Application of surplus production model on tuna fishery in Sabang, Weh Island, Indonesia

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Abstract. Production of tuna in Sabang on the last two years has decreased significantly. In 2015, for example, the number of tuna production was 6,124 tons per week, while in 2017 it fell to 5,200 tons per week, or decreased by around 15 percent. This study aimed to analyze the amount of biomass, catch, and effort of tuna in sustainable conditions in Sabang using a quantitative method and 11 years (2006-2016) time-series data. The data consisted of catches and inputs from each fishing gear per year during the observation period. The data were analyzed by the surplus production model that was processed using Excel and Shazam. The results showed that the sustainable and actual production function models of tuna in Sabang had trajectories with patterns that continued to increase during the observation period. The current level of production over the past few years has exceeded sustainable production, and if this condition continues, it is feared there will be overfishing and overcapacity.

1. Introduction

Sabang is a municipality in Aceh Province located at Weh Island, which is surrounded by the sea. Is is known to have abundant fish resources. According to [1] and [2] that maximum sustainable yield (MSY) on the west coast of Aceh reached 366,260 tons/year and the east coast was 127,670 tons/year. The typical species caught and traded in Sabang are tuna, skipjack, grouper. However, the wealth of fish resources and the high potential for sustainable production, as mentioned above, are not reflected in the socio-economic conditions of fishermen, some of them live in poor condition.

Based on the results of observations and interviews with fishermen and Panglima Laot Lhok Ie Meulee in Sabang on 12 November 2017, the number of captures by fishermen since the last two years has decreased significantly. In 2015 for example, the number of tuna capture at Ie Meulee Fishing Port was 6,124 tons per week, while in 2017 it fell to 5,200 tons per week, or decreased by around 15 percent (Panglima Laot Lhok Ie Meulee, 2017). The decline in the capture is due to reduced tuna biomass (stock) caused by overfishing, which is characterized by a decline in the capacity of tuna fisheries.

According to [3] capacity is the maximum amount that can be produced per unit of time with existing fishing boat and equipment, where the existence of various factors of production of variables is not limited. Salz (1994) in [4] states that fisheries capacity is a
number of fish that can be caught by certain vessels or certain fishing gear per year, depending on productivity per unit of capture time (e.g., CPUE per hour) and number of units of capture time (for example, fishing hours per year). Fisheries capacity has become the main topic of discussion in the international fisheries community. This is due to the overcapacity of world fisheries, which can threaten the sustainability of fisheries resources or the global fisheries crisis. Where there has been excess capacity, a mechanism should be in place to reduce capacity at an equivalent level with sustainable use of fisheries resources such as ensuring that fishers operate under economic conditions that support responsible fisheries [5]. According to [6], overcapacity in the fisheries sector will cause various problems. First, the performance of the fisheries sector is not healthy so that the issues of poverty and resource degradation and the environment become more persistent. Secondly, overcapacity will also cause intense pressure to exploit fish resources over its sustainability point. Third, excess capacity will also create inefficiencies and trigger existing economic waste resources in addition to causing complications in fisheries management, especially in open access situations.

To overcome the occurrence of excess capacity management instruments are needed; namely, incentive blocking instruments, which are short-term solutions and incentive adjusting instruments, which are long-term solutions [7]. Incentive blocking instruments are policies to overcome excess capacity through the limitation of activities in various forms such as limited entry programs, restrictions on vessels and fishing gear (gear and vessel restrictions), and others. The incentive adjusting instruction is designed to reduce excess capacity by approaching property rights where later the reduction in capacity is left to the market mechanism and policies. Initially, the management of fisheries resources was based largely on biological factors solely by the MSY approach. The highest capture rate that can be cultivated continuously from a fish stock under the average environmental conditions is often used as a resource management goal. The essence of this approach is that each fish species has the ability to produce itself that exceeds production capacity (surplus), so that if this surplus is precisely harvested (no more and no less) then the fish stock will be able to survive sustainably [6], [8], and [9].

In the production surplus model, the dynamics of biomass are described as the difference between natural production and mortality (biomass at \( t + 1 \) = biomass at \( t + \) production - natural mortality). That is, if production exceeds natural mortality, then biomass will increase, whereas if natural mortality is higher than production, then biomass will decrease. The term production surplus itself illustrates the difference or difference between natural production and mortality above. This is similarly stated by Hilborn and Walter (1992) in [10], that the production surplus describes the amount of increase in fish stocks in conditions of no fishing activity or in other words the amount that can be caught if the biomass is maintained at a fixed level. One type of production surplus commonly used is developed by [11].

2. Materials and Methods
In the surplus production model, the dynamic of the biomass is reflected as a delta of the production and natural mortality. Thus, during the situation where the production exceeds the natural mortality, the biomass will increase, or vice versa. This is in line with Hilborn and Walter, as it was adopted in [10] that the production surplus reflects the increase of the fish stocks in the no catch activities. In other words, the production surplus is the amount of catches in the situation where the biomass can be managed in sustainable level.

