Bioeconomic study and optimal use of the fourfinger threadfin (*Eleutheronema tetradactylum*) resource in Rokan Hilir Regency, Riau Province, Indonesia

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Abstract. Rokan Hilir is one of the regencies with the highest fish landings in Riau Province, Indonesia, which has various resources, mainly in capture fisheries. One of the catches with a high production quantity is fourfinger threadfin (*Eleutheronema tetradactylum*), and its sustainability resource is threatened with extinction when exploitation of the fish continues and control measures are not considered. This study was conducted in the Rokan Hilir Regency water from May-June 2021 and aimed to determine the optimum rate of utilization of the *E. tetradactylum* resources, by using the Gordon-Schaefer bioeconomic model, through an analysis in terms of optimal exploitation ratio compared to the actual production output. The catch at the maximum sustainable yield (C_{MSY}) of *E. tetradactylum* for the period of 2011-2020 reached 69,863.46 tons year^{-1}, with a maximum sustainable yield effort (E_{MSY}) of 1,021 units year^{-1}. The highest efficiency was obtained for effort in Maximum Economic Yield a 1,010 unit year^{-1}, under MEY constraints, and a C_{MEY} (Catch Maximum Economic Yield) of 69,855.39 tons year^{-1}. The lowest efficiency was reached at the open access equilibrium (O_{AE}), for an effort of 2020 units year^{-1}, with fish production (C_{OA}) reaching up to 2,971.22 tons year^{-1}. The optimum profit (π) of USD 558,946,766, from the utilization of *E. tetradactylum* resources, was obtained under MEY constraints, while in Maximum Sustainable Yield (MSY) conditions, it was up to USD 558,880,789. Regarding the Maximum Economic Yield (MEY) regime, the use of fishing gear must be reduced to 26% to maintain the existence of *E. tetradactylum* resources optimal and sustainable.
Key Words: MSY, MEY, bioeconomic, utilization rate.

Introduction. Rokan Hilir is a regency with the highest fish landings in Riau Province and a world-renowned marine potential. Generally, the central production of fisheries is located in Bagan Siapi-api, the capital city of Rokan Hilir Regency. Subsequently, in the 1930s, Bagan Siapi-api used to record the highest fish landings in Indonesia, with a fishery production of about 300,000 tons. This achievement made the it the seaport with the highest fishery production, on the second place after Norway. Unfortunately, Bagan Siapi-api has become history recently, its fame has faded due to the decrease of the fisheries resource. The condition occurs because the exploitation of fisheries resources continues gradually (Zakya 2017).

Most of fish catching activities play an important role in fulfilling the demand for sea fish in Riau Province, and these activities were carried out by traditional fishers. However, the government do not regulate their activity for an optimal resource exploitation by the capture fisheries and does not allocate enough funds to support a sustainable fishing. This condition causes fluctuating fisheries production, which potentially occurs mainly in three sub-districts, namely Bangko, Sinaboi, and Pasir Limau Kapas. One of the commodities is fourfinger threadfin (*Eleutheronema tetradactylum*) fish resource, which is the main

commodity, with a dominant production. *E. tetradactylum* is the main commodity, with a high economic value, therefore it may be susceptible of overutilization (Maulana et al 2020). The fishing gear used to catch the *E. tetradactylum* is a gill net. The gill net is a selective catching tool because the mesh can be customized with the size of the fish (Katarina 2019).

Based on the data from the Department of Fisheries Rokan Hilir Regency (2021), the yield of *E. tetradactylum* production has increased over the past nine years. This statement is confirmed by the increase in *E. tetradactylum* production yield from 3.940,78 tons year^{-1} in 2011, to 6.739,29 tons year^{-1} in 2019. The increase was followed by the number of catching gear units used by fishers. When the catching effort continuously increases, its intensity tends to increase as well, therefore the fish production will significantly decrease in time (Catch Per Unit Effort/CPUE), as a result of the fish resource depletion and habitat degradation (Kewila 2021). Overcapacity also causes overfishing. According to Angeles et al (2020), overfishing becomes one of main threats for the sustainability of fishery resources.

