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BIOLOGICAL REFERENCE POINTS OF PAINTED SPINY LOBSTER *Panulirus versicolor* (Latreille, 1804) IN KARIMUNJAWA WATERS, INDONESIA

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ABSTRACT

A biological reference point is a term used to explain of stock status using a biological approach as a basic of fisheries management. Biological reference points of painted spiny lobster *Panulirus versicolor* are limited in Karimunjawa waters. This study aims to investigate the stock status of *P. versicolor* and management options to ensure the sustainability of the resources. The research was conducted in Karimunjawa islands of the Java Sea by collecting lobster from local fishers from March to November 2016. A total of 495 lobster were measured, weighed, and their maturity status assessed to allow the size at maturity and selectivity of the fishery to be estimated. The size at maturity L_{50} (62.2 mm CL) and L_{95} (82.0 mm CL) were larger than SL_{50} (48.2 mm CL) and SL_{95} (75.0 mm CL), respectively. Natural mortality (M) which was 0.579 year⁻¹ is lower than fishing mortality (F). The current spawning potential ratio (SPR) of *P. versicolor* is 19% at the current F of 0.82, which is below SPR limit of 20% and target reference point of 40%. Hence, to increase SPR level to 40%, the fishing mortality should be reduced by about 40% to 60%. Closed season, legal size, and defining no take zone are options to consider by fishery manager with appropriate surveillance control. Single or combining those measures can reduce its fishing mortality and take back the stocks to the level of target reference point.

Keywords: Painted spiny lobster; size at maturity; mortality; SPR

INTRODUCTION

The painted spiny lobster (*Panulirus versicolor*), locally known as the bamboo lobster, is one of the most economically important species in Indonesia. Painted spiny lobsters are widely distributed in the Indo-West Pacific from eastern coast of Africa to the Red Sea, Japan, Micronesia, Melanesia, Northern Australia and French-Polynesia (Chan, 1998). In Indonesian waters, they are mainly distributed along the coasts and found in coral or rocky reef areas at depths range of 5 – 20 m (Milton *et al.*, 2012).

In general, the market demand of all spiny lobster continues to increase (Frisch & Hobbs, 2012). However, at the same time most of spiny lobster fisheries in the world are considered to be fully exploited or over exploited, indicated by the decline in the wild populations (Phillips & Melville-Smith, 2006; Verghese *et al.*, 2007). In addition, nationally the spiny lobster stock status within FMA 712 (Java Sea) has over exploited and FMA 714 (Banda Sea) has fully exploited (Suman *et al.*, 2016). Hence, appropriate

and effective management for spiny lobster in general is urgent.

One possible approach to manage spiny lobster is through using biological target and limit reference points (BRP). A biological reference point is a term used to explain of stock status using a biological approach. The BRPs integrates assessment the combination of life-history parameters in stock assessment and also fishing mortality into a single index or a single modeling framework (Maunder & Punt, 2013; Szuwalski *et al.*, 2016).

The spawning potential ratio (SPR) is one of model in BRP to determine stock status. The SPR is a relative rate index of reproduction in an exploited stock. The SPR is commonly used as a target and limit reference point for fisheries (Hordyk *et al.*, 2015a). Its method recommended for applying to stocks in data-limited fisheries (Brooks *et al.*, 2010). The concept of SPR is a proportion of the unfished reproductive potential left by fishing impact. By definition, the population in unfished stock has an SPR of 100%

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($SPR_{100\%}$) and mortality caused by fishing reduces the SPR from the unfished level to $SPR_{x\%}$ (Prince et al., 2015)

Karimunjawa Islands waters are a part of Indonesia's Fisheries Management Area (FMA) 712 (the Java Sea). The islands are designated as national marine park that serves as a marine resource conservation area. Karimunjawa waters is known as a coral reef ecosystem. Based on Yusuf (2013), the condition of most coral reefs in the Karimunjawa National Park was damaged and categorized as medium (25 – 49,9 % cover coral) while coral reefs in a small part of the park were classified as good (50 – 74,9% cover coral).

Data on BRP for *P. versicolor* in Karimunjawa waters are very limited. The aim of this study is to describe the stock status of *P. versicolor* through SPR and possible management advice to fishery manager to sustain of this resource.

