Growth, mortality and exploitation rate of Plectropomus maculatus and P. oligocanthus (Groupers, Serranidae) on Cenderawasih Bay National Park, Indonesia

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Growth, mortality and exploitation rate of *Plectropomus maculatus* and *P. oligocanthus* (Groupers, Serranidae) on Cenderawasih Bay National Park, Indonesia

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ABSTRACT

The present study aims to determine whether the rate of exploitation for grouper stocks is in accordance with their biological attributes (growth and mortality). The results showed that *Plectropomus maculatus* and *P. oligocanthus* taken from Cenderawasih Bay National Park (CBNP) were in the size category of actively productive spawning phase. *P. maculatus* could reach a maximum length ($L\infty$) of 484.05 mm and growth rate (K) of 0.34 per year. *P. oligocanthus* was capable of reaching $L\infty$ of 481.95 mm and K of 0.66 per year. Estimation of total mortality (Z) for *P. maculatus* was 0.988 and *P Oligocanthus* was 2.056. In addition, fishing mortality (F) for *P. maculatus* and *P. oligocanthus* were 0.564 and 0.399 respectively. Based on the estimated mortality values, it was estimated that the exploitation rate (E) of *P. maculatus* was 0.570, and *P. oligocanthus* was 0.681. Management settings for *P. maculatus* and *P. oligocanthus* can be separately based on the species so that the fishing can be sustainable. The introduction of minimum size limits for fish caught can be applied as a protection from hook and hand line fishing activities in CBNP.

Introduction

The high demand for groupers has led to an increase in the sale value of the fish and has brought about substantially high profits for trading business of this commodities. As consequently, this has been pushing an increase in fishing intensity for groupers and become primary fishing target of fishery in coral reef areas. Groupers are caught in the wild by traditional fishermen using hook and lines, and fish traps. High fishing intensity brings consequences to grouper sustainability. That is, grouper population experiences high fishing pressure. In some regions of Indonesia, it has been reported that total catch of groupers has decreased and the stock has been overexploited (Sadovy, 2005).

Fishing continuously on large sizes of fish or spawning fish stock could reduce the genetic characteristics and could change fish shape and behavior. The genetic diversity of the population would be likely affected thereby reducing its resilience in confronting with environmental change and variability (Vrijenhoek, 1998). Hurtado et al. (2005) and Nelson (2007) note that populations experiencing high exploitation is characterized by a change in the fish size composition, which is dominated by smaller sizes. This would significantly affect reproductive outcome since small fish size has less production potential than the large fish size. Large-scale of exploitation could cause structural changes in the fish. Sanchez (2000) suggests that in overfishing state of fish stock, the fish population are dominated by small sizes or young fish since fishermen tend to catch large size of fish.

Aside from fishing activities, the production of groupers in nature is strongly influenced by geomorphology and hydrographic characteristics of water; these affect the overall productivity and spawning aggregation (Coleman et al., 2011). Fish spawning areas of groupers, nowadays, become the target fishing areas by fishermen in order to increase their catch per unit effort. Although fisheries production increases in short term, such fishing practices in long term are likely to lessen fishery production as a result of the damage of spawning habitat, the decrease in reproductive output and the changes in sex ratio (Heyman et al., 2005; Koenig et al., 2000, 2005; Sadovy and Domeier, 2005). To protect grouper from

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overfishing and extinction, the International Union for the Conservation of Nature and Natural Resources (IUCN) Red List of Threatened Species 2015 declared several species of groupers such as *Plectropomus leopardus*, *P. maculatus*) and *P. oligocanthus* as endangered species.

