Bioeconomic analysis of skipjack tuna fisheries in North Gorontalo Regency, Indonesia

N Auliyah1*, F Rumagia2, A Sinohaji3, U Muawanah4

1 Department of Fisheries, Faculty of Agricultural, Gorontalo University, Gorontalo, Indonesia.
2 Study Program of Fisheries Resource Utilization, Faculty of Fisheries and Marine, Khairun University, Ternate, Indonesia.
3 Kwandang Fishing Port, Directorate General of Capture Fisheries, Ministry of Marine Affairs and Fisheries, Kwandang, North Gorontalo Regency, Indonesia.
4 The Research Center of Socio Economics of Marine Affairs and Fisheries, Ministry of Marine Affairs and Fisheries Republic of Indonesia, Jakarta, Indonesia.

* Email correspondent: nurulauliyah05@gmail.com

Abstract. The model of the skipjack tuna resource management that can provide maximum rent can be done with a clear ownership regime (sole owner) or in the condition of MEY balance. However, the management and utilization of skipjack tuna resources must also consider the factors that can result in overfishing of both biological and economics overfishing. This study aims to assess the management and utilization of skipjack tuna fisheries resources in North Gorontalo Regency using a bioeconomic approach. Data processing is done by approaching the bioeconomic model using skipjack tuna fisheries biological and economic parameters. The results showed that the maximum rent obtained in skipjack fisheries in North Gorontalo Regency was at the MEY regime compared to the MSY and OA regime. However, based on the actual data obtained, it is known that the average production of skipjack tuna in North Gorontalo Regency has not reached the optimum catch value in the equilibrium condition of MSY (h_{MSY}), but in some period the actual catch value has passed the optimal catch value (h_{MSY}), this means that skipjack tuna has overfished (biological overfishing). While the actual production value of skipjack tuna catches in North Gorontalo Regency has passed the production of optimum MEY (h_{MEY}). This condition indicates that actually skipjack tuna resources have experienced an economic overfishing.

1. Introduction

North Gorontalo Regency is known one of the center production of skipjack tuna in Gorontalo Province that supported by the existing of Kwandang and Gentuma Fishing Port. In 2017, the production of skipjack tuna from North Gorontalo is 51.391 ton from the provincial total production of 134.889 ton [1]. The production value of skipjack tuna in 2017 for Gorontalo Province were IDR 896,593,674,000 [2], while the production value of skipjack tuna in Kwandang Fishing Port are IDR 11,479,557,000 [3]. The skipjack tuna fisheries at North Gorontalo Regency was dominated by the purse seine and hand-line fishing. The common production of skipjack tuna fisheries from the region were fresh fish and processed fish products [1].
Bioeconomics is a field of science that integrates biological and ecological resources with the economic behavior of fisherman, within consideration the dimension of space, time and uncertainty. The relative importance of including some or all of the dimensions mentioned in the fisheries bioeconomic modelling and analysis, will depend on the questions related to fisheries management, stock mobility, and sensitivity to environment factors and possible behaviour of fisherman [4].

The surplus production models (SPMs) is one of modeling approach that use simple data to produce maximum sustainable yield (MSY) and reference point in a fisheries activities [5]. Despite its limitations, SPMs remain one of the integrated assessment tools for the estimation and management of fisheries resources with limited to moderate data [6] [7], and meta-analysis to global fisheries [8, 9].

SPMs approach in bioeconomic research of skipjack tuna fisheries can be used to assessing the utilization and management status through estimated the production value on the MEY and MSY equilibrium [10]. Therefore, this research aimed to assess the utilization and management status of skipjack tuna fisheries at North Gorontalo Regency using the bioeconomic approach.

2. Materials and methods

2.1. Location, time, and data collection

The research was conducted from November 2020 until March 2021. Data was collected through survey and in-depth interview to skipjack tuna fisheries stakeholder at Kwandang and Gentuma Fishing Port, government officer, and literature study. The research location was showed in Figure 1.

