Bioeconomic analysis of mackerel (*Rastrelliger* spp) in the Belawan Gabion Ocean Fishing Port, North Sumatra Province

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Abstract. Mackerel is a small pelagic fish with high economic value. Many fishermen catch mackerel in large scale to get high profits, so there is a concern that overfishing will occur in the future. This research was conducted to determine the potential size of mackerel fish resources from a bioeconomic analysis that consists of biological aspects (MSY) and economic aspects (MEY) and as well as the magnitude of the actual and optimal levels of mackerel fish utilization. This research used Gordon Schaefer Bioeconomic Model and the Slovin method with 85% confidence level in taking respondents by purposive sampling. The optimal utilization rate of mackerel does not exceed the MSY value which was 3,208,972 tonnes/year, and there is under the TAC value, which is 80% of the MSY value. The next management effort can take carried out based on bioeconomic analysis were a reduction in the level of effort by 3683 trips and a reduction in the number of catches by 1,861 tons so that the water resources will be sustainable again. This can be done by limiting the fishing fleet.

1. Introduction

High biological resources and diversity are some of the marine fisheries' potentials in Indonesia as a tropical country. Based on the Statistics Report on the Belawan Ocean Fishing Port (2018), the production of mackerel, which is one of the dominant small pelagic fish caught, has increased production by (11%) of the total fish production according to small pelagic types. Almost all of the catch of mackerel was consumed by the local community. The dominant fishing gear used to catch small pelagic fish, especially mackerel in the waters of the Malacca Strait, consists of purse seines and gill nets.

The role and existence of the mackerel fish population (*Rastrelliger* spp) is important as a source of income for fishermen and to maintain the balance of the ecosystem, it is necessary to maintain the availability of mackerel fish (*Rastrelliger* spp) populations in Indonesian marine waters. One of them is used by analyzing the bio-economic value of the mackerel fish (*Rastrelliger* spp).

The utilization rate of mackerel at the Belawan Ocean Fishing Port in 2013 has reached 96%, meaning that has exceeded the permitted fishing limit [1]. Increased of fish followed by an increase in production and the result of exploitation exceeds the carrying capacity, ultimately leading to overfishing and exploitation of fish resources in open access sea waters, making the use of mackerel resources (*Rastrelliger* spp) tends to free without any restrictions as long as there are benefits to be
obtained. Based on these circumstances, it is necessary to conduct an assessment of the management of mackerel resources (Rastrelliger spp) so that overfishing does not occur through bioeconomic studies and optimization of the management of mackerel resources (Rastrelliger spp).

2. Materials and methods

2.1. Research location
This research was conducted in June - July 2020 at the Belawan Ocean Fishing Port, North Sumatra. This location is the place for primary data collection from local fishermen who catch puffed fish (Rastrelliger spp) in some warehouses where fish are landing and the location for secondary data collection is at the Samudera Belawan Fisheries Port office. Location sampling can be seen in Figure 1.

![Figure 1. Research location: Belawan ocean fisheries port is located at geographical coordinates 03° 43 '00" LU and 98° 44" BT.](image)

2.2. Procedures
Primary data collection was obtained by direct interviews using a questionnaire. Secondary data is the production data of mackerel (Rastrelliger spp) for the last 5 years at the Belawan Ocean Fishing Port. Also, secondary data were obtained from related agencies, such as books, the internet, and supporting literature related to this research. Determination of respondents is done by purposive sampling, which is a method that is carried out deliberately based on the consideration of certain characteristics that are considered to be related to the characteristics of the previously known population. The number of samples determined using the Slovin method equation (2) with a confidence level of 85% is as follows:

\[
 n = \frac{N}{1 + Ne^2}
\]  

(1)