Groupers known as reef fish are the main component of reef fisheries in Cenderawasih Bay National Park (CBNP) (Bawole et al., 2014). There are three species in CBNP, *P. leopardus*, *P. maculatus* and *P. oligocanthus*, that are marketed commercially and are purchased by a commercial company. *P. leopardus* is the main target species for commercial fishermen (Bawole et al., 2017). However, other reef fish species known to be the fishing target are of *P. maculatus* and *P. oligocanthus*. These species are managed as a single species. Although as a group of high-economic species, little information is known about the two species. Numerous studies conducted on several places concerning the parameter of grouper growth, e.g. northwest coast of Africa (Burtos et al., 2009), west coast of Florida (Carlason et al., 2008), western Mediterranean Sea (Renones et al., 2001) and eastern Pacific (Craig et al., 1999), but no studies of *P. maculatus* and *P. oligocanthus* in the CBNP region. Information on the growth parameters of *P. maculatus* in the Great Barrier Reef was provided by Ferreira and Russ (1992) but there is no information about the mortality and exploitation aspects. The CBNP area has been a potential commercial fishing area of the grouper species since 2010. Yet, there is no specific-biological information available for the species in the fishing areas that could be used in assessing whether different species have the same response to fishing pressure. Therefore, this study aimed to determine whether the rate of exploitation is in accordance with the biological attributes (growth and mortality) of groupers in CBNP. The research is needed for the management of reef fish as a single species group and necessary management actions for the species in the fishing areas.

Material and method

The research location is situated in waters around Napan Yaur, a grouper fishing areas. Fishing area is inside CBNP. Geographically the study site is located at position of 02°54′43.00 S and 134°49′57.00 E (Fig. 1). In the area is also found coral reef ecosystem which is in good condition, in particularly in the west, north and east of Yaur Napan water. Because of the good condition of coral, this area is designated as one of core zone in CBNP area. As a core zone, Napan Yaur water functions as protection area for a variety of organisms that lives in association with coral reef.

This study was conducted in April and May 2016. Fish samples were collected from fishermen and local traders, who buy living groupers from local fishermen every day started from 4 April 2016 to 2 May 2016. Fishermen fished by using small boats (canoe, outboard engine) and handlining. The presence of local traders made fishing activities for the grouper become more intensive. There were 10 fishing fleets with the frequency of fishing 3–4 times per week during the study period. The groupers were recorded by species and number of individuals. Each individual was measured its total length by using a caliper with an accuracy of 1.0 mm. Then, it was weighed using hanging scales with accuracy of 5 g.

Analysis of growth models used von Bertalanffy growth model where fish length is a function of age (Pilling et al., 1999; Jennings et al., 2001). This growth model has become one of the bases in fisheries biology since it uses as a sub model in a number of more complicated models to explain various fish population dynamics (Sparre and Venema, 1998). The mathematical model of von Bertallanffy equation is:

$$L(t) = L_\infty(1 - e^{-k(t-to)})$$

where:

- $L(t)$ = Length at time t
- $L\infty$ = Asymptotic length
- K = Growth coefficient
- t_o = Theoretical age at length equals to zero.

The values of $L\infty$ and K were calculated using ELEFAN in FiSAT II package program. The value of t_O was calculated using empirical equation of Pauly (1984) as follows:

$$Log(-t_o) = -0.3922 - 0.2752 Log L_\infty - 1.038 Log K$$

The relative age at a variety of lengths was estimated by using derivative of von Bertalanffy formula (Sparre and Venema, 1998), as follows:

$$t = t_0 \frac{1}{K}.Ln\frac{(1 - Lt)}{L_\infty}$$

The estimation of total mortality rate used length frequency distribution data which was applied to Beverton-Holt method in which shows the functional relationship between Z and L (Sparre and Venema, 1998). The formula is as follows:

$$Z = K\frac{L_\infty - L}{L - L_c}$$

where:

- Z = Rate of total mortality
- L_∞ = Asymptotic length
- K = Growth coefficient
- L = Average length of the fish (mm)
- L_c = The smallest length of fish caught (mm)

Natural mortality of fish could occur due to predation, disease, age and environmental factors. Pauly (1984) suggests relationship between the natural mortality and water temperatures. An increase in water temperature will lead to the increase in natural mortality of fish. The natural mortality (M) can be estimated by using Pauly empirical equation (Pauly, 1984) as follows:

$$Log\ M = -0.0066 - 0.279 log(L_\infty) + 0.6543 log(K) + 0.4634 log(T)$$

where:

