The performance of stock indicators of grouper (Serranidae) and snapper (Lutjanidae) fisheries in Saleh Bay, Indonesia

[1,2]Diding Sudira Efendi, [3,4]Luky Adrianto, [3,4]Yonvitner, [3,4,5]Yusli Wardiatno, [6]Siska Agustina

[1] Doctoral Program in Coastal and Marine Resources Management, Graduate School of IPB University, Kampus IPB Darmaga, Bogor, Indonesia; [2] Directorate General of Capture Fisheries, Ministry of Marine Affairs and Fisheries, Jakarta, Indonesia; [3] Department of Aquatic Resources Management, IPB University, Bogor, Indonesia; [4] Center for Coastal and Marine Resources Studies, IPB University, Bogor, Indonesia; [5] Environmental Research Center, IPB University, Bogor, Indonesia; [6] Wildlife Conservation Society, Bogor, Indonesia. Corresponding author: D. S. Efendi, dsefendi75@gmail.com

Abstract. Continuous overexploitation is the biggest problem presently facing small-scale fisheries in Saleh Bay, Indonesia. To further address the fish population decline in this area, the Provincial Government of West Nusa Tenggara (NTB) has introduced the Governor Regulation No. 32 of 2018 since September 2018. This study aims to estimate the status of fish stocks of grouper and snapper in Saleh Bay under the current policy regime. The TropFishR Studio and the length-based spawning potential ratio (LB-SPR) analysis were used to assess stock status. The analysis showed that all species studied indicated overexploitation, with exploitation rates above 0.5: 0.57 for *Plectropomus leopardus*, 0.53 for *Plectropomus maculatus*, 0.6 for *Epinephelus coioides*, and 0.64 for *Lutjanus malabaricus*. The model results also indicated heavy exploitation for *Epinephelus coioides*, with estimated SPR for the species below the limit reference point of 0.2. Therefore, to reduce the phenomena of overfishing, the management measures regarding the minimum legal size and gear restrictions should be strengthened in combination with areas and seasonal fishing prohibition strategies in spawning aggregation sites for vulnerable species, as well as institutional development through capacity building mechanisms, and law enforcement.
Key Words: biological reference point, exploitation rate, Saleh Bay, SPR.

Introduction. Grouper (Serranidae) and snapper (Lutjanidae) are commercially-important species and play an essential role in providing livelihoods and food security for millions of fishermen and many local communities worldwide (Sadovy de Mitcheson et al 2013; Amorim et al 2019). Indonesia is the largest producer of these fish in the global seafood market (www.sustainablefish.org) with an increasing trend in the total catch from 2009 to 2018 (Amorim et al 2020). According to the fisheries statistics, the total landing of these species was approximately 195380 tons per year (KKP 2019) or 40% of the global production (FAO 2020). Indonesia has also become a major exporter of the commodity. In 2018, Indonesia reported that the export value of the commodity was approximately 56 million dollars (BPS 2019).

One of the potential resources of grouper and snapper is in the Saleh Bay waters, which is administratively included in the Sumbawa and Dompu Regencies, West Nusa Tenggara Province (NTB). Saleh Bay is part of the fisheries management area (FMA) 713, where there are small islands and coastal ecosystems, such as coral reefs, seagrass beds, and mangroves, which are essential habitats for fish resources (Natsir et al 2019). However, coral reef fisheries in Saleh Bay are currently threatened by overfishing, the use of the destructive fishing practices, and a decrease in the production of the species.

The local government has tried to control the excessive and destructive fishing techniques by initiating a policy that limits these activities as part of an intervention process in managing fisheries resources. Legally, this policy is stipulated under the West Nusa Tenggara (NTB) Governor Regulation No. 32 of 2018 on the Action Plan for Sustainable Management of Grouper and Snapper Fisheries in Saleh Bay and the adjacent waters from 2018-2023 (NTB 2018).

Presently, the NTB Province is the only region in Indonesia that specifically regulates the management of grouper (Serranidae) and snapper (Lutjanidae) fisheries. These regulations are now in the realm of fisheries policy at the local level. However, resistances are encountered when the objectives of the policy are not in line with those of the actors that are considered the target, such as small-scale fishermen. This situation, therefore, leads to a low effectiveness of the regulation.

The study on the effectiveness of small-scale grouper and snapper fisheries management at the local level in the limit reference point (LRP) is currently not widely conducted. Subsequently, research concerning grouper and snapper fisheries particularly in Indonesia is dominated by biological approaches, estimation of stock status, bioeconomic and fishing techniques (Tadjuddah et al 2013; Wahyuningsih et al 2013; Bawole et al 2017; Patanda et al 2017; Agustina et al 2018a; Agustina et al 2018b; Tirtadanu et al 2018; Agustina et al 2019a; Ernaningsih et al 2019; Setiawan et al 2019; Khasanah et al 2019a; Khasanah et al 2019b). Previous studies were carried out on the grouper and snapper fisheries, where there are no management interventions in place for these fisheries in the study sites. However, in designing the fisheries management policy, it is crucial to consider the potential risks posed cautiously. Therefore, a study on the performance of the stock status of small scale fisheries needs to be conducted. Thus, this study aims to assess the performance of stock in small-scale grouper fisheries in Saleh Bay, under the established policy. Furthermore, the research is necessary because it tends to contribute to the effective implementation of this policy in the future.

