Optimizing the utilization of scad fish (*Decapterus* spp.) resource in northern coast of Aceh

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Abstract. For ten years, the Scad fish production in the Northern Coast of Aceh has been increasing rapidly at 172.5%. This condition describes that the Scad fish resource exploitation is implemented under improper management that could encounter an overfishing case. This study aimed to analyze the Scad fish resource utilization level and recommend a management strategy to achieve an optimized Scad fish resource utilization in the Northern Coast of Aceh. This study was performed in the Ocean Fishing Port, Kutaraja, Banda Aceh. Bioeconomic analysis results showed that catching product and effort in MSY condition at 2,838.59 tons and 2,808 trips by economic rent was Rp23,902 million per year. In MEY condition, catching product at 2,748.01 ton with catching effort at 2,311 and economic rent was Rp25,056 million per year. The open-access condition of Scad fish resource with total catching effort at 5,386 trips and economic rent value obtained was Rp 0. Results demonstrated that the Scad fish resource utilization status in the Northern Coast of Aceh encounters biological and economical overfishing. The Scad fish resource management strategy for achieving MSY and MEY condition through input control and output control by establishing the total allowed catching product and catching quota.

1. Introduction

The Kutaraja Ocean Fishing Port (PPS) is an important fishing port in Aceh Province, mainly in the northern coast of Aceh. This location becomes a place for many fisheries business which can be expected to increase the regional, fishermen, and surrounding community incomes. The business activities in this port for 2009-2018 continued to develop marked from the increased annual production result. All production results were dominantly obtained from various pelagic fish types, such as Skipjack tuna, Mackerel tuna, Tuna, and Scad fish [1].

Scad fish (*Decapterus* spp.) is included in small pelagic fish as an important fishery commodity and distributes in all Indonesian water areas. As one of important fishery resource commodities, this fish is mostly searched and caught by fishermen in Indonesia, including in Northern coast of Aceh. The Scad fish production in PPS fluctuated from 2009 to 2018, with an increased trend. In 10 years, the Scad fish production result has been increasing quite rapidly. In 2009, the production result was at 2,030.78 tons, while the production result in 2018 was at 5,533.49 tons on 10 years later, which means that the production increased at 172.5% or increased at 17.25% each year [1]. This condition describes that the Scad fish resource exploitation is quite high and can occur an overfishing, if being managed improperly.

The Scad fish resource is basically included in a renewable resource with common property and open-access characteristics, which possibly occur an overfishing. Overfishing impacts on a faster
ecological extinction than anthropogenic disruption on coastal ecosystem, such as pollution, decreased water quality, and climate change [2]. This condition will threat the fish resource sustainability if not being maintained sooner [3]. Therefore, fishery resource utilization has to follow the socio-economical aspects, fish biological factors, and environmental sustainability condition to support sustainable utilization. To overcome this problem, an effort for sustainable fishery resource management is necessary to offer an optimal economical profit with preserved sustainable level [4,5].

Based on this condition, a further study is required by using bioeconomic analysis to analyse the condition and utilization level, besides implementing a proper strategy to manage the Scad fish resource in Aceh waters. The analysis results from this study may become a recommendation in terms of Scad fish utilization and resource management.

2. Methods

2.1. Location
This study was carried out in the northern coast of Aceh with Kutaraja Ocean Fishing Port (PPS), Banda Aceh as main data sampling base. This study was performed in November, 2019 – March, 2020.

2.2. Object and scope
Object in this study was fishermen who landed the Scad fish in Kutaraja Ocean Fishing Port (PPS), Banda Aceh. The study scope is limited in the bioeconomic analysis of Scad fish resource in northern coast of Aceh with the parameters observed contained biological and economical aspects in Scad fish resource utilization.

2.3. Population and sample
Sampling method used a purposive sampling method by taking the data source samples deliberately under a certain consideration [6]. Fishermen selected as respondents were Scad fish catching fishermen who used purse seine and hand line as catching equipment and could communicate well when filling the questionnaires [7]. Total fishermen used as samples were 25 fishermen, containing 15 purse seine boat fishermen and 10 hand line boat fishermen.