To manage sustainable capture fisheries with optimal economic benefits, the relationship between the biological and economic aspects of fish capturing must be considered. Based on this situation, an optimal management is required to maintain *E. tetradactylum* catches in sustainable conditions. This study aimed to determine the optimum utilization rate of *E. tetradactylum* resources in Rokan Hilir Regency waters, by analyzing the amount of actual production and sustainable production and economic rents of *E. tetradactylum* resources using the Gordon-Schaefer bioeconomic model.

Material and Method. This is a qualitative study with primary and secondary data. Primary data were collected through interviews using a questionnaire and in-depth interviews. Meanwhile, secondary data were obtained via fisheries statistics from the BPS of Rokan Hilir Regency, Department of Fisheries Rokan Hilir Regency, and other related literature. The map of the location of this study can be seen in Figure 1.

Study location and time. The location of this study is the Rokan Hilir Regency; the samples collection was performed in Bangko, Sinaboi and Pasir Limau Kapas Districts. This study was carried out from May to June 2021.

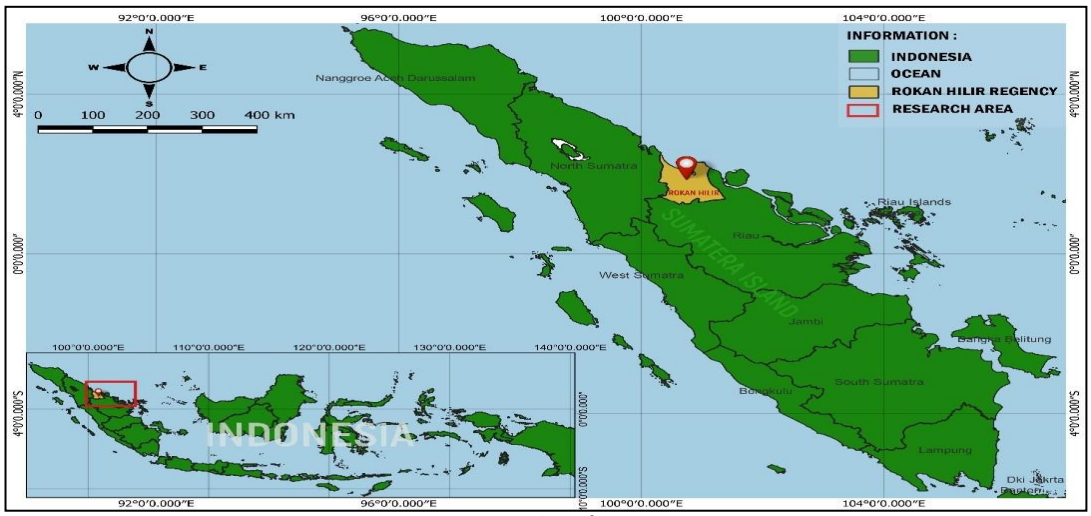

Figure 1. Study map.

Data analysis. This study used data time series for the last ten years (2011-2020). Secondary data were obtained from the Department of Fisheries Rokan Hilir Regency, while primary data were collected from in-depth interviews with fishers using a gill net at Tangkahan (the place of fish landing). Furthermore, a Gordon-Schaefer analysis was used, combining biological and economic parameters of fish resource management. The balance condition of the Gordon-Schaefer model is the condition of MSY (Maximum Sustainable

Yield), MEY (Maximum Economic Yield), and OAE (Open Access Equilibrium). The Gordon-Schaefer bioeconomic analysis was assessed using the formula (Usman et al 2022):

