Yield-per-recruit modeling as biological reference points to provide fisheries management of Leopard Coral Grouper (*Plectropomus leopardus*) in Saleh Bay, West Nusa Tenggara

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Abstract. Leopard coral grouper (*Plectropomus leopardus*) is an important fisheries commodity in Saleh Bay, both ecologically and economically. Continuous exploitation of this species has caused population collapses in some waters due to high fishing pressure. Therefore, it is very important to estimate its population stock. Yield per recruit models usually being used to evaluate population stock also to estimate biological reference point. We estimated life-history parameters using length-based stock assessment, while stock size was estimated by virtual population analysis (VPA), and finally, prediction models was estimated using Beverton & Holt’s yield per recruit model. We used the following variables: growth parameters, fishing mortality, length at first capture, and age at 50% recruitment into the fishery. From these variables we found that the $F_{current}$ (0.26) is higher than the target reference point ($F_{MSY}$= 0.24), which confirmed the indication of slight increased exploitation rate ($E$=0.62). It is shown that the *Plectropomus leopardus* was overexploited with spawner biomass-per-recruit at 20.6% of pristine levels. The regulation measures to correct the exploitation pattern and to reduce fishing mortality smaller than $F_{MSY}$ including limiting the catch size and control on fishing gear by limiting fishing effort.

Keywords: biological reference, coral grouper, West Nusa Tenggara

1. Introduction

The leopard coral grouper, *Plectropomus leopardus* Lacepède, is a member of the family Epinephelidae (grouper). These fishes are common species throughout their range and are the important component of the live reef food fish and commonly occurs in the western Pacific along southern Japan to northern Australia as well as eastwards to the Caroline Islands and Fiji [1]. Grouper are generally long-lived with low natural mortality rates [2-3]. Leopard coral grouper (locally known as *kerapu sumu merah*) is a major component of fishing in Indonesia. They have an extremely high market value and are heavily fished throughout its range mainly by hook and line (hand line and trolling) and speargun, but also occasionally by fish trap and in some areas of Indonesia with cyanide.

West Nusa Tenggara (NTB) as one of the most important sites for groupers fisheries nationwide. The production of groupers ranks third from the total fisheries production in NTB Province and is one of
the top ten contributors at the national level [4]. Considering that groupers are ecologically and economically important, undertaking sustainable fisheries for groupers is of paramount importance for their continuous supply for small-scale fishers.

Information about population and abundance of demersal and reef fish in NTB Province is currently limited, there are no time series of catch and effort in species level, caught by small scale fisheries (may be defined by vessel size < 10 gross tons), and multi-species fisheries and multiple gears. Therefore, to proceed stock assessment can be used length- or age-based catch data and other biological data important to the age-based stock assessment models application [5]. An alternative method to assess stock of the fisheries within a data limited situation is per-recruit analysis. The aimed of this study was to the estimated biological reference point such as $F_{0.1}$ or $F_{MSY}$ using per-recruit model (YPR).

2. Materials and Methods

The leopard coral grouper samples used from fish landing monitoring collected by monthly from Saleh Bay, West Nusa Tenggara. There were five landing sites, i.e. Labuhan Kuris village, Labuhan Jambu village, Labuhan Sangoro village, Soro Village, and Labuhan Sumbawa village (Figure 1). The length data were recorded every day, while data sampling was carried out 7-15 days each month in April 2016 to March 2017. A total of 1159 fish representing a wide range of total lengths (19-67 cm) were collected.

![Figure 1](image.png)

*Figure 1.* Map of Saleh Bay showing landing site and area fishing ground of *Plectropomus leopardus.*

These data were previously used to estimate von Bertalanffy growth parameters, mortality rate, age at 50% recruitment into the fishery, length at 50% capture, and 75% capture [6] (table 1).
Table 1. Biological parameters of leopard coral grouper in the water around Saleh Bay [6].

| Parameter                              | Value          |
|----------------------------------------|----------------|
| L∞ (asymptotic length)                 | 71.94 mm TL    |
| K (growth coefficient)                 | 0.12 year⁻¹    |
| t₀ (age theoretic at zero length)      | -1.17 year     |
| α (intercept length-weight parameter)  | 0.0118         |
| β (slope length-weight parameter)      | 3.06           |
| tr (age-at-50%-recruitment)           | 3.29 years     |
| M (natural mortality rate)             | 0.16 year⁻¹    |
| F (current fishing mortality rate)     | 0.26 year⁻¹    |
| max (maximum age of fish)              | 26 years       |