![Figure 1. Map of the research area](image)

2.2. Data analysis

The estimation of sustainable catch value from fish stock is important in the fisheries resource assessment which should ideally be done by stock by stock basis. This study is using a surplus production model that assumes fish stock as the sum of biomass with the equation:

$$\frac{\partial X}{\partial t} = F(X_t) - h_t$$

where $F(X_t)$ is natural growth rate, and $h_t$ is catch rate.
There are two forms of the functional model that describes the stock biomass, which is the logistics and Gompertz, but in this study we used the logistics form, which is:

\[
\frac{\partial X}{\partial t} = rX_t \left(1 - \frac{X_t}{K}\right) - h_t
\]

where \(r\) is the intrinsic growth rate, and \(K\) is environment carrying capacity.

If the stock of fishery resources began to be exploited by fishermen, the exploitation rate of fisheries resources in a certain time unit is assumed to be a function of the effort used in the fishing and the stock of available resources. The functional form of the relationship can be written as follows:

\[
H(t) = H(E(t), X(t))
\]

Furthermore, it is assumed that the catch rate linearly with biomass and effort, as written in the following equation:

\[
H_t = qE_t X_t
\]

where \(q\) is catchability coefficient, and \(E_t\) is fishing effort. By assuming equilibrium conditions, the yield-effort curve of the above function can be written with the following equation:

\[
h_t = qKE_t - \left(\frac{q^2K}{r}\right)E^2
\]

Estimation of parameters \(r, K\), and \(q\) for the yield-effort equation using a non-linear technique. However, by writing \(U_t = \frac{h_t}{E_t}\) the equation \(\frac{\partial X}{\partial t} = F(X_t) - h_t\) can be transformed into a linear equation so that the ordinary regression model can be used to estimate the biological parameters of the above function. The estimation of the \(r, K\) and \(q\) parameters of skipjack tuna in this study used four models, which is Clarke Yoshimoto Pooley (CYP), Walter and Hilborn (W-H), Schnute, and Fox. The results of the estimation of the biological parameters of skipjack tuna are chosen as the one that is closest to the bioeconomic model of skipjack tuna in North Gorontalo Regency. Mathematically the formulations of the four models are presented in Table 1 [11]:

| Models                                  | Equation                                                                 | Explanation                                                                                     |
|-----------------------------------------|--------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| Clarke Yoshimoto Pooley (CYP)           | \(\ln(U_{t+1}) = a \ln(qK) + b \ln(U_t) - c(E_t + E_{t+1})\)             | \(a = \frac{2r}{2+r}, \ b = \frac{2-r}{2+r}, \ c = \frac{q}{2+r}\) and \(U_t = \frac{C_t}{E_t}\) |
|                                         | \(\ln(U_{t+1}) = a \ln(qK) + b \ln(U_t) - c(E_t + E_{t+1})\)             | \(E_t\) is fishing effort                                                                     |
| Walter and Hilborn (W-H)                | \(X_{t+1} = X_t + rX_t \left(1 - \frac{X_t}{K}\right) - C_t\)            | \(a = \frac{2r}{2+r}, \ b = \frac{2-r}{2+r}, \ c = \frac{q}{2+r}\) and \(U_t = \frac{C_t}{E_t}\) |
|                                         | \(\frac{U_{t+1}}{q} = \frac{U_t}{q} + \frac{U_t}{q} \left(1 - \frac{U_t}{K}\right) - U_t E_t\) | \(U_t = \frac{C_t}{E_t}\)                                                                     |
|                                         | \(\frac{U_{t+1}}{q} = \frac{U_t}{q} + \frac{U_t}{q} \left(1 - \frac{U_t}{K}\right) - U_t E_t\) | \(a = r, \ b = \frac{r}{qK}\)                                                                  |
| Schnute                                 | \(\frac{dX}{dt} = rX_t \left(1 - \frac{X_t}{K}\right) - C_t\)            | \(a = r, \ b = \frac{r}{qK}, \ and \ c = q\)                                                 |
|                                         | \(\ln \left(\frac{U_{t+1}}{U_t}\right) = a - b \left(\frac{U_{t+1} + U_t}{2}\right) - \frac{C_t}{c(E_t + E_{t+1})}\) | \(C_t = qX_tE_t\)                                                                               |
| Fox                                     | \(C_t = qK E_t \exp \left[-\frac{a}{r} E_t\right]\)                      | \(a = \ln(qK)\) and \(b = \frac{q}{r}\)                                                      |
|                                         | \(U_t = qK E_t \exp \left[-\frac{a}{r} E_t\right]\)                      |                                                                |
Bioeconomic analysis in this study simulates the policy regime within three management regimes, which is open access where profit is dissipated, sole owner to maximize fishery profit (MEY) and the sole owner to maximize the biological yield (MSY) with the fish stock growth dynamics as the limiting factor is. Mathematically the bioeconomic equation in equilibrium conditions is calculated by the equations listed in Table 2 [12, 13].

