Assessing and managing demersal fisheries in Sunda Strait: Bio-economic modelling

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Abstract. Management of demersal fisheries in Sunda Strait has recently decreased productivity, especially Sulphur goatfish (Upeneus spp.), one type of demersal fish with economic value. The increasing demand for demersal fisheries causes high pressure on the existence of these resources due to the increasing intensity of capture. Based on these conditions, the study aims to determine the utilization level of demersal fisheries (Sulphur goatfish) in the Sunda Strait. The catch and fishing trips data were collected from Labuan Coastal Fishery Port (PPP), Pandeglang Regency, Banten, Fisheries Office of Pandeglang Regency, and Fisheries and Marine Agency of Banten Province during 2008-2017. Surplus production models are used to estimate the biological parameters of Sulphur goatfish. The regression and the modeling show that the CYP is the most suitable model based on the highest $R^2$ (0.74) and the values of the biological parameters consisted of the intrinsic growth rate (0.7670), the catchability coefficient (0.0002454), and the carrying capacity (5,914.06 tons per year). The bio-economic analysis shows that utilization of Sulphur goatfish (Upeneus spp.) have experienced biological and economic overfishing, as shown on the average of the actual catch of 1,734.84 tonnes/year, above the MSY and MEY values of 1,133 tonnes/year, and the actual effort of 4,198.81 trips/year, which is far above the effort of MSY and MEY in the range of 1,500 trips/year. Consequently, the management strategies that can be suggested are regulating catch effort, fishing time, and mesh size, as well as improving cooperation among stakeholders, thus creating sustainable fisheries management.

1. Introduction

In recent years, world fisheries have become a dynamically developing sector of the food industry, and many states have striven to take advantage of their new opportunities by investing in modern fishing fleets and processing factories in response to growing international demand for fish and fishery products [1]. Many fisheries resources could not sustain an often uncontrolled increase of exploitation [2], fisheries resources are under pressure from the increasing demand for protein, then driven by a rapidly growing human population [3], and showing a declining trend and the industry is plagued with economic and social problems [4] due to overexploitation and the consequently reduced yield from fish stocks [5]. The central issue for coastal fisheries in Asia is the depleted state of the resources due to the major
contributor to these declines is overfishing, although this is compounded by environmental degradation [6].

Indonesia is the second-largest capture fisheries producer in the world that contributed to world catch production by 7.19% (6.54 million tonnes) in 2016 or one level below China which amounted to 17.56 million tonnes (19, 29%) [7]. In order hand, over the past 40 years, many fish populations in Indonesia waters have been severely depleted [8]. In the Sunda Strait, fishing activities also in threat and potentially at a high risk of vulnerability because of increasing fishing capacity [9]. Based on several research, most of the fish resources in the Sunda Strait have experienced overfishing, [10–12]. Sulphur goatfish (Upeneus sulphureus) is one of the demersal fish in the Sunda Strait that had indicated growth overfishing [13,14].

Globally, the management that attempts to keep biomass at a level that will achieve MSY has become a widely accepted approach, endorsed by the Food and Agriculture Organization of the United Nations as the reference point that should be used to assess the sustainability of fish stocks for the Sustainable Development Goals Indicator 14.4.1.3 [15]. Bio-economic models of fisheries have been developed to study the dynamics of stock and catches towards a better understanding of fishery management since the 1950s [16]. To control the stock, catching, and fishing effort of the fishery and to get protection from overexploitation requires strong scientific research in the field of fisheries biology and economics that can be easily examined with the help of a suitable model using the empirical data of the resource. Bio-economic modeling has long been advocated as an important tool in managing single as well as multispecies fisheries for sustainable fisheries management [17]. This research is necessary to analyze the utilization level of Sulphur goatfish in the Sunda Strait therefore sustainable demersal fisheries management measures can be determined.

2. Material and method

2.1. Research area
The research was conducted in the Labuan Coastal Fishery Port (PPP), Pandeglang Regency, Banten. The choice of PPP Labuan was based on the consideration that most of the fish landed were caught by fishermen from fishing areas around the Sunda Strait waters, namely in the waters of Panaitan Island, Paraja Bay, Miskam Bay, and Krakatau Island. The fishing area is considered to represent the Sunda Strait waters (Figure 1). Data collection was carried out in May-October 2018.

2.2. Data and analysis
Primary data collection in the form of economic aspects related to information about the catch and operational costs obtained by direct interviews with respondents who were selected using the purposive sampling method. Secondary data including catches, fishing gear, and fishing trips were collected from the Coastal Fishery Port (PPP) Labuan, Pandeglang Regency, Banten, Fisheries Office of Pandeglang Regency, and Fisheries and Marine Agency of Banten Province during 2008-2017.

