Population dynamics of the red bigeye (*Priacanthus macracanthus* Cuvier, 1829) (Fish: Family Priacanthidae) in Palabuhanratu Bay, Indonesia

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Abstract. The red bigeye (*Priacanthus macracanthus*) is an economically important demersal fish species which is intensively exploited in Indonesia. A study on population dynamics of *P. macracanthus* has been conducted in Palabuhanratu Bay from January to December 2016. Fish sample was collected at Palabuhanratu Fish Landing Station of which the catch was mainly derived from bottom gillnet. Total length data was presented and calculated by Excel spreadsheet and analyzed further by ELEFAN I (FiSAT II). The results showed that the size of *P. macracanthus* ranged between 5-34 cmTL, with a mode between 21-22 cmTL. The growth coefficient (K) was equal to 1.38 year^{-1} which asymptotic length (L_∞) up to 35.7 cm TL, theoretical age (t_0) -0.21 years and growth performance index (Ø') 3.25. The rate of natural mortality (M), fishing mortality (F), and accordingly total mortality (Z) was 2.14 year^{-1}, 2.51 year^{-1}, and 4.64 year^{-1}, respectively. The recruitment occurs twice a year in February/March and August/September. The rate of exploitation (E_{cur}) 0.54 on Y'/R_{cur} 0.04378 is closer to the value (E_{10}) 0,553 than (E_{50}) 0.353, indicating at fully exploited condition of the fishery. It is suggested to adopt E_{10} (economic yield) as reference point of red bigeyes's fisheries management in Bay of Palabuhanratu.

Key Words: growth parameters, mortality rate, exploitation rate, recruitment pattern, fisheries management.

Introduction. The red bigeye (*Priacanthus macracanthus*) belongs to family Priacanthidae (Froese & Pauly 2017), among an important demersal target species in capture fishery of Palabuhanratu Bay, southern Java Sea, part of Indian Ocean. This species is mainly caught by bottom gillnet, and to the lesser extent by hand line as well as incidentally collected by lift net. They inhabit coral reefs environment (Starnes 1999; Ramachandran & Varghese 2009; White et al 2013), which plays a major role in the trophic structure (mainly in coral reef ecosystem) (Powell 2000).

In Asian countries, member of *Priacanthidae* family are mainly economic important species for its high protein content. They are major elements for a variety of typical Asiatic cullinaries including noodles, fish balls, sauces and surimi products. For instance, the moontail bullseye, *Priacanthus hamrur* with 20.8% protein content is used for fish powder (Sivakami et al 2003; Safitri et al 2016). In the following of high demand and increasing price, hence, exploitation rate of those priacanthids species is considered to be high leading to the importance of studying its population dynamic.

During the last decade, studies on *P. macracanthus* population dynamics has been reported in the Southeast Asia including Java Sea, the West and East Coast of Malaysia Peninsular, Taiwan Waters, the South and East China Sea (Nugroho & Rustam 1983; Lester & Watson 1985; Joung & Chen 1992; Liu et al 1992; Liu & Cheng 1999; Oki & Tabeta 1999; Silvestre & Garces 2004). Some authors concludes that *P. macracanthus* population has already over exploited such as in Java Sea (Dwiponggo et al 1986), Malaysia Peninsular (Ahmad et al 2003), the Northern part of South China Sea (Sun & Qiu 2004), Northern Taiwan (Ju et al 2016), and Chinese Beibu Gulf (Zhang et al 2016). However, *P. macracanthus* population in Palabuhanratu Bay has never been studied for such important aspects. In fact, this area is one of the important fishing ports in Indonesia where the *P. macracanthus* and other demersal species such as moonfish (*Mene maculata*), slipmouths (*Leiognathus* spp.), trasih prawn (*Mysis* sp.), and hairtails (*Trichiurus* spp.) were landed (PPNP 2015).

In order to understand the current status and for better management of the *P. macracanthus*, *P. macracanthus* in Palabuhanratu Bay, the present study has been focused on the population dynamic of this species. In this case the present paper deals with growth, mortality, capture probability, recruitment pattern, exploitation rate, and relative yield per recruit.

