Application of Surplus Production Model to the Yellowfin Tuna *Thunnus albacares* in the northern and western parts of Aceh waters

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Abstract. Yellowfin tuna *Thunnus albacares* is one of pelagic fish that has high potential and economic value in Banda Aceh. Utilization of this resource in Banda Aceh is using purse seine units, with the number of purse seines continuously increasing. Therefore, management needs to be done so that optimal productivity can be maintained. This study discusses the estimation of catch and effort at maximum sustainable yield (MSY) of yellowfin tuna based on catch per unit effort (CPUE) and purse seine production in Banda Aceh during 2013-2018. Mathematical analysis was carried out using the equilibrium approach with the Schaefer model. The highest catch of yellowfin tuna reached 191 tons (July) and the average CPUE for yellowfin tuna was 0.796 tons/trip with C<sub>MSY</sub> of 2,482 tons/year and E<sub>MSY</sub> of 2,765 trips/year. From 2015 to 2018, the trend of biomass continued to decline and overfishing occurred during this period.

1. Introduction

Indonesia has the potential for diverse and exploitable fish resources with high economic value, one of which is yellowfin tuna. This type is also the highest catch compared to other tuna species in Indonesia [1]. The migration area of tuna (including yellowfin tuna) in Indonesian waters is centered on the border of the Indian Ocean and the Pacific Ocean [2]. Many types of yellowfin tuna in Aceh Province are produced using purse seine and handline, one of which is landed at Kutaraja Fishing Port. Yellowfin tuna production has increased from 2013-2018 by as much as 63.78%. This condition was accompanied by an increase in the number of fleets from 223 units in 2013 to 264 units in 2018 [3]. An increase in the number of fishing fleets will affect the fishing capacity, which is indicated by the presence of overfishing activities [4]. Fishing capacity is the ability used by fishing units to obtain catches [5]. Possible problems that can occur if excessive fishing capacity continues, namely fishermen will experience economic losses and fish stocks will continue to decline. Variables that affect fishing capacity include ship size, ship engine size, net size, and technology of fishing equipment [6,7]. Therefore, to overcome this, careful management is needed so that optimum productivity can be maintained. The availability of the best scientific study results (best scientific evidence) is one of the requirements in the management of fisheries resources, which is stated in the United Nations Fish Stock
Agreement (UNFSA) in 1995 [8]. The purpose of this study is to examine the trend of monthly production of yellowfin tuna catches in 2018 and calculate the maximum sustainable yield (MSY) of yellowfin tuna in Kutaraja Fishing Port.

2. Material and Methods

2.1. Site and Time
This research was conducted for four months starting from August 29 to December 30, 2018. The research location was conducted at Kutaraja Fishing Port, Banda Aceh, Aceh Province, Indonesia.

2.2. Sampling and Measurement Procedures
The data was collected using a survey method. Primary data collection is done by the probability sampling method. Data collection is based on primary data and secondary data from the last five years. The primary data in this study is monthly fishing data with a sample of 66 vessels with a size of more than 30 GT, and secondary data in the form of statistical data on the number of vessels and fishing trips for the last five years.

2.3. Data Analysis
The production of yellowfin tuna catches in 2018 was analyzed using descriptive statistical methods, by classifying, tabulating and interpreting the data and presented in graphical form to describe the condition of the catch so that it is better understood by everyone [9]. This method is carried out through an approach to the trend of the catch of purse seine fishermen. The catch data includes the types and numbers of fish obtained from the UPTD (Regional technical management unit) of Kutaraja Fishing Port from January to August 2018, while from September to December, primary data is used from interviews using questionnaires. However, supporting data such as length of time at sea and fishing position were obtained from interviews with fishermen, especially ship handlers.