2.3. Effort standardisation
A further complication arises in many mixed, inshore fisheries namely the existence of a variety of gear types targeting the same group of species [18]. There are many fishing gears in the Sunda Strait waters, especially for demersal fisheries [9]. Standardization of fishing gears is needed to unify the existing fishing gears so that it can be assumed that the fishing effort can produce catches that are relatively the same as the fishing gear used as a standard. Fishing gear that is used as standard fishing gear is fishing gear that catches certain types of fish and has a Fishing Power Index (FPI) value equal to one. The FPI value of each fishing gear can be found by dividing the average catch for the fishing unit used as the benchmark. The FPI value is formulated as follows (Sparre and Venema, 1999):

\[
CPUE_i = \frac{c_i}{f_i}
\]

(1)
\[
FPI_i = \frac{CPUE_i}{CPUE_s}
\]

Where \( CPUE_i \) is catch per unit effort from the \( i \) fishing gear, \( C_i \) is the amount of catch from the \( i \) fishing gear, \( f_i \) is the number of fishing effort for the type of the \( i \) fishing gear, \( CPUE_s \) is catch per unit effort of the fishing gear standard, and \( FPI \) is fishing effort factor in the type of the \( i \) fishing gear.

Figure 1 Research location in Sunda Strait.

2.4. Surplus production models

In this study, to estimate the biological parameters of demersal fishery resources in the Sunda Strait waters, a surplus production model is used. It is used to assess the biomass and exploitation level of the marine populations in data-limited situations where age and size information are unavailable [19]. This model has been widely used by scientists because of its simple data requirements and applicability to solve long-run problems [20]. The surplus production concept is the basic concept of fisheries knowledge based on the idea that an increase in fish population will be obtained from the small fish that are produced every year while the decreasing population is caused by death, either due to natural factors or human exploitation. This model requires catch (yield) and effort data, two types of data that are collected and published in the fisheries sector statistics [21]. In bio-economic modeling, the surplus production model, which is an equilibrium model has the capability to determine the sustainable yield from a given fishing effort and is regarded as a valuable tool for its first approximation even in time or data limiting condition. These models are generally used to examine economic performance or rent dissipation in a fishery [17].

Surplus production models provide simple descriptions of harvested populations, in terms of annual biomass levels (\( x_t \)), the intrinsic growth rate (\( r \)), the carrying capacity of the environment (\( K \)), and the efficiency of fishing gear (\( q \)). The basic concepts underlying these models were introduced by Graham (1935) and developed by Schaefer (1954), Bevorton and Holt (1957), Pella and Tomlinson (1969), and Fox (1970) [22]. The sustainable catch equation for Schaefer, Gulland, Walter, and Hilborn, and Schaefer models use logistic growth (linear relationship), Fox and CYP models use Gompertz growth (exponential relationship), while Pella & Tomlinson model uses the generalized logistic growth [23].

The estimation of optimum catch effort (\( E_{opt} \)) and maximum sustainable catch (\( MSY \)) is approximated by the surplus production model, as it is known that between catch per unit effort (\( CPUE_i \)) and effort can be either linear or exponential (Gulland, 1983).
There are several types of surplus production models explaining stock (biomass) and production. In this study, seven surplus production models are used to explain the relationship between biomass and production and to estimate the biological parameters of demersal species in the Sunda Strait. Schaefer, Gulland, Pella Tomlinson, Fox, Walters and Hilborn, Schnute, and Clark, Yoshimoto, and Pooley are models that are used in this study. These models relate stock size, fishing effort, and yield to one another. Stock size adjusts to different levels of effort, and sustainable yield is a result of applied effort [24].

2.4.1. The Schaefer model. This model was developed by Schaefer (1954) who assumes that the model is a single species, growth function, logistical production, and limited area. Assuming that the production process and stock are dynamic in long-term equilibrium conditions, the catch and sustainable fisheries effort of the dynamic function can be mathematically written:

\[ h_t = qx_tE_t = rx_t \left(1 - \frac{x_t}{K}\right) \]  

(3)

where \( q \) is the coefficient of fishing gear capability; \( E_t \) is the fishing effort (trip); \( r \) is the coefficient of the natural growth rate of fish; \( x_t \) is the fish stock (tonnes); and \( K \) is the coefficient of environmental carrying capacity. If the above equation is converted into the \( x_t \) value where:

\[ x_t = K \left(\frac{qE_t}{r}\right) \]  

(4)

it will obtain a sustainable yield function with the equation:

\[ h_t = qE_tK \left(1 - \frac{qE_t}{r}\right) \]  

(5)

The equation of the sustainable yield function states that the Schaefer surplus production model assumption in the balance of the relationship between catch per unit of fishing effort (CPUE = \( U_t = \frac{h_t}{E_t} = qx_t \)) and fishing effort is linear. If the model uses the approximation \( \frac{dU_t}{dt} \approx (\bar{U}_{t+1} - \bar{U}_{t-1})/2 \) where \( \bar{U}_t \) is the average CPUE for a given year, so the equation can be:

\[ (\bar{U}_{t+1} - \bar{U}_{t-1})/(2\bar{U}_t) = r - (r/(qK))((\bar{U}_t) - q(\bar{E}_t)) \]  

(6)

where \( \bar{E}_t \) is the total effort in year \( t \).