Where:
- \( n \) = sample size
- \( N \) = population size
- \( e \) = fault tolerance limit
2.3. Data analysis
The analysis used is bioeconomic, namely analysis from biological and economic aspects. In bioeconomics, if the fishing gear is multi-gear, it is necessary to standardize the fishing gear [2]. Fishing equipment standardization consists of two steps. The first step is to specify the standard CPUE, where the standard capture tool is an apparatus that has complete data in chronological order (time series) and has the largest CPUE. The second step is calculating the Fishing Power Index (FPI), where the standard capture tool is the capture tool that has the time series data and has the largest CPUE. The FPI of each fishing gear must be calculated. The FPI value can be obtained through equation (3) in [3] of the fishing gear that is used as a standard is 1, while the FPI from other fishing gears varies with standard fishing gears as a comparison. The value of FPI can be obtained by this following equation:

\[
\text{CPUE}_r = \frac{\text{Catch}_r}{\text{Effort}_r} \quad (2) \\
\text{CPUE}_s = \frac{\text{Catch}_s}{\text{Effort}_s} \quad (3) \\
\text{FPI}_i = \frac{\text{CPUE}_r}{\text{CPUE}_s} \quad (4)
\]

Where:
- CPUE \(_r\) = total catch per catch from standardized gear
- CPUE \(_s\) = total catch per capture effort of standardized fishing gear
- FPI \(_i\) = Fishing Power Index from fishing gear to \(i\)
- \(i = 1,2,3,...k\)

After obtaining the CPUE and FPI values, the Gordon Schaefer bioeconomic analysis [4] can be obtained by these following equation:

| Variable          | MEY                              | OAE                              |
|-------------------|----------------------------------|----------------------------------|
| Catch (C)         | \(\alpha_{\text{MEY}} - \beta(\text{MEY})^2\) | \(\alpha_{\text{OAE}} - \beta(\text{OAE})^2\) |
| Effort (E)        | \((\alpha - c)/(2p\beta)\)       | \((\alpha - c)/(p\beta)\)       |
| Total Receipts (TR) | \(C_{\text{MEY}} \times p\)   | \(C_{\text{OAE}} \times p\)   |
| Total Expenditure (TC) | \(c \times E_{\text{MEY}}\) | \(c \times E_{\text{OAE}}\) |
| Advantage (\(\Pi\)) | \(TR_{\text{MEY}} - TC_{\text{MEY}}\) | \(TR_{\text{OAE}} - TC_{\text{OAE}}\) |

Where:
- \(\alpha\) = intercept
- \(\beta\) = slope
- \(p\) = price
- \(c\) = cost
- \(TR\) = total receipts
- \(TC\) = total cost of catching
- \(E\) = effort
- MEY = maximum economic yield
- OAE = open access

3. Results and discussion

3.1. Production of mackerel (Rastrelliger spp)
The catch of mackerel using purse seine fishing gear from 2015 to 2019 has tended to fluctuate as can be seen in table 2. This is due to a reduction in the fishing effort every year from 2016 to 2019. The
highest catch in 2019 was 37% and the lowest was in 2016 at 12% of the total catch of mackerel per year. The stock of mackerel in 2016 decreased, although the number of fishing trips was smaller than the number of fishing trips in the previous year. It is suspected that the number of stocks or the presence of mackerel fish is already small and has been overfishing in the waters of the Malacca Strait since 2014 [1]. The production of mackerel resources experiences fluctuating currents caused by various factors that influence each other in capture fisheries activities. This is consistent with [5] in [6], which states that fluctuation in the catch is influenced by the presence of fish, the number of fishing efforts, and the success rate of fishing operations.

Table 2. Value of bloated fish production for all fishing gears 2015-2019.

| Year | Production (Ton) | Price (Rp/Ton) | Production Value (Rp) |
|------|-----------------|----------------|----------------------|
| 2015 | 3030            | 32,045,424     | 97,097,634,000       |
| 2016 | 1994            | 29,908,232     | 59,637,014,000       |
| 2017 | 2215            | 30,379,480     | 67,290,549,000       |
| 2018 | 3219            | 42,542,914     | 136,945,639,000      |
| 2019 | 4608            | 45,677,109     | 210,480,116,000      |

The price of mackerel has fluctuated every year, but a very drastic price increase occurred in 2018 and 2019, namely Rp 42,500/kg and Rp 46,500/kg from the previous price in 2016 which was Rp 29,900/kg. It is not clear why the price fluctuation is important, but from the data obtained, it can be concluded that the price increase does not affect the demand for mackerel.