Material and Method. Study area was situated in Palabuhanratu Bay, where fishing ground has been defined participatorily by local fishermen on map, where the catch are transported to the nearest fish landing site (Figure 1). Data collection was done from January to December 2016 with monthly interval. Fish sample was collected from the catch using bottom gillnet, hand line and lift net, of which selected sample was total length measured (TL) with 0.1 cm accuracy. Length data is the main prerequisite for every analysis used in this study.

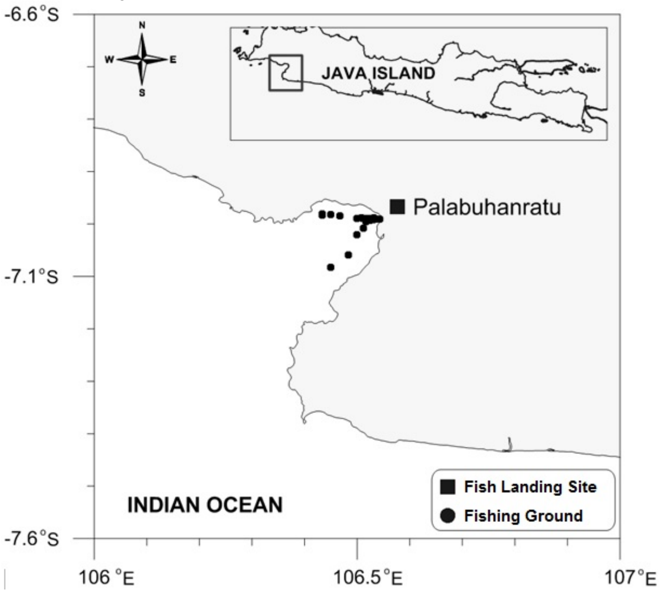

Figure 1. Fishing ground and fish landing site for *Priacanthus macracanthus* in Palabuhanratu Bay, West Java, Indian Ocean.

Growth parameters estimation. Growth coefficient (K) and asymptotic length (L_∞) was estimated using ELEFAN (Electronic Length Frequency Analysis) I model which made by FiSAT (FAO-ICLARM Stock Assessment Tools) II (Gayanilo et al 2005). First of all, the theoretical age (t_0) is determined by Pauly's formula (1983):

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

The values of length, K, and t_0 are then calculated to build von Bertalanffy's growth model (Sparre & Venema 1998) as follows:

$$L_t = L_\infty\left(1\text{-}e^{-K(t-t_0)}\right)$$

where L_t is the length at age t (cm), L_∞ is the asymptotic length (cm), K is the growth coefficient (year^{-1}) and t_0 is the theoretical age (year).

In order to explore the growth rate in *P. macracanthus* of several different stock, a growth performance index (Ø') is calculated (Pauly & Munro 1984):

$$Ø' = \text{Log}\,K + 2\,\text{Log}\,L_{\infty}$$

Mortality. Total mortality (Z) is predicted using Length-Converted Catch Curve made by FiSAT II (Gayanilo et al 2005). In estimating natural mortality rate (M), the formula from Pauly's (1983) is applied:

$$\text{Log}\,(M) = -0.0066 - 0.2795\,\text{Log}\,(L_{\infty}) + 0.6543\,\text{Log}\,(K) + 0.4634\,\text{Log}\,(T)$$

where M is the natural mortality ($year^{-1}$) and T is the average annual water temperature ($^{\circ}C$).

Having know Z and M values, fishing mortality (F) is accordingly estimated after Pauly (1983):

$$F = Z - M$$

Recruitment pattern. By projecting the length-frequency data backward onto the time axis down to zero length, using the von Bertalanffy growth equation and the estimated growth parameters, the recruitment pattern of the *P. macracanthus* was estimated. It used program package FiSAT II (Gayanilo et al 2005).