2.1. Yield per recruit analysis
The Y/R as a function of fishing mortality and was calculated using The Beverton and Holt (1957) method in [7]:

\[
\frac{Y}{R} = F \times \exp[-M \times (t_c - t_r)] \times W_\infty \times \left[ \frac{1}{Z} - \frac{3S}{Z + k} + \frac{3S^2}{Z + 2k} - \frac{S^3}{Z + 3k} \right]
\]

\[S = \exp \{-K \times t_c - t_0\}; W_\infty = \text{asymptotic weight.}\]

2.2. Biomass per recruit analysis
The B/R as a function of age calculated using the [7] model:

\[
\frac{B}{R} = \frac{Y}{R} \times \frac{1}{F}
\]

2.3. The biological reference point
The biological reference point, F₀.1 (the value of F at a marginal increase in Y/R is 10% of its value at F = 0) [8]:

\[
\frac{dV}{dF} = \frac{dY}{dF} - 0.1B_0 = 0 \text{ or } \frac{dY}{dF} = 0.1B_0
\]

V = Y – 0.1, dY is a variable of Y/R, dF is a variable of F and B₀ is the B/R when F = 0. Therefore, the value of F at dY/dF=0.1B₀ represent the value of F₀.1. F₀.1 can be calculated by emphasizing the function of V=Y-0.1B₀.1.

3. Results and Discussion

Yield per recruit as a function of F and the point estimates for the Fmsy, F₀.1, and F₀.5 are illustrated in figure 1. The Fmsy and F₀.1 were 0.25 and 0.20 year⁻¹, respectively. The current rate of fishing mortality (Fₜₚₑᵣₑ=0.26) was higher than F₀.1 and Fmsy, which confirmed the indication of the slightly high exploitation rate (E=0.62). It showed that Emsy can be obtained at 0.60 whereas the present E is 0.62. It was estimated that Fₜₚₑᵣₑ depleted leopard coral grouper SBR to 20.6% of pristine levels.
Figure 2. Yield and biomass per recruit curves. The yellow dashed line represent fishing mortality for maximum sustainable yield ($F_{\text{msy}}$) and the red dashed lines and fishing mortality to fish the stock at 50% of the virgin biomass ($F_{0.5}$) of leopard coral grouper in Saleh Bay.

According to Y/R model based on different length at first capture (Lc, figure 1), Y/R increased swiftly at low values of Lc at 29.82 (current Lc), 25.00 cm, 27.00 cm, 29.00 cm, 31.00 cm, 33.00 cm, and 35.00 cm, the Y/R were 633.95 g.recruit$^{-1}$, 581.02 g.recruit$^{-1}$, 602.09 g.recruit$^{-1}$, 624.52 g.recruit$^{-1}$, 646.99 g.recruit$^{-1}$, 669.85 g.recruit$^{-1}$, and 692.12 g.recruit$^{-1}$, respectively, indicating that the B/R showed a slight decrease for Lc at a larger size. The yield could be increased when fishing mortality and the mesh size of fishing gears is increased (figure 2). The Result of YPR from different Lc presented in table 2.

Leopard coral grouper is a slow growing, late maturity, long-lived, and has sex characterization of protogynous hermaphrodism [9]. Groupers are commercially important species in Southeast Asian countries including Indonesia. Population of leopard coral grouper in the Great Barrier Reef, Australia shown declined [10], and this problem is further exacerbated by the increasing harvest in the country. Other countries show a decline. Due to the declining trend of populations in various countries, fish can be classified as Nearly Threatened and with more data may need to be reclassified as Vulnerable. Overfishing may be a major threat to this species.

Maximizing harvests at safe sustainable yield levels, emphasized by Malawi’s fisheries policy [11], implies that YPR must be maximized without the risk of spawning failure. YPR peaks are achieved if unlimited fishing mortality is applied when the cohort biomass is at its maximum [12]. If this maximum is maintained after age-at-50%-maturity, the risk of spawning failure is reduced. However, if the age-at-maturity is less than or equal to the age-at-recruitment there could be an overfishing situation where the SBR would rapidly reach levels were recruitment would fail. This is particularly relevant for leopard coral grouper which has low fecundity and implies some from dependence on spawner biomass level. Coral leopard grouper in Saleh Bay were caught dominantly by speargun (63%), handline (19%), bottom longline (16%), and others (2%) with the proportion of immature catch was 60%. It’s represented that more than 50% catches of leopard coral grouper were caught at a young age and considered to have immature gonad and facing the high risk of overfishing [13], so the recruitment of the species would fail.
Figure 3. Exploration of the impact of different fishing mortality rates and Lc on the relative yield per recruit of leopard coral grouper in Saleh Bay.

