch per unit efforts so it was difficult to use for *P. polyphagus* in Sebatik because there are many unreported catches of lobsters in Sebatik Waters. The methods that could be used for assessing the reference point and exploitation status in Sebatik Waters were yield per recruit and length-based spawning potential ratio (Beverton & Holt, 1957; Goodyear, 1993; Hordyk *et al*., 2015a; Hordyk *et al*., 2015b).

The previous study related to the exploitation status of *P. polyphagus* from the exploitation rate (*E*) parameter in Sebatik Waters has been conducted from one year data in 2016 (Chodrijah *et al*., 2018). The reference point of *P. polyphagus* based on the yield per recruit model and the current exploitation status based on the annual spawning potential ratio in some years have not been reported yet. Multiple years annual spawning potential ratio was needed to know the exploitation level of *P. polyphagus* in some previous years. The objective of this research was to determine the reference point and exploitation status of *P. polyphagus* based on three years data. from 2016 to 2018.

MATERIALS AND METHODS

This research has been conducted for three years, in 2016-2019 in Sebatik, North Kalimantan. The samples were obtained from the catch of traditional fishers by gillnets. The mesh size of gillnet was 6 inches and the vessel size ranged from 2 to 3 GT. The fishing grounds of lobsters were still in the coastal waters of Tanjung Karang and Tanjung Aru in Sebatik Waters (Figure 1).

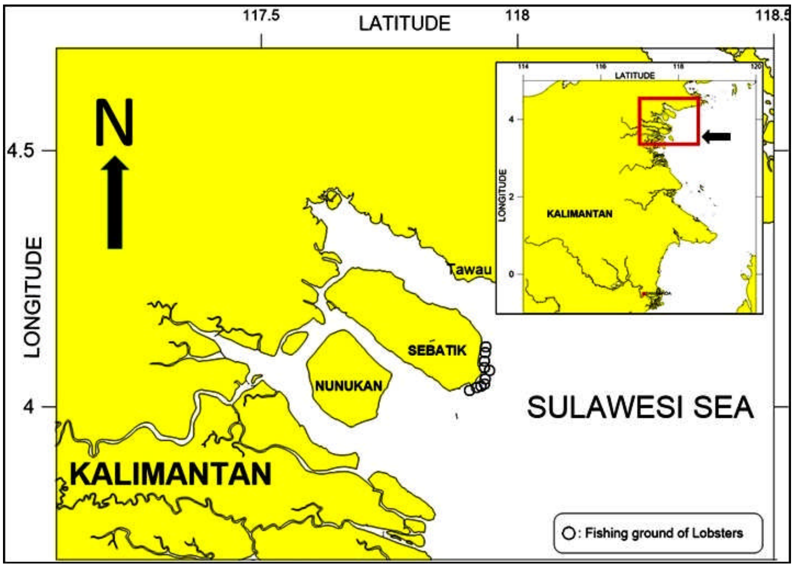

Figure 1. Fishing grounds of lobsters in Sebatik Waters.

The data was obtained from the monthly measurements of carapace length, weight, and maturity. The reference point and length-based spawning potential ratio were estimated from female-only data (Hordyk *et al*., 2015a). The histogram was used for size distribution, using 4 mmCL of length class. The length at first maturity (Lm_{50}) was estimated using a logistic model and the length-weight relationship was analysed by a cubic curve (King, 1995; MacDiarmid & Sainte-Marie, 2016; Sparre & Venema, 1992).