Catch at Maximum Sustainable Yield (MSY):

$$C_{MSY} = \frac{rK}{4}$$

Effort at MSY:

$$E_{MSY} = \frac{r}{2q}$$

Economic rent at MSY:

$$\Pi_{MSY} = TR_{MSY} - TC_{MSY}$$

$$\Pi_{MSY} = (c_{MSY} * p) - (C * E_{MSY})$$

Catch at Maximum Economic Yield (MEY):

$$C_{MEY} = \frac{rK}{4}(1 + \frac{C}{pqK})$$

Effort at MEY:

$$E_{MEY} = \frac{r}{2q}(1 - \frac{C}{pqK})$$

Economic rent at MEY:

$$\Pi_{MEY} = TR_{MEY} - TC_{MEY}$$

$$\Pi_{MEY} = (c_{MEY} * p) - (C * E_{MEY})$$

Catch at Open Access (OA):

$$C_{OA} = \frac{rc}{pq}(1 - \frac{C}{pqK})$$

Effort at OA:

$$E_{OA} = \frac{r}{q}(1 - \frac{C}{pqK})$$

Economic rent at OA:

$$\Pi_{OA} = TR_{OA} - TC_{OA}$$

$$\Pi_{OA} = (c_{OA} * p) - (C * E_{OA})$$

Where:
r - intrinsic growth rate;
p - price of *E. tetradactylum* (ton USD^{-1});
q - catchability coefficient (ton $unit^{-1}$);
k - carrying capacity (ton $year^{-1}$);
c - catch/production (ton $year^{-1}$);
C - cost of *E. tetradactylum* per unit (USD);
TC - total cost of *E. tetradactylum* (USD $year^{-1}$);
TR - total revenue *E. tetradactylum* (USD $year^{-1}$).

Results and Discussion. The production yield of *E. tetradactylum* tended to increase in the last nine years. This was proved by the increase of *E. tetradactylum* production yield in 2011 to 3,940.78 tons $year^{-1}$ which became to 6,739.29 tons $year^{-1}$ in 2019. However, the *E. tetradactylum* production yield decreased in 2020 to 5,196.46 tons $year^{-1}$ (Figure

2). This condition relates the study conducted by Listiani et al (2017), which found that a production peak of Lemuru fish, *Sardinella lemuru,* is followed by a significant decrease in the coming years. This occurs because *S. lemuru* populations require 2-3 years to recover (Harahab et al 2021).

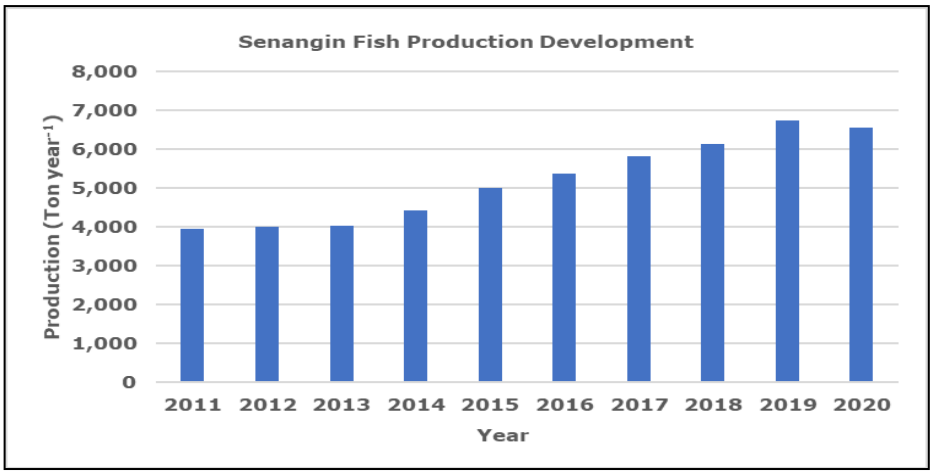

Figure 2. Development of *Eleutheronema tetradactylum* production in Rokan Hilir Regency.