2.4.2. The Gulland model. Gulland (1961) provided a method of examining the relationships between the present conditions of stock and past events. The Gulland method assumed that some relationships exist between abundance and past effort if recruitment and natural mortality are reasonably steady. The equation is written as:

\[ U_t = qK - q^2Kr(\bar{E}_t) \]  

(7)

Where \( U_t \) is CPUE at \( t \) period; \( q \) is the coefficient of fishing gear capability; \( r \) is the coefficient of the natural growth rate of fish; and \( K \) is the coefficient of environmental carrying capacity. \( \bar{E}_t \) is the total effort in year \( t \).

2.4.3. The Pella Tomlinson model. Pella Tomlinson (1969) proposed the use of generalized production equation:

\[ \frac{dx_t}{dt} = \frac{r}{n-1}x_t \left(1 - \left(\frac{x_t}{K}\right)^{n-1}\right) - Ftx_t \]  

(8)

Where \( x_t \) is the exploitable stock biomass; \( F_t \) is the instantaneous fishing mortality rate; \( r \) is the intrinsic growth rate of the population; \( K \) is the carrying capacity, and \( n > 0 \) is a unitless parameter determining the shape of the production curve. The term \( Ftx_t \) represents the instantaneous catch while the remaining part of the right-hand-side equation represents the instantaneous biomass surplus production of the stock following a theta-logistic growth function (Pedersen et al. 2011). The intrinsic growth rate \( r \) models
density-independent growth and natural mortality. The carrying capacity $K$ is a density-dependent growth penalty corresponding to the equilibrium $x_t$ of an unexploited stock ($F_t = 0$).

The equation will be:

$$U_t = qK - q^n K (F_t^{n-1})$$

Where $U_t$ is CPUE at $t$ period; $q$ is the coefficient of fishing gear capability; $r$ is the coefficient of the natural growth rate of fish; and $K$ is the coefficient of environmental carrying capacity. $E$ is the fishing effort (trip).

2.4.4. The fox model. Fox (1975) developed a surplus production model where the equilibrium estimation method is carried out based on the Schaefer model analysis in a steady state. If $x$ is the fish stock and $h$ is the harvest, the change in the stock is:

$$\frac{dx}{dt} = f(x) - h$$

where $f(x)$ is the biological growth function. Substituting the Gompertz growth function and the classical harvest function (Schaefer 1954), the Fox (1970) model is obtained:

$$\frac{dx}{dt} = rxln\left(\frac{K}{x}\right) - qEx$$

where $r$ and $K$ are the intrinsic growth rate and environmental carrying capacity; $q$ is the catchability coefficient; and $E$ is fishing effort. If catch per unit of fishing effort ($CPUE = U_t$) and fishing effort is linear based on the Schaefer model, so the Fox model is non-linear and lag:

$$\left(\frac{U_{t+1} - U_{t-1}}{2U_t}\right) = rl\left(\frac{qK}{x}\right) - qE_t$$

where $E_t$ is the total effort expended in year $t$. The parameters $r$, $q$, and $K$ are estimated by Ordinary Least Squares (OLS) with a time series of catch and effort data.

2.4.5. The walters and hilborn model. Walters and Hilborn (1976) have a different model from the Schaefer model. This model uses a concrete version of the biological model, whereas Schaefer does not. The estimation of biological parameters using the dynamic estimation method or better known as the regression method is relatively easier because it can estimate the parameters directly from the equation. The procedure for estimating biological parameters using Walter and Hilborn is:

$$x_t = \frac{U_t}{q}$$

Where $U_t = \frac{h_t}{E_t}$ is catch per unit effort ($CPUE$) and $x_{t+1} = x_t + r_h \left(1 - \frac{x_t}{K}\right) - h_t$, so the equation will be:

$$\left(\frac{U_{t+1}}{U_t} - 1\right) = r - r/Kq \left(\frac{U_t}{E_t}\right) - q(E_t)$$

This equation is a regression equation with dependent variables, namely changes in biomass and independent variables, namely CPUE and effort. The Walters and Hilborn model is linear, lag, and reciprocal.

