The sustainable utilization of skipjack tuna in Northern Aceh waters

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Abstract. In recent years, production of skipjack tuna in Aceh was fluctuative in decreased trend due to relatively smaller fish size production. This study was aimed to analyse the skipjack tuna utilization sustainability on actual, maximum sustainable yield (MSY), maximum economic yield (MEY), and open-access (OA) conditions in North Aceh Waters. This study used time series data in 2009-2018. The analysis method used was a Gordon-Schaefer bioeconomical model. The results that the utilization of skipjack tuna in North Aceh Waters were at economical and biological overfishing. In long-term condition, this will potentially cause a decreased fish stock that will finally disrupt the sustainability level. In actual condition, the average of skipjack tuna utilization level per year was 163.77% more than the allowed total catching product, namely 2,712.64 ton per year. To achieve sustainable point, the fishermen should decrease their effort at 19.32% of the actual condition effort. The highest biomass level was occurred in MEY regime, followed by MSY and OA regimes. This means that the management of skipjack tuna in MEY regime is more conservative than in other regimes due to not spending skipjack tuna resource maximumly, but proposing to an optimum production level, which results in a maximum profit.

1. Introduction

Skipjack tuna (Katsuwonus pelamis) is one of the Indonesian capture-fishery commodities with high economical value. Skipjack tuna has a great contribution in Indonesia and the world's fisheries sector [1]. In 2000-2016, the average contribution of skipjack tuna on total capture-fishery production in Indonesia was at 6.04%, while the total production of skipjack tuna in the world was at 12.8% [2]. Skipjack tuna are mostly found in the Indonesian waters, specifically in Aceh Province waters. The average production of skipjack tuna in Aceh Province in 2006-2018 was 14,344.1 tons per year [3].

Kutaraja ocean fisheries port (PPS) as the greatest fish port in Aceh becomes a fish landing location centre for fishermen's boats around the Northern Aceh waters [4]. This water area is directly bordered to the Indian Ocean (WPP 572) as the western part of Malacca Strait (571). This water area also has high fishery resource potential, mainly giant pelagic fish resources, such as tuna, skipjack tuna, and mackerel. Fishing equipment used to catch these fish is purse seine and handline [5].

The utilization level of skipjack tuna resources landed in PPS Kutaraja, Banda Aceh tends to be high. This condition can be notified in 2009-2018 as the total fish catch for skipjack tuna and total fishing trip in the same period also tended to be high. The average production of skipjack tuna in 2009-2018 was 4,442.84 tons per year, while the total average of fishing trips in the same period was 2,705.5 trips [6].
Fishery resource has an open-access characteristic and is considered as a common property resource. Access to skipjack tuna resources is unlimited which occurs uncontrollable increased production and fishing trips. If this condition continues to happen, there will be a main concern as the skipjack tuna resource stock in nature can be disturbed its sustainability level in the future [7]. Decreased quality and quantity of skipjack tuna will impact on the decreased economical value received by fishermen. Therefore, this resource utilization should be based on biological, economical, social, and environmental aspects to support sustainable skipjack tuna resource as fisheries resource basic is focused on how the utilization activity can produce high economical benefit for users with a preserved sustainability level. This study was aimed to analyse the management sustainability of skipjack tuna in Northern Aceh waters.

2. Materials and methods
This study was performed from November 2019 to February 2020. Data used in this study contained primary and secondary data. Primary data was composed of cost structure from fishing trips and skipjack tuna resource price. Secondary data was obtained as information from various parties or governmental institutions, such as the Department of Marine and Fisheries (DKP) of Banda Aceh, Bureau of Statistics (BPS) of Banda Aceh, and Kutaraja Ocean Fishery Port (PPS). Secondary data was collected in time series data containing production of skipjack tuna, total fishing equipment effort from using purse seine and hand line, and Consumer Price Index (CPI) in 2009-2018.

The method used in this research was the survey method. Meanwhile, the sampling technique used was purposive sampling on fishing boats using purse seine and hand lines, because the two fishing gears are the most dominantly used by fishermen to catch skipjack tuna. If the population was assumed as homogenous, a structured interview was performed to obtain primary data on 10 boats that used purse seine and 5 boats that used hand line. The analysis methods used were maximum sustainable yield and Gordon-Schaefer bioeconomic analyses. These methods have been used by many previous studies [8–13].