The growth parameters such as asymptotic length (L_∞) and growth rate (*K*) were estimated by the movement of monthly size distribution using Electronic Length Frequency Analysis (ELEFAN) with genetic algorithm in TropFishR packages (Mildenberger *et al*., 2019; Scrucca, 2013; R Development Core Team, 2008). The growth parameters were determined by the von Bertalanffy Growth model (Sparre & Venema, 1992):

$$L_t = L\infty\left[1-e^{-k(t-t_0)}\right] \quad (1)$$

Where L_t is the carapace length of *P. polyphagus* at age *t*, L_∞ is asymptotic carapace length of lobster, *K* is growth rate ($year^{-1}$) and t_0 is the point in time when the lobster has zero length. Theoretical age when lobster has zero length (t_0) was calculated based on the Pauly (1983):

$$\text{Log}(-t_0) = (-0{,}3922) - 0{,}2752 \log L_\infty - 1{,}038 \log K \quad (2)$$

The natural mortality (*M*) was estimated based on Zhang & Megrey (2006) :

$$M = \frac{\beta K}{e^{K\left(C_i . t_{\max} - t_0\right)} - 1} \quad ....(3)$$

Where M is the natural mortality, C_i is 0.440 for lobster as the demersal fishery, K is the growth rate, t_0 is the theoretical age when the lobster has zero length, t_{max} is maximum age and â is the coefficient growth from the length-weight relationship.

Yield per recruit was estimated based on the Beverton & Holt (1957) model:

$$\frac{Y}{R} = FxAxW\infty\left(\frac{1}{Z} - \frac{3U}{Z+K} - \frac{3U^2}{Z+2K} - \frac{U^3}{Z+3K}\right) \text{ ... (4)}$$

Where F is fishing mortality, A is calculated from $A = \left[\frac{L\infty - L_c}{L\infty - L_r}\right]^{M/K}$, $W\infty$ is asymptotic weight, U is obtained from $U = 1\frac{Lc}{L\infty}$, Z is total mortality, and K is growth rate. Based on the yield per recruit analysis, fishing mortality can be estimated maximum yield per recruit (F_{max}) and 10% of the slope of yield per recruit from the initial biomass ($F_{0.1}$) (Beverton & Holt, 1957; Cadima, 2003).

The length-based spawning potential ratio was estimated from the input of annual length composition, M/K ratio, asymptotic carapace length (L_∞), the length at 50% maturity (Lm_{50}), and the length at 95% maturity (Lm_{95}) (Hordyk *et al*., 2015a; Hordyk *et al.*, 2015b). The spawning potential ratio was estimated based on the Goodyear (1993) equation that the spawning potential ratio was the ratio of the spawning stock biomass per recruit in the exploited stock with the spawning stock biomass per recruit in the absence of fishing:

$$SPR = \frac{\text{SSBR}_{\text{fished}}}{SSBR_{unfished}} \quad .... (5)$$

Where SPR is Spawning Potential Ratio, $SSBR_{fished}$ is the spawning stock biomass per recruit in the exploitation condition and $SSBR_{unfished}$ is the spawning stock biomass per recruit in the absence of fishing.

RESULTS AND DISCUSSION

Results

Length Distribution

The carapace length of female *P. polyphagus* in Sebatik Waters ranged from 56 to 128 mmCL (Figure 2). Mean size of *P. polyphagus* catched by gillnet was 89.16 mmCL in 2016, 88.5 mmCL in 2017 and 88.4 mmCL in 2018. The length at first maturity (Lm_{50}) of female *P. polyphagus* was 87 mmCL. The length at 95% (Lm_{95}) maturity was 105 mmCL. There are 47-53% of female lobsters catched by gillnet had lower sizes than the size at first maturity.

