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Bioeconomic analysis of shortfin scads fish (*decapterus spp*) in the Flores Sea Waters of South Sulawesi Indonesia

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Abstract. The bioeconomic approach is a combination of scientists with a biological approach and fish entrepreneurs in the field with an economic approach, widely used in various countries and is one of the references in the management of fisheries resources. This study aims to evaluate the stock of shortfin scads fish in the marine waters of Flores, South Sulawesi. The research conducted from April to September 2019 using a survey method for pelagic fishing gear in Flores Sea of South Sulawesi. Data collection was carried out through interviews using a questionnaire and direct measurement of caught fish. Research locations include the districts of Jenepono, Bantaeng, Bulukumba and Selayar. Time series data on the number of fishing gear and catches for 10 years is calculated using the Microsoft excel program package. Result of this study showed that the actual production condition of the use of shortfins scads fish in the waters of the Flores Sea, South Sulawesi has exceeded the limits of the maximum sustainable potential and optimum sustainable yield. The optimal production is in OSY conditions of 31054.11 tons and the fishing effort of 102 purse seine units. To maintain the sustainability of elevated fisheries resources in the Flores Sea, required 59.5% reduction in fishing effort. The implication of the results of this study is the reduction of fishing units accompanied by the application of strict law enforcement so that the sustainability of short fin scads fish resources can be maintained.

1. Introduction

The Flores Sea waters of South Sulawesi is one of the dominant small pelagic fish producers (>50%) in South Sulawesi [1]. Purse seine is one of the dominant fishing gears used for catching shortfins scads fish, high fishing power capacity and tend to catch varieties of fish sizes, wondering the decreasing fish stock [2,3]. Knowledge about the potential of shortfins scads fish resources is an urgent matter in order to optimize the utilization of its resources. Estimating the potential of shortfins scads fish based on biological and economic factors is a new alternative approach in estimating fish stocks [2,4]. Such a model is known as dynamic bioeconomic, which is a development of the Schaefer production surplus model. The bioeconomic model has been adopted and developed by FAO as one of the instruments in estimating fish stocks [5,6].

To be able to utilize fish resources optimally and sustainably, a comprehensive study of fishing businesses in the field is absolutely required, so that concerns about the degradation of the carrying capacity of fisheries resources in the future can be overcome [7-9]. In addition, the field shows that not all fishing units used by fishermen meet to responsible criteria [2,3]. If the fishing gears used is not environmentally friendly, then the sustainability of fisheries resource utilization needs to be



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questioned [10-12]. To maintain the sustainability of capture fisheries in Indonesia, the government must change the pattern of development to fisheries management. Furthermore, it is stated that there still limited use of bioeconomic analysis and needs to be done in the future [11,12]. The sustainable development needs a macro approach based on local communities with integrated systems (bioecology, socio-economy, society and institutions) [13-15], on the ethics of responsible fisheries implementation is also the responsibility of resource users to apply them [15,16].

In estimating fish stock models that are widely used include: the production surplus model, the fox model. This model is widely used because the data used were secondary statistics on fisheries, which were not difficult to obtain. In this model only uses biological or economic factors [2-6]. In the biological model approach, the level of management of fish resources tends to be below the maximum, due to prudential factors. While the economic approach tends to exceed the maximum point [2,5]. While the reality on the ground, fishing activities as business activities always pay attention to profit factors, while biological factors tend to be ignored. Dynamic bioeconomic models combine biological and economic factors that produce the optimum sustainable yield (OSY= optimum sustainable yield) [5,6].

The bioeconomic model is a combination approach of biological, technological and economic aspects [5,6]. Research using bioeconomic models in Indonesia is still very limited including: shortfin scads fish in Mamuju District [2], coral trout grouper fish in Spermonde Archipelago [4], big pelagic fish in Bontang water [7], grouper fish in Seribu Island [11], red snapper in Tasikmalaya waters [12], snappers in East Kutai [13]. Until now there has not been found bioeconomic research on shortfin scads fish in this area. This study aims to analyse the optimum sustainable yield of shortfins scads fish resources and their sustainability in the Flores Sea Waters of South Sulawesi.