Exploitation rate. Based on a year data collection, the exploitation rate (E) is used as proxy to estimate current utilization of *P. macracanthus* (Gulland 1971):

$$E = \frac{F}{F+M} = \frac{F}{Z}$$

Relative yield per recruit (Y'/R). Relative yield per recruit (Y'/R) is estimated using Beverton and Holt Model (Sparre & Venema 1998) in FiSAT II program packages and also in Excel worksheet. From this, the values of exploitation rate at maximum relative yield per recruit (E_{max}) could be estimated. Also E_{10}, the value of E at which the marginal increase in Y'/R is 10% of its value at E=0; and E_{50}, the value of E corresponding to 50% of the relative biomass per-recruit (B'/R), were estimated. The formulae of Y'/R as follows:

$$\frac{Y'}{R} = EU^{\frac{M}{K}}\left\{1 - \left(\frac{3U}{1+m}\right) + \left(\frac{3U^2}{1+2m}\right) - \left(\frac{U^3}{1+3m}\right)\right\}$$

where $U = 1-(L_c / L_{\infty})$, m = (1-E) / (M/K) and E = F/Z

Results and Discussion

Growth parameters estimation. A total of 3,420 *P. macracanthus* individuals were collected from the catch of bottom gillnet, handline, and liftnet Palabuhanratu Bay during the year. These three fishing gears contribute to 87.7%, 11.9% and 0.3 % of total catch, respectively. Based on total length data, catch composition distributed skewedly where modus values were 21-22 cm, 23-24 cm, 19-20 cm, and 7-8 cm in range size (Figure 2).

Analyzed using TL data, growth coefficient (K) was 1.38 $year^{-1}$, with asymptotic length (L_{∞}) 35.7 cm, and theoretical age (t_0) -0.21 years (Figure 3). Based on these, growth model for *P. macracanthus* in Palabuhanratu could be formulated as $L_t = 35.7(1-e^{-1,38(t+0,21)})$ (Figure 4). Fish age of 1, 2, and 3 years old coincides with total length of 29, 34 and 35.3 cm, consequtively. A highest growth rate was found at 0-1 year with 1.82 cm $month^{-1}$ in average, followed by 1-2 years with 0.46 cm $month^{-1}$. The asymptotic length was 35.7 cm, i.e. size at maximum length is reached in 4.6 years.

In comparing growth from the different stock, it was found that growth performance index (Ø') ranged between 2.31 and 3.25, of which the highest Ø' value was obtained in Palabuhanratu Bay, indicating that *P. macracanthus* grow at fastest rate in this area (Table 1).