MATERIALS AND METHODS

Data Collection

A total of 495 lobsters were collected and measured between March and November 2016 in Karimunjawa Islands (Figure 1), consisted of 309 females and 186 males. Lobster fishers in Karimunjawa use small boats < 5 GT. The fishers dive to catch the lobsters directly by hand at night.

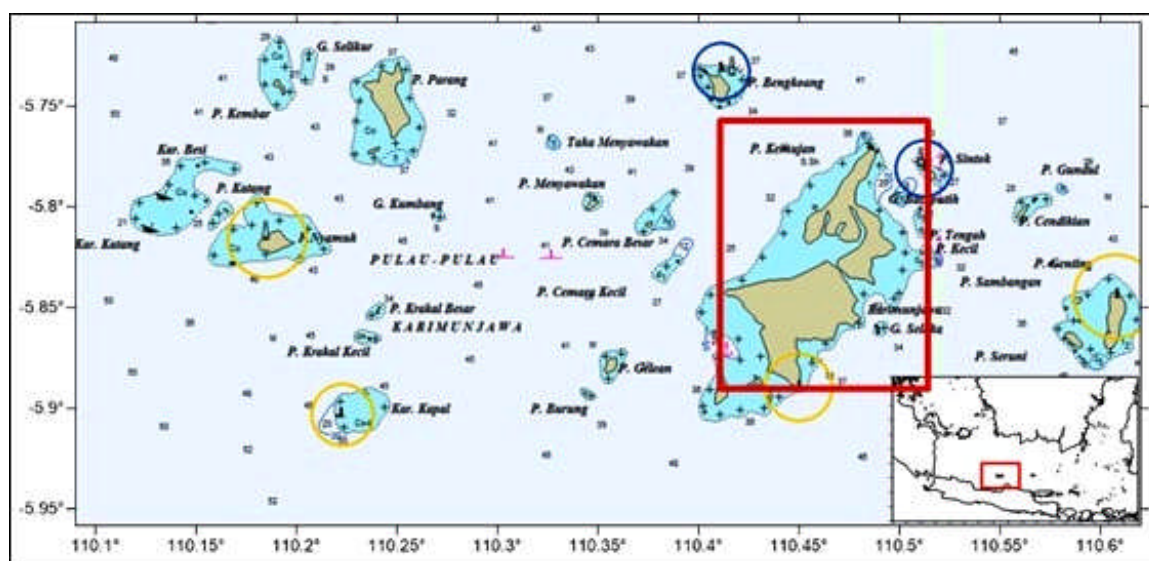


Figure 1. Map of locations of the research on *Panulirus versicolor* in the Karimunjawa Islands, off the Central Java coast, Indonesia.

All samples were measured and recorded for their carapace length, weight, and stages of ovarian development. Data collections were conducted monthly in private landing sites (collectors). The number of samples that were collected in every month was around 60 lobsters. The ovarian stages of female lobster were determined following Silva & Cruz-landim (2006):

- I. *Immature*, little forming of the ovaries with slim anterior and posterior lobes is limited to the body cavity, the color of ovaries is white, and difficult to differentiate from encircling muscles.
- II. *Prematuration*, the ovaries are growing in volume and expanded with color is pink or light yellow. The organ seems bloated and tough to the touch.
- III. *Mature*, the gonad is completely developed and will fill all available room in the body cavity. It grows more winding and is able to extend into the second

segment of stomach and the color is orange or reddish.

- IV. *Spawning or resorption*, the ovary might be reabsorbed ovulation oocytes and other cells. It is getting soft with pigmented zones and the spaces are internally empty. At this stage, ovary seems in the immature or premature level, though a spawned lobster ovary is not at all fully reinstated the original immature shape.

Data Analyses

Carapace-Length Size at Maturity

The mean of carapace-length at maturity was analyzed by fitting a logistic curve to the proportion of mature females lobster in each size class. The estimation of mean carapace-length of maturity was derived following equation of King (1995):

$$P = \frac{1}{(1 + \exp \exp(-a(L - L_m)))} \dots\dots\dots(1)$$

Where, *P* is the proportion of ovarian mature individual by carapace-length (*L*); *a* is the slope of the curve; *L_m* is the mean carapace-length at first maturity.