2.4.6. The schnute model. Schnute (1977) developed a modified version of the Schaefer model using an integration procedure. Substituting production function into a dynamic stock model by eliminating $t$, so the equation will be:

$$\frac{dx}{x} = \left(r - \frac{r}{K}x - qE\right) dt$$

Integration of the equation with a one-year time step will obtain the equation:
\[
\ln(x_{t+1}) - \ln(x_{t-1}) = r - \frac{r}{K} \bar{x} - q\bar{E}
\]  
(16)

Where \( \bar{x} = \int f^+ x \, dt \), and \( \bar{E} = \int f^+ E \, dt \), then the above equation is substituted with \( x_t = \frac{u_t}{q} \), so the equation will be:

\[
\ln \left( \frac{U_{t+1}}{U_t} \right) = r - \frac{r}{Kq} \bar{U} - q\bar{E}
\]  
(17)

Where \( \bar{U} \) is average of CPUE, and \( \bar{E} \) is average of effort, by using the geometric mean of the equation above, it can be written through algebraic modification:

\[
\ln \left( \frac{U_{t+1}}{U_t} \right) = r - \frac{r}{Kq} \frac{U_t + U_{t+1}}{2} - q \frac{E_t + E_{t+1}}{2}
\]  
(18)

Same as the Walters and Hilborn model, this model is linear, lag, and reciprocal.

2.4.7. The clark, yoshimoto, and pooley model. Clark, Yoshimoto, and Pooley (CYP) (1992) model is developed from the Schnute model and applies a similar approach to the Fox model, using a Taylor approximation (derivation in Appendix A). By assuming that the annual average catch per unit effort is roughly the geometric mean of its values at the beginning and end of each year (Schnute, 1977):

\[
\bar{U}_t = \sqrt{U_{t+1}U_t}
\]  
(19)

by combining the equation from Fox’s model, we obtain:

\[
\ln(U_{t+1}) = \frac{2r}{2+r} \ln(qK) - \frac{(2-r)}{(2+r)} \ln(U_t) - \frac{q}{(2+r)} (E_t + E_{t+1})
\]  
(20)

This equation showing that the CYP model is non-linear and lag. With annual data on \( U \) and \( E \), we can estimate the three coefficients in the equation above which can, in turn, be used to solve for the three original coefficients \( (r, q, \text{and } K) \). The error term is assumed \( N[0, \sigma^2] \).

2.5. Estimation of the cost of fishing

The data on the cost of catching is obtained from the interviews with respondents. The fishing cost consists of fixed and variable costs. In bio-economic studies, the fishing cost is based on the assumption that only fishing factors are calculated and are assumed constant so that in this study, the fishing cost is defined as the variable costs per trip. Fishing cost is calculated proportionally using the following formula (Zulbainarni 2016):

\[
c = \frac{h_{nt}}{\sum_{t=1}^{10} h_{nt}} C
\]  
(21)

Where \( c = \sum_{n=1}^{4} c_n \); \( c_n \) is the proportion of the cost of catching the species number \( n \) (IDR); and \( C \) is the total cost of fishing (IDR).

The costs that have been obtained are converted into real-measurements by adjusting them into the Consumer Price Index (CPI) prevalent in Pandeglang Regency, to eliminate the effect of inflation. Mathematically is written:

\[
c_{nt} = \frac{1}{1 + H_{K_{std}}} c_{std}
\]  
(22)

Where \( c_{nt} \) is the real-cost of species \( n \) in year \( t \); \( c_{std} \) is the nominal cost of species \( n \) in the standard year; \( H_{K_{t}} \) is the consumer price index for fish commodities in year \( t \); \( H_{K_{std}} \) is the fish commodity consumer price index in the standard year.
2.6. Estimation of the fish price

The fish price data is obtained from the production value of the catch in the time series data of the capture fisheries of the Fisheries Office of Pandeglang Regency. The data that has been obtained is then converted to real-measurement by adjusting the CPI applicable in Pandeglang Regency. Mathematically it is denoted as follows (Fauzi and Anna 2005):

\[ p_{nt} = \left( \frac{CPI_t}{CPI_{std}} \right) p_{std} \] (23)

Where \( p_{nt} \) is the real-price of species \( n \) in year \( t \) (IDR/tonne); \( p_{std} \) is the nominal price of species \( n \) in the standard year (Rp/tonne); \( CPI_t \) is the consumer price index for fish commodities in year \( t \); \( CPI_{std} \) is fish commodity consumer price index in the standard year.