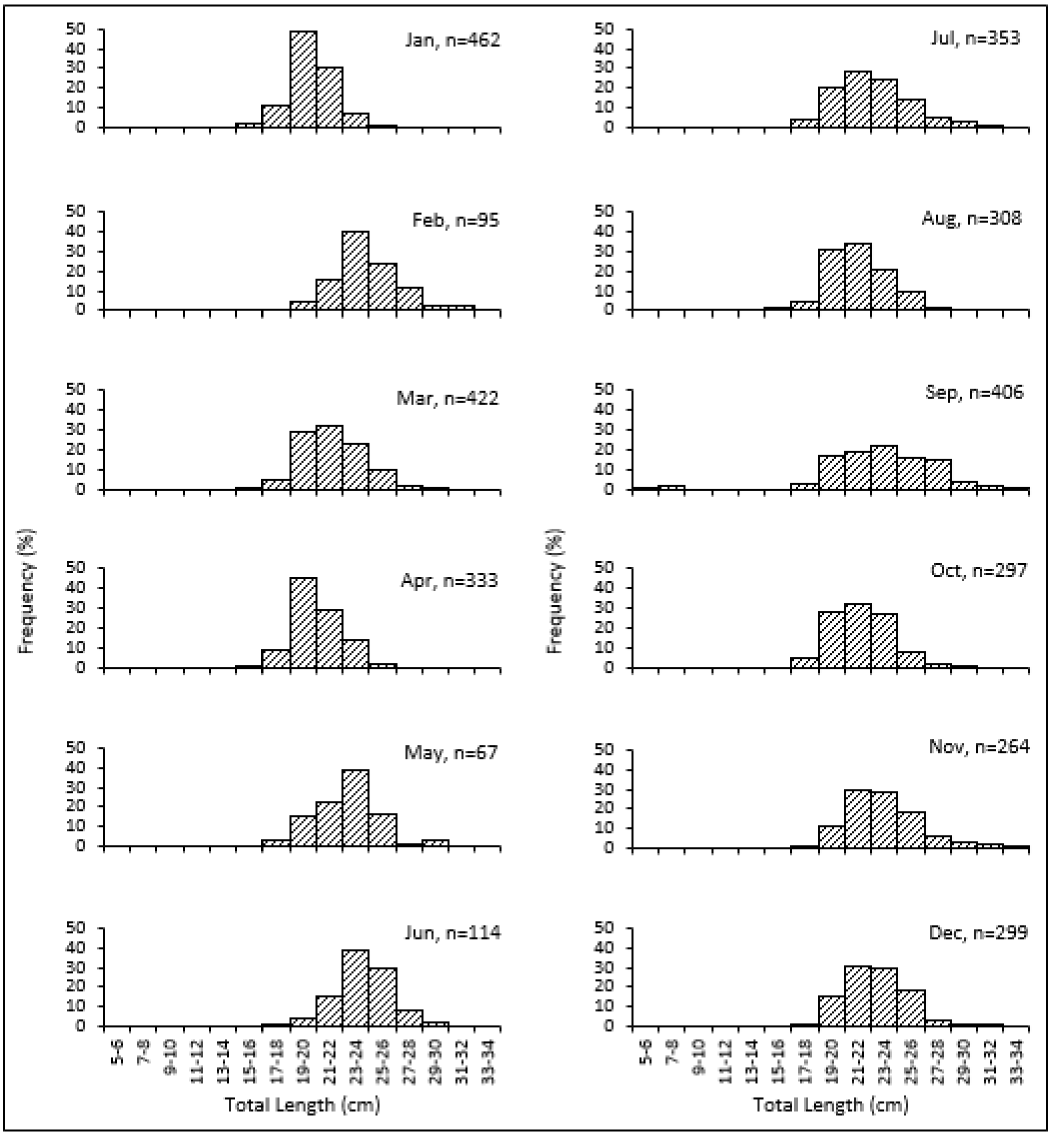

Figure 2. Length frequency distribution of *Priacanthus macracanthus* composed by catch from 3 fishing gears during research in Palabuhanratu Bay.

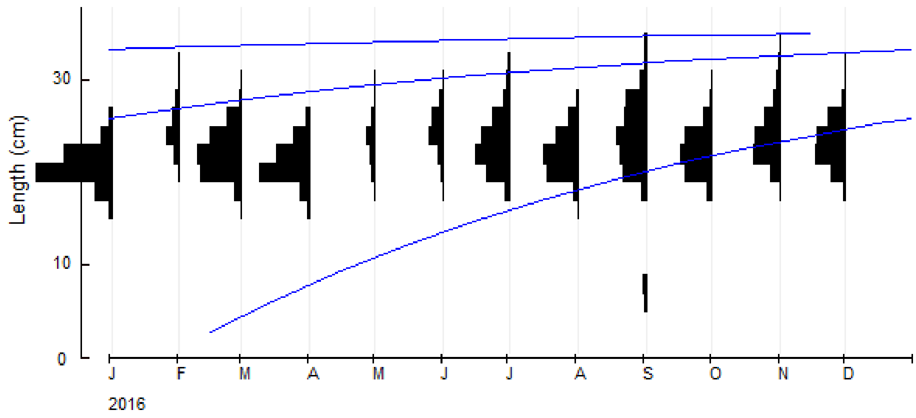

Figure 3. The growth model of *Priacanthus macracanthus* in Palabuhanratu Bay.