Meanwhile, the analysis of maximum sustainable potential uses the calculation of fishing effort and sustainable potential of yellowfin tuna as follows:

2.3.1. Calculation of the fishing effort of the purse seine fishing unit
Gulland [10] states that in the waters there are various types of fishing gear used, so one of these tools can be used as a standard fishing gear, while the other fishing gear can be standardized to the fishing gear. The fishing gear designated as standard fishing gear has a fishing power index (FPI) with a value equal to 1. The value of the catching ability of each fishing gear each year is obtained from the formula proposed by [11], namely:

\[ \text{CPUE}_{i} = \frac{G_i}{F_i} \] (1)
\[ \text{CPUE}_{st} = \frac{C_s}{F_s} \] (2)
\[ \text{FPI}_{st} = \frac{\text{CPUE}_{st}}{\text{CPUE}_{st}} = 1 \] (3)
\[ \text{FPI}_{i} = \frac{\text{CPUE}_{i}}{\text{CPUE}_{st}} \] (4)

For other fishing gear use the following equation:
Effort standard = \( \Sigma FPI_i \times \Sigma E_i \) (5)

Remarks:
CPUEst = catch per unit effort standard (st)
CPUEi = catch per unit effort standard (i)
Cs = catch (st)
Ci = catch(i)
Fst = fishing effort(st)
Fi = fishing effort (i)
The Fishing Power Index (FPI) of each fishing gear in each year is then averaged. The Fishing Power Index (FPI) is then multiplied by the effort or trip of each fishing gear to obtain a standard effort. After going through this standardization, the total actual production and total standard effort will be obtained which will be used in the next analysis method.

2.3.2. Calculation of the maximum sustainable yield (MSY) of yellowfin tuna

The method used is the Schaefer production surplus method to see the relationship between catch and fishing effort which was analyzed using Microsoft Excel. The relationship between these functions is:

\[ y = \alpha + \beta x + e \]  

(6)

Then it is entered into the linear regression equation, namely:

\[ y = a + bx \]  

(7)

Remarks:

- \( y \) = dependent variable (CPUE) (ton/unit)
- \( x \) = independent variable (effort)
- \( e \) = error
- \( \alpha, \beta \) = estimating regression parameter values of a and b
- \( a \) = Intercept
- \( b \) = Slope

Furthermore, the calculation of the MSY value can use the following formula:

\[ f_{\text{opt}} = \frac{-a}{2b} \]  

(8)

\[ \text{MSY} = \frac{-a^2}{4b} \]  

(9)

Remarks:

- MSY = Maximum sustainable yield
- \( f_{\text{opt}} \) = Optimum effort
- \( a \) = Regression constant (CPUE)
- \( b \) = Regression constant (Effort)

The calculation of maximum sustainable yield is generated from the CPUE value and standard effort which is analyzed using linear regression which produces intercept and slope values. The value of the linear regression results can be entered into the equations of the formula (8 and 9) so that it can produce the optimum effort value \( (E_{\text{MSY}}) \) and maximum sustainable yield \( (C_{\text{MSY}}) \). The results of the sustainable potential will be presented in the form of a graph that can describe the condition of the catch caught by purse seine with a certain fishing effort capacity.

3. Result and Discussion

3.1. Monthly production of yellowfin tuna

The production of ring trawl catches caught and landed in Kutaraja Fishing Port during the study was yellowfin tuna \( (T. \text{albacares}) \) which belongs to the fish family Scombridae. The catch of yellowfin tuna landed at Kutaraja Fishing Port has a total production of 1,368 tons in 2018. The results of the analysis of yellowfin tuna production landed at Kutaraja Fishing Port are shown in Figure 1.

Figure 1 shows that the production of yellowfin tuna obtained at Kutaraja Fishing Port in 2018 fluctuated, with an average production of 114 tons. The highest production of yellowfin tuna occurred in July at 191 tons, while the lowest production was 45 tons in December. Yellowfin tuna catches are
caught every month with varying amounts. Purse seine is capable of catching various types of pelagic fish that live in groups. The catches that are often caught by purse seine gear, especially those landed at Kutaraja Fishing Port, are yellowfin tuna, skipjack tuna, and tuna, and this type of fish has high economic value in Indonesia. However, based on the production of purse seine catches during 2018, the number of catches varies each month. The results of the analysis of yellowfin tuna production tend to fluctuate with an average production of 114 tons in 2018. From January to June 2018 the production of yellowfin tuna has increased. This is presumably because the condition of the waters that year was in a fairly good condition so that there was sufficient food availability to be utilized by migrating tuna. Minarro et al. (2016) [12] also explained that the biggest influence on fish migration was the food availability factor. The decline in yellowfin tuna production occurred from August to December 2018. The production of yellowfin tuna landed in that month is also small. It is suspected that the water conditions are not suitable, such as strong currents and waves, so that fishermen cannot operate their fishing gear properly.