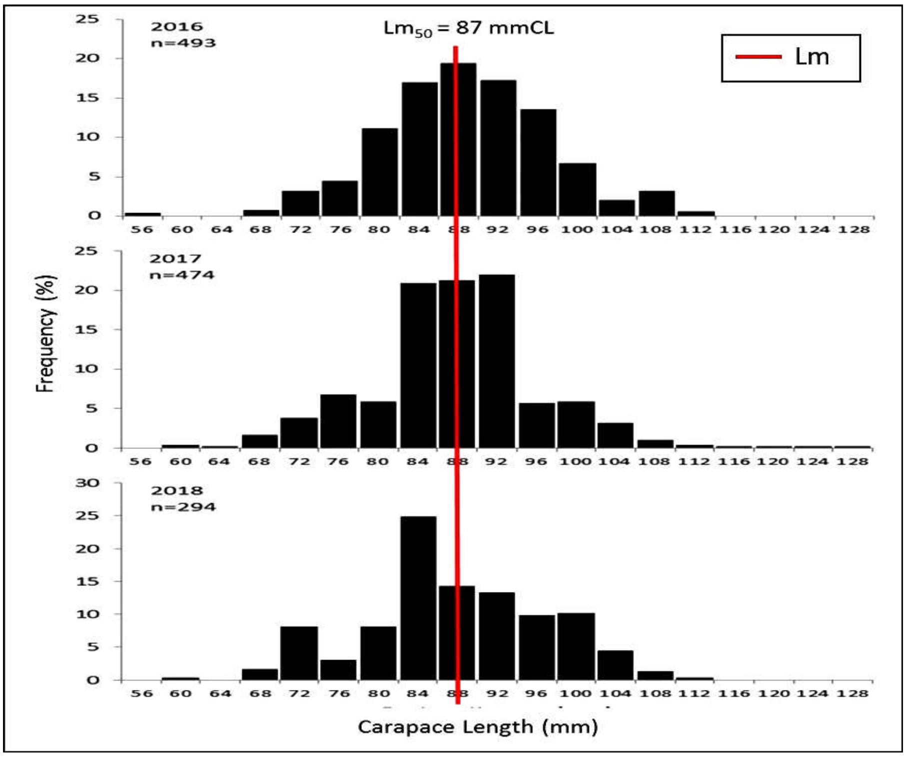

Figure 2. The length distribution of female *P. polyphagus* in Sebatik Waters, 2016-2018.

Length-Weight Relationship

The growth patterns of *P. polyphagus* were in the isometric condition in May and July while the growth patterns of *P. polyphagus* in other months were in the negative allometry. The highest growth coefficient of *b* was found in May (2.9409) while the low growth coefficient of *b* was found from November (2.6731) to December (2.6252) (Table 1). The combined length-weight relationship of female *P. polyphagus* in Sebatik Waters was following the equation of W=0.0024 x $L^{2.7462}$. The minimum length of *P. polyphagus* was 52 mmCL with the weight of 0.12 kg and the maximum length of *P. polyphagus* was 127 mmCL with the weight of 1.44 kg. The length at first maturity (Lm_{50}) was 87 mmCL with the weight of 508.77 grams.

Table 1. The length-weight relationship of female *P. polyphagus* in Sebatik Waters, 2016-2018.

Months	***n***	***a***	***b***	***R^2***	**95% Confidence interval of *b***	**Growth Pattern**
Mar	93	0.0105	2.4218	0.8506	2.2105-2.6331	Negative Allometry
Apr	128	0.0016	2.8417	0.9448	2.7183-2.9652	Negative Allometry
May	128	0.0010	2.9409	0.9672	2.8400-3.0417	Isometric
Jun	122	0.0031	2.6775	0.9157	2.5313-2.8238	Negative Allometry
Jul	117	0.0015	2.8572	0.9381	2.6973-3.0171	Isometric
Aug	150	0.0028	2.7152	0.9343	2.6085-2.8218	Negative Allometry
Sep	152	0.0018	2.8149	0.9484	2.7177-2.9120	Negative Allometry
Oct	151	0.0013	2.8794	0.9291	2.7617-2.9970	Negative Allometry
Nov	194	0.0033	2.6731	0.9369	2.5873-2.7589	Negative Allometry
Des	25	0.0041	2.6252	0.9366	2.3312-2.9192	Negative Allometry
Combined	1260	0.0024	2.7462	0.9344	2.7031-2.7893	Negative Allometry

Growth

The growth parameters of asymptotic length and growth rate were determined from the modal progression analysis using monthly length frequency data (Appendix 1). The asymptotic length of female *P. polyphagus* was 134.40 mmCL and the growth rate of *P. polyphagus* was 0.39 year^{-1} with the goodness of fit index (*Rn*) 0.29. The theoretical age when *P. polyphagus* has zero length (t_0) was 0.04 year^{-1} so the v on Bertalanffy growth model was $L(t)$=134.40(1-$e^{-0.39(t+0.04)}$) (Figure 3).