2. Material and methods

The research was carried out in the districts of Jeneponto, Bantaeng, Bulukumba and Selayar, from April to September 2019, on the basis of purse seine fishermen (figure 1). To get information from fishermen, a survey method was used by randomly selecting respondents for at least 10% of the population. The time series data on the number of fishes caught and the effort to catch shortfin scads fish were obtained from statistical fisheries data for the last 10 years [1].

Field data was carried out through direct observation of shortfin scads fishing units by following the operation of fishing equipment in the sea several trips per fishing area. The number of fishes caught was weighed according to its type to determine the portion of caught fish caught. The length and body circumference of the shortfin's scads fish were measured to determine and consider the management of the shortfin's scads fish at the study site.

Data collection using a questionnaire involve more fly fishing in each study location. This data provides information on the actual condition of shortfins scads fish at each research location so the data collection system must truly represent the population. This data were the key in this study. Therefore, sampling techniques at each fishing centre based on cluster sampling. Clusters were carried out based on the type of fishing gear, then in each fishing gear a random sample of 10-30% of the population chosen. Field data collection carried out directly by the research team and assisted by field staff and research students.

2.1. Data analysis

Field data were tabulated and synchronized with time series data and then analysed using multiple linear regression. Data on catch time series from production and fishing effort were analysed by catches per fishing effort to estimate the biological parameters and technology of the bioeconomic model. The fishing effort was stated in the unit.

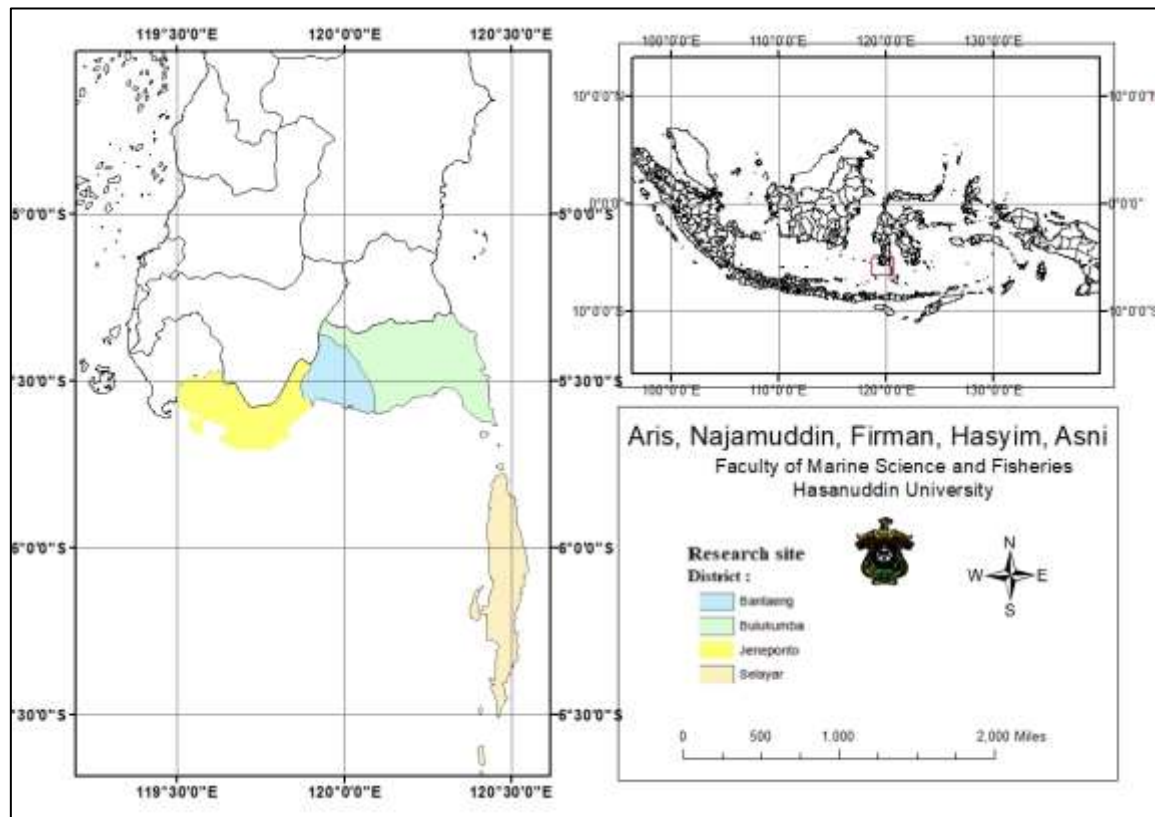


Figure 1. Map of research location

To estimate biological and technological parameters used multiple linear regression techniques with two control variables in accordance with the following equation model:

Model 1 (Shirakihara [17])

Model 1 (Shirakihara [17])

$$(CPUE_{t+1}-CPUE_t)/CPUE_t = \beta_0 + \beta_1 CPUE_t + \beta_2 E_t + e \quad (1)$$

Model 2 (Schnute [18])

$$\ln(CPUE_{t+1}/CPUE_t) = \beta_0 + \beta_1 (CPUE_{t+1} + CPUE_t)/2 + \beta_2 (E_{t+1} + E_t)/2 + e \quad (2)$$

Model 3 (Uhler [19])

$$(CPUE_{t+1}-CPUE_t)/CPUE_t = \beta_0 + \beta_1 (CPUE_{t+1} + CPUE_t)/2 + \beta_2 (E_{t+1} + E_t)/2 + e \quad (3)$$

Model 4 (Uhler [19])

$$\ln(CPUE_{t+1}/CPUE_t) = \beta_0 + \beta_1 CPUE_t + \beta_2 E_t + e \quad (4)$$

Model 5 (Clark, Yoshimoto and Pooley [20])

$$\ln(CPUE_{t+1}) = \frac{2r}{(2+r)} \ln(qK) + \frac{(2-r)}{(2+r)} \ln(CPUE_t) - \frac{q}{(2+r)} (E_t + E_{t+1}) \quad (5)$$

where:

$CPUE_{t+1}$: CPUE at time t+1

$CPUE_t$: CPUE at time t

E_{t+1} : fishing effort at time t+1

E_t : fishing effort at time t

β_0 : intercept

β_1 : regression coefficient of CPUE

β_2 : regression coefficient of fishing effort

e : errors

Determination of model validation by the F test ($\alpha = 5\%$). Only significant models will be used in subsequent calculations.

Regression coefficients (β_0 , β_1 , β_2) were used to estimate biological and technological parameters (indirect parameters or as indicators of technology) bioeconomic models k , r and q with equations [17, 19] as follows:

$$r = \beta_0 \quad (6)$$

$$K = r / (q \beta_1) \quad (7)$$

$$q = \beta_2 \quad (8)$$

Where:

r = constant growth rate of fish

K = water carrying capacity constant

q = capture coefficient

To calculate the economic parameters of the bioeconomic model the arithmetic mean formula is used:

$$c = \sum c_i / n_1 \quad (9)$$

$$p = \sum p_i / n_2 \quad (10)$$

Where:

c : average fishing costs (Rp) per year

c_i : fishing cost per unit of respondent i

p : average catch price per kg.

p_i : average price in season i

n_1 : number of respondents

n_2 : number of seasons (peak, usual, famine)

Catch costs consist of: (1) fixed costs which included maintenance costs (fishing gear, ships, machinery and auxiliary equipment), depreciation costs (fishing gear, ships, machinery and auxiliary equipment) and capital interest rates; (2) variable costs which include the cost of supplies, fuel and equipment, crew wages.

The parameters of the resource discount rate (δ) and time were the dynamic characteristics of the model. The discount rate was the natural logarithm of the real interest rate applicable to a particular year written with the equation [6]

$$\delta = \ln(1 + i) \quad (11)$$

Where:

i : investment interest rate.

Assumptions of the bioeconomic model (a) Population in a balanced state; (b) Under equilibrium, the capture mortality (F) was proportional to the capture effort (E) where the capture coefficient (q) is a proportionality constant, so that: $F = qE$; (c) The catch per unit effort (CPUE) was an index of relative abundance of the population; (d) Stock is limited by the carrying capacity of a constant environment (K); (e) The stock will respond quickly to variations in the scale of effort used; (f) Constant capture mortality (F); (g) Price and marginal costs were constant and do not depend on the level of effort used and (h) The total cost was proportional to the effort, and the change in slope on the total cost curve will give a change in the bioeconomic level and MEY.