Material and Method

Description of the study sites. This study was conducted in Saleh Bay (Sumbawa and Dompu Regencies, West Nusa Tenggara), as presented in Figure 1. The bay is one of the main fishing grounds in NTB, where marine wild capture fishery has a significant contribution in the total production of reef fisheries. The research location is focused on 5 villages, namely Labuhan Sumbawa, Labuhan Kuris, Labuan Sanggoro, Labuhan Jambu (Sumbawa Regency), and Soro (Dompu Regency), which are the main landing sites for grouper and snapper fishing vessels.

Data collection and data analysis. Secondary data from the Wildlife Conservation Society (WCS) was employed for one year (Agustina et al 2019c; WCS 2020). The total length (TL) of samples from each month were measured at the 5 landing sites. The study focused on the 4 dominant species in the catches stated in the Governor Regulation: leopard coral grouper (*Plectropomus leopardus*), spotted coral grouper (*Plectropomus maculatus*), orange spotted grouper (*Epinephelus coioides*), and Malabar blood snapper (*Lutjanus malabaricus*). The purposive method was used to collect data based on the size of the fish, which was carried out in clusters at the landing sites.

In this study, the parameters analyzed in the fish population are growth, lifespan, mortality, exploitation rate, length at first capture, length at first gonad maturity, recruitment pattern, and potential spawning ratio (SPR). The length frequency distribution method was employed with class 2 intervals. The ELEFAN method in the R studio software package TropFishR and fish methods for length-based assessment were used to analyze length-frequency data (Pauly 1984; Mildenberger et al 2017; Agustina et al 2019b). This application was applied to estimate growth parameters, such as asymptotic length (L_∞), exploitation rate (E), length at first capture (L_c), total mortality rate (Z). The estimated total mortality rate is obtained from the length-converted catch curve approach using the length-frequency data.

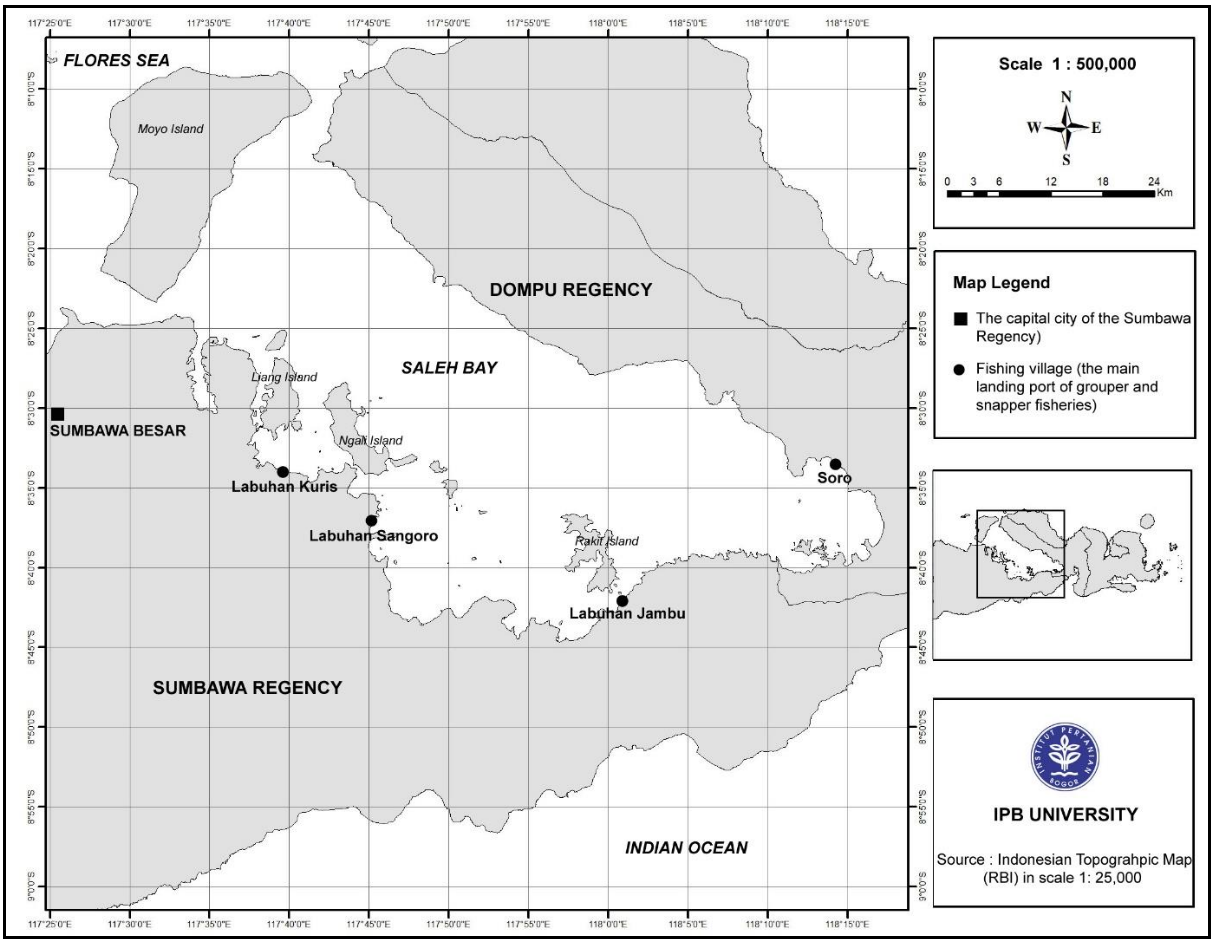

Figure 1. The location of Saleh Bay, West Nusa Tenggara.