3. Bio-economic modeling

In bio-economic analysis, there are static models and dynamic models. In this study, the Gordon Schaefer (G-S) static model is used because it considers the biological and economic aspects of the exploitation of fish resources. The static model does not pay attention to intertemporal aspects [25]. In equilibrium conditions, the change in fish stocks is equal to 0 so that the relationship between the growth rate of fish biomass and the catch volume is obtained. Furthermore, the relationship between fish biomass and the level of fishing effort is known, and through mathematical substitution, the relationship between the production function and sustainable business will be obtained. The relationship between results and efforts is written mathematically as:

\[ h = (qK)E - \left( \frac{q^2 K}{r} \right)E^2 \] (24)

this equation can be simplified to:

\[ h = \alpha E - \beta E^2 \] (25)

where:

\[ \alpha = qK, \quad \beta = \frac{q^2 K}{r} \] (26)

The sustainable production function of demersal fishery resources is a quadratic equation. In the Schaefer perspective model, the best management of fish resources is when sustainable production is at the highest point of the yield-effort curve. This point is called the Maximum Sustainable Yield (MSY). At an output level of MSY, the required input is \( E_{MSY} \). Mathematically, the input level can be obtained by solving the above equation for the effort equal to 0:

\[ \frac{dh}{dE} = qK - \frac{2q^2 KE}{r} = 0 \] (27)

or, the equation is written as:

\[ E_{MSY} = \frac{r}{2q} \] (28)

Where \( E_{MSY} \) is effort level to reach maximum production. If value of \( E_{MSY} \) is substituted for the sustainable yields function:

\[ h = qKE \left( 1 - \frac{qE}{r} \right) \] (29)

the catch at the MSY level (\( h_{MSY} \)) will be obtained:

\[ h_{MSY} = \frac{rK}{4} \] (30)

By knowing the values of \( h \) and \( E \) at the MSY level, using equation \( h = qxE \), the biomass level at the MSY level can be calculated:
$$x_{\text{MSY}} = \frac{h_{\text{MSY}}}{qE_{\text{MSY}}} = \frac{(rK/4)}{q(r/2q)} = \frac{K}{2}$$

(31)

Where $x_{\text{MSY}}$ is value of fish stocks at maximum production.

The Gordon Schaefer model (1954) assumes that income is in accordance with fix equilibrium condition of stock resource, where the price per output unit ($p$) and the cost per effort unit ($c$) are constant or perfectly elastic demand curve. With this assumption, the economic benefit or economic rent obtained from fisheries activities is derived from the margin between revenue and incurred cost ($\text{Total Revenue} = \text{TR}$). A simple economic model, in which Total Cost ($\text{TC}$) is proportional to effort, and Total Revenue ($\text{TR}$) is proportional to catch, was introduced by Gordon (1954):

$$\text{TR} = ph(E)$$

(32)

$$\text{TC} = c(E)$$

(33)

The economic benefits can be calculated from the margin between revenues and costs so that by combining the two equations, the economic benefits of fishing can be written as:

$$\pi = ph - cE$$

(34)

where $\pi$ is the rent or profit from fish resources (IDR); $p$ is the price of fish (IDR/ton); $h$ is the catch (ton); $c$ is the cost of catching (IDR/trip); and $E$ is the catch or effort (trip). By substituting the equation $h = \alpha E - \beta E^2$ into the equation $\pi = ph - cE$, we will obtain the revenue from the input side. Mathematically is written as follows:

$$E_{\text{MEY}} = \frac{r}{2q} \left[1 - \frac{c}{pqK}\right]$$

(35)

with the assumption that the system is in equilibrium (sustainable) with $h = F(x)$, then the fish stock function ($x$) obtained in MEY condition is:

$$x_{\text{MEY}} = \frac{K}{2} \left[1 + \frac{c}{pqK}\right]$$

(36)

Then by substituting the $E_{\text{MEY}}$ and $x_{\text{MEY}}$ equations into the sustainable yields equation (29), the $h_{\text{MEY}}$ value will be obtained as follows:

$$h_{\text{MEY}} = \frac{rK}{4} \left[1 + \frac{c}{pqK}\right]\left[1 - \frac{c}{pqK}\right]$$

(37)

The level of effort in open access conditions can be done by calculating the lost economic rent where $\pi = 0$, then:

$$x_{\text{OA}} = \frac{c}{pq}$$

(38)

The optimal catch value under open access ($h_{\text{OA}}$) condition can be determined by the following notation:

$$h_{\text{OA}} = \frac{rc}{pq} \left[1 - \frac{c}{pqK}\right]$$

(39)

with algebraic substitution and with the help of the equation $h = qxE$, the optimal level of effort in open access condition can be calculated as follows:

$$E_{\text{OA}} = \frac{r}{q} \left[1 - \frac{c}{pqK}\right]$$

(40)

The calculations of the catch, biomass, the effort, and the economic benefits under the management conditions of MSY, MEY, and Open Access were carried out for each fish species.
4. Result and discussions

4.1. Biological parameters

The waters of the Sunda Strait are one of the utilization sources of the capture fisheries, where 30% of the capture fisheries production of Banten Province comes from the Sunda Strait. Capture fisheries production in the Sunda Strait accounts for about 2% of the total production of fish resources in WPPNRI 572 (Department of Marine Affairs and Fisheries of Banten Province 2017). One of the types of demersal fish caught is Sulphur goatfish (Upeneus spp.). Demersal fisheries in the Sunda Strait use a variety of fishing gears, namely mini bottom trawls (jaring arad), seine nets (payang), demersal danish seine (dogol), purse seine, gillnets (jaring rampus), shore operated stationary lift nets (bagan tancap), and fishing lines.