2.4. Data collection
Data used in this study were primary and secondary data. Primary data were obtained through observation and direct interviews to fishermen using questionnaires. Secondary data used in this study were fishermen population, production, and Scad fish catching effort data in 10 years (2009-2018), and Consumer Price Index (CPI) in 2009-2018 obtained from the Aceh Department of Marine and Fisheries, Unit for technical implementation in Kutaraja PPS, and Banda Aceh Bureau of Statistics.

2.5. Data analysis
This study used a qualitative analysis with descriptive method and quantitative analysis with Gordon-Scheafer bioeconomic analysis approach to identify the status and utilization level of Scad fish. Biological parameter estimation of Scad fish was performed with the Fox Algorithm model. These models were used for tropical multi-species fisheries.

2.5.1. Catching equipment standard. Standardization was performed by converting various catching equipment to standardized catching equipment. Standardized catching equipment were determined by observing which catching equipment that obtained the greatest productivity [8]. Productivity was calculated from catch per unit effort (CPUE) under the following equation [9]:

\[ CPUE_t = \frac{c_t}{f_t} \]  

Whereas \( c_t \) was catch for time \( t \) and \( f_t \) was effort for time \( t \). If the Fishing Power Index for standardized
catching equipment (FPIs) was equal to 1, then:

\[ FPI_i = \frac{CPUE_i}{CPUE_s} \quad (2) \]

Whereas, catching effort standardization was calculated under the following equation:

\[ SE = \sum FPI_i \times f_i \quad (3) \]

2.5.2. Biological parameter estimation. To gain biological parameters, such as internal rate (r), catching capacity coefficient (q) and environmental carrying capacity (K), a method that could be used was the Fox Algorithm coefficient estimation model (1975), which could be mathematically written as:

\[
q = \left[ \prod_{t=1}^{n} \ln \left( \frac{X_t}{Y_t} \right) \right]^{\frac{1}{r}} \\
X_t = \left( \frac{Z}{U_t} + \frac{1}{\beta} \right) \\
Y_t = \left( \frac{Z}{U_{t+1}} + \frac{1}{\beta} \right) \\
z = \left[ \left( -\frac{\alpha}{\beta} \right) - \left( \frac{E_t + E_{t+1}}{2} \right) \right] \\
K = \frac{\alpha}{\beta} \leftrightarrow r = \frac{Ka^2}{\beta} \quad (4) \]

2.5.3. Economic parameter estimation. According to Fauzi [10], to gain maximum economical yield which could obtain maximum profit, Gordon added the economic variables, namely cost and price. Profit was obtained from the difference of total Revenue and total cost that could be calculated under the following equation [10]:

\[
\Pi = TR - TC = (p \cdot h) - (c.E) = p \left[ qKE \left( 1 - \frac{q}{r}E \right) \right] - c.E \quad (5)
\]

Whereas TR was total revenue (Rp), TC was total cost (Rp), \( \Pi \) was profit (Rp), \( p \) was average fish price (Rp), \( c \) was catching effort cost (Rp), and \( E \) was total catching effort (Trip). After obtaining biological parameter values (r, q, K) and economical parameter values (p and c), then the fishery resource management solution can be stated through bioeconomic approaches, namely Maximum Sustainable Yield (MSY), Maximum Economic Yield (MEY), and Open-access Equilibrium (OAE). In general, the equation formula for Gordon-Scheafer bioeconomic analysis in various management regimes can be seen in Table 1 [9].