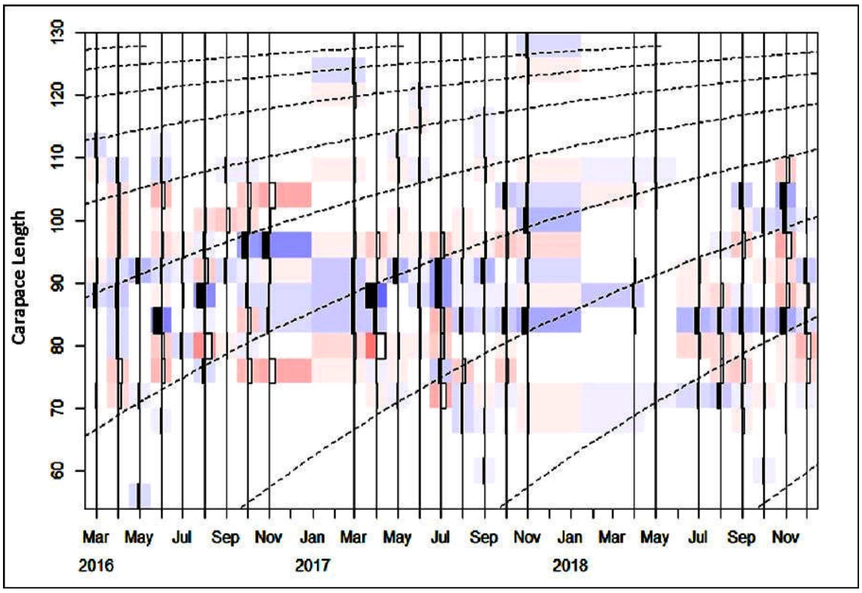

Figure 3. The von Bertalanffy Growth Curve of female *P. polyphagus* in Sebatik Waters, 2016-2018.

The minimum length of female *P. polyphagus* captured by gillnet was 52 mmCL, which has the age of 1 year and 3 months. Female *P. polyphagus* reached the maximum length at the age of 7 years and 8 months. Female *P. polyphagus* reached the length at first maturity (Lm_{50}=87 mmCL) by the age of 2 years and 7 months (Figure 4).

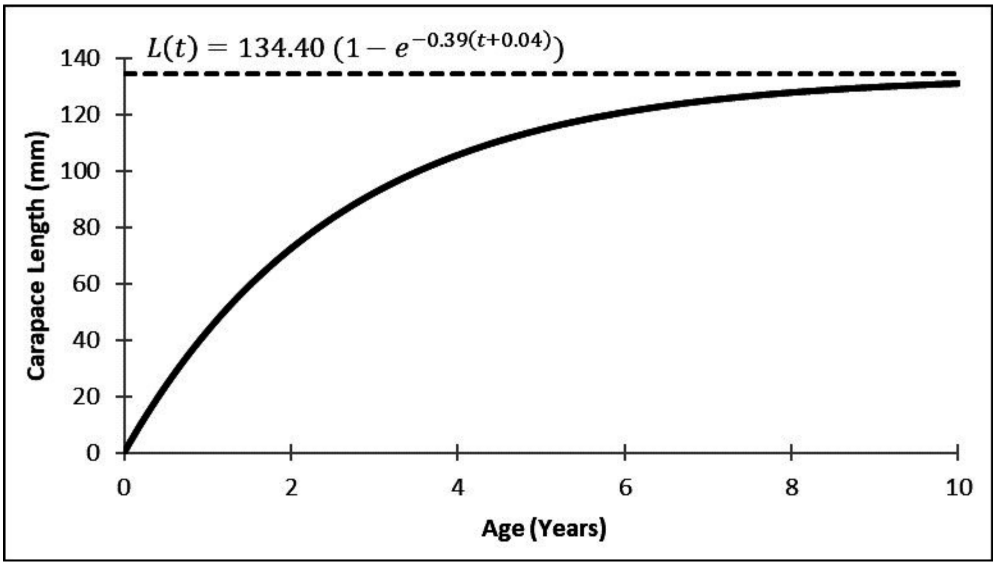

Figure 4. The von Bertalanffy Growth curve of female *P. polyphagus* in Sebatik Waters, 2016-2018.