Based on Figure 2, the production yield of *E. tetradactylum* increases significantly every year. This increase is caused by the abundance of its resource, characterized by an increased yield. This put a high pressure on the resource in Rokan Hilir Regency water. One of the ways that can be used to keep the stock of *E. tetradactylum* sustainable is by calculating the CPUE value. The value of CPUE can be used to view the effort of resource exploitation in order to support its sustainability (Saimona et al 2021).

The development of CPUE (Catch Per Unit Effort). CPUE is the ratio between the catch and effort deployed for exploiting the *E. tetradactylum*. The catch yield is mainly the output, while the effort required is the input of the fishing activity (Aryasuta et al 2020). In terms of economic production, the ratio between output and input reflects the technical efficiency level from input usage (Budiasih 2015). Therefore, the CPUE value can be used as an indicator of the technical efficiency level for a better effort usage (Fauzi 2010; Juniko et al 2018; Utami & Gumilar 2012). The trend of the CPUE of *E. tetradactylum* fishing in Rokan Hilir Regency for the period of 2011-2020 tends to decrease. The decline in this value is one of the indicators of overfishing. The trend of CPUE is shown in Figure 3.

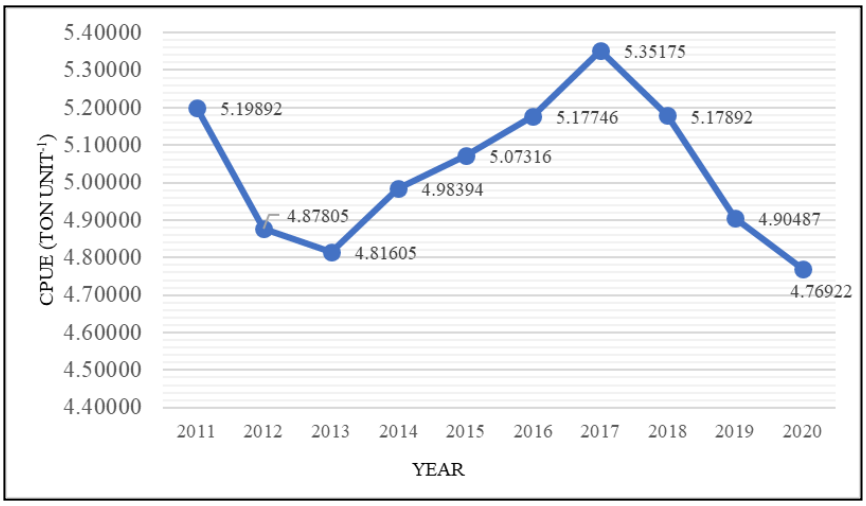

Figure 3. Development of CPUE *Eleutheronema tetradactylum* for the period of 2011-2020.

Based on Figure 3, the highest CPUE value occurred in 2017, with a quantity of 5.35175 tons effort unit^{-1} and an effort of about 1,085 units year^{-1}, meanwhile, the lowest value was recorded in 2020, with an amount of 4.76922 tons effort unit^{-1} and an effort of 1,374 units year^{-1}, and the average value was recorded from 2011 to 2020, with about 5.0332 tons effort unit^{-1}. The CPUE value from 2011 to 2020 decreased by 8.27%, due to the use of catching gears in the exploitation period. This condition indicates that the productivity of the gill net as a catching tool will decline when the utilization is constant and control measures are not taken into account. According to Sampaga et al (2019), the decline in the CPUE value of *Katsuwonus pelamis* indicated that the resource potential could not afford to produce a high level even though the catch effort has been upgraded.

The exploitation of *E. tetradactylum* catch was conducted using a gill net. The number of gill nets used increased from about 735 units year^{-1} in 2011 to 1,374 units year^{-1} in 2020. The increase in catching gear indicates the high pressure on the *E. tetradactylum* catch.

