Bioeconomic model of largehead hairtail fisheries (*Trichiurus lepturus*) in Cilacap waters, Central Java, Indonesia as an approach to fisheries management

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Abstract. The main fishery product in Cilacap district is the largehead hairtail (*Trichiurus lepturus*), a high value added commodity. The environmental management of small scale fisheries does not lack complexity, under economic imperatives, and it should be carried out properly, by considering factors like the size of the fishing gear, the uncertainty of the catch and the trips number, which tends to increase. have a marked preference for *T. lepturus*, due its elevated price on the international trade markets, under a strong demand pressure. The study aims to provide a sustainability management tool based on the evaluation of the catch per unit effort (CPUE), the Fishing Power Index (FPI), the Maximum Sustainable Yield (MSY), the Maximum Economic Yield (MEY) and the actual conditions. The results suggested an MSY value of 505,300 kg year^{-1} and an optimal effort (F_{MSY}) of 24,139 trips, a MEY value of 497,098 kg year^{-1} and its corresponding effort of F_{MEY} 21,064 trips. MSY profits were 844,591.46 USD and MEY profits were 860,343.61 USD.

Key Words: status stock, CPUE, MSY, MEY, fishing policy.

Introduction. Cilacap is one of the legal regencies located in the south of Central Java province which is a center of fishery activities (capture fisheries and aquaculture). This is a minapolitan area established by the Ministry of Maritime Affairs and Fisheries (MMAF). Cilacap coastal area is part of the Fisheries Management Area Republic of Indonesia (FMA RI-573), with many types of demersal fish having various density structures and a dominant species, the largehead hairtail (*Trichiurus lepturus*) (Suman et al 2014) and specifically in Cilacap water and its surrounding (Panggabean et al 2015; Apriliani et al 2018). Based on the Ministry of Maritime Affairs and Fisheries decree No. 47 of 2016, *T. lepturus* exploitation rate has reached the maximum authorized limit.

The carrying capacity of the region has a significant potential, the coastline length of 103 km being much longer than in other districts from the eastern part of Kebumen Regency (52 km), Purworejo Regency (32 km) and Pangandaran Regency (91 km), situated at the West. The potential is directly proportional with the number of fishing vessels and with the number of fishermen, and it generates employment opportunities. In exchange, fisheries management can be a real challenge, as the main priority is to keep fish resources in a sustainable condition without reducing the local fishermen livelihoods. Many large rivers pass through the area and there is a sea inlet, the "Segara Anakan", which determines an ecosystem with a large number of fish and other marine life. The area of mangrove land coverage in Cilacap reaches 2,618 ha (Pangesti et al 2015), which is suitable as a nursery ground area, being a habitat for demersal fish (including *T. lepturus*) and shrimp, species living in the muddy zones of river mouths (Nakamura & Parin 1993). The eating habit of *T. lepturus* is carnivor, because they eat damersal fish, shrimp and squid (Abidin et al 2013; Prihatiningsih & Nurulludin 2014).

T. lepturus became a high-value commodity on both the domestic and export markets, and consequently a preferred target for fishermen, due to: (1) a high export demand and a diversified processing, adding economic value, and (2) a catch season during most of the year, even if the fish population is reduced during the fish famine season. However, a standardized reference is necessary for the *T. lepturus* exploitation control and sustainable fishing.

T. lepturus fishing in Cilacap Regency is operated through various methods, ships and fishing gears. Small scale fisheries are identified by their simple technology, having limited capital assets and depending on the catch season. Fisheries management should consider that fish resources are renewable, but the process is rather slow, therefore an approach based on time series data provides a more accurate assessment, avoiding the fish resources depletion, while the fisheries business is still preserved and social conflicts avoided. Uncertainty patterns in the catches productivity trends and its seasonal dependence demonstrate the need of appropriate policies promoting environmentally friendly fishing gear, fishing trip arrangements, open close season, zoning arrangements for fishing areas, supervision of fisheries resources by the government (Nikijuluw 2012).

T. lepturus can be caught with various fishing gear namely gill net, Danish seine “paying” and Danish seine “arad”. According to Facrudin & Hudring (2014) gill net is the most ecofriendly fishing gear than danish seine "payang" and danish seine “arad”. It catches fish selectively based on the mesh size and has species target. On the other hand, payang and arad are not selective in *T. lepturus* fishing. Both fishing gears have very small mesh size, and fish caught are still small (immature) even jouvenil. So it is not based on the FAO Code of Conduct for Responsible Fisheries (CCRF 1995). The three of them have different sensitivity in catching fish with a different number of fishermen: the gill net team numbered 2-3 people per boat, the payang 10-15 people and the arad 3-4 people. The benefits for each fishing gear are limited, in a sustainable management bioeconomic approach related to the *T. lepturus* fisheries.