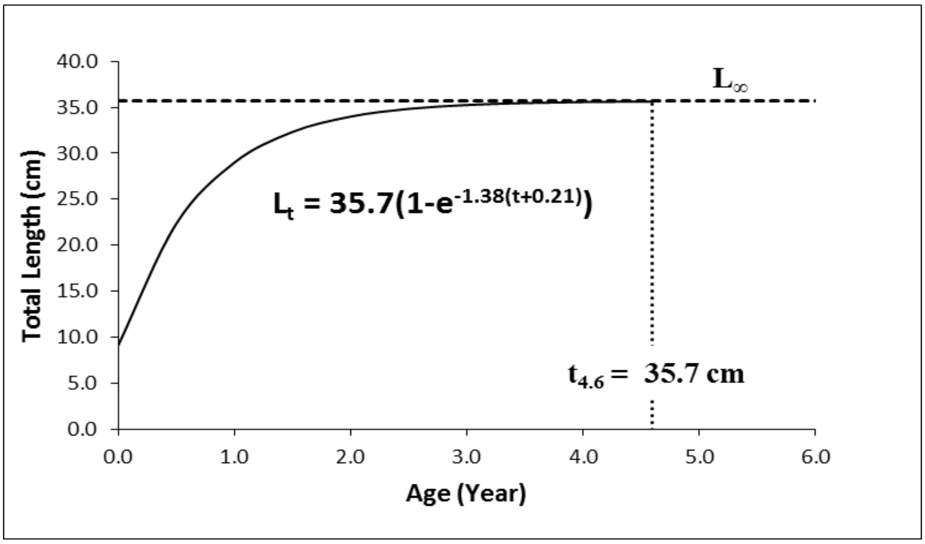

Figure 4. Length and ages relationship curve of *Priacanthus macracanthus* in Palabuhanratu Bay.

Table 1 shows the spatial variability of K ranged between 0.08-1.38 year^{-1}, of which K's *P. macracanthus* population in Palabuhanratu Bay was the highest. A slight differ in growth coefficient occurred with the stock in similar larger sea ecosystem. The previous reports (Sparre & Venema 1998; Pardo et al 2013) pointed out that K≥0.5 of *P. macracanthus* was categorized into rapid growth species. This was the case for population in Palabuhanratu Bay, Java Sea, South China Sea, and Indian Ocean. A slower growth was found in Taiwan waters. Accordingly, fastest growth rate is associated with smaller L_∞ (length infinity), meaning that *P. macracanthus* belongs to short live fish, of which fish reaches its maximum size of 35.7 cm for 4.6 years which constituted by 20 cm, 5 cm and 1.3 cm of annual growth rate. In comparison, in Taiwan water, the same species reached the length infinity at the age of 6 with the estimated combined growth rate of male and female fish during the first, second and third year respectively 10.7 cm, 4.2 cm, and 3.75 (Joung & Chen 1992). In general, in addition to its dependence on behavior, fish growth is highly dependent on environmental factors, especially the food availability, optimum temperatures and genetic factors (Magnussen 2007). The implication is that there may be major differences between waters and interestingly, some areas (ecosystems) are more productive than others. Gjedrem (2000) found that 70-80% of fish growth in temperate regions is determined by environmental factors, while the rests are thought to be influenced by genetic factors.

P. macracanthus in waters adjacent to the Indian Ocean (including Palabuhanratu Bay) have a higher Ø' value than those found in other areas, as presented in Table 1. *P. macracanthus* in the Java Sea and South China Sea have a lower Ø' value than those observed in the Indian Ocean but higher than in the waters of Taiwan. Specific ecological factors in different areas such as population density, water environmental temperature and prey density may cause variations in the value of growth parameters (Ju et al 2016). Differences in growth parameters and growth performance indexes between different regions can be attributed to differences in species-to-species composition and method of analysis (Mehanna et al 2013).

Mortality. Natural mortality rate (M) of *P. macracanthus* in Palabuhanratu Bay was 2.14 year^{-1} at annual average temperature 29^{o}C. Fishing mortality rate (F) was 2.51 year^{-1} and accordingly total mortality rate (Z) 4.64 year^{-1} (Figure 5).

Table 1

Estimation of growth parameter of the *Priacanthus macracanthus* stock in some areas