In general, fish catching aims to increase catch and economic rentability by adjusting the effort of catch. Meanwhile, an increasing effort does not always generate an increased production (Zulbainarni 2012). According to the law of sequential impoverishment, as fishing effort increases, the fish population that becomes a primary target will decrease, with a decreasing CPUE and a fishing effort becoming economically unsustainable. This situation will change the target of catch, which will become the second or third type of captured fish (Link et al 2020).

Relationship between CPUE and effort. The relationship between CPUE value and effort is required to identify the productivity trend of catching gear. This relationship is calculated by using a simple linear regression analysis. Based on the calculation, the value of the coefficient intercept (α) was -0,004 and the slope (β) was 5.551. The simple linear regression equation of the effort of catching per unit is CPUE = -0,004x+5,0551. The relationship between CPUE and the effort of *E. tetradactylum* is shown in Figure 4.

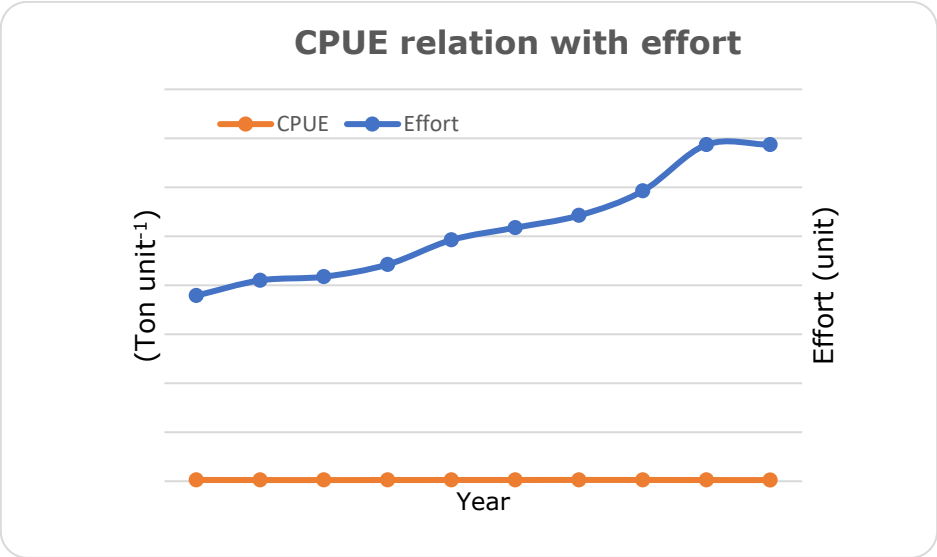

Figure 4. The relationship between CPUE and effort *Eleutheronema tetradactylum* resource.

Figure 4 shows that the value of CPUE decreases while the effort of catch increases, indicating the *E. tetradactylum* productivity has a negative trend. Therefore, the increase in catch effort will significantly decrease the CPUE value (Hermawan et al 2020).

Bioeconomy assessment. Bioeconomic analysis was used to determine the exploitation level in the utilization of fishery resources (Haryani 2019; Gough et al 2020). The development of the fishing industry does not only depend on the biological aspect but also

the economic aspect of the fishery resources. The result of the bioeconomic analysis indicates an overfishing. As shown in Table 1 and Figure 5.

Table 1

The result of bioeconomic analysis on *Eleutheronema tetradactylum*

Description	*MEY*	*MSY*	*OA*	*Actual*
Production (ton year^{-1})	69,855.39	69,863.46	2,971.22	5,196.46
Effort (unit year^{-1})	1,010	1,021	2,020	1,030
Total revenue (USD)	571,092,157	571,158,134	24,290,782	129,636,509
Total cost (USD)	12,145,391	12,277,345	24,290,782	190,714,351
Economic rentability (USD)	558,946,766	558,880,789	0	3,819.51