Fisheries management conducted by the government has not yet been comprehensive and still tends to remain unchanged, giving the difficulties to achieve prosperity and fair revenues among fishermen. The Maximum Sustainable Yield (MSY) and Maximum Economic Yield (MEY) are basic concepts in determining fisheries policy. The concept of the bioeconomic approach was first introduced by Gordon in 1954. Other studies suggest the ecosystem management approach (Airlangga et al 2018), the Rapfish method (Hutapea et al 2019), the quota output approach using the Total Allowable Catch (TAC) (Widagdo et al 2019).

The current research analyzed the Catch per Unit Effort (CPUE), optimum effort, catch MSY, MEY, profit, total revenue, total cost of *T. lepturus*. Considering that each fishing trip is expected to provide an economic benefit, a MEY approach was performed for a cost efficiency evaluation, but the priority remained the control of the catch effort, like fishing trips number and duration, or gear, as suggested by Widodo & Suadi (2006).

Material and Method. This research used the survey descriptive method. Material researches cover *T. lepturus* catch and efforts reported by the auction fish centers of the Cilacap fishing port. The data on the *T. lepturus* catches collected for this research focused on small-scale fisheries with 1 day fishing duration, without using auxiliary engine, except the native vessel engine, according to the specification. In this study there are 2 types of data, namely primary data and secondary data. Primary data were obtained from questionnaires with fishermen, direct observation and interviews. Secondary data was obtained through the collection of the Cilacap fisheries department's annual report literature from 2013-2018, presenting all combined production and effort data from all fish auction place (TPI) and Cilacap Ocean Fisheries Port.

Research location and time. The study was conducted in the Cilacap district, Central Java Province in July-October 2019.

Data analysis. Catch effort and production annual time series data for *T. lepturus* catches were collected from the Cilacap district fisheries service for the past 6 years (2013-2018). Then it was processed in depth and complemented by information extracted from fishermen through questionnaires and, finally, it was validated directly at the fish auction place (TPI) and by direct observation on the gill net vessels, at the research location. This research is restricted by using fishing gears such as gill net with a mesh size of 1.75 inches to 2.5 inches, Danish seine "payang" and Danish seine “arad”. The data are combined from the Cilacap district marine and fisheries service and from the Cilacap Ocean Fishery Port (PPSC 2018). Data analyzed were the *T. lepturus* CPUE, MSY and F_{MSY}, MEY and F_{MEY}.

Catch per unit effort (CPUE). The data needed for the CPUE calculation is the catch data and the capture attempt data. The effort is reflected by the the number of ships and fishing gear used during the fishing trip period (number of days at sea). In this research, the effort data used are trip fishing data of gill net Danish seine “payang” and Danish seine “arad”, in accordance with the conditions in the field. If only the number of vessels was used as surrogate for the effort, a bias would be induced in the estimation of the fish resources: vessels could use various gear, making the fishing trips different, in terms of efficiency. So the CPUE is calculated by dividing the total capture with the catch per trip (Sparre & Vanema 1998; Widodo & Suadi 2006; Fauzi 2010).The mathematic formula is as follows:

$$CPUE = \frac{Ci}{Fi}$$

Where:
CPUE - Catch per unit effort;
C - Total number of total catches of the fishing fleet per unit of time;
F - Number of capture attempts of the fleet from one fishing trip per unit of time.

Fishing power index (FPI). The highest value of CPUE defines the standard CPUE. Each fishing gear has different *T. lepturus* catching capabilities and needs to be standardized, based on the value of the Fishing Power Index (FPI). The fishing gear with the highest FPI value can be used as the standard or reference. In general, the fishing gear with the highest CPUE value has FPI value of 1. The FPI value of other fishing gears can be calculated by dividing the CPUE value of the fishing gear with the standard CPUE of the fishing gear. The mathematical formula is presented as follows:

$$CPUE = \frac{Cs}{Fs}$$
$$FPIs = \frac{CPUEs}{CPUEi}$$
$$StdEffort\ i = FPIi\ x\ Fi$$
$$CPUEi = \frac{Ci}{Fi}$$
$$FPIi = \frac{CPUEi}{CPUEs}$$
$$StdEffort\ s = FPIs\ x\ Fs$$
$$StdEffort\ (total) = (\sum FPIi\ x\ Fi)) + (FPIs\ Fs)$$