![Fish Production Graph](image)

**Figure 1.** Production of yellowfin tuna *Thunnus albacares* in 2018 landed at the fishing port of Kutaraja, Banda Aceh.

The catches of yellowfin tuna are fluctuated. This is presumably due to the influence of bad weather, so it is difficult for fishermen to carry out fishing activities optimally. Information obtained from fishermen, in December 2018 fish had begun to be very difficult to obtain. This is due to unfavorable sea conditions, such as wind and high waves. This condition occurred allegedly due to the change of the east season which entered the west season. Kurniawan (2013) [13] stated that the arrival of the west monsoon made sea conditions unfavorable, such as heavy rains, high winds and waves, so this caused fishermen not to dare to go to the sea and fish resources also became difficult to catch. So, even though the availability of fish is abundant in the sea, if the weather does not support the catch, the catch will also continue to decline.

3.2. **Maximum sustainable yield of yellowfin tuna**

3.2.1. **Catch per unit effort (CPUE) of purse seine**

The results showed that purse seine obtained the highest CPUE value compared to hand line fishing gear, so that purse seines were used as standard fishing gear to catch yellowfin tuna. Total catch, total effort, and catch per unit effort (CPUE) of yellowfin tuna showed in Table 1.
Table 1. Catch, effort and CPUE of yellowfin tuna *Thunnus albacares* at the fishing port of Kutaraja, Banda Aceh.

| Year | Catch (ton) | Effort Standard (trip) | CPUE Standard (ton/trip) |
|------|-------------|------------------------|--------------------------|
| 2013 | 1,599       | 948                    | 1.69                     |
| 2014 | 1,474       | 2,447                  | 0.60                     |
| 2015 | 2,112       | 3,776                  | 0.56                     |
| 2016 | 2,453       | 3,976                  | 0.62                     |
| 2017 | 2,293       | 3,488                  | 0.66                     |
| 2018 | 2,507       | 3,838                  | 0.65                     |
| Average | 2,073      | 3,079                  | 0.80                     |

Table 1 shows the production of yellowfin tuna has increased along with the increase in fishing effort that occurs. The highest production of yellowfin tuna reached 2,507 tons in 2018 with 3,838 trips of fishing effort. However, the lowest production reached 1,474 tons in 2014 with a fishing effort of 2,447 trips. Yellowfin tuna is exploited every year with varying amounts of production and fishing efforts. Gemaputri (2013) [14] explains that if the highest CPUE value can be interpreted as catches caught in large quantities, but with little effort. This can be interpreted that the availability of fish in the waters is still very much and can regenerate. The addition of fishing effort can reduce the production of the catch, this is presumably due to the large fishing effort so that the catch also increases. However, when the fishing effort increases in the following year, it will be able to reduce catch production and also reduce CPUE. A decrease in CPUE may indicate a decrease in fish biomass in the waters [15]. Catch production and fishing effort for yellowfin tuna continued to increase from 2015 to 2018. However, CPUE from 2015 to 2018 fluctuated.

3.2.2. *Maximum sustainable yield (MSY)*

The results show that increased fishing effort does not result in higher production. The relationship between CPUE and the effort to catch of yellowfin tuna tends to decrease in Figure 2.

![Figure 2](image-url)  
*Figure 2. Linier regression of CPUE and effort standard of yellowfin tuna Thunnus albacares.*

The results of the regression analysis (Figure 2) show the relationship between standard effort and catch per unit of a standard effort. The regression parameter value is the intercept of 1.795 and the slope of -0.00032x, resulting in a coefficient of determination of 0.768. The regression equation shows that CPUE tends to decrease if there is an increase in the effort to catch yellowfin tuna. These results also indicate that fishing effort will affect the catch. The calculation of the optimum fishing effort (E<sub>MSY</sub>)
resulted in a value of 2,765 trips/year with the maximum sustainable production yield \((C_{\text{MSY}})\) of yellowfin tuna of 2,482 tons/year. The maximum sustainable yield point curve is shown in Figure 3.

![Figure 3](image_url)

**Figure 3.** Determination of MSY of yellowfin tuna *Thunnus albacares* in the northern and western parts of Aceh waters.