Table 1 shows that the result of catch at the maximum sustainable yield (C_{MSY}) of *E. tetradactylum* in 2011-2020 reached 69,863.46 tons year^{-1}, with an effort at the maximum sustainable yield (E_{MSY}) of 1,021 units year^{-1}. The highest efficiency was obtained at MEY condition (E_{MEY}), with 1,010 units year^{-1} and a C_{MEY} of about 69,855.39 tons year^{-1}. Meanwhile, the lowest efficiency was obtained for the OAE regime, with an effort of 2020 units year^{-1} and a C_{OA} = 2,971.22 tons year^{-1}. The optimum profit (π) from the exploitation of the *E. tetradactylum* resource in the water of Rokan Hilir Regency at MEY reached USD 558,946,766, while at the Maximum Sustainable Yield (MSY) it was of about USD 558,880,789.

According to the MEY regime, the number of gill nets should be reduced to 1,010 units. The required decrease in fishing gears is due to the actual conditions of gear use exceeding the optimal limit. The actual number of gears used is 1,030 units. The policy of reducing the fishing gears is not easy to apply as it may affect the socio-economic level of fishers' families. As mentioned by Damayanti (2018), the government and fishers are the main executors in managing the fishery resources. The regime of MEY is appropriate to determine the strategy of optimum and sustainable utilization of *E. tetradactylum*, as stated also by Wijayanto et al (2019), indicating the optimum profit of the capture fisheries using gill nets under the MEY condition. This statement is proved by the economic rentability value at MEY regime, with a profit of USD 558,946,766, while under the MSY condition the profit was of only USD 558,880,789.

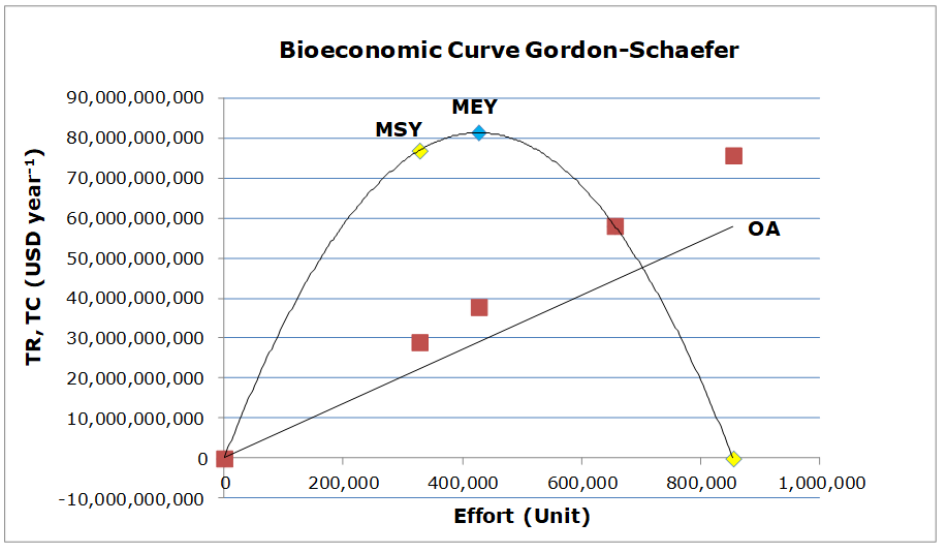

Figure 5. Bioeconomic curve of *Eleutheronema tetradactylum.*

Utilization rate and capacity level of E. tetradactylum resource. The utilization rate of fisheries resources is a ratio between the actual amount of production with maximum sustainable fish production in percentage, while the level of fishing capacity must be able to handle the annual fishing effort, setting the maximum sustainable fishing effort as a percentage (Kristiana et al 2021). The result of the utilization rate and capacity level of *E. tetradactylum* in Rokan Hilir Regency is shown in Figure 6.