Table 2. YPR estimated of different fishing mortality and Lc of leopard coral grouper in Saleh Bay.

| Lc  | tc  | F_{01} | F_{msy} | F_{05} | E_{01} | E_{msy} | E_{05} |
|-----|-----|--------|---------|--------|--------|---------|--------|
| 29.82 | 3.29 | 0.20 | 0.25  | 0.10  | 0.56  | 0.61  | 0.38  |
| 25.00 | 2.39 | 0.15 | 0.20  | 0.10  | 0.48  | 0.56  | 0.38  |
| 27.00 | 2.75 | 0.20 | 0.20  | 0.10  | 0.56  | 0.56  | 0.38  |
| 29.00 | 3.13 | 0.20 | 0.25  | 0.10  | 0.56  | 0.61  | 0.38  |
| 31.00 | 3.53 | 0.20 | 0.25  | 0.10  | 0.56  | 0.61  | 0.38  |
| 33.00 | 3.95 | 0.25 | 0.30  | 0.10  | 0.61  | 0.65  | 0.38  |
| 35.00 | 4.38 | 0.25 | 0.35  | 0.10  | 0.61  | 0.69  | 0.38  |

To prevent spawning failure of the species and maximization of harvests within safe sustainable yield levels, YPR model is often to evaluate population stock and estimate biological reference point such as F_{01} or F_{msy}, which can be used to guide fisheries management decision. F_{msy} was defined as being the value of F which produces the maximum yield in the long-term. F_{msy} relates to the maximization of sustainable yield and it is a most useful reference point. F_{01} and F_{msy} more precisely and more conservatively, and thus is preferred from the conservation viewpoint in fisheries management. In other fisheries. Furthermore, these reference points can be used by fishery managers to evaluate and manage fish stocks in their various locations and systems, as has been reported by many authors [14-20]. Previous studies have used various reference points, and reference points differ according to the conditions of the stocks and the availability of application of the reference points that provide better management of these stocks. F_{01} is the most stable reference point and could be adopted with the least risk of stock depletion [16,17]. In this case, the reference point assign for F_{msy} as a target reference point and F_{01} as a target reference point to controlling catches and fishing pressure.

Our result indicates that the F_{current} (0.26) was higher than the target and limit reference point (F_{01}=0.20 and F_{msy}=0.24), which confirmed the indication of a slight increased exploitation rate (E=0.62). It is shown that the leopard coral grouper was overexploited with spawner biomass-per-
recruit at 20.6% of pristine levels. Figure 1 suggested that decreasing the value of current $F$ to the level of reference points ($F_{01}$ or $F_{msy}$) would increase of yield. Figure 2 shows that increasing $L_c$ from $L_c$ current (28 cmTL) to 31–35 cmTL would increase relative yield per recruit. Furthermore, from the length composition 60% catches of leopard coral grouper was immature which in turn indicates of overfishing.

Leopard coral grouper is recruited into the fishery as juvenile. Ideally, an increase in mesh size leads to a length at capture approximating the size at which maturity is attained (length at maturity), would need to be implemented in this fishery.

The reproductive strategy of leopard coral grouper implies that initial targets should focus on maintaining spawner-biomass at relatively high levels. Bouth et al. suggested that spawner-biomass not be dropped to below 40%, the maintenance of spawner-biomass at levels of 35% and 50% of pristine biomass was taken as an initial management target for leopard coral grouper [16, 17].

Based on our result, we recommend reducing the present $F$ of leopard coral grouper stock in Saleh Bay to the level of a target reference point ($F_{01}$=0.2 year$^{-1}$). Such a reduction in $F$ would likely result in a higher spawner-biomass per recruit than under current levels. It also appears that mortality of leopard coral grouper in Saleh Bay has a stronger effect on the spawner-biomass per recruit than $L_c$.

The regulation measures to correct the exploitation pattern and to reduce fishing mortality smaller than limit reference point including limiting the catch size and control on fishing gear by limiting fishing effort. The recommended catch size is increased length at first capture from 29.82 cm to 33 cm, and from table 2 its can be increased limit reference point to ($F_{msy}$) from 0.20 year$^{-1}$ to 0.30 year$^{-1}$ and also relative yield-per-recruit can increased (figure 2). Any fishing activities or resource utilization on these species can still be carried out by maintaining fishing efforts (duration of fishing trip or number of the boat) at the same or stable value, and it is not recommended to add fishing efforts. According to the proportion of fishing gear used, coral leopard grouper was caught by speargun (63%) as immature fish around 60% from total catches, so we suggested that control on spearguns by limiting the catch size and fishing efforts will give positive impact to the fish stock recovery.