The output of the bioeconomic model includes estimating optimal stock (X^*), optimal catch (Y^*) and optimal capture effort (E^*) which is calculated by the following equation:

$$X^* = k/4[(c/qpk+1-\delta/r)+\{(c/qpk+1-\delta/r)^2+8c\delta/qpk\}^{1/2}] \quad (12)$$

$$Y^* = rX^* (1-X^*/k) \quad (13)$$

$$E^* = Y^*/qX^* \quad (14)$$

Research methods were detailed and described as needed. Research methods were complemented by well-researched research charts, clear research locations, uncommon data collection techniques that

need to be described, as well as analysis performed, external per year, and measurable access indicators. Also described in the study was the division of tasks in the research of each member and the insecurity based on the achievements that have been achieved in the field of research that was currently underway.

3. Results

3.1. Fishing gear condition

Purse seine vessels were generally made of first-class wood with a length range of 20-30 m, width range 4-6 m and height range 1-2 m. The engine power has a of 24-33 hp and is equipped with electric scaffolding and drawstring roller. The tools used are FADs and lights. FADs are installed permanently at certain water locations, while lights are installed around FADs at night.

Purse seine dimension used namely length 300-500 m, depth 30-50 m and made of polyamide twine number 6 for wing and body parts while number 9 for bag part with 1-inch mesh size (figure 2). Shortfins scads (figure 3) fishing in the Flores Sea can take place for 10 months a year with the peak season were in August-October, the usual were in November; March April; and January-February were off season. However, in reality on the ground, the seasons change and were greatly influenced by wind movements at sea. The wind was very instrumental in determining the success of fishing operations with purse seine.



Figure 2. Purse seine fishing gear



Figure 3. Shortfin scads fish

3.2. Bioeconomic

Data time series of shortfin scads fish production and purse seine units during 10 years used to perform bioeconomic analyses (table 1).

Table 1. Fisheries statistic data of short fin scads fish production and fishing effort of purse seine during year 2009-2018.

Year	Catches (tons)	Fishing Efforts (units)	Catches/Efforts (tons/units)
2009	32330.6	511	63.2693
2010	36024.7	577	62.4345
2011	14966.7	385	38.8745
2012	20668.1	234	88.3252
2013	44102.1	289	152.6024
2014	43061.9	295	145.9725
2015	42957.0	285	150.7263
2016	41867.0	270	155.0630
2017	41176.0	267	154.2172
2018	38657.0	252	153.4008
Average	35581.11	336.5	116.4886

Source: Fisheries Statistic Data of South Sulawesi Province after analysed

The statistical analysed conducted using 5 models and result showed that model 5 had the highest correlation coefficient and also had significant in analyses of variance ($P < 0.05$). The following analyses used model 5. The results showed the biological and economic parameters of the management of shortfins scads fish resources in the Flores Sea, South Sulawesi, with a natural individual growth rate (r) of 0.999212072, the coefficient of capture ability (q) was 0.005064407, the carrying capacity of the environment (K) was 124,504.1828 tons, the cost of catching (c) that is Rp. 616 million per unit per year, the price of fish (p) is Rp. 15,000,000 per ton and the discounted rate of resources (δ) was 0.1031.

The results showed a comparison between actual production and sustainable production with a total effort of 101 units of purse seine per year with an average actual production of 35581.11 tons while the average sustainable production was only 31054.11197 tons. This shows that actual production has exceeded the sustainable production.

The results of the analysis showed the highest production level was in the MEY condition of 56258,10085 tons, followed by MSY at 31101.5206 tons, OSY at 31083.07583 tons and OA at 7574.78 tons. The level of effort in the condition of open access is far more compared to the condition of MSY, MEY and OSY which were 184 units of purse seine, while for MSY there were 99 units of purse seine, MEY of effort 92 units of purse seine and OSY of 101 units of purse seine (Table 2). The highest economic rent was obtained in the MEY regime of Rp. 787,060,660,040, MSY which is Rp. 405,754,130,143, Open Access is Rp. 0 and OSY is Rp. 403,997,581,474. The highest profit gained in the MEY condition is due to this management regime, the level of effort required is smaller when compared to the efforts in the MSY, OA and OSY regimes (Table 2)

Table 2. Comparison of benefits at various management levels

	MEY	MSY	OA	OSY
X (ton)	120449.7429	62252.09139	8108.88	60736.08933
Y (ton)	56258.10085	31101.5206	7574.78	31083.07583
E (units)	92.22541034	98.65045277	184.4508	101.0528506
π (Rp)	787,060,660,040	405,754,130,143	0	403,997,581,474

4. Discussion

This study showed that the average actual production of shortfins scads fish in the Flores Sea was much higher when compared to the amount of production in each management regime. Based on the actual production, it can be said that the use of shortfins scads fish in the Flores Sea indicates that it has experienced biological overfishing because the actual production was greater when compared with the proposed production from each management regime.