The most popular approaches to assess the surplus production model is the Schaefer model [11]. Generally, the model can be explained as follows: if \( x \) is the stock biomass, \( r \) is the natural growth of the population, \( K \) is the carrying capacity, then under the non-fishing activities, the growth of biomass during \( t \) can be formulated as:

\[
\frac{dx}{dt} = f(x)
\]
Where \( f(x) \) is the growth function. One typical of the growth functions is the logistic growth function, and the formulation can be described as:

\[
\frac{dx}{dt} = rx \left(1 - \frac{x}{K}\right)
\]

If the production function \( H = qxE \) is introduced in the equation (2), and the catch is assumed to be linear with the biomass \( x \) and production inputs \( E \), then the biomass growth rate function can be written as:

\[
\frac{dx}{dt} = rx \left(1 - \frac{x}{K}\right) - qxE
\]

Where \( q \) is the catch capacity coefficient, and \( E_t \) is the effort. Under the equilibrium assumption, then the yield-effort function can be written as:

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

The estimated parameters \( r, K, \) and \( q \) for the yield-effort equation of the models above involve non-linear techniques. However, by writing \( U_t = \frac{h_t}{E_t} \), the equation can be transformed into a linear equation so that the usual regression method can be used to estimate the biological parameters of the function above. Parameter estimation techniques developed by [12] or often known as the CYP method, are as follows:

\[
\ln \left(\frac{U_t}{E_t}\right) = \frac{2r}{2+r} \ln \left(\frac{qK}{2+r}\right) + \frac{2r}{2+r} \ln \left(\frac{qK}{2+r}\right) - \frac{q}{(2+r)} \left(E_t + E_{t+1}\right)
\]

The values of the parameters \( r, q, \) and \( K \) in the above equation can be obtained through the following equation [13]:

\[
r = \frac{2(1-\beta)}{(1+\beta)}
\]

\[
q = -\gamma \left(\frac{2+r}{2+r}\right)
\]

\[
K = \frac{e^{\alpha(2+r)/(2r)}}{q}
\]

From the production time-series data for 11 years, it is used as the basis for the calculation of the yield effort curve using the SHAZAM 8.0 and Microsoft Excel 2016.

3. Results and Discussion

3.1 Fish production

Tuna production in Sabang for the past 11 years is shown in Table 1.

3.2 Total trip (effort)

Generally, tuna fishing gear in the Sabang is hand line and troll line. Both devices are owned by each boat and are operated simultaneously. Therefore, the number of trips between the two fishing gears is the same and counts as one unit. The amount of fish production and the number of trips to catch tuna are shown in Table 2.
Table 1. Production of tuna in Sabang (2006–2016).

| Year | Bigeye tuna | Yellowfin tuna | Total (Tons) |
|------|-------------|----------------|--------------|
| 2006 | 235.8       | 101.1          | 336.9        |
| 2007 | 310.5       | 107.4          | 417.9        |
| 2008 | 288.2       | 103.6          | 391.8        |
| 2009 | 147.2       | 149.0          | 296.2        |
| 2010 | 197.3       | 188.1          | 385.4        |
| 2011 | 148.4       | 247.4          | 395.8        |
| 2012 | 395.9       | 396.9          | 792.8        |
| 2013 | 436.7       | 101.1          | 537.8        |
| 2014 | 337.3       | 101.1          | 438.4        |
| 2015 | 282.7       | 208.2          | 490.9        |
| 2016 | 282.7       | 676.0          | 958.7        |

(Source: Aceh Marine and Fisheries Agency 2006–2016)

Table 2. Total trip (effort) of tuna fishing in Sabang.

| Year | Production (Tons) | Trip (effort) | CPUE |
|------|-------------------|---------------|------|
| 2006 | 336.9             | 16,315        | 20.65|
| 2007 | 417.9             | 11,866        | 35.22|
| 2008 | 391.8             | 10,080        | 38.87|
| 2009 | 296.2             | 8,474         | 34.95|
| 2010 | 385.4             | 8,474         | 45.48|
| 2011 | 395.8             | 7,118         | 55.60|
| 2012 | 792.8             | 7,996         | 99.15|
| 2013 | 537.8             | 5,864         | 91.72|
| 2014 | 438.4             | 6,275         | 69.86|
| 2015 | 490.9             | 6,688         | 73.40|
| 2016 | 676.0             | 9,979         | 67.74|

From Table 2, it has been seen that tuna production has increased from 2006 to 2016, even though there were several years which were rather fluctuating. Likewise, there has increased Capture Per Unit Effort (CPUE) from year to year, although in some years it has been fluctuating.

3.3 Estimated biological parameters

Some biological parameters needed in this study are growth parameters (r), carrying capacity (K), and capture coefficient (q). Estimation of biological parameters is carried out by Clarke, Yoshimoto, and Pooley (CYP) methods, as stated in the equation in the method chapter above. Parameter estimation is done by using the SHAZAM 8.0 software after the stationery test from the data, and the Cochran-Orcutt procedure is done to test the auto correlation of the variables used.