The growth coefficient used in this formula follows the von Bertalanffy model:

$$L_t = L_\infty \, [1 - e^{(-K(t-t_0))}]$$

Where: L_t - the length at age t (cm); L_∞ - asymptotic length (cm); K - the growth coefficient ($year^{-1}$); t_0 – the hypothetical fish age at zero-length (years).
Estimation of the t_0 value is based on the empirical equation of Pauly (1983):

$$Log\,(-t_0) = -0.3922 - 0.2752 \log (L_\infty) - 1.038 \log K$$

The K parameter is used to estimate the longevity of the fish (lifespan) or the maximum age (t_{max}) of the grouper and snapper species (Pauly 1984):

$$t_{max} \approx \frac{3}{K}$$

The natural mortality (M) of the species was estimated by employing an empirical approach (Pauly 1980):

$$Log\,(M) = -0.066 - 0.279 \log (L_\infty) + 0.6543 \log (K) + 0.4634 \log T$$

Where: L_∞ - asymptotic length (cm); K – growth coefficient ($year^{-1}$); T – mean annual water temperature (°C).

The estimated fishing mortality rate (F) is given by the subtraction of M from Z (Pauly 1980; Pauly 1983; Pauly 1984):

$$F = Z - M$$

The relationship between F and M can estimate the exploitation rate (E) of the stock (Pauly 1983), as follows:

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

The length at first maturity (L_m) is calculated using the Froese & Binohlan (2000) equation:

$$\text{Log } L_m = 0.8979 * \log L_\infty - 0.0782$$

The size of length at first capture (L_c) is the length at which 50% of the fish are retained, while the rest escape the gears. L_c is analyzed based on the estimated logistic curve or the estimated selection ogive function (SL_{est}) in the following equation (Sparre & Venema 1998):

$$SL_{est} = \frac{1}{1 + \exp(S_1 - S_2 * L)} \quad ; \quad L_c = \frac{S_1}{S_2}$$

Where: SL_{est} - the estimated logistic curve or the estimated selection ogive function; S_1 - the intercept; S_2 - the slope in logistic curve.

The recruitment patterns were analyzed by inputting the values of the asymptotic length (L_∞) and the growth rate (K) using the Recruitment Pattern menu in the FISAT program (Gayanilo et al 2005).

The status of fish stock was estimated using the Spawning Potential Ratio (SPR). The SPR is a biological reference point (the limit and the target reference points) most commonly used as fisheries management indicators (Brooks et al 2010). The estimation of SPR was carried out by online analysis of the Length-based Spawning Potential Ratio (LB-SPR) on the website www.barefootecologist.com.au developed by Hordyk et al (2014). The LB-SPR model requires data on the length composition (catch/landings) and life-history parameters of the species (L_∞, L_m, L_{95}, and M/K ratio), where the estimated L_{95} value is based on average values of 123 species of tropical reef fish, $L_{95}=1.1*L_m$ (Prince at al 2015). Estimates of SPR for each species can be compared to the appropriate limit and target reference values of 20 and 30% (Agustina et al 2019c).

Results and Discussion. Information on stock conditions of grouper and snapper fisheries in Saleh Bay is an essential reference point in fisheries management, consisting of life-history parameters, such as growth parameters, mortality, exploitation rates, and Spawning Potential Ratio. With the availability of the most basic biological information, management practices that will be able to reverse the alarming trends indicated can be established (Sadovy de Mitcheson et al 2013).

Size structure. The individual species data used in this study were 4478 fish, as presented in Table 1. The average lengths of *P. leopardus* (locally called 'sunu halus'), *P. maculatus* (locally called 'sunu kasar'), *E. coioides* (locally called 'kerapu tutul'), and *L. malabaricus* (locally called 'kakap merah') are 42 cm, 44 cm, 55 cm, and 54 cm, respectively. The overall mean lengths of groupers collected in Saleh Bay from the present study were considerably larger than those of Agustina et al (2018a). The minimum length of fish captured also increases compared to the previous study, except for *L. malabaricus*. The increase in both lengths occurs due to changes in fisherman behavior responding to current regulations, including enforcing appropriate size limits (Agustina et al 2019c).

Table 1

Sample size and length of grouper and snapper

Species	Fish sample (n)	Length (cm)			
		Mean	Standard deviation	Mininum	Modal
Plectropomus leopardus	1498	42	8.2	22	40.5-42.5
Plectropomus maculatus	941	44	9.57	24	36.5-38.5
Epinephelus coioides	814	55	15.84	25	52.5-54.5
Lutjanus malabaricus	1225	54	9.32	20	52.5-54.5
Total	4478				

Note: source - Agustina et al (2019c).

Growth parameters. The estimate of growth parameters is based on length-frequency distribution data, which is reported by WCS (Agustina et al 2018a). The results from estimating the growth parameter of grouper and snapper in Saleh Bay are presented in Table 2.

Table 2

Growth parameters of grouper and snapper

Species	*L∞ (cm)*	*K (year^{-1})*	*t_0 (year)*	*Lifespan (years)*
Plectropomus leopardus	71.94	0.12	-1.17	24.74
Plectropomus maculatus	76.55	0.10	-1.34	28.62
Epinephelus coioides	110.21	0.10	-1.20	28.39
Lutjanus malabaricus	85.56	0.22	-0.57	12.99

Note: L_∞ - asymptotic length, K - the growth coefficient; t_0 - fish age at size=0. Source: Agustina et al (2018a).