Reference point

The natural mortality was estimated as 0.36 year^{-1}. The length at first captured ($Lc_{50\%}$) was estimated as 88 mmCL and $Lc_{95\%}$ as 93 mmCL. Based on the yield per recruit analysis, the increasing fishing mortality increased the yield per recruit until reaching the maximum of 304.76 gr per recruit at the F_{max} of 1.65 and at the spawning potential ratio of 0.21 (Figure 5). $F_{0.1}$ was estimated as 0.88 year^{-1} which gives the yield per recruit of 297.43 gr per recruit and the spawning potential ratio of 0.29. The fishing mortality, which gives 40% spawning potential ratio ($F_{40\%}$), was estimated as 0.49, which gives yield per recruit of 270.86 gr per recruit. The $F_{40\%}$ was lower than F_{max} and $F_{0.1}$ so $F_{40\%}$ with the *F/M* ratio of 1.38 can be suggested as the target reference point for lobster fishery in Sebatik Waters.

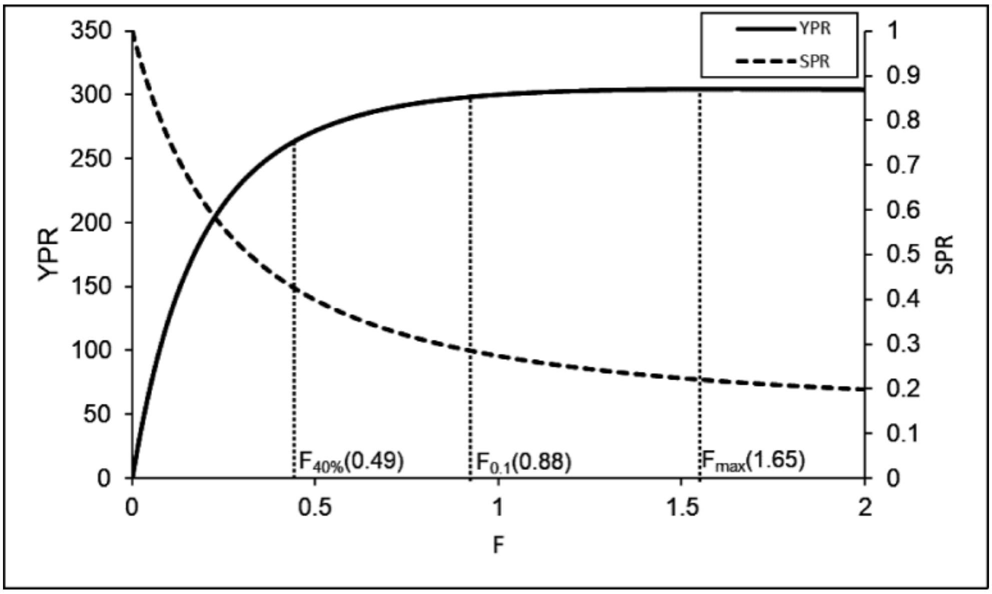

Figure 5. Yield per recruit and reference point of spawning potential ratio for *P. polyphagus* in Sebatik Waters.

Spawning potential Ratio

The annual spawning potential ratios of *P. polyphagus* in Sebatik Waters were 20% in 2016, 19% in 2017, and 22% in 2018 (Table 2). The spawning potential ratios of *P. polyphagus* in 2016 (20%) and 2017 (19%) were lower than the *SPR* at F_{max}(21%), which showed the overexploited condition. The spawning potential ratio in 2018 was higher than *SPR* at F_{max}, but it was lower than the *SPR* at $F_{0.1}$ and target reference point so the current status of *P. polyphagus* in Sebatik Waters was in the fully-exploited condition.

Table 2. Reference points, annual fishing mortality, and annual spawning potential ratios of *P. polyphagus* in Sebatik Waters.

