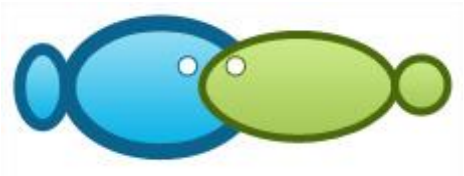

Bioeconomic analysis of anadromous fish *Tenualosa ilisha* in the Barumun River, Labuhanbatu Regency, Indonesia

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Abstract. *Tenualosa ilisha* is an anadromous fish that can be found in the Bilah River and Barumun River, Labuhanbatu Regency, Indonesia, among other places. *T. ilisha* is a significant target for fishermen because it has high economic value. However, T. *ilisha* populations continue to decline due to overfishing. Good management is needed so that the economic value can be utilized sustainably. This study aims to analyze the bioeconomics of *T. ilisha* in the Labuhanbatu District, Indonesia. The data used in this study was collected from purchases by wholesalers between 2017-2021. The results showed that the maximum sustainable yield (MSY) value was 959.93 kg year^{-1}, and the optimal effort (F_{MSY}) value was 456.82 trips. MSY's profit was 5031.13 USD, and the maximum economic yield (MEY) was 5574.79 USD. Based on the results, it was concluded that the high economic value of *T. ilisha* would lead to overfishing.
Key Words: maximum economic yield, maximum sustainable yield, *Tenualosa ilisha*.

Introduction. The hilsa shad (*Tenualosa ilisha*) is an anadromous fish found in Labuhanbatu District, Indonesia, among other places (Jihad et al 2014; Machrizal et al 2019a). The natural habitat of *T. ilisha* in this area is in the Bilah River (Machrizal et al 2019b) and Barumun River (Jihad et al 2014; Lubis et al 2016). *T. ilisha* is a fishery export commodity in Labuhanbatu Regency. According to Lubis et al (2016), *T. ilisha* eggs in salted preparations are marketed at 166.67–233.33 USD per kg. *T. ilisha* meat is usually used as a traditional food typical of Labuhanbatu.

The high economic price of *T. ilisha* has made this species a primary target for fishermen (Rumondang 2018). Intensive fishing can reduce the population of *T. ilisha* (Siregar 2019). IUCN (2023) data shows that *T. ilisha* has the "Least Concern" status. The Indonesian government has carried out limited protection of *T. ilisha* in Labuhanbatu Regency through the Decree of the Minister of Marine Affairs and Fisheries Number 43/KEPMEN-KP/2016. The contents of this decree prohibit the catching of *T. ilisha* at the peak of spawning, namely from January to April (Siregar 2019). Based on this limited protection status, a bioeconomic study is needed to determine the impact of fishing on the maximum sustainable yield (MSY) and maximum economic yield (MEY) values of *T. ilisha* in Labuhanbatu District. Bioeconomic studies of *T. ilisha* in Labuhanbatu District have never been carried out. References for fisheries bioeconomics generally include the works of Kar & Matsuda (2006), Bakht et al (2017), De Azevedo et al (2021), Liyana & Sin (2022). Research related to the bioeconomics of economically important fish was conducted by Gunawan et al (2022) on *Thunnus albacares*, Auliyah et al (2021) on *Katsuwonus pelamis*, Lai et al (2021) on *Clupea harengus*, *Halichoerus grypus*, and *Salmo salar*, Baso et al (2020) on *Decapterus* spp. and Hakim et al (2014) on *Scomberomorus commerson*. *T. ilisha* in Labuhanbatu Regency must be managed wisely to continuously obtain its biological and economic value. This research aims to provide a

sustainable management model based on the evaluation of the catch per unit effort (CPUE), the maximum sustainable yield (MSY), and the maximum economic yield (MEY).

Material and Method. This research used a descriptive survey method. Data were collected from fishermen's sale of *T. ilisha* to collectors in Ajamu Village, Panai Tengah District, Labuhanbatu Regency, from 2017 to 2021. Based on these data, statistical analysis was conducted to obtain the effort, catch, and CPUE values for five years.

Data analysis. In this study, the analysis data refer to Hermawan et al (2020), and include: catch per unit effort (CPUE), maximum sustainable yield (MSY), and maximum economic yield (MEY).

Catch per Unit Effort (CPUE). According to Hermawan et al (2020) and Susilo (2010), CPUE can be calculated using the following formula:

CPUE=catch/effort

Where: catch (C) - total number of catches of the fishing fleet per unit of time; effort (F) - the number of capture attempts of the fleet from one fishing trip per unit of time.

Maximum Sustainable Yield (MSY). MSY is a management parameter resulting from the production of natural catches that is useful in assessing the potential of fishery resources. According to Hermawan et al (2020), MSY and F_{MSY} are calculated using the following equations:

$MSY=a^2/(4b)$

$F_{MSY}=a/(2b)$

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

Maximum Economic Yield (MEY). MEY analysis uses the Gordon-Schaefer model, as presented in Table 1.