| Variable   | MSY                        | MEY                        | OAE                        |
|------------|----------------------------|----------------------------|----------------------------|
| Biomass (x)| \( \frac{K}{2} \left( 1 + \frac{c}{pqK} \right) \) | \( \frac{K}{2} \)         | \( \frac{c}{pq} \)       |
| Catch (h)  | \( \frac{rK}{4} \)       | \( \frac{rK}{4} \times \left( 1 + \frac{c}{pqK} \right) \times \left( 1 - \frac{c}{pqK} \right) \times \left( \frac{rc}{pq} \right) \times \left( 1 - \frac{c}{pqK} \right) \) | \( \frac{r}{q} \times \left( 1 - \frac{c}{pqK} \right) \) |
| Effort (E) | \( \frac{r}{2q} \)      | \( \frac{r}{2q} \times \left( 1 - \frac{c}{pqK} \right) \times \left( \frac{c}{pqK} \right) \times \left( \frac{r}{q} \right) \times \left( 1 - \frac{c}{pqK} \right) \) | \( \frac{r}{q} \times \left( 1 - \frac{c}{pqK} \right) \) |
| Economic Rent (\( \pi \)) | \( (p \cdot h)_{MSY} - (c \cdot e_{MSY}) \) | \( (p \cdot h)_{MEY} - (c \cdot e_{MEY}) \) | \( (p \cdot h)_{OAE} - (c \cdot e_{OAE}) \) |
2.5.4. **Strategical analysis.** The fishery resource management strategy could be analysed using the fishery resource utilization management instruments. Instruments that could be used were:

1) Input control or fishery input usage limitation was performed with a **limited entry** application method. The limited entry applications used in this study were [11]:

\[
\text{Limited Entry (MSY)} = \text{E}_{\text{Actual}} - \text{E}_{\text{MSY}} \\
\text{Limited Entry (MEY)} = \text{E}_{\text{Actual}} - \text{E}_{\text{MEY}}
\]

2) Output control or fishery output limitation was performed using the calculation instruments, namely total allowed catching product (TAC) and catching quota [11].

3. **Results and discussion**

The catch per unit effort (CPUE) of Scad fish in PPS Kutaraja for 10 years (2009 – 2018) continued to fluctuate with an increased trend [1]. The result of catching effort standardization can be clearly seen in Table 2.

| Year | Effort (Trip) | CPUE | FPI | SDT Effort |
|------|--------------|------|-----|------------|
|      | Purse Seine  | Hand Line | Purse Seine | Hand Line | Purse Seine | Hand Line | Hand Line SDT | Total SDT | CPUE SDT |
| 2009 | 3,604        | 1,247 | 0.513 | 0.147 | 1 | 0.286 | 357 | 3,961 | 0.51 |
| 2010 | 3,184        | 1,102 | 0.402 | 0.115 | 1 | 0.286 | 315 | 3,499 | 0.40 |
| 2011 | 2,688        | 930   | 0.482 | 0.138 | 1 | 0.286 | 266 | 2,954 | 0.48 |
| 2012 | 2,606        | 902   | 0.589 | 0.168 | 1 | 0.286 | 258 | 2,864 | 0.59 |
| 2013 | 2,427        | 840   | 0.840 | 0.240 | 1 | 0.286 | 240 | 2,667 | 0.84 |
| 2014 | 2,065        | 714   | 0.960 | 0.275 | 1 | 0.287 | 205 | 2,270 | 0.96 |
| 2015 | 1,750        | 605   | 1.789 | 0.512 | 1 | 0.287 | 173 | 1,923 | 1.79 |
| 2016 | 3,510        | 982   | 0.736 | 0.147 | 1 | 0.199 | 195 | 3,705 | 0.74 |
| 2017 | 3,038        | 1,124 | 1.243 | 0.351 | 1 | 0.283 | 318 | 3,356 | 1.24 |
| 2018 | 2,883        | 1,119 | 1.688 | 0.595 | 1 | 0.353 | 395 | 3,278 | 1.69 |

Based on Table 2, the highest CPUE value occurred in 2015 at 1.79 ton/trip, while the lowest CPUE value occurred in 2010 at 0.40 ton/trip. The CPUE value was influenced from total catching product and catching effort, as significant increase of CPUE value was occurred in 2017 due to increased total catching product from previous year, although total catching effort decreased.