Catch per unit effort (CPUE) describes the productivity level of capturing effort. The higher the CPUE value is, the higher the productivity of fishing gear will be [23]. In this analysis, purse seine is a standard effort for the Sulphur goatfish production because a purse seine has a Fishing Power Index (FPI) value equal to one. The standard fishing gear CPUE value has fluctuated in the last 10 years. In 2017, the CPUE value experienced a drastic decline (Table 1).

Table 1. The value of production (tonne), standard efforts (trip), and CPUE (tonne/trip) of Sulphur goatfish in the Sunda Strait (2008-2017).

| Year | Actual Production (tonne) | Total Standard Effort (trip) | CPUE (tonne/trip) |
|------|--------------------------|-----------------------------|------------------|
| 2008 | 1,486.60                 | 3,236.36                    | 0.4593           |
| 2009 | 1,391.60                 | 3,268.22                    | 0.4258           |
| 2010 | 1,243.43                 | 2,917.64                    | 0.4262           |
| 2011 | 1,215.70                 | 2,945.58                    | 0.4127           |
| 2012 | 2,232.70                 | 3,121.64                    | 0.7152           |
| 2013 | 2,117.49                 | 3,473.30                    | 0.6096           |
| 2014 | 2,257.12                 | 3,743.35                    | 0.6030           |
| 2015 | 2,005.50                 | 5,634.78                    | 0.3559           |
| 2016 | 2,323.60                 | 7,178.54                    | 0.3010           |
| 2017 | 1,074.70                 | 5,928.73                    | 0.1813           |

Based on data from the Pandeglang Regency Fisheries Service (2018), the fishing production of this type of fish tends to decline and fishing effort tends to increase (Figure 2). The production of Sulphur goatfish in 2013 was 2,117.49 tonnes but then decreased in 2017 to 1,074.70 tonnes. On the other hand, the number of fishing fleets in 2015-2016 has increased from 2,179 units to 2,293 units with various types of fishing gear used, from purse seines (payang, dogol, and mini trawl/arad), gill nets, to the hook and lines. Increasing the number of fishing fleets as well as fishing efforts will cause more pressure on fish resources. This condition will initially provide profit, but in the long run, it will affect the income of fishermen whose lives are very dependent on fishing activities. Based on data from the Fisheries Office of Pandeglang Regency (2017), the value of capture fisheries production in Pandeglang Regency for the last 3 (three) years has decreased (2015-2017) from 29,517 tonnes in 2015, 23,215 tonnes in 2016, and 18,872. 67 tonnes in 2017 (Figure 2).
The estimation of biological parameter of Sulphur goatfish in the Sunda Strait uses the surplus production models i.e. Schaefer, Gulland, Pella Tomlinson, Fox, Walters and Hilborn, Schnute, and Clark, Yoshimoto, and Pooley. Walters-Hilborn, Schnute, and CYP models used multiple regressions, whereas Schaefer, Pella & Tomlinson, Fox, and Gulland models used simple regression. Basically, $R^2$ was obtained from a regression between CPUE (Y-axis) and standard effort (X-axis) [23]. The results of statistical performance analysis of the surplus production model of the development of Schaefer, Gulland, Pella Tomlimson, Fox, Walters and Hilborn, Schnute, and Clark, Yoshimoto, and Pooley models are indicated in Table 2.

**Table 2. Analysis of biological parameters using various models of surplus production.**

| Model                      | Coefficient | $R^2$  |
|----------------------------|-------------|--------|
| Schaefer                   | 0.7086      | 0.41319|
| Gulland                    | 0.7822      | 0.56061|
| Pella Tomlinson            | 0.5670      | 0.39544|
| Fox                        | -0.1803     | 0.45996|
| Walters and Hilborn        | 2.3404      | 0.49266|
| Schnute                    | 0.3554      | 0.37613|
| CYP                        | 0.2066      | 0.73787|

The most suitable surplus production model will have different opportunities for different species and under different aquatic conditions. When viewed from the statistical indicator, namely the coefficient of determination, the greatest $R^2$ value is in the Clarke, Yoshimoto, and Pooley (CYP) model. The multiple linear regression (OLS) results on various models of surplus production show low statistical performance, except for the CYP model. The CYP model has the highest $R^2$ value at 74.8%, which means that the dependent variable can be explained by the explanatory variable by 74.8% and the rest by other variables outside the model. The value of determination or $R^2$ is commonly used to measure the goodness of fit of the dependent variable in the model, where the greater the $R^2$ value indicates that the model is getting better [26]. The coefficient of determination $R^2$, provides information about the goodness of fit of the regression model: it is a statistical measure of how well the regression line approximates the real data points. $R^2$ is the percentage of variance in the dependent variable that is explained by the variation in the independent variable [27].