- M = Natural mortality
- L_∞ = Asymptotic length
- K = Growth coefficient
- T = Average surface temperature of the water (°C)

Pauly (1984) state that the total mortality rate is summation of natural mortality and fishing mortality (F) or written as:

$$F = Z - M$$

Rate of exploitation (E) is ratio of fishing mortality (F) and total mortality (Z) (Pauly, 1984), and written as follows:

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

Gulland (1983) states that the optimal exploitation for a fish stock occurs when fishing mortality (F) is proportional to the natural mortality:

$$F_{optimum} = M$$

Thus, the optimal rate of exploitation ($E_{optimum}$) is 0.5. Resource is said to suffer from overexploitation (overfishing) if the rate of exploitation is greater than 0.5.

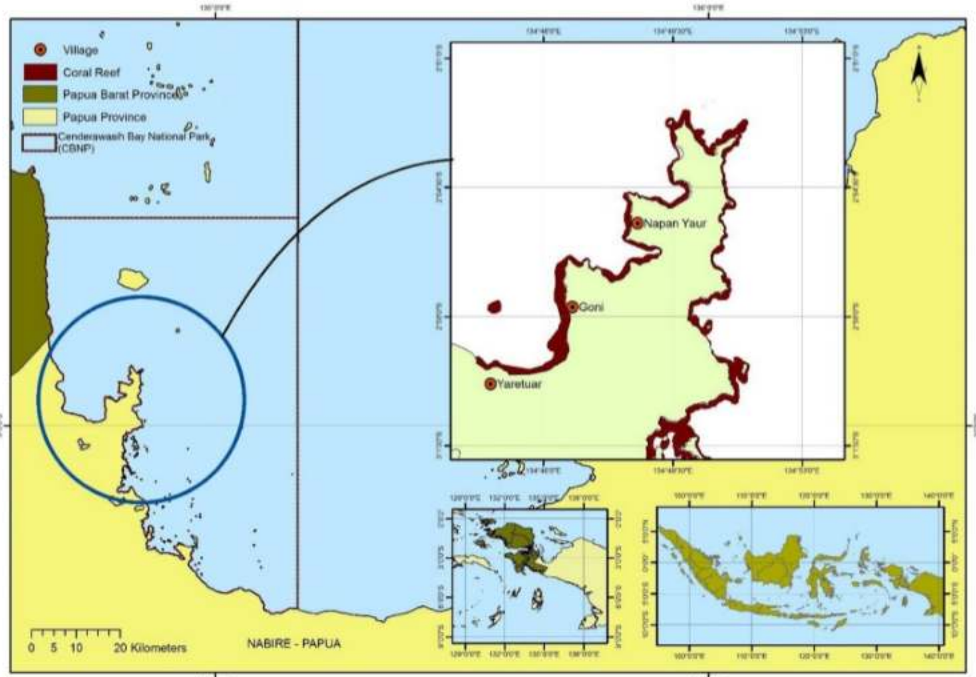

Fig. 1. Map of the study area in the Napan Yaur water, Cenderawasih Bay National Park, Papua, Indonesia.

Results and discussion

Length and weight

P. maculatus had total length range between 230 and 485 mm, and weight between 180 and 615 g. *P. oligocanthus* had total length range between 235 and 485 mm, and weight between 200 and 775 g (Table 1). The highest frequency distribution of *P. maculatus* was in length range of the 298–331 mm (44 individuals) and the 264–297 mm (43 individuals) (Fig. 2, upper). For *P. oligocanthus*, the highest frequency distribution (62 individuals) was in length range of 268–300 mm with (Fig. 2, lower).

The results of measurements in Table 1 dan Fig. 2 when compared to the data of biological characteristics of the two species published in FishBase.org (Table 2), the groupers caught by fishermen in Napan Yaur water were in the category of actively spawning phase. The average length of *P. maculatus* was 278 mm and *P. oligochantus* was 275 mm which were within the range of spawning size of the two species. This means that the fish caught in the study had been spawning even though still in the early stages of spawning ages. Thus, the management efforts should be made to ensure the spawning process can take place better (i.e. fish spawn more than once). Settings minimum legal size of larger than 350 mm, as applied in the Coastal Waters of Africa in controlling catches of groupers (Burtos et al., 2009), can be adopted for management of grouper fishery the CBNP. Thus, it would allow fish to spawn effectively and guarantee the successful reproduction of fish in generating new fish generation (recruitment).