Fishing mortality at			SPR at			Annual F and SPR		
F_{max}	$F_{0.1}$	$F_{40\%}$	F_{max}	$F_{0.1}$	$F_{40\%}$	Year	F	SPR
1.65	0.88	0.49	0.21	0.29	0.40	2016	2.08	0.20
						2017	2.09	0.19
						2018	1.52	0.22

Discussion

The size of *P. polyphagus* in Sebatik Waters ranged from 56 to 128 mmCL and the mean size was from 88 to 89 mmCL. Female *P. polyphagus* in Sebatik Waters was bigger than ones reported by Ikhwanuddin *et al*., (2014) in Johor-Malaysia, where the size ranged from 53 to 120 mmCL and the mean size was at 74 mmCL. The length at first maturity (*Lm*) of *P. polyphagus* in the study site was 87 mmCL. Kizhakudan & Patel (2010) reported that the length at first maturity of female *P. polyphagus* ranged from 66 to 75 mmCL so the length at first maturity of *P. polyphagus* in Sebatik Waters was quite large.

About 47% to 53% of female *P. polyphagus* has the size that is less than its length at first maturity. This condition was caused by the fishing ground of the gillnet vessel that was still near the coast with depth of less than 10 m. *Panulirus polyphagus* lived in the depth of 3 to 90 m with the juvenile occupied shallow water and the adult lobster migrated to the deeper water for spawning (Carpenter & Niem, 1998; Radhakrishnan & Manisseri, 2003).

The combined growth pattern of *P. polyphagus* in Sebatik Waters was in the negative allometry, with the monthly growth patterns of *P. polyphagus* were isometric in May and July and negative allometry in other months. The monthly length-weight relationship that showed different patterns in some months could be caused by the condition of the spawning season, availability of food, and migration. The lowest coefficient of *b* was found from November to December that could be caused by the releasing eggs in that period. The high nutrient-release for migration could also decrease its growth coefficient (King, 1995). The highest growth coefficient of *b,* which was in the isometric condition. was found in May that showed the good condition of female lobster in this month. It could be caused by the rich availability of food or the highest development of maturity (Kamaruddin *et al*., 2011). Some studies of length-weight relationship for lobsters showed negative allometry condition including *P. ornatus* in Sorong Waters, *P. homarus* in Tabanan-Bali, and *P. versicolor* di the South Coast of India, while the growth pattern of *P. versicolor* in Ambon Waters was in isometric condition (Aisyah & Triharyuni, 2010; Tirtadanu & Yusuf, 2018; Kembaren *et al*., 2015; Ongkers *et al*., 2014).

The asymptotic length of female *P. polyphagus* was 134 mmCL and the growth rate was 0.39 $year^{-1}$. The growth rate of *P. polyphagus* in Sebatik Waters was still in the range of spiny lobsters, which were reported from the previous studies, from 0.21 to 0.60 $year^{-1}$ (Table 3). The maximum size of female lobster was reached in the age of 7 years and 8 months and the length at first maturity of female lobster was reached in the age of 2 years and 7 months. After *P. polyphagus* reached its length at first maturity, it still needed more than 3 years to reach the maximum length so the female *P. polyphagus* could spawn yearly for 3 years. Kagwade (1998) noted that *P. polyphagus* was the multiple spawner, which spawned throughout the year, and it could become ovigerous in one until two months after impregnation and the eggs will hatch after 2 until 3 months after the incubation.

The natural mortality of *P. polyphagus* in Sebatik Waters was quite low compared to some previous studies (Table 3) due to the natural habitat of Sebatik Waters and low pollution, which is good for the growth of this species. Most of spiny lobsters such as *P. ornatus*, *P. longipes*, *P. penicillatus,* and *P. homarus* were found in coral reef habitat, but *P. polyphagus* was usually found in the muddy substrate (Pitcher, 1993; Carpenter & Niem, 1998).

Table 3. Asymptotic length, growth rate, and natural mortality of spiny lobsters in some areas.