**Figure 2.** Production and value production of capture fisheries in Pandeglang Regency in 2013-2017
The biological parameters analyzed from the surplus production models consisted of the intrinsic growth rate \((r)\), the catchability coefficient \((q)\), and the carrying capacity \((K)\). The results of the analysis using the surplus production models show that the biological parameter values randomly for \(r\) ranged from 0.016-2.341; \(K\) between 5,914.07 tonnes to 801,761,457.19 tonnes and \(q\) between -0.0000144 up to 0.0002454 (Table 3).

Table 3. Comparison of Intrinsic Growth Parameters \((r)\), Catching Coefficient \((q)\), Environmental Carrying Capacity \((K)\) in Surplus Production Models of Sulphur goatfish.

| Model                | \(q\)        | \(r\)   | \(K\) (tonne)          |
|----------------------|--------------|---------|------------------------|
| Schaefer             | 0.0000045    | 0.0519  | 156,404.2778           |
| Gulland              | 0.0000052    | 0.0504  | 151,045.6689           |
| Pella Tomlimson      | 0.00000000   | 0.0682  | 801,761,457.19         |
| Fox                  | -0.0000144   | 0.0159  | 12,558.2610            |
| Walters and Hilborn  | 0.0001726    | 2.3405  | 9,228.2321             |
| Schnute              | 0.0001194    | 0.3554  | -36,710.6148           |
| CYP                  | 0.0002454    | 0.7670  | 5,914.0628             |

The CYP model shows a more logical result when viewed from the value of \(K\). Its value is relatively logical if looking from the actual production conditions. Several previous studies related to fish resources in tropical regions such as Indonesia with fish resources in multi-species waters and multi-gears, the use of the CYP model is considered the most appropriate compared to using other models [21,28,29], and becomes the model that generates the best fit on biological parameter estimations of fish resources in Indonesia [30].

Biological parameter from the CYP model shows that the intrinsic growth rate \((r)\) value indicates that Sulphur goatfish resources can grow naturally without human disturbance with a coefficient of 0.7670 tonnes per year. The intrinsic growth rate \((r)\) of the Sulphur goatfish is considered high. The greater the \(r\) value, the faster the fish will grow than other species so that the possibility of being caught quickly is higher and the possibility of extinction or scarcity is higher [25]. The coefficient of catching capacity \((q)\) indicates that every increase of one effort unit will affect the increasing catch of the Sulphur goatfish resources by 0.00025 tonne per trip. The value of the environmental carrying capacity \((K)\) shows that the ability of aquatic ecosystems can support the production of the Sulphur goatfish by 5914.0628 tonnes per year.

4.2. Economic parameters

The economic parameters estimation includes costs incurred per fishing trip (cost per unit effort) and price per kg or tonne. The variable costs are operational costs per fishing trip which are assumed to be constant. The fishing cost data is obtained from the interviews with fishermen, then it is converted to real-measurement by adjusting it with the Consumer Price Index (CPI) in order to minimize the effects of inflation.

In Gordon Schaefer's bio-economic analysis, fishing costs are based on the assumption that only fishing factors are taken into account and are considered constant. Therefore, in this study, the fishing costs are variable costs per trip that include fuel (diesel and gasoline), ice, water, and food. The average cost incurred from fishing activities using various fishing gears in the Sunda Strait is 3,267,619,047 IDR/trip. The real-cost of catching the Sulfur goatfish is obtained by dividing the CPI of the year to be found by the CPI of the standard year (2012) times the nominal cost in the standard year (2012). The nominal cost incurred to catch the Sulfur goatfish in the standard year (2012) is IDR 171,946.11/trip, therefore the average fishing cost of the Sulfur goatfish is IDR 0.17 million/tonne.

Price is a factor that greatly influences the incomes or profits obtained from fishing activities. The price estimation is obtained from the production value of each species comprised in the statistical data of the Marine and Fisheries Office of Pandeglang Regency. The measurement of the price in the fisheries
sector is adjusted to the CPI to reduce the effect of inflation. The price used in this study is the real-price, that is, the nominal price is multiplied by the CPI of 2008-2017 with that of the base year 2012 (2012 = 100). The nominal price of Sulphur goatfish in 2017 is IDR 17.5 million/tonnes. By multiplying the nominal price of Sulphur goatfish with the CPI of the base year 2012, the obtained average price was IDR 8.52 million/tonnes. The higher price of the fish makes the fishermen keep on trying to increase their catch to get higher profits [31].