Table 1
Length and weight of groupers taken from Napan Yaur waters, Cenderawasih Bay National Park.

Species	Number	Total length (mm)		Weight (g)	
		Min	Max	Min	Max
P. maculatus	98	230	485	180	615
P. oligocanthus	104	235	485	200	775

Growth model

The results of growth parameter analysis of *P. maculatus* and *P. oligocanthus* are presented in Table 3. *P. maculatus* could reach an asymptotic length (L_∞) of 484.05 mm, with an average growth rate (K) of 0.34 per year and the age of t_0 at −0.27 years. *P.oligocanthus* could reach an asymptotic length of 481.95 mm, with an average growth rate of 0.66 per year and the age of t_0 at 0.11 years. The asymptotic length of the two species is smaller than that of the Seranide group found in several other research sites in the world (Table 3). This may because most the fishermen in CBNP used small hook sizes (fishing lines with hook numbers of 9–15). Handling with the hook sizes is likely to catch groupers of sizes less than 400 mm.

P. maculatus and *P. oligochantus* in this study had a faster growth. Food availability and favorable oceanographic environmental conditions in CBNP supported the rapid growth of grouper fish (Bawole et al., 2014) since fish growth influences by physiological and environmental conditions such as temperature, pH, salinity and water geography (Jennings et al., 2001).

By knowing the parameter values of K, L_∞, and t_0, then Lt can be estimated. The growth curves for the two grouper species followed the relationship of $Lt = 484.05\ [1 - e^{-0.34(t-(-0.27))}]$ for *P. maculatus*

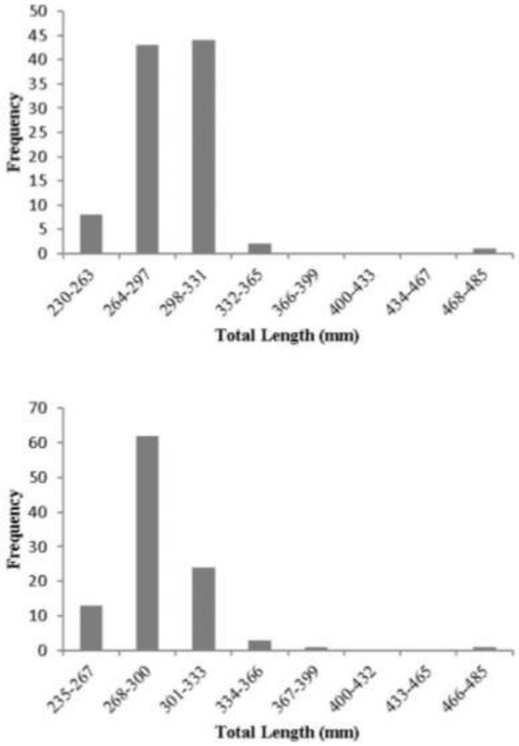

Fig. 2. Total length distribution frequency of *P. maculatus* (upper) and *P. oligocanthus* (lower) taken from Napan Yaur water, Cenderawasih National Marine Park.

Table 2
Size of length at first maturity, length range at active spawning, and mean length of catches.

Species	First Mature gonads (mm)*	Length range at active spawning (mm)*	The mean length of catches (mm)
P. maculatus	210	250–410	278
P. oligocanthus	200	210–420	275

* *Source:* Fasebase.org (2014)

and $Lt = 481.95\ [1 - e^{-0.66\ (t-(-0.11))}]$ for *P. oligocanthus*. These growth curves can be plotted as shown in Figs. 3 and 4. The growth curves show that length increases linearly with time at young ages, whereas growth slows down as the fish approach their asymptotic length. This is a general phenomenon for fish growth where the rapid growth occurs at young ages. On other hand, old fish grow slower because most the energy obtained from food are used for maintenance of the body and movement.