The analysis results show that *E. coioides* has the largest L_∞ (110.21 cm) among the grouper species, whereas the 2 species of the genus *Plectropomus* are smaller than the other species, with 71.94 cm for *P. leopardus* and 76.55 cm for *P. maculatus*. *P. maculatus* age 28.62 years, while *L. malabaricus* tend to reach the L_∞ value at 12.99 years. Meanwhile, the growth rates (K) of these species ranged from 0.1 to 0.22 per year. For example, *P. leopardus* could reach an average K of 0.12 per year and the age of t_0 at -1.17 years. The K value 1 indicates that these species are relatively slow-growing (Sparre & Venema 1998; Ault et al 2008). Following the growth parameters, groupers are relatively long-lived, slow-growing species, with late sexual maturation, and aggregation spawning (Haight et al 1993; Heemstra & Randall 1993; Sadovy de Mitcheson et al 2013). Many groupers change their sex at a certain age from female to male (Sadovy de Mitcheson 2016), such as *E. coiodes* (Widodo 2006), and *P. leopardus* (Khasanah et al 2019a). Due to their life-history characteristics, some groupers and snappers are currently vulnerable (included in the Red List of International Union for the Conservation of Nature or IUCN), due to fishing pressure (Setiawan et al 2019; Khasanah et al 2019b).

Relative fishing mortality and exploitation rate. The mortality of fish can be caused by natural mortality, such as predation, starvation, disease, and aging; and due to fishing factors (Sparre & Venema 1998). The natural mortality rates (M) using length-frequency data, were estimated at 0.16 for *P. leopardus*, 0.16 for *P. maculatus,* 0.16 for *E. coioides*, and 0.32 for *L. malabaricus* (Agustina et al 2018a). The model results also estimated relative fishing mortality to natural mortality (F/M) for all species (Table 3), with F/M>1.12 for all species, ranging from 1.12 (*P. maculatus*) to 1.75 (*L. malabaricus*). These values indicate that the fish are more likely to die due to fishing activities. Table 3 also presents the exploitation rates of grouper and snapper in Saleh Bay, estimated by employing the mortality parameter. According to Gulland (1971), optimum exploitation level (E_{opt}) occurs when fishing mortality is equal to natural mortality ($F_{opt} \approx M$), or the optimum rate of exploitation is equal to 0.50 (Pauly 1983; Pauly 1984; King 1995). Overall, the grouper and snapper species in Saleh Bay have experienced overexploitation based on the optimum exploitation rate, where E value is above E_{opt}. Exploitation rate (E) of *P. leopardus*, *P. maculatus, E. coioides,* and *L. malabaricus* are 0.57, 0.53, 0.6, and 0.64, respectively. This situation is very similar to the relative fishing mortality (F/M), where *L. malabaricus* has the highest value of exploitation rate.

Table 3

Relative fishing mortality and exploitation rate of grouper and snapper

Species	*F/M**	*E*
Plectropomus leopardus	1.35	0.57
Plectropomus maculatus	1.12	0.53
Epinephelus coioides	1.50	0.60
Lutjanus malabaricus	1.75	0.64

Note: M - natural mortality; F - fishing mortality; E - exploitation rate. Source: Agustina et al (2019c).

The exploitation rate for *L. malabaricus* in Saleh Bay has deteriorated from 0.46 (Agustina et al 2018a) to 0.64 in the last years. Similarly, *E. coioides* suffers relatively high fishing pressure conditions compared to both *Plectropomus* (*P. leporadus* and *P. maculatus*). However, the exploitation rate of *P. leopardus* is higher than the level of utilization of this species in other waters in Indonesia, such as in Cendrawasih Bay, Papua (0.52) (Bawole et al 2017), Karimunjawa, Central Java (0.45) (Agustina et al 2018b), in Sarrapo Islands, Lasongko Bay, Southeast Sulawesi (0.52) (Prasetya 2010). The high intensity of fishing in Saleh Bay is also caused by the continual increase in the demand for groupers, an essential commercial commodity, with a relatively high price compared to other fish, approximately 7-21 USD per kg. The results showed the fish had an exploitation rate of 0.57 per year, with most individuals of this species being caught at immature or juvenile stages, with small sizes, and without ever having spawned.

The length at first capture (L_c) and estimated fish length at first gonad maturity (L_m). To avoid overfishing, the length at first capture (L_c) needs to be higher than the mean length at first maturity (L_m); thus, fish can spawn before being caught. A comparison between the values of L_c and L_m of the grouper and snapper species studied is stated in Table 4. Based on the estimated selectivity parameter (Figures 2 to 4), the groupers captured are far below their length at first maturity (L_m). In contrast to the groupers, the snapper (*L. malabaricus*) indicates that its size of capture is well above the size of maturity (Figure 5).

Table 4

The length at first capture and fish length at first gonad maturity

Species	L_c	L_m
Plectropomus leopardus	33	38.83
Plectropomus maculatus	40	41.06
Epinephelus coioides	47	56.95
Lutjanus malabaricus	50	45.37

Note: L_c - length at first capture; L_m - length at first maturity. Source: Agustina et al (2019c).