The Schaefer surplus production method used linear regression analysis with two variables, namely total effort (trip) data and catch per unit effort (CPUE) data[12]. The regression analysis result between CPUE and effort obtained \( R^2 = 0.214 \) and a linear equation of \( y = -0.00036x + 2.0206 \) that explained the correlation between the two variables. The \( R^2 0.214 \) shows that 21.4% CPUE value is influenced by the effort. Meanwhile, 78.6% are influenced by other factors such as season, weather, and other biological factors. The constant value (α) at 2.0206 and β value at -0.00036 explain that if there is an increased effort, then the catching product will decrease at 0.00036 ton, and vice versa, as if there is a decreased effort, then the catching product will increase at 0.00036 ton. The correlation of effort and CPUE demonstrated a negative growth value, which means that higher effort will decrease the CPUE value. This condition indicates that Scad fish resource in North Aceh waters continues to decrease and encounters a biological overfishing. If this condition occurs continuously, decreased effort is necessary to provide the Scad fish resource an opportunity to grow [13]. Reduce fishing effort through diverting scad fish catching activities to others such as collecting seaweed and shellfish or rural development.
programs that provide alternative or supplementary sources of income [13,14]. Daily fishing effort decreased in the number of boat launches per day, restrictions on entry or fishing effort, such as quotas, licensing, minimum size of catches, minimum mesh sizes, and other gear restrictions [14–17]. The main benefits in reducing fishing efforts come from allowing small fish to live longer and grow [18].

Figure 1. CPUE and effort correlation graphic.

3.1. Biological parameter estimation on scad fish resource utilization

Biological parameter values used in bioeconomic analysis contained internal growth rate (r), catching capacity coefficient (q), and environmental carrying capacity (K). Biological parameter estimation may use many kinds of methods. In this study, biological parameters were estimated using the Fox Algorithm model, which stated the most appropriate model approach based on the contrast analysis. The fitter sustainable production curve with actual data, the more acceptable the model [19]. The calculation using the Fox Algorithm, the biological parameter estimation value result is shown in Table 3.

Table 3. Biological parameter estimation result with fox algorithm model approach.

| Biological Parameter                  | Unit       | Value     |
|---------------------------------------|------------|-----------|
| Intrinsic growth rate (r)             | Ton/Year   | 0.9636    |
| Catchability coefficient (q)          | 1/Trip Effort | 0.0002   |
| Environmental carrying capacity (K)   | Ton        | 11,755.02 |

Based on the data obtained as presented in Table 3. The intrinsic growth was 0.9636, which means that the fish would grow naturally without disturbance from natural phenomena with a coefficient of 0.9636 tons per year. The Environmental carrying capacity (K) was 11,755.02 indicated that the environment supports the production of Scad fish 11,755.02 tons per year from biological aspects. The catch coefficient (q) was 0.0002 refer to scad fish caught per fish available per effort unit.

3.2. Economical parameter estimation on scad fish resource utilization

The economical parameter estimation contained actual input cost and output price. The cost input was Scad fish average operational catching cost per trip obtained from respondent data in the study location. The price used in this study was normal price for Scad fish in 2009-2018. Cost and price were then compared with the CPI of fresh fish at Banda Aceh in 2012 as the main year [20]. The estimation results of all input cost and output price can be seen in Table 4.
Table 4. Estimation result of input cost and output price of scad fish resource.

| Year | CPI in 2012 | Input Cost (Million) | Output Price (Million) |
|------|-------------|----------------------|------------------------|
| 2009 | 93.01       | 4.580                | 17.347                 |
| 2010 | 92.91       | 4.575                | 8.827                  |
| 2011 | 102.43      | 5.043                | 11.380                 |
| 2012 | **100.00**  | **4.924**            | **19.850**             |
| 2013 | 97.55       | 4.803                | 8.945                  |
| 2014 | 83.79       | 4.126                | 9.736                  |
| 2015 | 87.45       | 4.306                | 10.004                 |
| 2016 | 88.60       | 4.362                | 11.934                 |
| 2017 | 97.48       | 4.800                | 16.454                 |
| 2018 | 101.89      | 5.017                | 15.844                 |
| Average | 94.51       | 4.654                | 13.032                 |

Based on Table 4, the average cost of input from 2009-2018 was 4.654 million/trip, and the average output price is 13.032 million/ton. Input cost doesn’t have specific differences every year. Meanwhile, output price has fluctuated. The highest output price happens in 2012 with an output price of Rp 19.850 million/ton. In 2013, output price decreasing half to 8.945 million, and in 2018 increasing to 15.844 million.