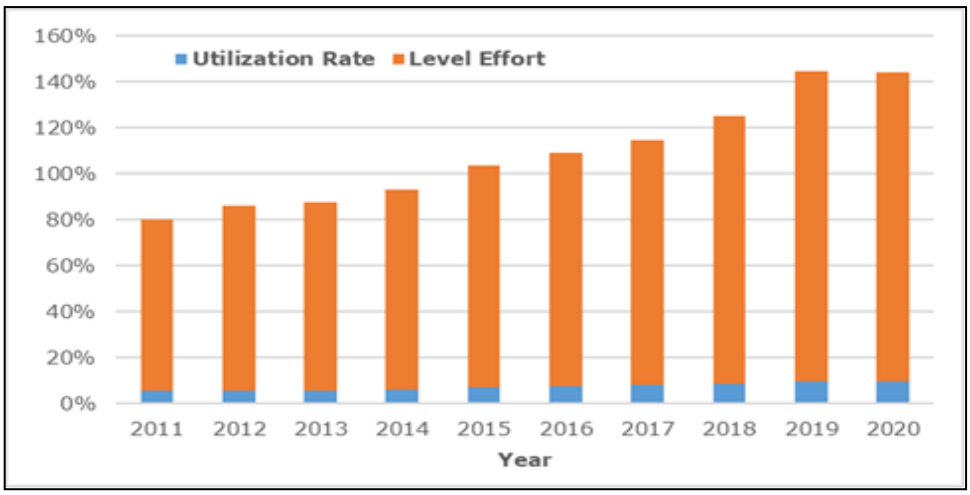

Figure 6. Utilization rate and capacity level of *Eleutheronema tetradactylum* fishing in Rokan Hilir Regency.

Figure 6 shows that the utilization rate of *E. tetradactylum* in the last ten years has fluctuated. The lowest utilization rate was recorded between 2011-2014 at 6%, with an average production amount of 4,093.24 tons year^{-1}, and the highest rate was recorded in 2019 at 10%, with an average production amount of 6,739.29 tons year^{-1}. Meanwhile, the capacity level of fishing increases yearly. The highest capacity level increase was recorded in 2019 and 2020, with 135%, compared to the previous year, and an effort level of about 1,374 units year^{-1}. The lowest level of increase was recorded in 2011, with 74%, compared to the previous year, and a total effort of 735 units year^{-1}. The average capacity level of *E. tetradactylum* fishing is 101%, indicating that the capacity deployed has exceeded the effort at maximum sustainable yield (EMSY). The time series indicate that when the effort of catching increases, the production amount of *E. tetradactylum* per unit of effort decreases, due to the continuous activity of fish catching occurring when stocks are unable to fulfill the production capacity.

The capacity level which exceeds the MSY may harm the sustainability of fisheries resources. This statement is supported by Listiani et al (2017), which showed that the utilization rate of *S. lemuru* in the Bali Strait is below the optimum catch (C_{MSY}) but the level of effort has exceeded 100% or above the optimum effort (E_{MSY}) *S. lemuru*. Meanwhile, based on Irhamsyah et al (2021), exceeding the catching rate at MSY will cause a decrease of fish production. A catch capacity that exceeds the optimal value leads to overcapacity, which is a condition where the input (effort and vessel) exceeds the output (catch) (Banurea 2021). When overcapacity persists, overfishing will result in the production status exceeding the maximum catch limit (Hufiadi & Wiyono 2010; Jamilah & Mawardati 2019; Module of Ministry of Marine Affairs and Fisheries 2020). Overcapacity can affect the sustainability of fisheries (Adrianto et al 2013).

Conclusions. The utilization status of *E. tetradactylum* has been overcapacity by the level of fishing capacity, which has exceeded the utilization limit of fish resources. Furthermore, the total economic rent of *E. tetradactylum* resource in the water of Rokan Hilir Regency at MEY reached USD 558,946,766, which has provided economic benefits for fishermen in Rokan Hilir Regency.

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Conflict of interest. The authors declare no conflict of interest.

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