4. Conclusion

$F_{01}$ is defined as a target reference point to a maximization of harvests within safe sustainable yield levels and $F_{msy}$ is defined as a limit reference point. In conclusion, these results indicated that the current level of $F$ (0.26) in leopard coral grouper fisheries in Saleh Bay should be reduced to $F_{01}$=0.20 year$^{-1}$ or $F_{msy}$= 0.24 year$^{-1}$. To reduce fishing mortality smaller than limit reference point including limiting the catch size and control on spearguns fishing by limiting fishing effort.

References

[1] Craig M T, Sadovy de M Y J and Heemstra P C 2011 Groupers of the world: a field and market guide (South Africa: NISC)
[2] Ferreira B P and Russ G R 1994 Age validation and estimation of growth rate of the coral trout, Plectropomus leopardus, (Lacepede 1802) from Lizard Island, Northern Great Barrier Reef Fishery Bulletin 92 (1) 46–57
[3] Grandcourt E M, Al Abdessalaam T Z, Francis F and Al Shamsi A T 2005 Population biology and assessment of the orange-spotted grouper, Epinephelus coioides (Hamilton, 1822), in the southern Arabian Gulf Fish. Res. 74 55–68
[4] KKP (Kementerian Kelautan dan Perikanan) 2015 Kelautan dan Perikanan dalam angka 188
[5] Quinn T J II and Deriso R B 1999 Quantitative fish dynamics (Oxford: Oxford University Press) 542
[6] Agustina S, Panggabean A S, Natsir M, Jimmi, Retnoningtyas H and Yulianto I 2018 Profile of grouper and snapper fisheries stock in Saleh Bay, West Nusa Tenggara Province Wildlife Conservation Society 2016
[7] Sparre P and Venema S C 1998 Introduction to tropical fish stock assessment Part 1: Manual FAO Fisheries Technical Paper No. 306.1 Rev. 2, 407
[8] Cadima E L 2003 Fish stock assessment manual FAO fisheries technical paper (393) (Rome: DANIDA) 66
[9] Oh S R, Kang H C, Lee C H, Hur S W, and Lee Y D 2013 Sex reversal and masculinization according to growth in longtooth grouper Epinephelus bruneus Dev. Reprod. 17
[10] Ayling A M, Ayling A L and Mapstone B D 1991 Possible effects from protection by fishing pressure on recruitment rates of the coral trout (Plectropomus leopardus: Serranidae) In Recruitment processes (D. A. Hancock, ed.) 210–215 (Hobart: Australian Society for Fish Biology Workshop)
[11] Government of Malawi 2001 National Fisheries and Aquaculture Policy Ministry of Natural Resources and Environmental Affairs
[12] Pereiro J A 1992 Some conceptual remarks on yield per recruit. Fish. Res. 13 423–428
[13] Froese R 2004 Keep it simple: three indicators to deal with overfishing Fish and Fisheries 5 86-91
[14] Hilden M and Lehtonen H 1982 Management of the bream, Abramis brama (L.) stock in the Helsinki sea area. Finnish Fish. Res. 4 46–61
[15] Clark W G 1993 The effect of recruitment variability on the choice of a target level of spawning biomass per recruit. In G Kruse, D M Eggers, R J Marasco, C Pautzke and T J Quinn (eds.) Proceedings of the International Symposium on Management Strategies for Exploited Fish Population Alaska Sea Grant College Program Report 233–246
[16] Punt A E 1993 The use of spawner biomass-per-recruit in the management of linefisheries In L E Beckley and R P van der Elst (eds.). Fish, fishers and fisheries Proceedings of the Second South African Marine Linefish Symposium, Durban 23–24 October 1992, Oceanographic Research Institute, Special Publication, 2 80–89
[17] Mace P M 1994 Relationship between biological reference points used as thresholds and targets for fisheries management Common strategies Canadian J. Fish. and Aqua. Sci. 51 110–122
[18] Griffiths M H 1997 The application of per recruit models to Argyrosomus inodorus, an important South African sciaenid fish. Fish. Res. (4) 46–61
[19] Booth A J and Buxton C D 1997 Management of the panga Pterogymnus laniarius (Pisces: Sparidae) on the Agulhas Bank, South Africa using per recruit models Fish. Res. 32 1–11
[20] Kirchner C H 2001 Fisheries regulations based on yield–per-recruit analysis for the linefish silver kob Argyrosomus inodorus in Nambian waters Fish. Res. 52 155–167
[21] Booth A J 2004 Determination of cichlid specific biological reference points. Fish. Res. 57 307–316