Where:
Cs - The catch per year of standard fishing gear (kg);
Fs - The effort of catching per year of standard fishing gear (trip);
Ci - Catch per year other types of fishing gear (kg);
Fi - Attempts to effort per year other types of fishing gear (trip);
FPIs - Fishing Power Index standard fishing gear;
FPIi - Fishing Power Index of other types of fishing gear;
$CPUE_s$ - Catch per capture per year of standard fishing gear (kg $trip^{-1}$);
$CPUE_i$ - Catch per capture per year of other types of fishing gear (kg $trip^{-1}$);
$StdEffort_s$ - Fish cathing effort (trip) after standardization;

$StdEffort_i$ - Other fishing gear after standardization;
StdEffort (total) - Over all capture effort after standardization.

Maximum sustainable yield (MSY). The formula of the surplus production model only apply if the slope parameter (b) is negative; if it is positive, then stock estimation or optimum effort cannot be made, but it can only be concluded that fishing can still increase efforts. The surplus production method according to Schaefer (1954), the effort and catch relationship produces a symmetrical parabolic curve (Zulbainarni 2012).

$$MSY = \frac{a^2}{4b}$$

$$F_{MSY} = \frac{a}{2b}$$

Where:
a - intercept;
b - slope in the linear regression equation.

Maximum economic yield (MEY). The bioeconomic model used is static, in which the determination of the cost of fishing and the price of fish is fixed. The model used is the Gordon-Schaefer model (Gordon 1954; Purwanto 1988; Zulbainarni 2012; Anna 2016). Landing *T. lepturus* calculations were based on data selected from database records for the dominant TPI, the Fish Auction Place (TPI) Jetis, PPSC, at Pandanaran and Sentolo kawat, which were published in fisheries production data statistics report by the Cilacap Fisheries Agency (DKP 2018). This model is stated as a function of the capture effort. The assumptions underlying this model are: (1) changes in the level of output (production) do not affect the price, because the fishery analyzed is one of the numerous small fisheries, (2) there is no restriction in initiating or stopping the attempts to catch fish, (3) all natural conditions and biological relationships are constant, (4) selectivity of fishing gear does not change, and (5) there is a linear relationship between costs and the level of effort (Zulbainarni 2012).

According to Wijayanto (2008), the bioeconomic approach included MSY and MEY, as depending on catch, effort, total revenue, total cost and profit, according to the formulas from Table 1.

Table 1

Gordon-Schaefer equilibrium formulas

	MSY	*MEY*
Catch (C)	$a^2/4b$	$aF_{MEY} - b(F_{MEY})^2$
Effort (F)	a/2b	(pa-c)/(2pb)
Total revenue (TR)	$C_{MSY}*p$	$C_{MEY}*p$
Total cost (TC)	$c*F_{MSY}$	$c*F_{MEY}$
Profit	$TR_{MSY} - TC_{MSY}$	$TR_{MEY} - TC_{MEY}$

a-Intercept; b-Slope in the linear regression equation; p- Fish price *T. lepturus* (kg USD^{-1}); C- Cost of *T. lepturus* fishing per trip (USD); TC- Total cost *T. lepturus* fishing (USD $year^{-1}$); TR- Total revenue *T. lepturus* fishing (USD $year^{-1}$).

Results and Discussion. *T. lepturus* production in 2013-2018 has fluctuated, with a tendency to decrease. The highest production occurred in 2013 with a total of 603.48 tons. The research data shows that the gill net is thedominant fishing gear, optimal for a *T. lepturus* targeted capture, while in the payang and arad fishing gear there can be found byproducts. From the capture fisheries statistics, 72% is the result of gill net fishing, while 22% represents the payang catches and the remaining 7% correspond to the arad catches. Overall, the production of *T. lepturus* in Cilacap waters experienced uncertainty and significant fluctuations, as shows the Figure 1 histrogram.