### Table 2. Bioeconomic equations for each management regime

| Parameter | Management regime | Maximum Economic Yield (MEY) | Maximum Sustainable Yield (MSY) | Open Access (OA) |
|-----------|------------------|------------------------------|---------------------------------|------------------|
| Biomass ($x$) | ($x$) = $\frac{K}{2} \left(1 + \frac{c}{p \cdot q \cdot K} \right)$ | ($x$) = $\frac{K}{2}$ | ($x$) = $\frac{c}{p \cdot q}$ |
| Catches ($h$) | ($h$) = $\frac{r \cdot K}{4} \left(1 + \frac{c}{p \cdot q \cdot K} \right) \left(1 - \frac{c}{p \cdot q \cdot K} \right)$ | ($h$) = $\frac{r \cdot K}{4}$ | ($h$) = $\frac{r \cdot c}{p \cdot q} \left(1 - \frac{c}{p \cdot q \cdot K} \right)$ |
| Fishing Effort ($E$) | ($E$) = $\frac{r \cdot K}{2q} \left(1 - \frac{c}{p \cdot q \cdot K} \right)$ | ($E$) = $\frac{r}{2q}$ | ($E$) = $\frac{r}{q} \left(1 - \frac{c}{p \cdot q \cdot K} \right)$ |
| Rent ($\pi$) | ($\pi$) = $\left(p - \frac{c}{q} \cdot x \right) \cdot \left(1 - \frac{x}{K} \right)$ | ($\pi$) = $p \left(\frac{r \cdot K}{4} - \frac{r \cdot c}{2q} \right)$ | ($\pi$) = $p \cdot h - \frac{c \cdot h}{q \cdot x}$ |

Note: $X$ = skipjack biomass; $h$ = skipjack sustainable catch; $E$ = skipjack fishing effort; $\pi$ = economic rent of skipjack; $r$ = intrinsic growth rate; $q$ = catchability coefficient of skipjack; $K$ = environment carrying capacity.

The selection of the bioeconomic model used in the data analysis process was carried out using two value, the R-Square and Adjusted R-Square values. R-Square is a coefficient of determination, that ranges from 0 – 1. An important property of R-Square is that its value always increases as the number of independent variables increases. Therefore, the researcher cannot compare the two models using this R-Square ($R^2$) if the number of independent variables is not the same. Based on this, to compare the model with a different number of independent variables, there is an alternative coefficient of determination called the Adjusted R-Square. R-Square is always positive, but Adjusted R-Square can be negative even though the R-Square is positive. This can be explained by the equation [14]:

$$R^2 = 1 - \frac{RSS/(n - k)}{TSS/(n - 1)} = 1 - \left(1 - R^2\right) \frac{n - 1}{n - k}$$

where $n$ is number of observation, $k$ is number of variable (dependent and independent), RSS is the square of the difference between the predicted and the average of Y value, and TSS is the square of the difference between the actual and the average of Y value.

The R-Square equation shows that the Adjusted R-Square will be negative when the R-Square value is too small while the ratio between the number of observations ($N$) and the number of variables ($k$) is too small (meaning there are too few data or too many variables). However, if the R-Square has a high value, even though the number of data is small or there are many variables, then the Adjusted R-Square will remain positive. This means that if the Adjusted R-Square is negative, it indicates that the model is not good (small R-squared). Based on the Adjusted R-Square and R-Square values, the model chosen is the one with the high R-Square value and the positive Adjusted R-Square value.