Natural Mortality

Natural mortality (*M*) is one of the essential parameters of life-history. By estimating *M*, fishing mortality can be estimated from the age or size composition of commercial or independent-survey catches (Gislason *et al.*, 2010). The estimating of *M*, particularly for data-poor stocks, uses an updated Hoenig method when *t_{max}*, the maximum age in years, is available, following the formula of Then *et al.*, 2015:

$$M = 5.109/t_{max} \dots\dots\dots(2)$$

Growth

Growth paramater as an input for SPR estimation was obtained by fitting the von Bertalanffy growth function,

$$L_t = L_\infty * (1 - e^{-k(t-t_0)}) \dots\dots\dots(3)$$

Where, *L_t* is the carapace length at the time *t*; *L_∞* is the asymptotic carapace length; *k* is the growth coefficient; *t₀* is the theoretical carapace length at age 0. The analyses were done using Electronic Length Frequency Analysis (ELEFAN) in TrophFishR packages (Mildenberger *et al.*, 2017). The maximum age (*t_{max}*) can be estimated by growth parameter *k*. The calculation of *t_{max}* was defined from Pauly (1980) equation:

$$t_{max} \approx 3/k \dots\dots\dots(4)$$

Spawning Potential Ratio (SPR)

SPR is one of biological reference points of determining stock status of a species in the population. The reference points of SPR used are: SPR 20% is as limit reference point and SPR 40% is a target reference point (Bunnell & Miller, 2005; Kilduff *et al.*, 2009; Hordyk *et al.*, 2015a). Estimating SPR needs parameters of life history. The SPR was defined

as (Hordyk *et al.*, 2015b):

$$SPR = \frac{\sum(1 - \tilde{L}_x)^{(M/k[(F/M)+1])\tilde{L}_x^b}}{\sum(1 - \tilde{L}_x)^{M/k} \tilde{L}_x^b} \text{ for } x_m \leq x \leq 1..(5)$$

Where, *L_x* is carapace length (female lobsters); *M* is natural mortality; *k* is growth rate; *F* is fishing mortality; and *b* is exponent usually close to 3. Estimating SPR with those functions need the simple assumptions of asymptotic or logistic selectivity and no variation in length at age.

Based on the equation (5), *F/M* ratio can be estimated from the length composition of the catch (Hordyk *et al.*, 2015b). The relationship between *F/M* and SPR is asymptotic and determined by the selectivity parameters. There are many combinations of *F/M* and selectivity produce similar values of SPR at high fishing pressure (Prince *et al.*, 2015).

As informed above, the lobsters are caught by hand directly, not using any gears, so the size compositions are truncated and also uninformative for estimating the size of full selectivity. To address this issue, an approach following Prince *et al.* (2015) by bounding the selectivity parameters was adopted.

RESULTS AND DISCUSSION

Results

Carapace-Length at Maturity

The length of carapace at 50% maturity for female lobster (*L_m* or *L₅₀*) was defined as the size at which 50% of all female population has entered into a stage of matured (Kizhakudan & Patel 2010). The *L_m* of *P. versicolor* was estimated to be at 62.2 mm *CL* and the *CL* at which 95% of females were mature (*L₉₅*) was 82.0 mm (Figure 2).

The Carapace-Length Distribution

Based on the carapace-length (*CL*) distribution of all female lobster caught, about 51% of painted-spiny lobster were less than the *L_m* of 62.2 mm (Figure 3). The mean size of spiny lobster was 58.9 ± 19.4 mm *CL*, and ranged from 18.4 mm to 124.2 mm *CL* (Figure 3).