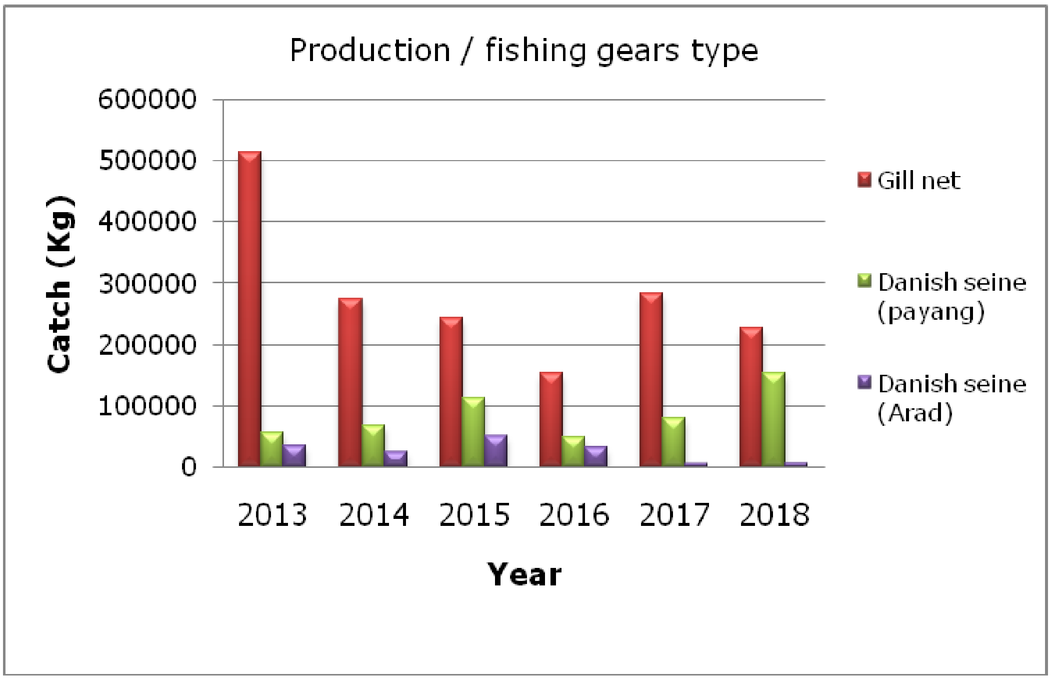

Figure 1. Histogram of *T. lepturus* production in the Cilacap waters between 2013-2018.

Fishing power index. The fishing power index was used to determine the standard effort. This calculation is necessary because each fishing gear has different capabilities in catching a species of fish. Therefore it is necessary to standardize fishing effort first the fishing gear that should have a constant CPUE and the highes value is the rationale of using standards for the fishing gear. The calculation results are found in Table 2.

Table 2

Production, fishing effort (trip), CPUE of *Trichiurus lepturus*

Year	*Gill net*			*Danish seine "Payang"*			*Danish seine "Arad"*		
	Catch (kg)	*Effort (Trip)*	*CPUE (kg trip^{-1})*	*Catch (kg)*	*Effort (Trip)*	*CPUE (kg trip^{-1})*	*Catch (Kg)*	*Effort (Trip)*	*CPUE (kg trip^{-1})*
2013	511,813	20,490	22.66	56,031	7,097	7.90	35,632	7,869	4.53
2014	274,992	24,484	11.23	67,075	7,678	8.74	24,736	7,302	3.39
2015	242,095	23,746	10.20	113,507	12,633	8.98	50,398	7,768	6.49
2016	152,749	24,037	6.35	49,703	4,734	10.50	33,108	9,668	3.42
2017	284,184	26,520	10.72	79,179	8,420	9.40	5,604	1,412	3.97
2018	227,085	22,972	9.89	153,781	3,861	39.83	6,971	3,402	2.05

Based on the table above, there are three fishing gears to catch *T. lepturus* fishing (gill net, payang & arad). The gill net has a constant value to catch *T. lepturus* so it becomes a standard fishing gear. The highest CPUE value in 2013 was 22.66 kg trip^{-1}, the lowest CPUE value in 2016 was 6.35 kg trip^{-1}. The other fishing gears have lower CPUE value than the gill net.

Table 3 explains that to get a standardized effort, the payang and arad trips are reduced according to the value of the fishing power index of each fishing gear so that a standard trip is obtained.