Maximum Sustainable Yield (MSY) was calculated by [7], namely:

\[ h_{\text{MSY}} = qKE - \left( \frac{qK}{r} \right)E^2 \]  

Whereas \( h_{\text{MSY}} \) = maximum sustainable yield production; \( r \) = intrinsic growth; \( q \) = catchability coefficient; \( K \) = carrying capacity; and \( E \) = fishing Effort. While, the value of biological parameters above could be calculated by the Fox Algorithm estimation model [1975].

\[ x = \left[ \left( \frac{z}{u_t} \right) + \left( \frac{1}{\beta} \right) \right] \]  
\[ y = \left[ \left( \frac{z}{u_{t+1}} \right) + \left( \frac{1}{\beta} \right) \right] \]  
\[ z = \left[ \left( -\frac{a}{b} \right) - \left( \frac{E_t + E_{t+1}}{2} \right) \right] \]  
\[ q = \left[ \prod_{t=1}^{n} \ln \left( \frac{x}{y} \times \frac{z}{x} \right) \right]^{1/t} \]  
\[ K = \frac{a}{q} \]  
\[ r = \frac{kq^2}{\beta} \]

The profit obtained was the difference between total revenue and total cost used. Mathematically, it was written below [12].

\[ \Pi = TR - TC = p.h - c.E = p.q.K.E \left( 1 - \frac{q.K.E}{r} \right) - c.E \]
3. Results and discussion

The calculation result using the (5)(6)(7) equations obtained biological parameter estimations on skipjack tuna as shown in Table 2.

Table 2. Biological parameter estimation on skipjack tuna.

| No | Parameters              | Unit    | Value   |
|----|-------------------------|---------|---------|
| 1  | Intrinsic growth (r)    | ton/year| 0.57841 |
| 2  | Catchability coefficient (q) | ton/trip | 0.00012 |
| 3  | Carrying capacity (K)   | ton/year| 36,879.47 |

If the biological parameters above were included in the (1) equation, then the sustainable yield effort function was produced, namely the (9) equation, and the sustainable yield effort curve can be shown in Figure 1.

\[ h_t = 4.4255E_t - 0.0009E_t^2 \]  

Figure 1 shows that the actual production of skipjack tuna has been over the sustainable production in an increasing trend based on the observations on several years of production. This condition indicates that the skipjack tuna resource at Northern Aceh waters on the following year is in a biological overfishing state. If this condition continues to occur in the future, the skipjack tuna resource stock will be degraded and no longer unsustainable. The similar condition also occurred in giant trevally and tuna fish in Northern Aceh and Sabang waters [9–11].
Furthermore, the MSY model was included in economical variable, called as the bioeconomic model [7]. This model was used to identify the optimal fish resource utilization level with maximal profit gain. Output from this bioeconomic analysis can become a standard for fishermen and stakeholders in sustainable fish resource utilization [15]. The calculation result on optimal utilization level of skipjack tuna using the model from Table 1 with several regimes can be shown in Table 3.

Table 3. Bioeconomic analysis in various management regimes.

| Model | MEY         | MSY         | OA           | Actual Condition |
|-------|-------------|-------------|--------------|------------------|
| x (ton/year) | 4.311.56    | 3.333.07    | 1.956.98     | -                |
| h (ton/year)  | 3.098.57    | 3.390.80    | 2.812.83     | 4.442.40         |
| E (trip/year) | 1.613.29    | 2.283.72    | 3.226.57     | 2.830.44         |
| π (IDR millions/year) | 23.989.06   | 19.846.20   | 0            | 27.997.66        |

From Table 3, the highest biomass level occurred in MEY regime, followed by MSY and OA regimes. This means that the MEY management regime was relatively more conservative than other management regimes as this regime did not deplete fish resources maximally, but proposing for optimum production level, which could gain maximum profit. Also, input (effort) in the MEY condition was far lower than effort in OA and MSY regimes. In contrast, the economic rent in the MEY condition was higher than economic rent in the MSY condition, while the open-access condition obtained a zero economic rent value. According to [14], the economical maximum production in the MEY condition can be obtained as a social optimum effort level.

The results showed that the total production of skipjack tuna in actual condition was 4,442.40 tons higher than the production level identified from MEY, MSY, and OA regimes. However, to achieve the following total production, fishing boats have to increase a significant effort above the MEY effort. As a result, the biomass stock will be reduced, and if this condition continues to happen, biological overfishing will occur and the skipjack tuna population will be degraded and unsustainable. Another interesting condition was that the highest gross acceptance value was found in the actual condition regime compared to other regimes, but obtaining smaller net profit than MEY regime profit. The average economic rent in actual condition is IDR 9.89 million/trip, while in the MEY and MSY regimes, respectively, IDR 14.89 million/trip and IDR 8.68 million/trip. This condition demonstrates an
economic overfishing incident as fishermen have to spend the higher cost to gain a certain amount of skipjack tuna [11].

The description of skipjack tuna fishery management in the Northern Aceh waters can be graphically shown in Figure 2.