3.3. Bioeconomic analysis on scad fish resource

Bioeconomic analysis divided the fishery resource management into 3 regimes, namely Maximum Sustainable Yield (MSY), Maximum Economical Yield (MEY), and Open-access (OAE). The analysis results of these three regimes on fishery resource management are presented in Table 5.

Table 5. Bioeconomic analysis of scad fish resource utilization.

| Model | Management Regime |
|-------|-------------------|
|       | MSY               | MEY               | OAE               |
| x (Ton) | 5,887.51          | 6,927.91          | 2,091.79          |
| h (Ton) | 2,838.59          | 2,748.01          | 1,729.26          |
| E (Trip) | 2,808             | 2,311             | 5,386             |
| π (Rp Millions) | 23,902         | 25,056             | 0                 |

Maximum Sustainable Yield (MSY) or sustainable production result produced in a water area without causing fish resource sustainability disruption. In Table 5, the MSY condition in biomass value (x) was 5,887.51 ton per year, catching product (h) was at 2,838.59 ton per year with total catching effort (E) at 2,808 trips per year and economic rent obtained at Rp 23,902 million per year.

Maximum Economic Yield (MEY) is a condition where fish catching product will gain maximum profit with fish resources remain preserved. In MEY condition, the biomass value (x) was 6,927.91 ton per year, catching product (h) was 2,748.01 ton per year with total catching effort (E) at 2,311 trips per year and maximum economic rent at Rp 25,056 million per year. In MEY condition, economic rent was gained maximally due to more optimal input use and catching effort.

The open-access condition is a condition where fishery catching business does not gain profit or gains loss (economic rent = 0). Based on the calculation result using Fox Algorithm model approach, the biomass value (x) was 2,091.79 ton per year, catching product value (h) was 1,729.26 ton per year with total catching effort (E) at 5,386 trips per year and economic rent value obtained was Rp 0. In fishery regime with open-access characteristic, production availability will support the fishery business to increase its exploitation capacity much higher until the economic rent will be spent fully [20].
Figure 2. Bioeconomic analysis results with fox algorithm model approach.

Based on Figure 2, by comparing the actual utilization value with bioeconomic analysis results, the Scad fish resource utilization in North Aceh waters has occurred overfishing either biologically or economically. This condition based on the actual catching effort level ($E$) at 3,048 trips which was higher than the catching effort level in MSY and MEY conditions, but the actual catching product ($h$) at 2,683.57 tons was still less than the catching product in MSY and MEY conditions. This condition was also supported by the economic rent calculation in the actual condition regime at Rp 20,790 million which indicates that the profit gained is still lower than the economic rent in the MEY regime at Rp 25,056 million and in the MSY regime at Rp 23,902 million. In actual conditions, a greater effort level obtains less economic rent than in MSY and MEY conditions. MSY was the option involving the least reduction in catches and catch methods in a fishery that was already over-exploited [21]. MEY is efficient of level fishing effort, better production, and the maximum rent. In the MEY condition, the amount of effort needed is smaller than in MSY and OA conditions and stock biomass levels greater than at MSY. It's means, in MEY more fish is conserved. The biological reference point (MSY) and the economic reference point (MEY) are always compliments to each other and they should be employed in formulation of any fishery management policies in the country [22,23].

The correlation among total revenue (TR), total cost (TC), and economic rent and effort in each management regimes (MSY, MEY, OAE) can be seen in Figure 3.

Figure 3. Bioeconomic balance curve on scad fish resource
From Figure 3, bioeconomic balance was found in OAE point as the total revenue value (TR) was equal to total cost value (TC), producing economic rent equal to 0. This condition was also called as bioeconomic equilibrium of open-access fishery. In OAE management condition, the catching effort level was greater than in MSY and MEY conditions, which means that the cost spent is greater than other conditions. Increased catching cost will cause an economic overfishing marked from low biomass stock due to highly resource exploitation which can disrupt the resource sustainability. Fishermen will gain maximum economic rent in MEY condition based on vertical axis between TC and TR points which are higher than in MSY and OAE management conditions. This condition is also called as optimal economic effort level which indicates that the catching effort performed in this condition has been efficient with maximum economic rent and preserved resource sustainability.