### 3. Result

#### 3.1. Skipjack tuna production, trip and CPUE

The catch production of skipjack tuna in North Gorontalo Regency based on data from 2003 to 2020 (Table 3 and Figure 2) shows that the average skipjack tuna production reaches 1,486,448 kg per year (1,486.45 tons per year) with decrease of production growth 5.56 percent per year on average. During the 2003-2020 period, the largest skipjack tuna production occurred in 2005 which reached 2,414,000
kg (2,414 tons), while the lowest production occurred in 2010 which only reached 1,147,000 kg (1,147 tons).

Table 3. The number of catch, fishing effort and CPUE of skipjack tuna in North Gorontalo Regency from 2003 to 2020 after fishing gear standardization

| Year | Number of catch (kg) | Fishing effort (trip) | CPUE (kg/trip) |
|------|----------------------|----------------------|----------------|
| 2003 | 1,805,000            | 29,052               | 62.13          |
| 2004 | 1,556,000            | 13,080               | 118.96         |
| 2005 | 2,414,000            | 13,884               | 173.87         |
| 2006 | 1,884,000            | 19,988               | 94.26          |
| 2007 | 1,361,000            | 25,232               | 53.94          |
| 2008 | 1,641,000            | 34,025               | 48.23          |
| 2009 | 1,938,000            | 20,721               | 93.53          |
| 2010 | 1,147,000            | 24,807               | 46.24          |
| 2011 | 1,242,876            | 20,861               | 59.58          |
| 2012 | 1,286,739            | 16,915               | 76.07          |
| 2013 | 1,397,475            | 12,970               | 107.75         |
| 2014 | 1,116,165            | 9,024                | 123.69         |
| 2015 | 1,155,230            | 5,078                | 227.50         |
| 2016 | 1,194,295            | 1,132                | 1,055.03       |
| 2017 | 1,403,499            | 1,239                | 1,132.77       |
| 2018 | 1,733,117            | 1,486                | 1,166.20       |
| 2019 | 1,500,663            | 1,279                | 1,173.31       |
| 2020 | 1,325,255            | 1,051                | 1,260.95       |

Source: Standardization analysis results of data from Marine and Fisheries Office of North Gorontalo, Kwanang Fishing Port, and Gentuma Fishing Port.

Figure 2. Progress chart of the number of catches and efforts to skipjack tuna fishing in North Gorontalo Regency in the 2003-2020 period.

The number of skipjack fishing trips in the 2003-2020 period averaged 13,990 trips per year. The highest number of trips was occurred in 2008 with a total of 34,025 trips, while the lowest number of trips is in 2020 which was only 1,051 trips. CPUE analysis results show that in the 2003-2020 period, the average CPUE reached 392.12 kg per trip. The highest CPUE value occurred in 2020 which reached a value of 1,260.95 kg per trip, while the lowest value occurred in 2010 with a value of 46.24
kg per trip. Graphically, the trend of the CPUE value of skipjack tuna in North Gorontalo Regency is showed in Figure 3.

![Graph of CPUE trend](image)

**Figure 3.** Graph of CPUE trend of skipjack tuna fishing in North Gorontalo Regency in the period 2003-2020.

The results of the regression analysis on four biological models of skipjack tuna show that the CYP model has an R-Square value that is greater than the other three models with a positive Adjusted R-Square value. The R-Square value of the CYP model reaches 90.51% or in other words the variable number of fishing trips (E) can explain about 90.51% of the number of skipjack catches. While the Adjusted R-Square value is 0.89. The R-Square values of the Fox, WH and Schnute models are 81.81%, 13.57% and 16.21%, respectively, with positive Adjusted R-Square. Based on these results, the CYP biological model was chosen as the model used in the bioeconomic analysis of skipjack tuna in North Gorontalo Regency. The estimated value of the biological parameters of the CYP model for the values of $r$, $q$ and $K$ respectively are 1.12% per year, 0.00022055 per unit trip, and 6,084,825.61 kg per year. The estimated values of skipjack biological parameters from the four models are presented in Table 4.