Table 3

Value of fishing power index (FPI)

Year	Fishing power index (FPI)			Effort standard			Total effort
	Gill net	*Danish seine (Payang)*	*Danish seine (Arad)*	*Gill net*	*Danish seine (Payang)*	*Danish seine (Arad)*	
2013	1	0.35	0.20	20,490	2,473	1,573	24,536
2014	1	0.78	0.30	24,484	5,972	2,202	32,658
2015	1	0.88	0.64	23,746	11,133	4,943	39,823
2016	1	1.65	0.54	24,037	7,821	5,210	37,068
2017	1	0.88	0.37	26,520	7,389	523	34,432
2018	1	4.03	0.21	22,972	15,557	705	39,234

Table 4 explains that the average catches of *T. lepturus* in 2013-2018, the catch value and CPUE fluctuated and tended to decrease.

Table 4

Standarization data on *Trichiurus lepturus* fishing efforts

Year	*Total catch (Kg)*	*Effort standardized (Trip)*	*CPUE (Kg trip^{-1})*
2013	603,476	24,536	22.66
2014	366,803	32,658	11.23
2015	406,000	39,823	10.20
2016	235,560	37,068	6.35
2017	368,967	34,432	10.72
2018	386,627	39,234	9.89
Average	394,572	34,625	11.84

Correlation between CPUE and effort. Based on the linear regression from Figure 2, is obtained a constant value is 41,86 and the constant value b is - 0,0009, where "a" is intercept and "b" is Slope in the linear regression. To find out the assessment stock, the next step is to look at the relationship between CPUE and effort. CPUE value of *T. lepturus* fishing experienced a negative productivity tendency, the results of the correlation analysis between CPUE and effort show a relationship where the addition of effort (trip) will decrease the catch.

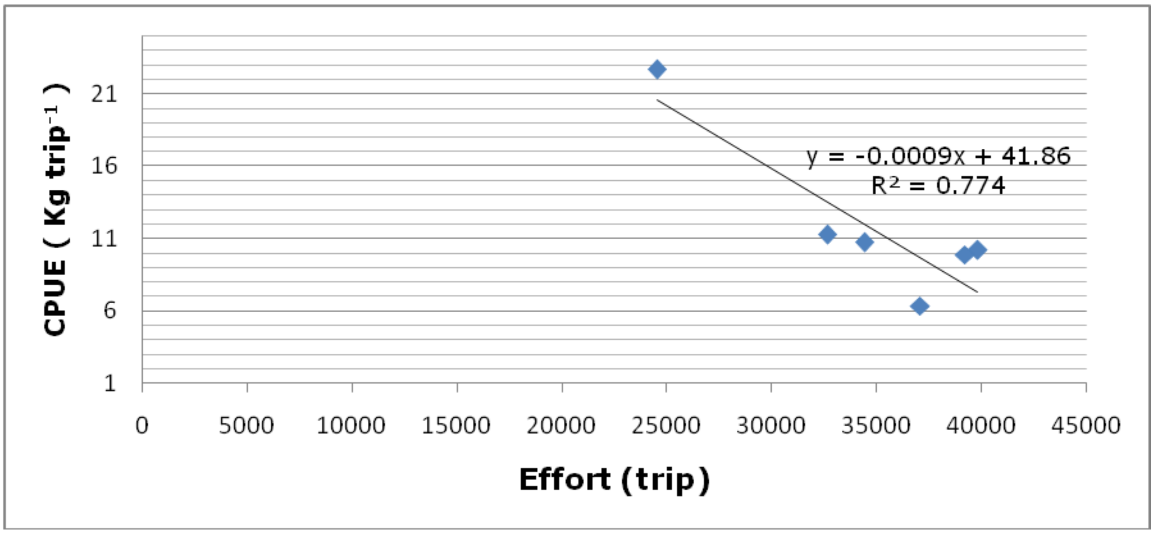

Figure 2. CPUE correlation with the effort.