4.3. Analysis of bio-economic model

The biological and economic parameters obtained are used to determine the optimum catch (\(h\)), the optimum catch effort (\(E\)), and the economic profit (\(\pi\)) in the MEY, MSY, and actual management regimes. The information on the results of the bio-economic analysis using G-S model is presented in Table 4.

| Management Regime | \(x\) (stock) | \(h\) (tonne) | \(E\) (trip) | \(\pi\) (IDR million) |
|-------------------|--------------|--------------|-------------|---------------------|
| MSY               | 2,957.03     | 1,133.99     | 1,562.51    | 7,640.52            |
| MEY               | 3,006.53     | 1,133.67     | 1,536.36    | 7,642.74            |
| Open Access       | 99.01        | 74.66        | 3,072.71    | 0.00                |
| Actual            | -            | 1,734.84     | 4,198.81    | 6,487.59            |

Based on the results of the analysis, it is known that the actual conditions for Sulphur goatfish are above optimal in both MSY and MEY conditions, as seen from the amount of effort and catch. The average actual catch is 1,734.84 tonnes/year, above the MSY and MEY values of 1,133 tonnes/year, which indicates that the Sulphur goatfish in the Sunda Strait fishery has biological overfishing symptom. Catching fish that exceeds the carrying capacity that causes the decreasing resource's ability to produce at the maximum sustainable yield (MSY) level is a symptom of biological overfishing [22]. Likewise, the actual effort of 4,198.81 trips/year is far above the effort of MSY and MEY which is in the range of 1,500 trips/year, even OA effort is only 3,072.71 trips/year.

The high average actual effort value that exceeds the MSY and MEY effort levels indicate a symptom of economic overfishing. Demersal fisheries in the Sunda Strait in recent years have experienced overexploitation as indicated by the increase in the number of fishing fleets and fishing gears along with the increase in fishing trips. Several studies conducted in the Sunda Strait show decreasing stocks, high fishing efforts, and symptoms of overfishing [10,11,30,32–34]. According to some experts, the actual average production conditions that are greater than the MSY and MEY levels indicate that fisheries stocks are in critical condition due to high pressure on resources due to increasing efforts. Eventually, higher pressure on resources will deplete these resources (Malthusian overfishing). The high effort will cause economic inefficiency which in turn will cause economic losses (negative economic rent). An increase in the catch will cause an increase in the negative economic returns. This situation is explained graphically in Figure 3.
Profits received from actual demersal fisheries are below the profits at the MSY and MEY levels, which indicates that demersal fisheries in the current business conditions do not provide optimal profits and tend to be inefficient. This situation encourages unsustainable fisheries utilization if the catch and effort are not controlled. Some scientists consider that the condition of fisheries in Indonesia, especially the small scale fisheries, both pelagic fisheries and demersal fisheries, experience complex challenges ranging from weak governance, socioeconomic conditions, local organization, and ecosystem change [35]; a marked degradation of fish habitats and regulatory regime [8]; decentralized management of fisheries causing weak supervision [36].

The demersal fishery is an economic asset like other assets that have opportunity costs, so that demersal fishery resources have a choice whether to be exploited now to get present value or exploited in the future to get future value. However, sustainable use is the main choice that must be made. Several approaches that can be used, especially for demersal fisheries with multi-gears, are meant to maintain existing fishing units with their full crews by rationing gear use or fishing time to reduce their operating costs. Gear rationing may be carried out, for example by limiting the length of the permitted headline on the trawls, the numbers and sizes of traps used, allowed gillnet spacing, the allowed number of hooks, and permitted length of longlines. The fishing time can be reached either by periodic closures of the entire fishery by requiring different components of the fleet to fish in alternating periods [37].

5. Conclusion
The utilization of demersal fisheries, especially Sulphur goatfish in the Sunda Strait, should be controlled immediately in its management due to the biological and economic overfishing conditions. This condition will not provide fisheries actors with economic benefits nor contribute to the regional economy since the economic rents are not optimal. Limiting the number of fishing fleets, fishing time, and fishing trips needs to be done immediately in accordance with the operational level of maximum economic yield (MEY) so that the utilization of demersal fisheries can be sustainable. The catch must be controlled at 1,133 tons/year, and fishing trips in the range of 1,500 trips/year. Proper regulation and contributions from stakeholders as well as good governance need to be executed immediately. It takes the commitment of all stakeholders and the consistency of business actors in carrying out the applied regulations.
Authorship contribution
Lindawati: writing - original draft; Yeyen Mardyani: writing and data analysis; Novita Dwi Yanti: data analysis; and Mennofatria Boer: conceptualization, data curation, and methodology.

Acknowledgment
The authors are grateful for the involvement of the deceased Achmad Fahrudin who had given contribution to this research. Labuan Coastal Fishery Port (PPP), Pandeglang Regency, Banten are thanked for their cooperation. Fully appreciations and thanks are given to the translator Rusni Budiati who has translated the transcript of this article.

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