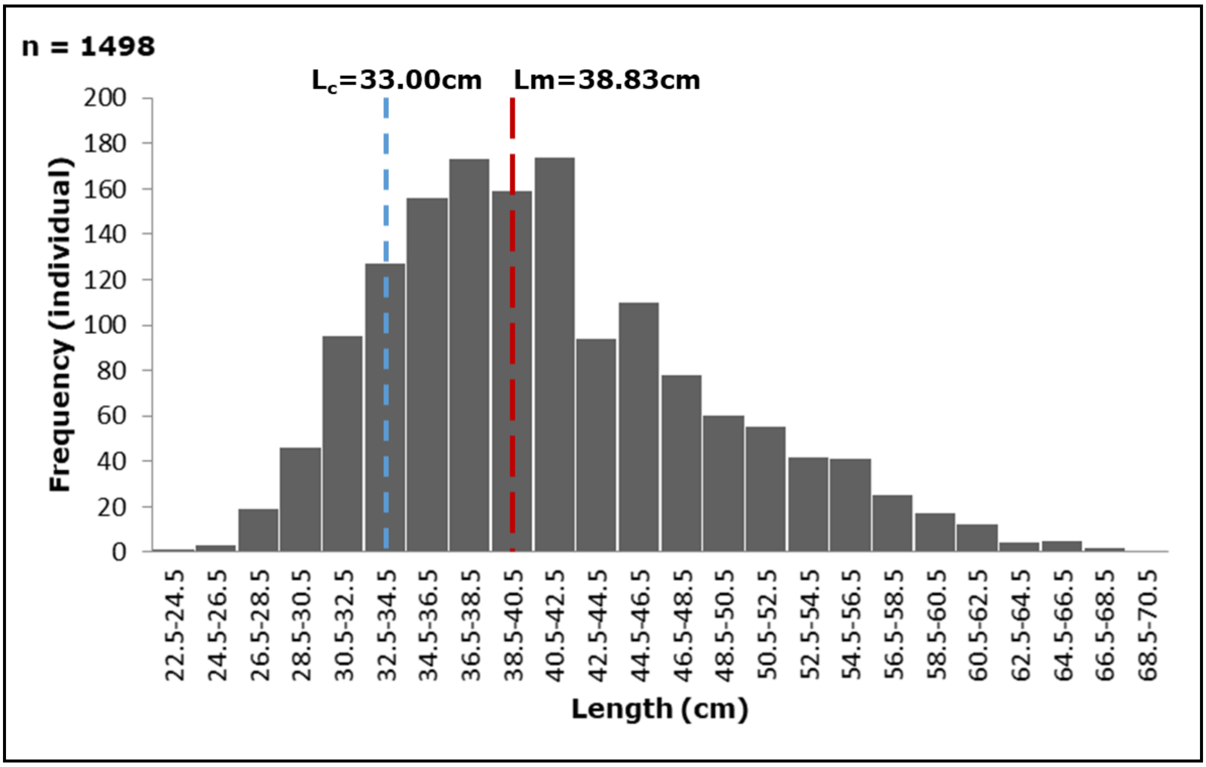

Figure 2. Total length distribution frequency of *Plectropomus leopardus.*

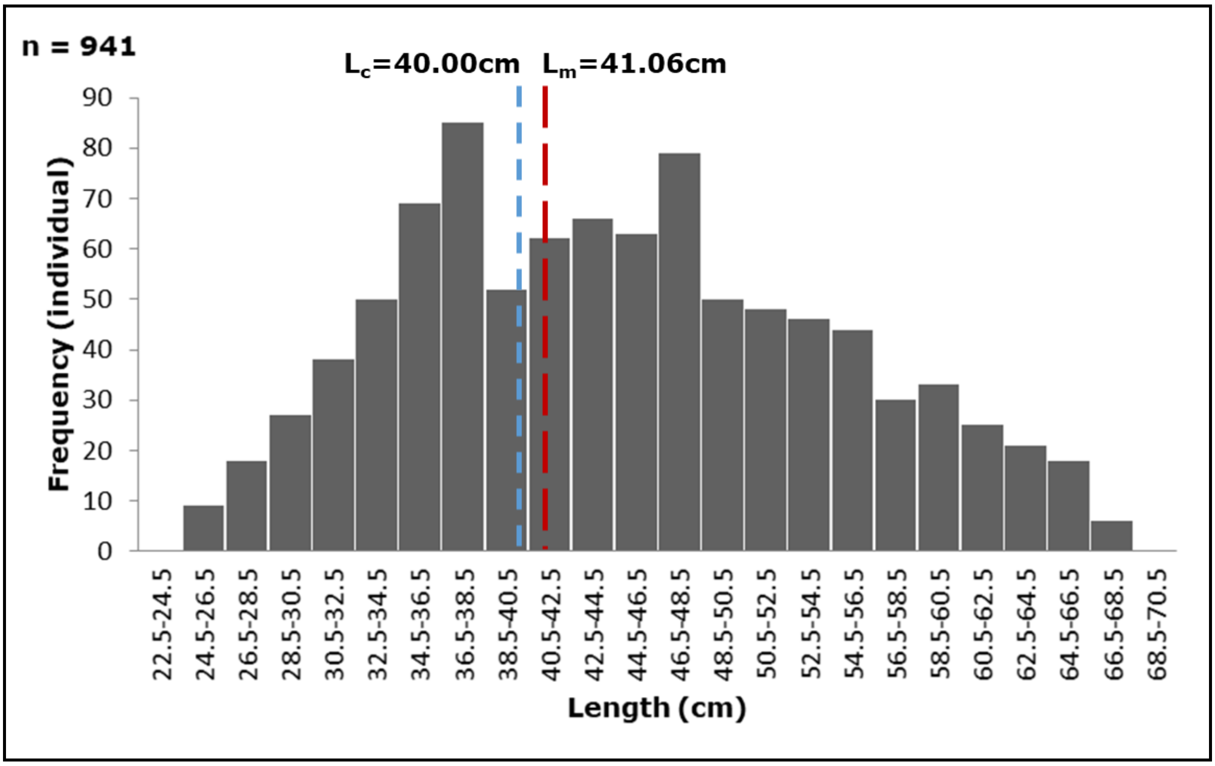

Figure 3. Total length distribution frequency of *Plectropomus maculatus*.