| Estimation model | $r$ (% per tahun) | $q$ (1/ unit effort) | $K$ (Kg per year) |
|------------------|-------------------|---------------------|------------------|
| CYP              | 1,12              | 0.00022055          | 6,084,825.61     |
| W-H              | 2.49              | 0.00117458          | 1,804,401,58     |
| Schnute          | 0.98              | 0.00004022          | 37,400,715,59    |
| Fox              | 6,69              | 0.00010793          | 61,954,78        |

Source: data analysis results

3.2. *Estimation of skipjack tuna bioeconomic*

The bioeconomic estimation of skipjack tuna is carried out in three equilibrium conditions, that is open access (OA), maximum sustainable yield (MSY) and maximum economic yield (MEY). The estimation results of bioeconomic model are presented in Table 5 and graphically shown in Figure 4. The unit cost of fishing effort ($p$) from the fishing fleet is IDR 6,820,000 while the average unit price of the catch ($c$) is IDR 20,000.
Table 5. Bioeconomic estimation for skipjack tuna using CYP model

| Parameter       | Unit | MSY            | MEY            | OA               |
|-----------------|------|----------------|----------------|------------------|
| Biomass (x)     | Kg   | 3,042,412.8    | 3,815,489.92   | 1,546,154.23     |
| Catches (h)     | Kg   | 1,704,643.4    | 1,594,580.00   | 1,292,346.02     |
| Fishing effort (E) | Trip | 2,540          | 1,895          | 3,790            |
| Rent (π)        | IDR  | 16,766,871,901 | 18,968,139,740 | 0                |

Source: data analysis results

Figure 4. Bioeconomic estimation chart of skipjack tuna fisheries in North Gorontalo Regency

4. Discussion
The management of skipjack tuna resources aims to obtain the maximum economic benefits while still paying attention to the sustainability of its resources. Based on the results of the bioeconomic analysis (Table 5) in this study, it can be seen that the maximum rent obtained from skipjack fishing activities in North Gorontalo Regency is in the MEY regime compared to the other regimes. Optimal production in equilibrium conditions MEY ($h_{MEY}$) reaches 1,594,580.00 kg per year with the optimal number of trips reaching 1,895 trips and the maximum rent is IDR 18,968,139,740. However, based on the actual data (Table 3), in several catch periods, the actual production value of skipjack tuna catches has passed the MEY optimum production ($h_{MEY}$). The same thing was also found in the number of actual efforts in the 2003-2015 period which had exceeded the optimal efforts of the MEY regime. This condition shows that in actual fact the skipjack tuna resources have experienced economic overfishing.

The decrease in the number of fishing efforts in the 2014-2020 period is suspected due to the impact of the moratorium on capture fisheries business permits and the prohibition of transhipment since December 2014 as stated in the MMAF Regulation No. 56 and 57 of 2014 concerning moratorium on licensing and prohibition of transhipment of capture fisheries business. Based on the results of FGD with stakeholders of skipjack tuna fisheries in North Gorontalo Regency, information was obtained that there was a decrease in the number of fishing fleet units, especially purse seines based at Kwandang Fishing Port from 28 to 10 unit of fishing fleet. Meanwhile in Gentuma Fishing Port, skipjack fishing is mostly by fleets under 30 GT (16 units). This condition is also as obtained in the research results of Widodo and Suryanto [15] which state that in the period of December 2014-August 2015 all large pelagic purse seine fleets in Bitung have temporarily stopped for fishing operations due to the moratorium policy on capture fisheries business permits and prohibition of
transhipment. This condition affects the income level of fishery entrepreneurs, as stated in the research of Kondo et al. [16] which states that capture fisheries production in Bitung, which began to decline drastically in 2015 due to the moratorium on capture fisheries business permits and the prohibition of transhipment, had an impact on employment, so that fishing businesses rely solely on vessels with a size of 30 GT, entrepreneurs are forced to reduce manpower to increase their productivity.