3.4. Strategic analysis on scad fish resource management in northern water area of Aceh

Apriyanti [24] recommended 2 conditions that could be performed in managing the fishery resource by limiting the input and output of fishing business activity.

3.4.1. Input control implementation. The Scad fish resource management in northern water area of Aceh can be directed in 2 management regimes, namely in MEY condition to gain maximum economic rent and MSY condition to gain maximum sustainable catching product. The catching effort (trip) and total catching equipment use control rationalized in MSY and MEY management can be seen in Table 6.

| Catching Equipment Type | Total Catching Equipment | Actual Effort Proportion (E_{Actual}) | Effort Proportion | Effort Surplus (Trip) |
|-------------------------|--------------------------|---------------------------------------|-------------------|----------------------|
|                         |                          | MSY Regime | MEY Regime | E_{MSY} | E_{MEY} | MSY Regime | MEY Regime |
| Purse Seine             | 261                      | 2,216      | 2,236      | 2,041   | 1,680   | 175        | 556        |
| Hand Line               | 98                       | 832        | 840        | 767     | 631     | 65         | 209        |
| Total                   | 359                      | 3,048      | 3,076      | 2,808   | 2,311   | 240        | 765        |

Table 6 shows an actual effort by using purse seine was 2,216 meanwhile MSY Effort was 2,041. This condition shows an effort surplus of 175 that indicates overfishing. The actual effort proportion using Handline was 832, indicating that the actual effort slightly exceeded the MSY effort that allowed at 767. If seen from the total surplus effort, the resource of Scad fish was overfishing. Comparing MEY effort (E_{MEY}) with Actual effort with Purse Seine has surplus effort proportion was 556 and with a handline was 209. The total surplus effort in the MEY regime shows the effort has passed the sustainability capacity economically. Input control by limiting the efforts can allow the stock of Scad fish resources to be maintained. This input can work if there is any interference from the government [22].

3.4.2. Output control implementation. In Indonesia, the TAC value is commonly used as main reference on the number of optimum production and fish catching product that can be utilized. The TAC value used in Indonesia is 80% of maximum sustainable yield (MSY) [25]. By using the production value in MSY management regime at 2,836.59 ton, the TAC value of Scad fish in northern water area of Aceh is 2,269.27 ton. In general, output control is more complicated to implement than input control [21]. The success of output control implementation depends on fishing business actors. It needs order and monitoring in following the rule to succeed in controlling this output. Total catching quota calculation for each catching equipment using the data from 2018 as basic year can be seen in Table 7.
Table 7. Catching quota calculation on scad fish resource in Aceh northern waters.

| Catching Equipment | Production (Ton) | Ratio | TAC (Ton) | Quota (Ton/Year) |
|--------------------|-----------------|-------|-----------|------------------|
| Purse Seine        | 4,886.97        | 0.88  | 2,269.27  | 1,996.92         |
| Hand Line          | 666.52          | 0.12  | 272.35    |                  |
| **Total**          | **5,553.49**    | **1** | **2,269.27** | **2,269.27**    |

4. Conclusions

The Scad fish resource in Aceh northern waters had obtained the highest production in MSY management at 2,838.59 ton/year with an effort (E) of 2,808 trip/year and economic rent of Rp 23,902 million/year. However, under MEY condition, the economic rent had reached a maximum value of Rp 25,056 million/year with an effort of 2,311 trips and a production of 2,748.01 ton/year. Based on the bioeconomic analysis, the Scad fish (Decapterus spp.) resource utilization status in Aceh northern waters is in biological and economical overfishing conditions. The utilization of Scad fish resource still does not direct to either MSY and MEY management, which can be stated that the Scad fish resource in Aceh northern waters remains unutilized optimally. The Scad fish resource management strategy can be aimed for MSY and MEY condition through input control and output control by establishing the total allowed catching product (TAC) and catching quota. Therefore, it is recommended that the utilization of Scad fish resource in Aceh northern waters should be directed to MEY management condition. Suggestions for future research are to analyze the proper harvest strategies by defining the objectives, targets, limits, and good management control rules to aim sustainability of Scad fish.

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