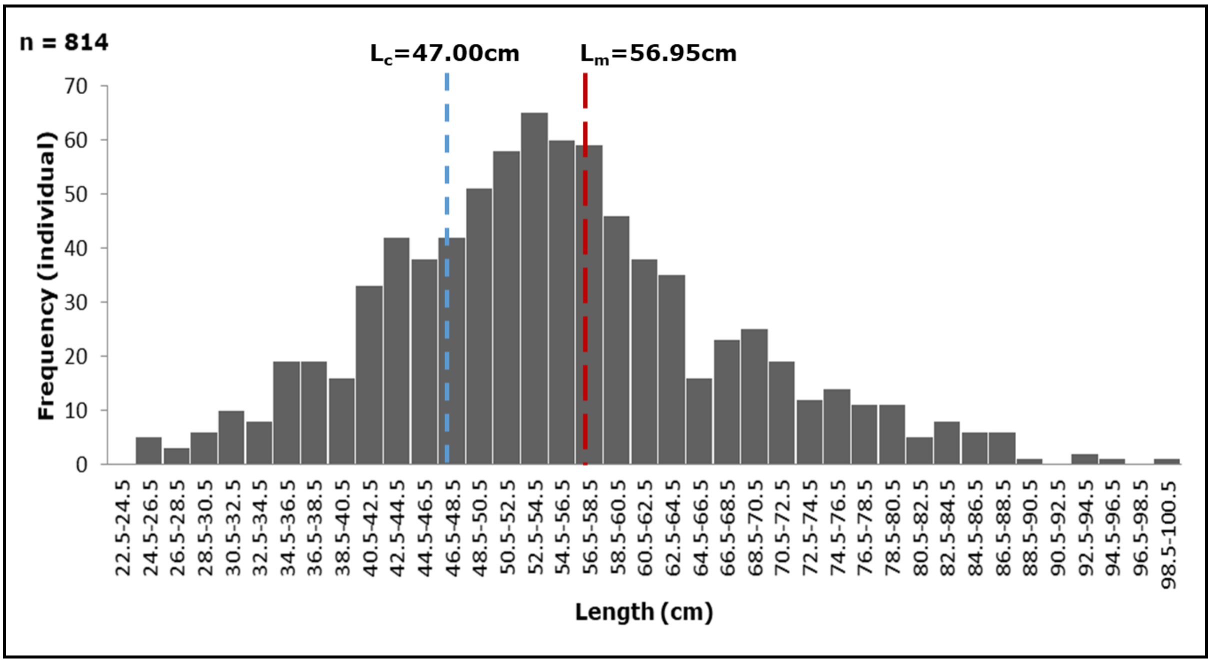

Figure 4. Total length distribution frequency of *Epinephelus coioides*.

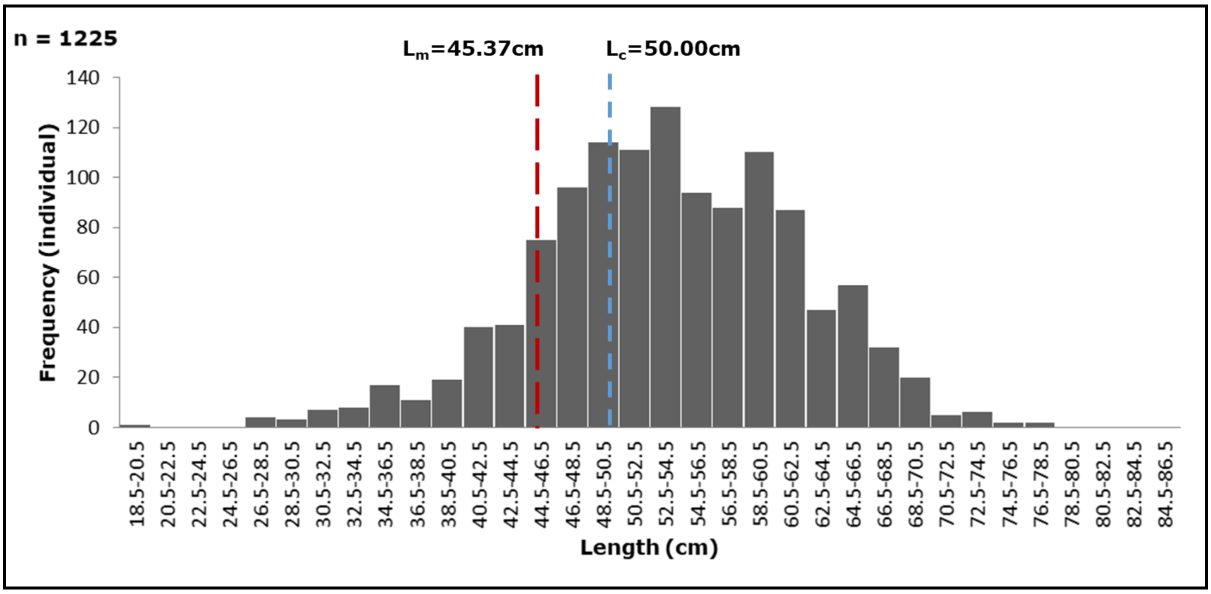

Figure 5. Total length distribution frequency of *Lutjanus malabaricus*.