The estimation results of the optimal catch value of skipjack tuna fisheries in MSY equilibrium ($h_{\text{MSY}}$) at North Gorontalo Regency have obtained a value of 1,704,643.39 kg per year with the optimal number of trips reaching 2,540 trips and the maximum rent were IDR 16,766,871,901. The actual data indicate that the average production of skipjack tuna in North Gorontalo Regency has not yet reached the optimum catch value at MSY equilibrium conditions ($h_{\text{MSY}}$), but in several periods the value has passed the optimal catch value ($h_{\text{MSY}}$), meaning that skipjack fishing has experienced overfishing (biological overfishing) as happened in 2003 and 2005-2006, as well as in 2018.

In the open access condition, the economic rent for skipjack management is zero. This is due to capture fisheries actors competing in increasing fishing inputs (e.g. increasing ship tonnage, increasing hold volume or adding labor) so that in aggregate the input (effort) will increase. This will continue until economic rent is dissipated [13]. The management model that can provide maximum rent for skipjack tuna fisheries can be done with a clear ownership regime (sole owner) or in a condition of MEY equilibrium. However, the management and utilization of skipjack tuna resources must also consider factors that can lead to overfishing both biologically and economic overfishing. This condition occurs in fish resources throughout Indonesia Fisheries Management Area (WPPNRI) at this time [17]. Therefore, a policy is needed to control skipjack fishing in North Gorontalo Regency. It is meant that the MEY equilibrium approach can provides maximum rent while maintaining the sustainability of skipjack fisheries resources and businesses in North Gorontalo Regency.

5. Conclusion
The management model of skipjack tuna fisheries that can provide maximum rent can be done with a clear ownership regime (sole owner) or in a condition of MEY equilibrium. However, the management and utilization of skipjack tuna resources must also consider factors that can lead to overfishing both biologically and economic. Therefore, a policy is needed to control skipjack tuna fishing in North Gorontalo Regency. This is so that the equilibrium approach can provides maximum rent while maintaining the sustainability of skipjack tuna resources and businesses in North Gorontalo Regency.

Reference
[1] DKP Provinsi Gorontalo 2020 Statistik Perikanan Provinsi Gorontalo 2019 (Gorontalo: Dinas Perikanan dan Kelautan Provinsi Gorontalo)
[2] BPS 2018 Nilai Produksi Perikanan Tangkap di Laut Manurut Komoditas Utama tahun 2017 available at: https://www.bps.go.id/indicator/56/1516/1/nilai-produksi-perikanan-tangkap-di-laut-menurut-komoditas-utama.html
[3] PPN Kwandang 2019 Statistik Perikanan 2019 (Kwandang: Kementerian Kelautan dan Perikanan Direktorat Jendral Perikanan Tangkap Pelabuhan Perikanan Nusantara Kwandang)
[4] Anderson L G and Juan C S 2010 Bioeconomics of Fisheries Management (Iowa:Wiley-Blackwell Publication) p. 297
[5] Winker H, Carvalho F and Kapur M 2018 Fisheries Research 204 275–288
[6] Dichmont C M, Deng R A, Punt A E, Brodziak J, Chang Y J, Cope J M, Ianelli J N, Legault C M, Methot R D, Porch C E, Prager M H and Shertzer K W 2016 Fisheries Research 183 447–460
[7] Punt A E, Su N-J and Sun C-L 2015 Fisheries Research 166 103–118
[8] Froese R, Demirel N, Coro G, Kleissner K M and Winker H 2017 Fish and Fisheries 18 506–526.
Acknowledgments
This research was funded by Conservation Strategy Fund (CSF) through the 2020-2021 Groundwork Analysis (GWA) Program (Grant No. GA06-CSFIDN-GWAII-2020) by CSF and Faculty of Fisheries and Marine Sciences of IPB University (FPIK-IPB). Therefore, the author would like to thank CSF and FPIK IPB University for the funding and trust given to the implementation of this research. We were also grateful for all stakeholder that provides data for the research.