3.2. Catch per effort unit (CPUE) standard purse seine fishing gear
More than one fishing gear is used for fishing in Belawan Fishing Port, so fishing gear standardization is needed to determine the effort value and standard CPUE of the mackerel fishing gear. The results of the standardization of fishing gear are presented in table 3.

Table 3. Results of standard purse seine fishing equipment standardization.

| Year | Catch (ton) | CPUE | ln CPUE | FPI | Effort |
|------|-------------|------|---------|-----|--------|
| 2015 | 2877.2      | 0.435082413 | -0.83221981 | 1   | 6613   |
| 2016 | 1853.9      | 0.297433018 | -1.21256623 | 1   | 6233   |
| 2017 | 1996        | 0.371902366 | -0.989123915 | 1   | 5367   |
| 2018 | 2477.7      | 0.68634349   | -0.376377062 | 1   | 3610   |
| 2019 | 4363        | 1.382446134  | 0.323854491  | 1   | 3156   |

This study uses a purse seine as standard fishing gear because this fishing gear has a higher CPUE value per year than other fishing gears. Standardization of fishing gear needs to be done because the mackerel fish at PPS Belawan are caught using more than one fishing gear. Fishing gear that can be used as a standard is a fishing tool that has complete data over time and has the largest CPUE and the value of FPI = 1. This is by [7] which states that the fishing gear that is used as a standard is fishing gear that has high (dominant) productivity in capturing fishery resources that are the object of research or have the largest average CPUE in time and have a power factor value. The catch is equal to one. The highest CPUE value was in 2019 with a value of 1.38245 and the lowest CPUE value in 2016 was 0.29743. The amount of production, trip, and CPUE of the purse seine standard fishing gear is shown in table 3. The CPUE increase graph can be seen in figure 2.
Catch per unit effort (CPUE) reflects the ratio between catch and effort. A higher CPUE value reflects a better level of effort efficiency. The CPUE value from 2015 to 2019 has fluctuated and tends to increase. This happened because during the year there was a reduction in the number of fishing efforts (effort). This is consistent with [8] which states that CPUE is inversely proportional to the capture effort. The higher the capture effort, the lower the CPUE value. The increasing fishing effort will reduce the catch. This is due to increased competition between operating fishing gears and limited resource capacity. Linear regression between the effort and ln CPUE of mackerel (Fox model) in (figure 3), the α value is 1.0954, β is -0.0003 and $R^2$ is 0.7602.

The analysis of the surplus production method the value of determination ($R^2$) of the Fox model is 76%. This shows that the Fox model is more representative because the coefficient of determination is larger, which can explain that the model has a closer relationship with the actual model on the dynamics of mackerel stock in the waters of the Malacca Strait from 2015 to 2019 [9]. The value of closeness (correlation coefficient / R) between ln CPUE and effort is 0.76. This indicates that ln CPUE and effort have a high or strong closeness value because the correlation coefficient lies in the range of $0.7 < KK \leq 0.9$ [10].