Age Character	*Location*	*Year of sampling*	*K*	*L_∞*	*t_0*	*ϕ'*	*Source*
TL-F	Palabuhanratu Bay (Indian Ocean)	2016	1.38	35.7	-0.21	3.25*	Present study
LF	Waters off the west coast of Peninsular Malaysia (Indian Ocean)	1997	1.30	37.0	-	3.25*	(Ahmad et al 2003)
FL-F	North Coast of Java	1980s	1.36	26.7	-	2.99	(Nugroho & Rustam 1983)
TL-F	Java Sea	1978-1979 1977-1978	1.15 1.30	23 23.75	-	2.78* 2.87*	(Dwiponggo et al 1986)
SL-F, O	North-central Taiwan Strait	2006	0.4647	27.379	-0.9140	2.54*	(Ju et al 2016)
LF	Waters off Northeastern Taiwan	1997 1996 1995 1994	0.118 0.119 0.119 0.139	46.8 45.4 46.5 42.4	-1.26 -1.41 -1.37 -1.17	2.41* 2.39* 2.41* 2.40*	(Liu & Cheng 1999)
S, O, V	Surrounding water of Guei-Shan Island, Taiwan	1981-1982	0.113 (M) 0.088 (F)	48.2 (M) 62 (F)	-1.335 (M) -1.05 (F)	2.42* 2.53*	(Joung & Chen 1992)
S	Tungkang waters. Southwestern Taiwan	1981-1982	0.128 (M) 0.136 (F)	40.168 (M) 44.107 (F)	-2.632 (M) -2.900 (F)	2.31* 2.42*	(Liu et al 1992)
LF	Beibu Gulf, (South China Sea)	1997-1999 and 2011-2015	0.70	29.1	-	2.77*	(Zhang et al 2016)
LF	Waters off the east coast of Peninsular Malaysia (South China Sea)	1998	0.56	39.0	-	2.93*	(Ahmad et al 2003)
M	East China Sea	1995-1998	-	40.22 (M) 52.88 (F)	-	-	(Oki & Tabeta 1999)
LF	Brunei Darussalam (South China Sea)	1989-1990	0.95	29.0	-	2.90	(Silvestre & Garces 2004)
LF	North continental shelf of South China Sea	1990s and 1960s	0.60	31.5	-0.44	2.77*	(Sun & Qiu 2004)
FL-F	South China Sea	1965-1967 (all) Spring Autumn	0.7 1.0 0.7	32 28 34	1.0 1.1 2.1	2.86* 2.89* 2.91*	(Lester & Watson 1985)

Note: TL-F – total length frequency; SL-F – standard length frequency; FL-F – fork length frequency; LF – length frequency; M - mesopterygoid; S,O,V – scale, otolith, vertebrae; (M) – male; (F) - female; * - growth performance index (ϕ') were estimated in this study.

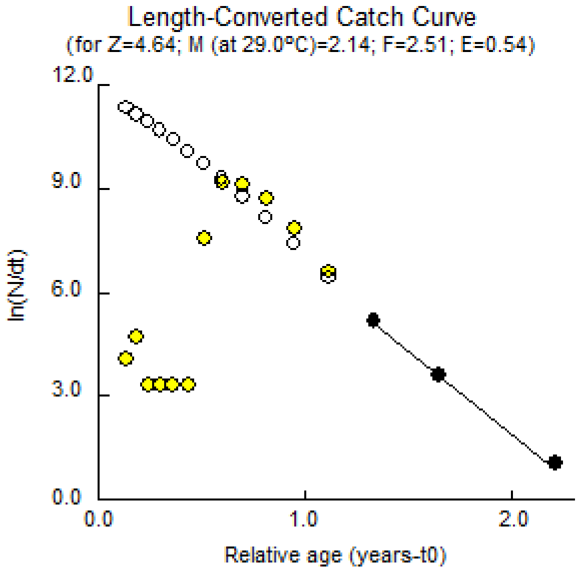

Figure 5. Length converted catch curve of *Priacanthus macracanthus* in Palabuhanratu Bay. The black circles depicted an exploited group suspected to be >1 year old.

The total mortality rate (Z) of *P. macracanthus* in the Indian Ocean, Java Sea, Taiwan Waters, and China Sea ranged from 0.88 to 8.45 year^{-1} (Table 2).

Table 2

Estimation of exploitation and mortality rate of *Priacanthus macracanthus* in some areas

Location	*Year of sampling*	*M*	*F*	*Z*	*E*	*Source*
Palabuhanratu Bay (Indian Ocean)	2016	2.14	2.51	4.64	0.54	Present study
Waters of the west coast of Peninsular Malaysia (Indian Ocean)	1997	2.06	6.39	8.45	0.76	(Ahmad et al 2003)
Java Sea	1978-1979 1977-1978	2.13 2.28	2.07 4.10	4.20 6.38	0.49 0.64	(Dwiponggo et al 1986)
North-central Taiwan Strait	2006	1.0218	1.0875	2.1093	0.5156	(Ju et al 2016)
Waters of Northeastern Taiwan	1997 1996 1995 1994	0.33 0.33 0.33 0.37	1.24 1.64 1.03 0.51	1.56 1.97 1.36 0.88	-	(Liu & Cheng 1999)
Beibu Gulf (South China Sea)	1997-1999 and 2011-2015	1.38	-	4.57	0.70	(Zhang et al 2016)
Waters of the east coast of Peninsular Malaysia (South China Sea)	1998	1.17	5.43	6.60	0.82	(Ahmad et al 2003)
Brunei Darussalam (South China Sea)	1989-1990	1.74	0.34	2.08	0.16	(Silvestre & Garces 2004)
North continental shelf of South China Sea	1990s and 1960s	1.07	1.87	2.94	0.64	(Sun & Qiu 2004)
South China Sea	1967 1966 1965	1.27 1.27 1.27	0.65 0.37 1.05	1.92 1.64 2.32	0.34 0.23 0.45	(Lester & Watson 1985)