This increasing level of effort will also increase operational costs. If the effort conditions were not relegated to the MEY regime, it will cause an increase in the cost component with reduced revenues and economic rent received by fishermen will decrease further. The fish catching more economically or economic overfishing was essentially a situation where fisheries that were supposed to be able to generate positive economic rents, but apparently produce zero economic rents due to excessive use of input (effort) [21]. In fisheries economic jargon, economic overfishing was often referred to as the "too many boats chasing too few fish" jargon. In this situation both fishermen and the community in general do not benefit from the resources they should enjoy if the resources were managed properly [22, 23].

In the MSY management regime, fishing stock capture activities were directed at achieving the highest level of sustainable production. The approach in this concept was based entirely on biological parameters without regard to the costs of resource exploitation as mentioned. MSY states that fish management was based on a biological approach, with the aim of obtaining the highest production. If fish resources were harvested at the MSY level, the use of fisheries resources did not interfere with the sustainability of resources, where the number of fishes harvested or caught was within the limits of surplus production [21-23].

The main problem with MSY was that it was not economically relevant. This was because it took into account the benefits of resource exploitation, but ignores the costs of resource exploitation. This will lead to a situation where the cost of harvesting will be higher than the benefits [2, 4].

However, if we only saw the maximum production that will be obtained as in the MSY regime, then the costs incurred to extract resources will be higher than the MEY and OSY regimes. This was because the highest amount of effort in the OA regime when compared to the other regimes was 184 units, while the lowest effort was in the MEY regime which was 92 units and OSY which was 101 units.

The development of the complexity of the problems in fisheries management encourages new thinking to formulate a better optimum harvest concept. The old concept, which proved to be quite capable of answering problems related to the use of fisheries resources over the years, was felt to be unable to answer new problems that emerged some time later. In fact, it is proven that the assumptions used in the old concept have the potential to destroy the sustainability of fisheries resources [24,25].

As suggested by social science experts [26, 27], the MEY concept proved to be not flexible enough to deal with the development of the complexity of the problem. The weakness of the MEY concept was also recognized by some of its supporters, for example [26,27] said that optimum yields should not only include economic variables directly related to production (exploitation costs, sales value, and interest rates), but must also summarize indirect variables such as conservation value, social value, and so on.

Management in the OSY regime, where fishing activities were directed at achieving sustainable production that provides the highest social value (socially optimum yield). This concept was based on the opinion of critics of the MEY concept [14,15,27] that the consideration in determining the optimal capture rate should not be limited to economic and biological variables, but must cover all related aspects. In the management of the OSY regime provides optimal value in terms of production or harvest and economy.

The results of this study suggested reducing the number of fishing units to maintain the sustainability of laying fishing. The condition of the use of short fin scads fish resources in the study location has indicated overfishing. Therefore, if there was no management effort, then its sustainability

will be difficult to maintain. Without a reduction in fishing units will have an impact on the decline in fishermen's catches to the break-even point where there were no more profits and so will lose.

Many management alternatives can be applied, but the implementation depends on control and law enforcement in the field. Strict law enforcement efforts will be able to maintain the implementation of policies and will ultimately have an impact on the sustainability of the fishing effort. The combination of fisheries management such as bioeconomic and closed area, marine protected area, could also adopted.

5. Conclusion

The actual production condition of the use of shortfins scads fish in the waters of the Flores Sea, South Sulawesi has exceeded the limits of the maximum sustainable potential and optimum sustainable yield. The optimal production is in OSY conditions of 31054.11197 tons and the fishing effort of 102 purse seine units. To maintain the sustainability of elevated fisheries resources in the Flores Sea, required 59.5% reduction in fishing effort. The implication of the results of this study is the reduction of fishing units accompanied by the application of strict law enforcement so that the sustainability of short fin scads fish resources can be maintained

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