In 2019 the catch has increased vary drastically from the previous year, meaning that it has doubled from the previous year, namely in 2018 amounting to 2,477.7 tons. This is due to an increase in fishing effort. The allowable utilization rate (TAC) or the allowable catch (JTB) is 80% of the maximum sustainable potential. The allowable utilization rate of mackerel is 3208.97 tons. The actual use of mackerel in the Malacca Strait waters of 4,363 tons in 2019 has exceeded the TAC. This is by the FAO Code of Conduct for Responsible Fisheries, 1995 in [4], which states that the level of utilization of pelagic fish resources can be known after CMSY is obtained. The utilization rate is calculated by the percentage the number of catch in a certain year against the value of TAC (Total Allowable Catch) or the amount of catch allowed.
3.3. Bioeconomic analysis of purse seine standard fishing gear

Based on the results of calculations with the Gordon Schaefer bioeconomic model by the Purse Seine fishing gear from 2015 to 2019, the results of MEY, and OAE values on mackerel fish resources landed in the Belawan Ocean Fishing Port shown in table 4 and table 5.

**Table 4.** Conditions of MEY (Maximum Economic Yield).

| Year | C (Ton) | E (Trip) | TR (Rp)       | TC (Rp)       | Profit (Rp) |
|------|---------|----------|---------------|---------------|-------------|
| 2015 | 870.89  | 1427.38  | 27,907,932,304| 5,709,506,971 | 22,198,425,333|
| 2016 | 874.94  | 1463.43  | 26,168,056,505| 4,390,288,972 | 21,777,767,532|
| 2017 | 867.95  | 1405.21  | 26,367,946,268| 5,972,137,122 | 20,395,809,145|
| 2018 | 868.91  | 1412.18  | 36,966,007,316| 8,120,026,167 | 28,845,981,149|
| 2019 | 852.19  | 1313.13  | 38,925,525,873| 12,146,481,879| 26,779,043,994|

**Table 5.** Conditions of OAE (Open Access Equilibrium).

| Year | C (Ton) | E (Trip) | TR (Rp)       | TC (Rp)       | Profit (Rp) |
|------|---------|----------|---------------|---------------|-------------|
| 2015 | 356.34  | 2854.75  | 11,419,013,942| 11,419,013,942| 0           |
| 2016 | 293.58  | 2926.86  | 8,780,577,945 | 8,780,577,945 | 0           |
| 2017 | 393.17  | 2810.42  | 11,944,274,245| 11,944,274,245| 0           |
| 2018 | 381.73  | 2824.36  | 16,240,052,335| 16,240,052,335| 0           |
| 2019 | 531.84  | 2626.27  | 24,292,963,757| 24,292,963,757| 0           |

The results of the bioeconomic model under controlled conditions of MEY (Maximum Economic Yield) obtained optimal production (CMEY) of 867 kg/year and optimum fishing effort (EMEY) of 1,404 fishing gears/year, with a profit or economic benefit of Rp 23,999,405,431. Meanwhile, when the OAE balance (Open Access Equilibrium), the optimal production (Copt) is 391 kg/year, and the optimum fishing effort (Eopt) is 2,809 fishing gears/year.

In 2019, in MEY conditions with economic parameters, it can be seen that the type of mackerel will provide maximum benefits if the catch is 852 tons with an effort of 1,313 trips. The catch for the MEY value that is too high is caused by too high operational costs, while the price of mackerel is too low. In terms of fishing effort, the effort to catch mackerel at PPS Belawan was higher every year so that it exceeds the optimum limit in sustainable fishing efforts. Fishermen will benefit from mackerel if the effort made does not exceed the allowable effort. Also, if based on the catch and effort of the MEY value, fishermen will tend to carry out fishing activities below the sustainable limit. This is good for the sustainability of the fishing business at PPS Belawan. This is by [11] which states that the fundamental thing in fishery resource management is how to use these resources to produce higher economic benefits for users, but their sustainability is maintained. One approach that is often used in solving this problem is the bioeconomic approach.

4. Conclusions

The actual and optimal utilization rate of the mackerel fishery (Rastrelliger spp.) At the Belawan Ocean Fishing Port in 2019 has reached 136%, meaning that it has exceeded the permitted fishing limit. The next management effort was carried out through bioeconomic analysis and reduction in the level of effort by 3683 trips and a reduction in the number of catches by 1,861 tons so that the water resources are sustainable again. This has been done by limiting the fishing fleet.
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