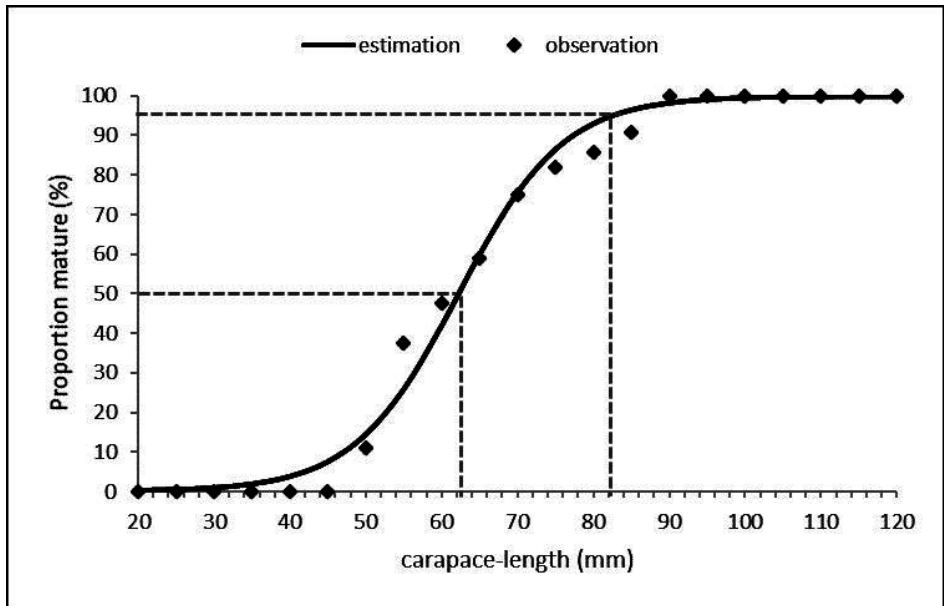


Figure 2. The carapace-length at which 50% and 95% of female painted spiny lobster (*P. versicolor*) are mature (L_{50} and L_{95}) in Karimunjawa waters, Java Sea, Indonesia.

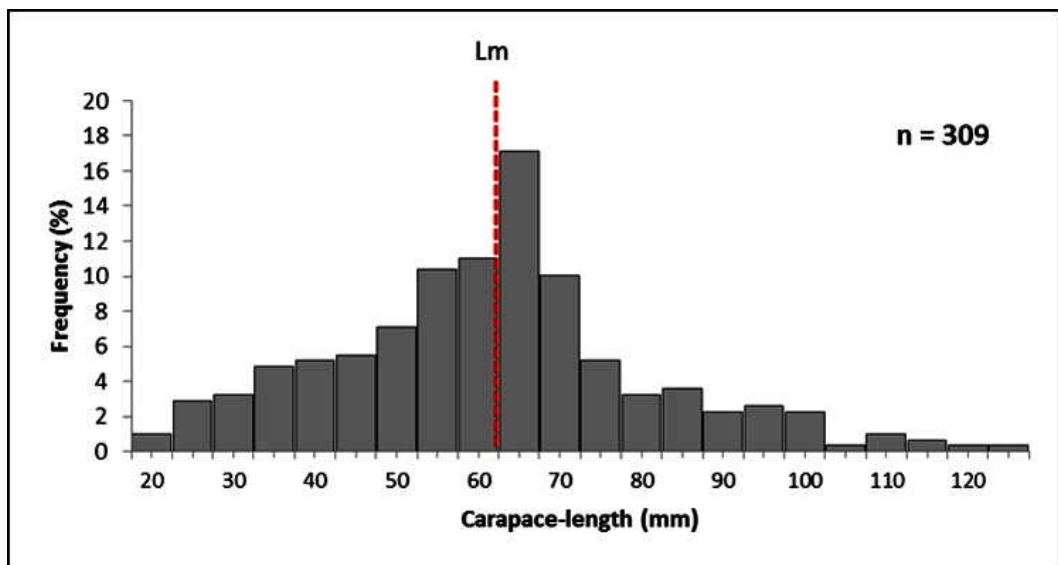


Figure 3. The carapace-length distribution of females *P. versicolor* from Karimunjawa waters. The red line is L_m or L_{50} .

Growth

The von Bertalanffy growth model, which basically determines growth as continuous over a time scale has been adjusted to several lobster species. The model was used to account analytical method and other size-based stocks (Cobb & Caddy, 1989). Figure 4 shows monthly carapace length distributions of

combined males and females *P. versicolor* and .Figure 5 shows their fitting of ELEFAN using von Bertalanffy model. The carapace length asymptotic (L_{∞}) was acquired at 131 mm. The maximum age was gained at about 8.8 years with relatively slow growth ($k = 0.34$). The carapace-length at first maturity (L_m) for *P. versicolor* in Karimunjawa could be reached at the age of about 2 years (Figure 6).