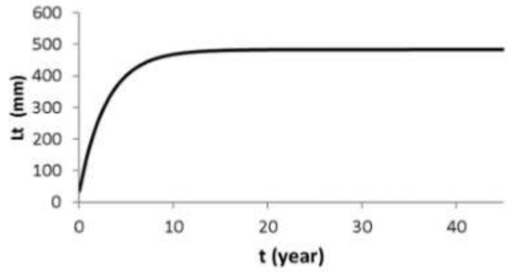

Fig. 3. The growth curve of *Plectropomus maculatus* taken from Napan Yaur water, Cenderawasih National Marine Park.

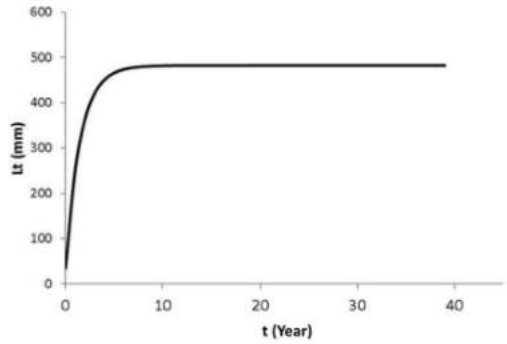

Fig. 4. Growth curve of *Plectropomus oligocanthus* taken from Napan Yaur water, Cenderawasih National Marine Park.

Mortality and exploitation rates

Total mortality rate (Z) was estimated by using Beverton-Holt method (Sparre and Venema, 1998), which found Z of 0.988 for *P. maculatus* and Z of 2.056 for *P. oligocanthus*. The value of natural mortality rate (M) obtained using empirical equation of Pauly (1984), by applying the estimated value of K = 0.34, $L\infty$ = 484.05 mm for *P. maculatus* and value of K = 0.66, $L\infty$ = 481.95 mm for *P. oligocanthus*. The average water temperature (T) in the CBNP was 31 °C (Bawole, 2012). Then, it was obtained the estimated Z of 0.988 and M of 0.425 for *P. maculatus*, and estimated Z of 2.056 and M of 0.656 for *P. oligocanthus*). The value of fishing mortality rate (F) is obtained by subtracting Z by M. It was obtained that F values for *P. maculatus* and *P. oligocanthus* were 0.564 and 0.399 respectively. The value of the exploitation rate (E) is obtained by dividing F by Z. The estimated of E was 0.570 for *P. maculatus* and 0.681 for *P. oligocanthus*. The comparison of the estimated values of the fourth parameters with other studies are presented in Table 4.

Table 3
Growth parameters some *Plectropomus*.

Species	Parameters			References
	L_∞ (mm)	K (year^{-1})	t_0	
P. maculatus	484.05	0.34	−0.27	Current Research Current Research
P. oligocanthus	481.95	0.66	−0.11	
P. maculatus	600	0.21	−0.95	Great Barrier Reef (Ferreira and Russ, 1992)
P. leopardus	75.70	0.21	−0.24	Indonesia (Prasetya 2010)
P. leopardus	92.40	0.75	−0.15	Indonesia (Landu 2013)

Table 4
Total mortality rate (Z), natural mortality rate (M), fishing mortality rate (F), and optimal exploitation rate (E) of *P. maculatus* and *P. oligocanthus*.

Species	Parameters ($year^{-1}$)				References
	Total mortality rate (Z)	Natural mortality rate (M)	Fishing mortality rate (F)	The rate of exploitation (E)	
P. maculatus	0.988	0.425	0.564	0.570	Current ResearchCurrent Research
P. oligocanthus	2.056	0.656	1.399	0.681	
P. maculatus	0.569	–	–	–	Great Barrier Reef (Ferreira and Russ, 1992)
P. leopardus	1.01	0.49	0.52	0.52	Lasongko, Indonesia (Prasetya, 2010)
	1.90	0.60	1.30	0.70	Kolaka, Buton, Indonesia (Landu, 2013)
	1.60	0.75	0.86	0.52	Cenderawasih Bay National Park, Indonesia (Bawole et al., 2017)