Species and locations	L_∞ (mm)	K (year^{-1})	M (year^{-1})	Authors
P. homarus				
Palabuhanratu, West Java	103-110	0.40	0.56-0.71	(Zairion *et al*., 2018)
Aceh waters	119.5	0.39	0.67	(Kembaren *et al*., 2016)
P. penicillatus				
Wonogiri waters	133-142	0.32-0.37	0.55-0.62	(Beni *et al*., 2020)
Enewetak	97-147	0.21-0.58	0.36-0.48	(Ebert & Ford, 1986)
P. versicolor				
Karimunjawa waters	131	0.34	0.58	(Ernawati *et al*., 2019)
P. ornatus				
Sorong waters	174.05	0.34	0.55	(Tirtadanu & Yusuf, 2018)
P. polyphagus				
North Kalimantan	124.1	0.60	0.87	(Chodrijah *et al*., 2018)
Veraval, India	124.7-135	0.38-0.46	-	(Kizhakudan *et al*., 2013)
Sebatik waters	134.4	0.39	0.36	This study

Yield per recruit model was used to determine the reference point by the point of exploitation level which gave the maximum yield per recruits. The reference point from the yield per recruits has high correlation to fishing mortality and selectivity (Beverton & Holt 1957). The maximum yield per recruits of *P. polyphagus* in Sebatik Waters was 305 gram per recruit that showed the recruitment of 100.000 lobsters will give the yields of 30 ton. The maximum yield per recruits was obtained when the fishing mortality (F_{max}) was 1.65 year^{-1}. The fishing mortality that was more than its F_{max} will decrease the yield per recruit.

The maximum fishing mortality remained 21% of spawning potential ratio so 24% *SPR* was used for the limit reference point and 40% *SPR* can be suggested as target reference point for *P. polyphagus* in Sebatik Waters. In particular, the reference point ranged from 20% to 40% (Gabriel & Mace, 1999). Mace & Sissenweine (1993) and Goodyear (1993), suggested 20% *SPR* for the recruitment overfishing threshold. Ault *et al*., (2008) recommended 30% *SPR* for coral reef fish and Rosenberg *et al*., (1994) recommended 20% *SPR* as an overfished threshold for spiny lobster fishery in Puerto Rico.

The spawning potential ratio was the reproduction potential proportion of the unfished stock based on its exploitation level or the measurement of the fishing impact on the potential productivity of stock (Goodyear, 1993; Mace & Sissenwine, 1993; Walters & Martell, 2004). The spawning potential ratio ranged from 0 (depleted condition) to 100% (unexploited stock) (Goodyear, 1993; Brooks *et al*., 2010). The spawning potential ratio of *P. polyhagus* in Sebatik Waters in 2016 (SPR_{2016}=20%) and 2017 (SPR_{2017}=19%) was lower than the limit reference point (21%) so the overexploited has occurred in those years. The current spawning potential ratio in 2018 was higher than the limit reference point but it still lower than the target reference point of 40% *SPR* so the current status for *P. polyphagus* in Sebatik Waters was in the fully-exploited condition. Based on the results of this study, it is suggested that the control rule was needed by applying the minimum legal size of 87 mmCL or the minimum legal weights of 500 gram and not increasing the fishing vessel. The stock assessment of *P. polyphagus* in Sebatik Waters should continue for evaluating the management strategy to reach the reference point of 40% *SPR*.

CONCLUSION

Annual spawning potential ratios (*SPR*) of *P. Polyphagus* from 2016 to 2018 ranged from 19% to 22%. The limit reference point was suggested at 21% *SPR,* with 40% *SPR* as the target reference point. The current spawning potential ratio in 2018 was higher than the limit reference point but it is still lower than the target reference point of 40% *SPR* so the current status for *P. polyphagus* in Sebatik Waters was in the fully-exploited condition. From those results, it is suggested to apply the quota, which was not more than the current effort, and the minimum legal size of 87 mmCL or minimum legal weights of 500 gram. The stock assessment of *P. polyphagus* in Sebatik Waters should be continued for monitoring the target reference point of 40% *SPR*.

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