Natural mortality rate (M) was around >0.5 in all areas except in the waters off northeastern Taiwan. The high value of M is due to the rapid growth and short life of the P. macracanthus. Differences in M values closely related to life history parameters such as growth rate, length at first maturity, reproduction and maximum age (Vetter 1988). Sparre & Venema (1998) suggested that predation, disease, environmental conditions, stress associated with ecosystems and others can also be determinant factors. The fishing mortality rate (F) during the study period was higher than the natural mortality rate (M). This indicates that mortality of P. macracanthus in Palabuhanratu Bay is more influenced by catch, factor of the fisherman. On the other hand, fishing mortality is directly proportional to fishing effort and catch ability, implying that the increase in deaths from capture will be followed by an increase in fishing effort (Atmaja & Nugroho 2004).

Recruitment pattern. Recruitment pattern was apparently occured throughout the year with two peaks in February-March and August-September. The recruitment level was presumably higher in September compared to March, i.e. 14.66% compared to 11.56% (Figure 6).

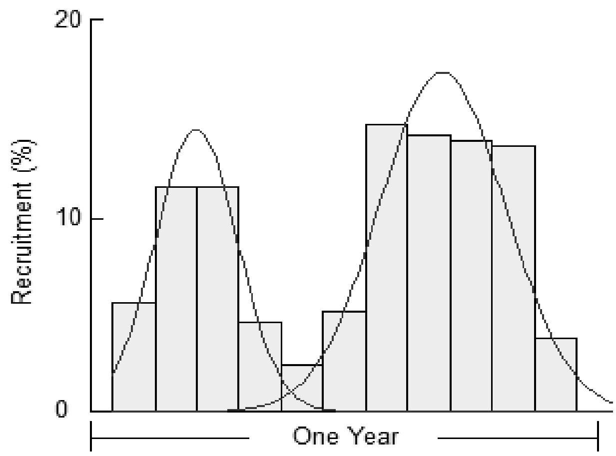

Figure 6. Recruitment pattern of *Priacanthus macracanthus* in Palabuhanratu Bay.

P. macracanthus in Palabuhanratu Bay has presumably two recruitment modes (peak and lean recruitment). The major peak occurs during east monsoon season in August/September and the minor ones during west monsoon season in February/March. It was characterized by the finding of many small samples on the peaks and it was assessed that spawning season occurs in the months before the peaks appear. The presence of two recruitment peaks in this study is similar to those reported in the Java Sea (Dwiponggo et al 1986). The occurrence of bimodal recruitment peaks may be related to the rainy season in a region (Pauly & Navaluna 1983; Ingles & Pauly 1984).

Exploitation rate (E) and relative yield per recruit (Y'/R). The Beverton and Holt's Model finding (Figure 7) shows that sustainable yields is achieved at which exploitation rate 0.35, 0.68, and 0.53 for sustainable yield optimum target (E_{50}), maximum sustainable yield (E_{max}), and economic yield (E_{10}), successively. After mortality rate being calculated, the exploitation rate (E_{cur}) was 0.54. As it is shown by Figure 7 below, the current relative yield per recruit (Y'/R_{cur}) 0.04378 which is just 0.0033 less than Y'/R_{max}. The relative yield per recruit (Y'/R) increases steadily until the exploitation rate reaches 0.68 and subsequently decreases with increasing of exploitation.