Figure 3 shows that in 2013 yellowfin tuna production was 1,599 tons which were still below the maximum sustainable production \((C_{\text{MSY}})\), while in 2014 it decreased. The production of these fish from 2014 to 2017 ranged from 1,400 to 2,450 tons which is almost close to the maximum sustainable potential \((C_{\text{MSY}})\). However, in 2018 the production of tuna fish experienced a significant increase to 2,507 tons which has exceeded the maximum sustainable potential production \((C_{\text{MSY}})\). Catching efforts also continued to increase from 2013 as many as 948 trips to 3,838 trips in 2018.

Estimation of sustainable potential is carried out using data from catches landed in Kutaraja Fishing Port as well as fishing efforts using purse seine, handline, and longline fishing gear [3]. This is done to see the condition of the fishing capacity that occurs in the Kutaraja fishing port. Estimation of sustainable potential was carried out on yellowfin tuna. The graph of the correlation between standard CPUE and standard effort of yellowfin tuna shows a linear equation relationship, which means that if there is no fishing effort, then the condition of potential resources of yellowfin tuna is still stable. However, if the fishing effort is \(x\) units per year, it will reduce the CPUE value by 0.00032 tons/year and vice versa. The value of the coefficient of determination is 0.768 or 76.8\% which indicates that the increase and decrease in CPUE are caused by the fluctuation of the value of fishing effort, while the remaining 23.2\% is caused by other variables not discussed in the model. It can be concluded that the fishing effort greatly affects the catch. The number of fishing efforts made in these years can also increase the level of competition between fishermen so that catches also decrease [16]. Jaya et al.[17] explains that the decline in CPUE also occurred due to the density of fishing efforts, this occurred in the Sendangbiru area from 2013 to 2015.

The value of this regression calculation will be able to produce a calculated value of the estimated potential resources of yellowfin tuna in Kutaraja Fishing Port showing that the optimum fishing effort \((E_{\text{MSY}})\) is 2,765 trips/year with the maximum sustainable production \((C_{\text{MSY}})\) of yellowfin tuna is 2,482 tons/year. year. Based on the MSY curve (Figure 3), yellowfin tuna caught by purse seine from 2013 to 2018 have exceeded their optimum fishing effort, which means that overfishing has occurred in a certain year. However, the amount of yellowfin tuna production in 2013 to 2017 was below the maximum sustainable production \((C_{\text{MSY}})\). It can be concluded that since 2013, the carrying capacity of the environment has not been able to sustain the recovery of the yellowfin tuna resource stock that was landed at Kutaraja Fishing Port due to excessive fishing effort.
The total production of yellowfin tuna in 2018 increased by 2,507 tons/year to exceed the maximum sustainable production (CMSY). This can be due to changes in the pattern of fishing activities carried out by fishermen with purse seine, namely the addition of fishing effort (number of fishing gear operations), and the fishing area being the target of fishing has a longer distance. So that in 2018 there has been overfishing of yellowfin tuna resources. The fishing effort in 2013 and 2014 had a number of trips below the optimum effort, while in 2015 to 2018 the fishing effort increased beyond the optimum effort. Based on interviews with fishermen, the influence of weather and waves also greatly affects the catch, so this has an impact on increasing fishing effort and fishing grounds.

The condition of the maximum sustainable yield of yellowfin tuna has experienced overfishing in 2018. Rihi [18] explained that this has also begun to occur in the waters of NTT that yellowfin tuna has experienced overfishing but by using handline, this condition is due to production the actual amount of tuna fish was 997.41 tons which had exceeded the maximum production limit (CMSY), with an average actual effort of 4,532 units of standard fishing gear exceeding the capacity (EMS). Jaya et al. [17] also stated that the utilization of tuna fish resources in the Sendangbiru area was already at an over exploited level. Sibagariang [19] also explained that the sustainable potential of tuna fish resources in Cilacap Regency, Central Java is 1,439.86 tons/year and the optimum effort is 155 units/year. The utilization rate in the area is in overfishing conditions using long line tuna fishing gear. Sustainable fisheries management can be done so that it does not become an impact in the future. The steps that can be taken are reducing fishing effort and limiting the catch caught. This is to keep fish resources able to regenerate in a sustainable.

4. Conclusion
The conclusions of this study are the highest production catch of yellowfin tuna occurred in July reaching 191 tons with the average CPUE of yellowfin tuna in 2013 to 2018 was 0.796 tons/trip with CMSY 2,482 tons/year and EMS 2,765 trips/year.

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