Fishing mortality rates for *P. maculatus* and *P. oligocanthus* were significantly larger than the rates of natural mortality. This indicated that the mortality of the groupers in CBNP largely was caused by fishing activities. This was the same as the mortality of *P. leopardus* as reported by several studies research in some places in Indonesua, for example in Southeast Sulawesih (Landu, 2013; Prasetya, 2010) and CBNP (Bawole et al., 2017). Furthermore, low natural mortality rate and high fishing mortality may indicate the occurrence of growth overfishing, in which more young fish were caught than old fish (Sparre and Venema, 1998). The high fishing mortality of the two species might be related to the increase in fishing activities in the traditional fishing zones. In addition, there were still fishing activities in the protected zones (core zones) as a result of ineffective monitoring and surveillance by the CBNP authority. Therefore, controlling and surveillance on fishing activities including restriction on the minimum fish size of the groupers by taken fishermen in the traditional fishing zones as well as in the protected zones should be improved.

The rate of exploitation of 0.57 for *P. maculatus* and E of 0.68 for *P. oligocanthus* indicated that the exploitation for the groupers was higher than the optimum exploitation level. Gulland (1983) suggests the optimum rate of exploitation of a resource is 0.5. Therefore, precautionary management approaches are necessary by controlling and restricting the number of fishing fleets targeting groupers to maintain the sustainability of the fish stock in CBNP.

Concern and management directions

High demand on the target fish species and the particular interval fish size has contributed to the increase in fishing pressure on the species. This causes the symptom to capture more fish. Biologically, most groupers grow slowly and are known to be very vulnerable to fishing. Most of catch consists of young fish and high market value. As such type of fish is very popular with consumers. Furthermore, several species of groupers with high market values are often found in low densities in reef waters. Unfortunately, the species are now being fishing targeted by fishermen. Species such as *P. maculatus* and *P. oligocanthus* have been included in the IUCN Red List due to the potential harmful impact of trafficking of live groupers (Hudson and Mace, 1996). The decline in grouper stocks in the wild as consequence of trade live groupers has been reported, such as in Palau and Papua New Guinea (Johannes and Reipen, 1995) and in some other spawning areas (Heyman et al., 2005; Sadovy and Domeier, 2005). In many cases, the spawning areas (where many of grouper individuals aggregate for spawning), become specific targets of fishing activities and has resulted in degradation number of reproductive individuals.

In anticipation of ongoing development changes and the dynamics of reef fish utilization, especially grouper species, management efforts are needed to achieve sustainable reef fisheries (Bawole et al., 2013). Management activities can be done by applying management of entry (input and output controls). Control on fishing inputs can be done by regulating fishing efforts (i.e. number of fishing boats, type of fishing auxiliary, number and specification of fishing gears, number of fishing days, and fishing boat propulsion). In addition, output control can be performed by setting the maximum quota for sustainable fishing and the minimum legal size of fish caught. Also, it is suggested to set minimum legal size of fish groupers taken from CBNP to be larger than 400 mm or larger than 700 grams (Ananta et al., 2016). This can be achieved when the handlining fishermen who targeting groupers use hook size of number 6 or 7.

Control of grouper fish demand can also be applied to the granting of business permits to local collectors since there is tendency of increase in fishing pressure to meet the demand of grouper fish market. Stakeholders in CBNP (Bawole et al., 2011; Bawole, 2011) can form a community economic development path that begins with an environmental conservation approach. This serves as an effective buffer for extractive economic shifts to conservation economies.

Conclusion

P. maculatus was substantially different from *P. oligocanthus* in aspects of growth, mortality and exploitation (fishing). Although it was difficult to predict fish response to fishing activities, *P. oligocanthus* was more vulnerable to being caught by fishermen than *P. maculatus*. The size of the captured *P. oligocanthus* was smaller and but it was larger in quantities. Management setting of *P. maculatus* and *P. oligocanthus* may be separate or species by species so that the fishery can be sustainable. The introduction of the minimum legal size of captured fish can be applied as a protective measure for the highly dominant hook and hand lining activities in CBNP.

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