Recruitment patterns. The recruitment patterns of groupers and snappers in Saleh Bay is suspected to occur twice a year. The peak of the recruitment for *P. leopardus, P. maculatus, E. coioides,* and *L. malabaricus* usually occurs in April and September, as presented in Figure 6. This is in line with previous research findings conducted by Khasanah et al (2019a), which reported that spawning of *P. leopardus* in Eastern Indonesia waters occurred around the new moon, from September to April. Meanwhile, Agustina et al (2018b) stated that leopard coral trout (*P. leopardus*) in Karimunjawa waters had experienced peak recruitment in May and October, with a slight difference in time. The peak recruitment of a fish species is the basis for determining the spawning period.

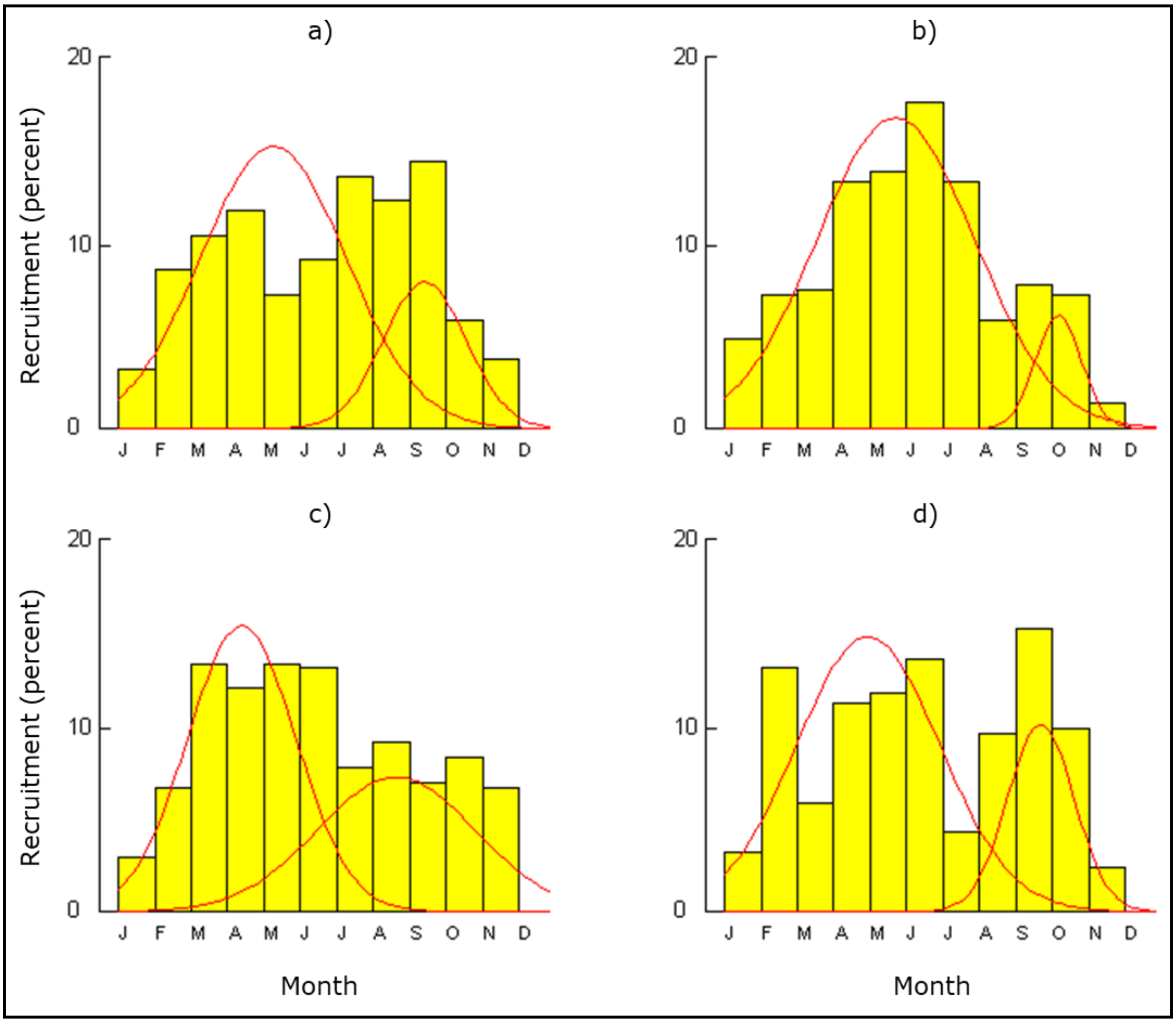

Figure 6. Recruitment pattern of: a - *Plectropomus leopardus*; b - *Plectropomus maculatus*; c - *Epinephelus coioides*; d - *Lutjanus malabaricus*.

Spawning potential ratio (SPR). The SPR value of these species in Saleh Bay was determined and presented in Table 6. The SPR value for *E. coioides* is below the 20% SPR limit reference point (Mace & Sissenswine 1993; Hordyk et al 2015; Badrudin 2015; Prince 2017), which signifies that the stock status is overexploited. The estimated SPR for *E. coioides* was very low, 0.14. It means that the species has been mainly caught before reaching adulthood. The SPR value of *E. coioides* showed a declining trend from 2016 to 2018 due to the high exploitation of small/immature fish in recent years, most of which were caught using spearguns. The low SPR of the species highlights the importance of implementing management measures to increase fish biomass stock in Saleh Bay. Globally, this species has decreased in population and is overfished because of fishing pressure in spawning aggregations areas and degradation of juvenile and adult habitats (Amorim et al 2018). In contrast to these species, the estimated SPR for *P. leopardus, P. maculatus* and red snapper (*L. malabaricus*) is above the SPR limit of 0.2 (Table 5) and below the SPR target reference point of 0.30 or 30% (Goodyear 1993; Brooks et al 2010; Agustina et al 2019c), indicating that their stock status is moderate (fully exploited). However, the SPR value of *L. malabaricus* decreased from 2016 to 2018.