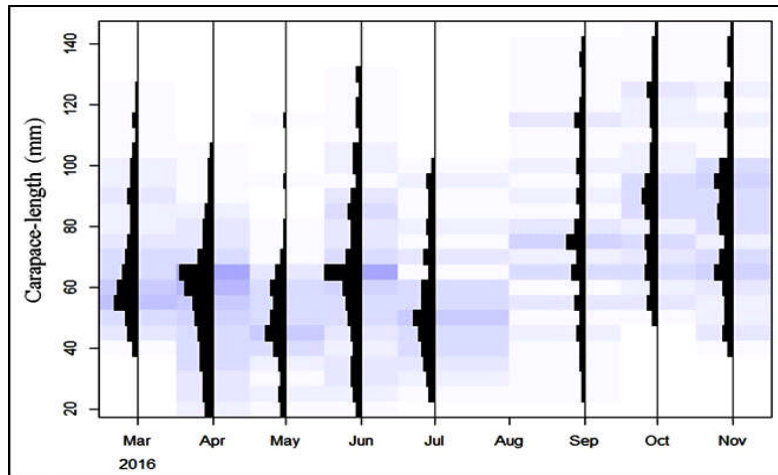


Figure 4. Monthly carapace length frequency distributions of combined males and females *P. versicolor* in Karimunjawa waters.

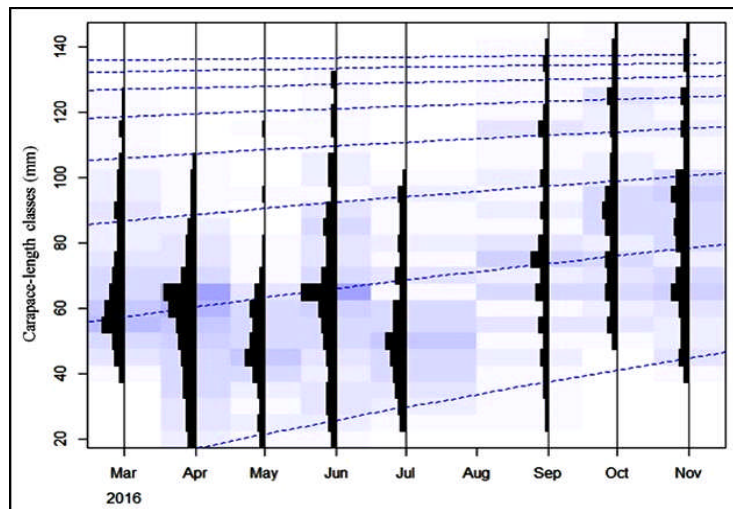


Figure 5. Fitting of ELEFAN based on von Bertalanffy growth model of *P. versicolor* without separating males and females in Karimunjawa waters.

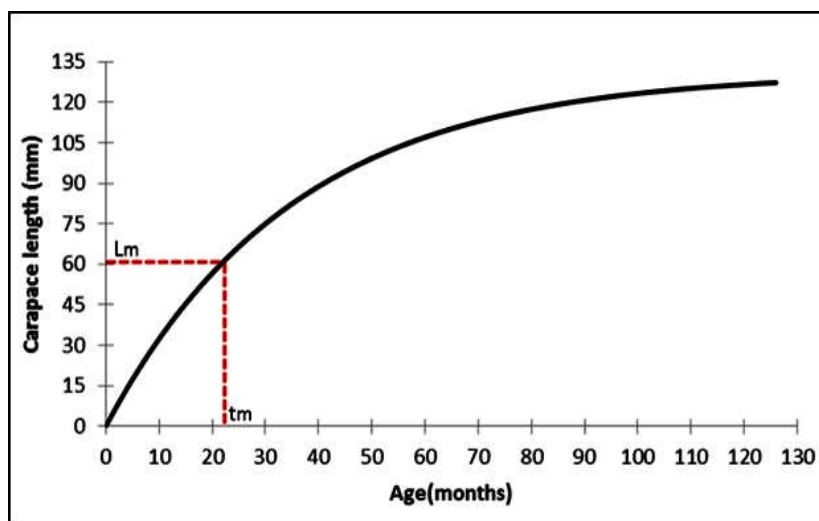


Figure 6. The growth curves of painted spiny lobster *P. versicolor* and age of females first maturity from Karimunjawa waters.