Table 3. Dickey Fuller's test results in Sabang.

| No. | Variable         | No Trend | With trend |
|-----|------------------|----------|------------|
| 1   | Ln CPUE          | -2.6469  | -2.3558    |
| 2   | (E_t + E_{t+1})  | -0.2543  | -1.4198    |

Note: asymptotic critical t-test at 10%: -2.57 for no trend and -3.13 for trend
Stationary test results using the Dickey-Fuller test procedure show that there are symptoms of non-stationary (trending) on variable effort, both effort for the east coast and west coast. This is indicated by the critical value of the Dickey-Fuller test which is smaller than the absolute value of 2.57, while the CPUE Log, for both the east coast and the west coast, without trend shows stationary data, because the critical value of the Dickey-Fuller test is greater than the absolute value 2.57. With these results, a co-integration technique approach is used to deal with non-stationary problems in estimating these parameters. After co-integration techniques were carried out and through the Cochrane-Orcutt iteration to eliminate autocorrelation, biological parameters were generated for analysis as presented in Table 4.

**Table 4.** The results of the analysis of the values of biological parameters

| No. | Parameter       | Value |
|-----|----------------|-------|
| 1.  | r              | 0.4241|
| 2.  | K              | 2021.45|
| 3.  | q              | 0.0032|
| 4.  | Durbin-Watson  | 1.8776|
| 5.  | R²             | 0.5821|

(Description: r = intrinsic growth, K = carrying capacity, q = capture power coefficient, and R = coefficient of determination)

3.4 Estimated sustainable production

Based on the values of biological parameters as listed in Table 4, the estimation of a sustainable production function is carried out by using the Gompertz yield-effort curve in the equation (4). The results of sustainable production of the previous calculation is compared with actual production to see how the performance of fish production during the time period 2006 -2016. Comparison of actual production and sustainable production according to the location of the study can be seen in Table 5.

**Table 5.** Actual and sustainable production (tonnes) in Sabang.

| Year | Effort     | Actual production | Sustainable production |
|------|------------|-------------------|------------------------|
| 2006 | 16315.200 | 336.900           | 273.508                |
| 2007 | 11865.600 | 417.900           | 477.222                |
| 2008 | 10080.000 | 391.800           | 500.283                |
| 2009 | 8474.400  | 296.200           | 492.318                |
| 2010 | 8474.400  | 385.400           | 492.318                |
| 2011 | 7118.400  | 395.800           | 464.423                |
| 2012 | 7995.600  | 792.800           | 484.683                |
| 2013 | 5863.500  | 537.800           | 421.336                |
| 2014 | 6275.400  | 438.400           | 437.309                |
| 2015 | 6687.600  | 490.888           | 451.503                |
| 2016 | 9979.200  | 676.000           | 500.583                |

Based on Table 5 it can be seen that the actual production in the year 2006 -2016 is relatively constant. In the year 2012, there was a significant increase followed by a decrease in 2013 although it was not significant. Whereas for sustainable production in Sabang, it is below the current actual production. This is the allegation that in Sabang has overcapacity. This is in accordance with the latest data from FAO (2009) in Fauzi (2010) showing that 28% of the world's fish stocks are generally in overexploited and depleted conditions. Around 52% of the world's fish stocks are already fully exploited, making space for expansion increasingly difficult. The comparison between actual and sustainable production in Sabang can be seen in Figure 1.
If the value of the biological parameters (Table 4) is inserted into logistics Schaefer above, it will obtain the sustainable production curve (yield-effort curve) Schaefer to Kota Sabang as follows:

\[ h_t = 0.1028E_t - \left[ \frac{0.00003^2 \cdot 3412}{0.5872} \right]E_t^2 \]

By using the production function equation at above, the sustainable production curve for the Sabang can be described as follows Figure 2.

Figure 1. Actual and sustainable production in Sabang.

Figure 2. Schaefer's sustainable production function in Sabang.
Sustainable function graph above illustrates that the maximum catch (MSY) of tuna with the Schaefer model is 500.42 tons per year, and the optimal effort is 9,500 trips per year. This is also one of the conjectures that overcapacity has occurred in certain years where the actual catch is far above the current sustainable catch. The principle of caution is needed in the management of tuna fish resources in Sabang. Besides that, it is also suspected that economic overfishing in tuna fishing in Sabang has been seen from a significant increase in operating costs per trip (after accounting for inflation). In 2006, the cost of catching fish per trip was Rp234.53, whereas in 2016 the cost increased to Rp665.47 per trip.

4. Conclusions
a) The model of the sustainable and actual production of fish in Sabang show a trajectory with an increasing pattern in recent years. Based on observations over the past 11 years, the actual production level has exceeded the sustainable and optimal production. It means overcapacity of tuna has occurred in Sabang.
b) It is expected that in the future, there will be effort control and fishing fleets by optimizing the existing fleet usage so that the welfare of fishermen can continue to be improved.

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