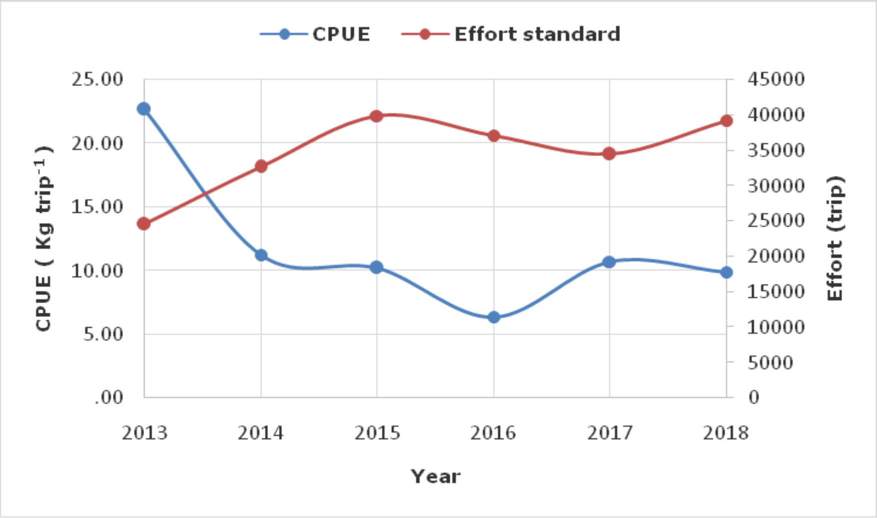

Figure 3. CPUE relation with effort concerning *Trichiurus lepturus* exploitation.

Based on Figure 3, CPUE condition and effort fluctuated, but the intensity of fishing effort (trip) tended to increase and CPUE value tended to decrease from 2013-2018. The intersection of CPUE line and standard effort occurred between 2013 and 2014, indicated that in that year there had been a decrease in catch as a result of increased fishing effort.

MSY and F_{MSY}. The Maximum Sustainable Yield (MSY) is the value of the highest catch and F_{MSY} is the maximum amount of fishing effort (fishing trips) produced as a limit to the safe stock of fish resources (Widodo & Suadi 2006). Based on the linear regression from Figure 2, is obtained value of a:41.86 and value of b:-0,0009, so that the MSY analysis and optimum effort F_{MSY} was calculated as follows:

MSY = $a^2/4b$
= $(41.86)^2/4*(0.0009)$
= 505,300 kg year^{-1}
F_{MSY} = $a/2b$
= $(41.86)/2\ (0.0009)$
= 24,139 trips.

From the calculations using the Schefer equation the fishing effort has exceeded the optimal F_{MSY}, because the average annual trip yield (2013-2018) was 34,625 trip year^{-1}. The interpretation of MSY and F_{MSY} can be seen in Figure 4.

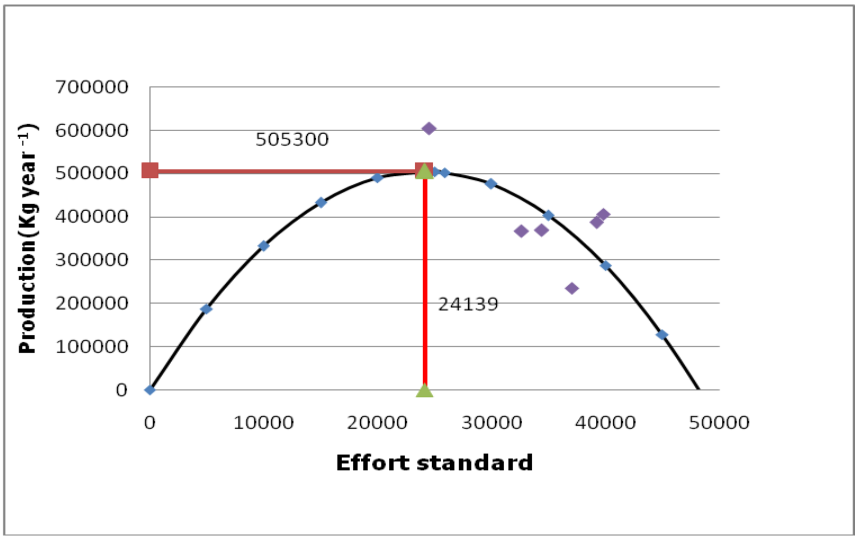

Figure 4. *Trichiurus lepturus* MSY.

Bioeconomic approach. The MSY and MEY points are a reference to the fisheries management approach based on the catches, which exist in ports and other fish landing sites in an area. The MSY approach provides an impact of leeway on resources, economic efficiency approaches and the effectiveness of fishing trips. Both conditions are simulation of fisheries management. Stakeholders and fisheries managers can choose which approach to use depending on the condition of fish resources and the available fishing fleet. Actual condition is the condition in the last year of production data collection, the three conditions are summarized in Figure 5.