Mortality and Spawning Potential Ratio (SPR)

Natural mortality (M) was estimated by using maximum age (t_{max}) of *P. versicolor*. Based on t_{max} of 8.8 years, M of painted spiny lobster was obtained at 0.579 year⁻¹. Based on the ratio of F/M at 1.42, the F (fishing mortality) was 0.82 year⁻¹. The ratio of L_m/L_∞ and M/k of lobsters in Karimunjawa were 0.47 and

1.70, respectively. With these parameters and size composition data, we estimated the 50% selectivity $SL_{50} = 48.2$ mm CL and 95% selectivity as $SL_{95} = 75.0$ mm CL. From all the parameters, SPR then was obtained at 19% (Table 2). Target reference point of SPR 40% was at F level of 0.38 as a proxy value. The correlation of SPR with F is illustrated in Figure 7.

Table 2. The results of spawning potential ratio (SPR), fishing pressure (F/M) and selectivity (SL_{95} , SL_{50}). CV = coefficient of variation

Parameters	Values
SPR (%)	19
SL_{50} (mm carapace-length)	48.2
SL_{95} (mm carapace-length)	75.0
F/M	1.4
CV_{Linf}	0.1

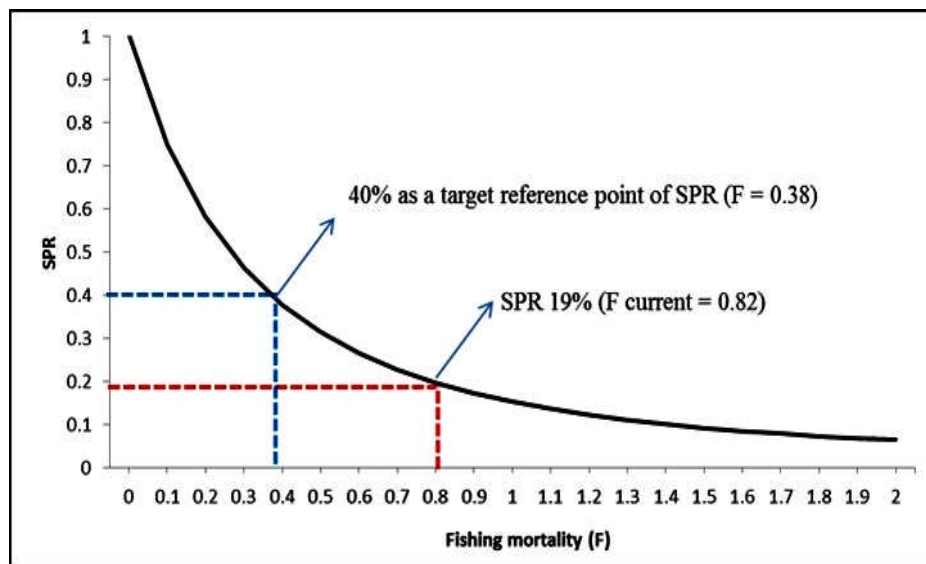


Figure 7. The relationship between Spawning Potential Ratio (SPR) and different levels of fishing mortality for painted spiny lobster *P. versicolor* in Karimunjawa Islands, Java Sea, Indonesia. The estimated fishing mortality for the target SPR of 40% is also shown.

Discussion

The mean size at first maturity (L_m or L_{50}) in this study was 62 mm CL. Table 3 shows its comparison to other studies, including the mean size at capture (SL_{50}). The difference in mean size at maturity in different areas can be caused by biotic and abiotic environmental variables, such as temperature, population density, food availability, and shelter (Chittleborough, 1976; DeMartini *et al.*, 2003; Chang *et al.*, 2007; Polovina, 1989). In addition, the ability to determine sexual maturity is an essential requirement to accurately identify the maturation state. Among other approaches, the histological method of the oocytes developmental stages is the most accurate method to determine sexual maturity (Chang *et al.*, 2007).