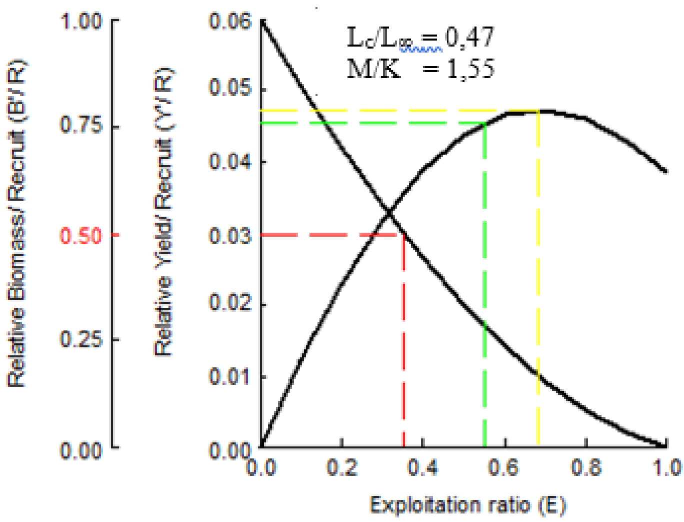

Figure 7. E values of the *Priacanthus macracanthus* by Y'/R Beverton and Holt E_{10}=0.55 (green), E_{50}=0.35 (red), E_{max}=0.68 (yellow).

The exploitation rate (E) in several areas in Table 2 generally indicates that the species has been over exploited. The current exploitation rate (E_{cur}) of *P. macracanthus* in Palabuhanratu Bay is 0.54 between E_{50} (0.353) with E_{10} (0,553), but closer to E_{10} (Figure 7). The E_{cur} score 0.54 is higher than the optimum (Eopt≈0.5 as in Gulland (1971) and Eopt≈0.4 as in Pauly(1987)). This indicates that the stock of *P. macracanthus* in Palabuhanratu Bay is fully exploited, that means the utilization must be carefully managed where the unit of fishing effort should not be added.

The current exploitation rate (E_{cur}) 0.54 results in Y'/R_{cur} 0.04378, only 0.0033 less than Y'/R_{max} (Figure 7). By increasing the current exploitation from 0.54 to E_{10} = 0.553 (2.4% increase in fishing effort) then Y'/R_{cur} will increase from 0.04378 to 0.04426 (1.1% increase). However, if we consider the reference point option E_{50} = 0.353 (the exploitation rate) is in which the biomass per recruit is 50% of the virgin stock biomass value at E = 0, then the current exploitation should be reduced by 34.6%, leading to a decrease in Y'/R by 23.5%. According to the three options of the biological reference point, it is more optimal to adopt the value obtained from E_{10} (0,553) as the target reference point of *P. macracanthus*'s fisheries management in Palabuhanratu Bay.

Conclusions. The *P. macracanthus* in Palabuhanratu Bay can grow up to asymptotic length (L_∞) = 35.7 cm, with growth coefficient (K) of 1.38 $year^{-1}$ and the estimated maximum age of 4.6 years. The natural (M), fishing (F) and total (Z) mortality rates of the *P. macracanthus* were 2.14 $year^{-1}$, 2.51 $year^{-1}$, and 4.64 $year^{-1}$, respectively. The recruitment pattern showed two peaks, in February/March and August/September. The exploitation rate (E) of *P. macracanthus* in Palabuhanratu Bay has reached 0.54. Therefore, it might recommended that the value obtained from E_{10} (0,553) can be used as the target reference point for its management purposes.

Acknowledgements. The authors would like to thank the Head of Indonesia Research Institute for Marine Fisheries, Dr. Fayakun Satria, M.App.Sc and person in charge (PIC) for Fisheries Management Area (FMA) 573 in 2016, Anthony Sisco Panggabean, M.Si., for providing the facilities mainly in the beginning of the research. Also, to Ilham, Ph.D., Kadarusman, Ph.D., Mr. Thomas Hidayat and Mr. Muhammad Albab, for their technical help. Our sincere thanks for the valuable discussions to all of them.

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Received: 02 September 2017. Accepted: 03 October 2017. Published online: 14 October 2017.
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How to cite this article:
Jabbar M. A., Kamal M. M., Boer M., Suman A., Suyasa I. N., Nurdin E., 2017 Population dynamics of the red bigeye (*Priacanthus macracanthus* Cuvier, 1829) (Fish: Family Priacanthidae) in Palabuhanratu Bay, Indonesia. AACL Bioflux 10(5):1198-1209.