![Figure 2. Bioeconomic equilibrium curve of skipjack tuna](image)

Figure 2 shows an equilibrium condition in the open-access regime at OA point with $E_{OA}$ effort. In this condition, the TR value is equal to the TC value, resulting in zero (Rp 0) economic rent as all fishermen do not gain profit, but only receiving opportunity cost. The effort level in this position is called as a bioeconomic equilibrium of open access fishery [7,14]. If the effort is increased, then the profit will become negative (loss). In this condition, all managers will withdraw from the fishery business.

Maximum sustainable profit will be obtained at the $E_{MSY}$ effort level. At this point, the economic rent gained by the fishermen was maximum, based on Figure 2 shown by the greatest difference of TR and TC (AB line). Thereby, the MEY concept describes the optimal fishery management economically, as input factor is utilized as efficiently as possible to gain maximum resource rent. The MEY condition is obtained on a lower effort level than the equilibrium point in the open-access condition. This means that the sustained biomass (stock) will be relatively more abundant, followed by higher catch per unit effort and profit levels. If the effort level on OA equilibrium is compared to the social optimal effort level ($E_{MEY}$), the effort level on OA condition requires more effort level than before to gain sustainable optimum profit. Therefore, this open access equilibrium can cause false natural resource allocation as input resource excess (labours and capital) should be allocated for other productive economical activities. This condition becomes the Gordon main prediction that the OA condition will cause economic overfishing [14,16]. In Figure 2, it can also be concluded that the $E_{MEY}$ level is more conservative-minded than the $E_{MSY}$ level.

To preserve sustainable skipjack tuna biomass availability, two regulations can be performed. First, limited entry regulation can be performed by regulating the total fishing trip from the fishery management regime. Table 3 shows an input (effort) excess that requires to be rationalized from the actual condition to MSY and MEY regime conditions.

Based on Table 4, $E_{actual}$ should be reduced by the fishermen at 148 trips for hand line fishing equipment and 398 trips for purse seine fishing equipment to gain MSY condition. A similar condition should be performed to gain maximum profit in MEY condition as the fishermen should reduce more of their effort at 330 trips for hand line fishing equipment and 887 trips for purse seine fishing equipment. The effort reduction policy also applies to the hilsa fishery in India [13].
Table 4. Limited entry of skipjack tuna in Northern Aceh waters.

| Fishing equipment | E_{Actual} | E_{MSY} | Effort (Trips) excess | E_{MEY} | Effort (Trips) excess |
|-------------------|------------|---------|-----------------------|---------|----------------------|
| Handline          | 768.37     | 619.95  | 148.42                | 437.95  | 330.42               |
| Purse Seine       | 2,062.07   | 1,663.77| 398.30                | 1,175.34| 886.73               |

Second, limited output regulation can be performed by applying the Total Allowable Catch (TAC) with the MSY regime as a benchmark. The TAC value used in Indonesia is 80% of MSY. If the MSY production of skipjack tuna is 3,390.80 tons per year, then the TAC value is 2,712.64 tons per year. Table 5 shows the TAC value per fishing equipment for skipjack tuna in Northern Aceh waters.

Table 5. Skipjack tuna fishing equipment quota in PPS Kutaraja.

| Fishing equipment | Production (Tons) | Ratio | TAC (Tons) |
|-------------------|-------------------|-------|------------|
| Handline          | 1,191.21          | 0.138 | 373.73     |
| Purse Seine       | 7,454.93          | 0.862 | 2,338.91   |
| Total             | 8,646.14          | 1     | 2,712.64   |

The percentage value of skipjack utilization level in the Northern Aceh waters landed in PPS Kutaraja in 2009-2018 tended to increase significantly. The highest utilization level percentage value occurred in 2018 at 318.74% and the lowest utilization level percentage value occurred in 2010 at 96.61%. The average percentage value of utilization level was 163.77%. This condition indicates that the utilization level of skipjack tuna resources has been in an overfishing state. In the future, effort reduction should be performed to gain sustainable skipjack tuna fishery management. In fisheries, the most common management practices include controlling fishing effort and controlling catch. These are usually managed through close seasons, gear restrictions, allocation of quotas and limited entry [13,17].

4. Conclusions
The skipjack tuna fishery management in Northern Aceh waters landed in PPS Kutaraja has been in economical and biological overfishing state. In the long-term, this condition will cause a reduced fish stock potential that will finally disturb the sustainability level. In actual conditions, the average utilization level value of skipjack tuna per year was 163.77% over the allowed total catching product. To achieve a sustainable point (MSY), the fishermen should reduce their effort by 19.32% from the actual condition effort.

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