The size at maturity L_{50} and L_{95} were larger than SL_{50} (48.2 mm CL) and SL_{95} (75.0 mm CL), respectively. This indicated that most of lobsters had not matured yet when they were fished. For the long term, this condition can potentially threaten the sustainability of lobster resources in this area. Common evidence show high fishing pressure can cause smaller size lobster with low quantity and quality of eggs. The worst case scenario is when the lobster populations declining due to less number of brooders and recruitment failure. The SL_{50} of *P. versicolor* lobsters in Karimunjawa waters is similar to ones from the southern West-Java waters, which was 50.0 mm CL (Nuraini & Sumiono, 2008). However, this was still smaller than *P. versicolor* lobsters from Flores waters, which was 73.67 mm CL (Ernawati *et al.*, 2014).

Fishing pressure on lobster in the Flores waters to date is still very low. It seems that lobster in Karimunjawa and southern West-Java waters has had higher fishing pressure than lobsters in Flores waters.

Nationally, the minimum legal size of lobsters is regulated for the size at 80 mm CL (Regulation Minister of Marine and Fisheries, the Republic of Indonesia No. 56, 2016) for all species of spiny lobsters. Based on the result of length at maturity (L_m) of *P. versicolor* in this study, in the waters of Karimunjawa, it is ~75% smaller than the legislated

legal size, similar to the L_m for this species in Ekas Bay, Lombok (Table 3). The regulation should be reconsidered, every species of lobster have different characteristics. Therefore, the regulation of minimum size should not be equated for all species of spiny lobsters.

The growth of *P. versicolor* in Karimunjawa waters can be categorized as a slow growth which is shown by the growth coefficient 0.34 year^{-1} ($k < 1$) (Sparre & Venema, 1999). The variation growth coefficient (k) and carapace length asymptotic (L_∞) of other Palinurids has been reported from previous studies (Table 4).

Table 3. Summary of the estimated size at maturity of the bamboo lobsters *P. versicolor* from different studies and regions. L_{50} or L_m is the mean size at maturity (in mm CL) and SL_{50} is the mean size at capture (in mm CL)

Region	Author	L_{50} or L_m	SL_{50}	Method
Great Barrier Reef, Australia	Frisch (2007)	78		the size of smallest ovigerous female
Southern West-Java	Nuraini <i>et al.</i> (2008)		50	logistic function
Ekas bay, Lombok	Junaidi <i>et al.</i> (2010)	61 -71		the ovarian development
Flores waters	Ernawati <i>et al.</i> (2014)		73.67	logistic function
Karimunjawa, Java	This study	62		the ovarian development

Table 4. Summary of Palinurids growth parameters from different researches and geographical area.

Region	Species	L_∞ (mm CL)	$k \text{ year}^{-1}$	Geography area	Author
South Africa	<i>Palinurus gilchristi</i>	95.75-111.2 (male); 78.5 - 96.11 (female)	0.05 - 0.092 (male); 0.065 - 0.129 (female)	temperate	Groeneveld, (1997)
GBR, Australia	<i>Panulirus versicolor</i>	144.7 - 185 (male); 116 (female)	0.27 - 0.10 (male); 0.16 (female)	temperate	Frisch, (2007)
Western Sardinia	<i>Palinurus elephas</i>	135 (male); 124.7 (female)	0.46 (male); 0.38 (female)	temperate	Bevacqua <i>et al.</i> (2010)
North-west coast India	<i>Panulirus polyphagus</i>	146.7 (male); 119.5 (female)	0.44 (male); 0.39 (female)	tropical	Kizhakudan <i>et al.</i> (2013)
Northern Sikka, Flores	<i>Panulirus versicolor</i>	110.5 (male); 103.2 (female)	0.29 (male); 0.40 (female)	tropical	Ernawati <i>et al.</i> (2014)
Western Aceh	<i>Panulirus homarus</i>	131 (male); 131 (female)	0.34 (male); 0.34 (female)	tropical	Kembaren & Nurdin, (2015)
Palabuhanratu, Western Java	<i>Panulirus homarus</i>	131 (male); 131 (female)	0.34 (male); 0.34 (female)	tropical	Zairion <i>et al.</i> (2017)
Karimunjawa, Java	<i>Panulirus versicolor</i>	131	0.34	tropical	This study