Table 5

Estimation of spawning potential ratio and indication of stock status compared to suggested reference points

Species	*SPR*	*Limit reference points*	*Fish stock status*
Plectropomus leopardus	0.24	0.2	Moderate
Plectropomus maculatus	0.30	0.2	Moderate
Epinephelus coioides	0.15	0.2	Overexploited
Lutjanus malabaricus	0.25	0.2	Moderate

Note: SPR - spawning potential ratio. Source: WCS (2020).

Holistic management strategy in place. Although the Governor Regulation issuance marks a change in the improvement of captured fish length, the study results show that many species have been reported to suffer overexploitation based on several indicators: exploitation rate, relative fishing mortality, and SPR (biological reference points). The biological performance could be depicted through a rapid depletion of the status stock in the wild due to an increase in fishing intensity. Therefore, it is urgent to manage the prevention of further population decline in this area. This study highlighted that the current management plan should be strengthened by seasonally closed areas to protect nursery areas during peak recruitment in April and September. According to Yulianto et al (2015), limitations of the fishing season combined with the regulation in catch size have a positive effect on grouper biomass. The strategy is mainly carried out in locations known as spawning aggregation areas for groupers, especially for *P. leopardus* and *E. coioides*, in the waters around Gili Tapan, Ngali, Tanjung Labuan Aji, Pulau Putri, Tanjung Tete, and Teluk Buluh (Setiawan et al 2017).

However, the challenges facing the effectiveness of the current fishery management are the lack of compliance of the fishermen and middlemen and the weaknesses of law enforcement. The effective policy requires substantial efforts to improve fishermen compliance with the rules, such as gear restriction and size limits. Strict law enforcement against the practice of destructive fishing (potassium, compressor equipment, and bombing) is a priority step. More technical effort should be taken through the improvement of human resources capacity. This effort is needed for fisheries managers and related stakeholders to enhance the degree of regulatory compliance in fisheries (Jentoft 2000), as well as the provision of incentives and alternative income sources for affected fishermen within the framework of stock sustainability and fishermen protection, according to Law No. 7 of 2016. Therefore, a tactical step is required in the form of the Governor Regulation Socialization Program (awareness increasing campaigns) to increase public awareness and understanding and further encourage the participation of fishermen and collectors in fish resources sustainability will ensure improvement in the effectiveness of this regulation. The involvement of collectors or traders in determining the size of catch to be traded (minimum legal size) is one of the market-based management actions (market-driven) that needs to increase its effectiveness, particularly in ensuring that the fishermen comply with the existing rules.

Conclusions. This study has estimated the fish population indicators of grouper and snapper fisheries in Saleh Bay based on the biological performance indicators, as an implementation result from the NTB Governor Regulation No. 32 of 2018. The status of *E. coioides* is in a worrisome condition compared to other species, indicated by a very low SPRs (0.14), a wide range of L_c and L_m (selectivity parameter), an exploitation rate of 0.6, and relative high fishing mortality (F/M), 1.75. Based on the population parameters, fishing activities targeted at *E. coioides* need to be restricted for approximately 6 months (by closing the fishing season) to recover the fish stocks. These conditions indicate that the grouper and snapper fisheries in Saleh Bay have been experiencing overfishing. However, the challenges faced in government regulation implementation depend not only on biological aspects, but also on the human-dimensions perspective. Therefore, the future scope for the research area should be extended to include socio-economic conditions (technical efficiency, fishermen behavior, institution, etc.).

Disclaimer. This study used length-composition data from the Wildlife Conservation Society (WCS). The views expressed here are those of the authors and do not necessarily represent the views of WCS or other data contributors. Any errors are attributable to the authors.

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Authors:
Diding Sudira Efendi, Graduate School of IPB University, Study Program for Coastal and Marine Resources Management, Dramaga Bogor 16680, Indonesia; Directorate General of Capture Fisheries, Ministry of Marine Affairs and Fisheries, 10110 Jakarta, Indonesia, e-mail: dsefendi75@gmail.com
Luky Adrianto, IPB University, Department of Aquatic Resources Management, 16680 Dramaga Bogor, Indonesia; Center for Coastal and Marine Resources Studies, 16127 Baranangsiang Bogor, Indonesia, e-mail: lukyadrianto@apps.ipb.ac.id
Yonvitner, IPB University, Department of Aquatic Resources Management, 16680 Dramaga Bogor, Indonesia; Center for Coastal and Marine Resources Studies, 16127 Baranangsiang Bogor, Indonesia, e-mail: yonvitr@yahoo.com
Yusli Wardiatno, IPB University, Department of Aquatic Resources Management, 16680 Dramaga Bogor, Indonesia; Center for Coastal and Marine Resources Studies, Baranangsiang Bogor 16127, Indonesia; Environmental Research Center, IPB University, 16680 Bogor, Indonesia, e-mail: yusli@ipb.ac.id
Siska Agustina, Wildlife Conservation Society, Bogor Tengah, 16128 Bogor, Indonesia, e-mail: sagustina@wcs.org

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