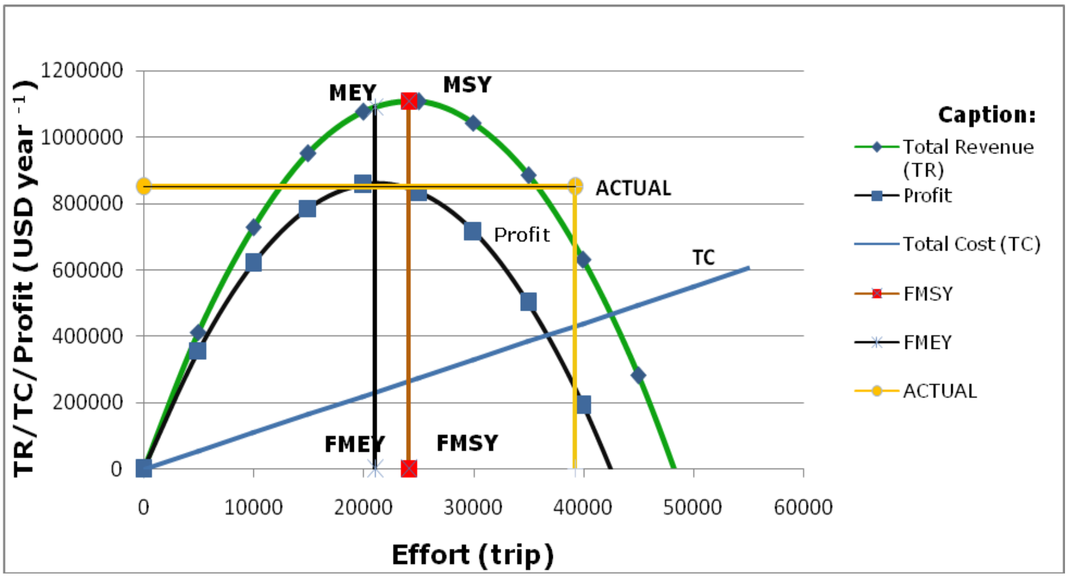

Figure 5. Bioeconomic curve Gordon–Schaefer.

The bioeconomic equilibrium curve in Figure 5 provides a view for relevant stakeholders in policy making. The explanation of the picture above is the value of F_{MEY} to the left of the F_{MSY}, this condition shows that the catch trip approach in F_{MEY} is more profitable, because with fewer trip, but resulting in greater profit, the actual condition in 2018 still had a profit of USD 418,243.00 with fishing effort (trip) 39,234 year^{-1}. The *T. lepturus* fishing in Cilacap water, MEY condition is better implemented because of the diversity of fishing gears and fishing system used is a one day fishing. Thus, the economic benefit gained is getting reduced. The first indicator of decreasing fish resources is a decrease in CPUE value from year to year, when the annual production value exceeds the MSY point limit and the number of trips exceeds F_{MSY} and F_{MEY}.

Table 5

Calculation of values from MSY, MEY and actual condition

	MSY	*MEY*	*ACTUAL*
Catch (C) (kg year^{-1})	505,300	497,098	386,627
Effort (F) (Trip)	24,139	21,064	39,234
Total revenue (USD)	1,109637.32	1,091626.01	903,137.88
Total cost (USD)	265,045.86	231,282.4	430,788.73
Profit (Π) (USD)	844,591.46	860,343.61	418,243.00

Table 5 shows that the highest profit value was found at the MEY point with a total profit of 860,343.61 USD, while at the MSY point the profit was 844,591.46 USD. The actual price obtained from the gill net fishermen survey results, the average fish price in Cilacap district was 2.2 USD kg^{-1}, while the cost incurred for an average of 1 fishing trip was 10.98 USD trip^{-1}. The results of the calculation showed that, at the MSY effort of 24,139 trips, the level of profit gained was 1,111,660 USD year^{-1}, for a capture of 505,300 kg year^{-1}. With the MEY model approach the calculated profits were 860,343.61 USD on trip 21,064.

Conclusions. The MSY approach recommendations provide the threshold for a balance of resources and production, while the MEY approach provides the threshold for a higher efficiency with an optimal effort. In the current study scenario, the catching effort has not passed the MSY point, but the trip of overcapacity in laying fisheries in Cilacap is characterized by an excess of effort, which is not adjusted to the optimal effort values, F_{MSY} and F_{MEY}. The policy strategy suggested by the study results would be to reduce the number or the capacity of vessels and fishing gear.

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