The growth of lobsters as in many crustaceans was impacted by water temperature (Chittleborough, 1975), availability and quality of food (Robertson *et al.*, 2000), salinity (Field & Butler, 1994), and injury (Hunt & Lyons, 1986). Overall, the results show that lobsters in tropical waters tend to grow faster than lobsters in temperate waters. These can support the theory that aquatic animals grow faster with decreasing latitude, possibly due to the effects of temperature on metabolism (Heibo *et al.*, 2005). The temperatures in tropical waters are relatively stable and in Karimunjawa waters are generally above 25°C, while those in temperate waters are fall below 20°C during winter, inhibiting metabolism and growth.

Panulirus versicolor mortality was mainly driven by fishing intensity that was indicated by the greater value of F compared to M . As fishing intensity can be obtained from the size of catches (Zairion *et al.*, 2017), it was then revealed that the carapace length was dominated at 58.9 ± 19.4 mm and mean length at first capture (SL_{50}) was at 48.2 mm, less than the L_m or L_{50} . Hence, this can support the assumption that high fishing intensity occurred in Karimunjawa thus explained why smaller or young lobsters dominate the catch. However, further investigation is needed since fishing activities of lobster fisheries in Karimunjawa waters generally were utilized by diving and catching directly with their hands. Therefore, they have limited capacity to reach the deeper waters. Consequently, fishermen are only able to catch lobsters in shallow waters where younger and smaller lobsters are found (Dennis *et al.*, 1997).

Managers should consider that lobsters and other invertebrates might be difficult to manage because their productivity were closely related to the environmental conditions (Botsford 2001; Linnane *et al.*, 2010). The population of lobsters are frequently resilient to depletion of low biomass (Breen, 1994; Pollock, 1993). Many lobsters are managed using reference points which are less precautionary than that has been estimated (Szuwalski *et al.*, 2016). For example, SPR 10% and 5% were used as target for *Homarus americanus* in the USA and Canada, respectively, and 5% for *Panulirus argus* in the USA, but unfortunately recruitment decreases in the 2000s raised questions about these target levels (Caddy, 2004).

The SPR of *P. versicolor* estimated for the Karimunjawa waters of 19% at the current F of 0.82, which was slightly under the Limit reference point (LRP) 20%. Hence, to reach the target SPR of 40%, F level should reach 0.38 by reducing the fishing

mortality about 40% to 50%. To reduce fishing mortality, several options can be considered to be forwarded to lobster fishery manager, such as: 1) continuing the socialization and implementation and compliance to reduce the capture of lobster < 62 mm CL i.e. the L_m , 2) applying closed fishing season for lobster during lobster recruitment phase where the scientific advice available, and 3) Karimunjawa nationally is designated for conservation area then might be expanded as well for its lobster habitat as no take zones. The fishery manager can consider the social and economic impacts on the local fishers when considering the potential measures to apply. For the third option, it is the most appropriate way to rebuild the stock for reducing the fishing mortality. As a conservation area, it will be not complicated in the surveillance.

CONCLUSION

The L_{50} , SL_{50} , ratio of fishing to natural mortality (F/M), and SPR as biological reference points can be used to determine the stock status for painted spiny lobster. The size at maturity (L_{50}) was ~ 25% longer than the mean length at capture (SL_{50}). This indicated that most of lobsters had not matured before they were fished. Fishing mortality F was greater than natural mortality M . It means that most of mortality is caused by fishing intensity. Stock status of painted spiny lobster in Karimunjawa waters was just below the SPR limit reference point of 20%. Thus, management actions are needed if the SPR is to be increased above the limit reference point and shift the SPR of this stock towards the target reference point of 40%. Reducing the fishing intensity about 50% is required to achieve the SPR level above the LRP. Therefore, this is an appropriate management measure at national level, while continuing on current legal size with strong implementation and enforcement. A closed fishing season and no take zone for Karimunjawa are also possible options to consider by fishery manager while the socio-economic impacts of these measures need to be considered as well.

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