Table 1

Bioeconomic analysis with the Gordon-Schaefer model

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

Note: a - intercept; b - slope in the linear regression equation; p - fish price of *T. ilisha* (kg USD^{-1}); C - cost of *T. ilisha* fishing per trip (USD); TC - total cost of *T. ilisha* fishing (USD $year^{-1}$); TR - total revenue from *T. ilisha* fishing (USD $year^{-1}$); source: Hermawan et al (2020).

Results and Discussion

The effort, catch, and CPUE value. *T. ilisha* production from 2017-2021 fluctuated, with a tendency to increase. The increase in *T. ilisha* production was also accompanied by an increase in fishing effort, resulting in a decrease in CPUE values. Complete data can be seen in Table 2.

Table 2

Production, fishing effort (trips), catch per unit effort (CPUE) of *Tenualosa ilisha*

Year	*Effort (trip)*	*Catch (kg)*	*CPUE (kg trip^{-1})*
2017	370	910	2.46
2018	380	925	2.43
2019	395	995	2.52
2020	450	970	2.16
2021	485	955	1.97
Average	416	951	2.31

A higher effort will lower the CPUE, and a lower effort will increase the CPUE value. Compared to the catch, the effort value shows a unidirectional trend, with a higher effort value increasing the catch value, and vice versa. However, this is not the case with the catch value with CPUE, sometimes the catch value is high, but the CPUE value is low. It is suspected that the number of trips only sometimes guarantees an abundance of catches for *T. ilisha* in the Barumun River. Rahman et al (2013) explained that this condition is caused by increased competition between operating fishing gears, where resource capacity is limited and tends to decrease due to increasing fishing effort. The results of Piliana et al (2015) on *Decapterus* spp. obtained an effort value of 128.49 trips, but this could still be increased to 213.73 trips as an actual effort to provide maximum sustainable catch.

CPUE correlation with effort. Based on the analysis of the relationship between CPUE and effort, it is known that the value of b (slope in the linear regression) is -0.0046 and the value of a (intercept) is 4.2. Data from the correlation analysis results can be seen in Figure 1.

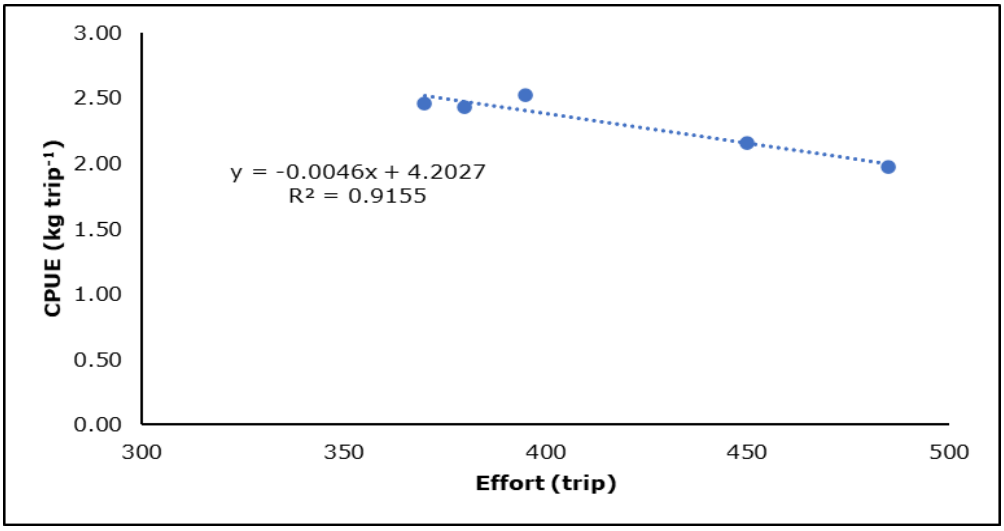

Figure 1. Catch per unit effort (CPUE) and effort correlation curve of *Tenualosa ilisha* from Barumun River.

The CPUE correlation with effort had an R^2=0.92. Based on this value, it was concluded that there was overfishing of *T. ilisha* in the Barumun River. It is clear from Figure 2 that the effort increased, but the CPUE decreased. Hermawan et al (2020) reported that the economic benefits of *Trichiurus lepturus* in Cilacap waters are decreasing. The first indicator of the decline in *T. lepturus* resources was the decline in CPUE values from year to year, where the annual production value exceeded the MSY point limit and the number of trips exceeded F_{MSY}. For *T. ilisha* there was a decrease in CPUE value every year during 2017-2021. Therefore, this condition is the primary concern of all parties. Conservation in nature must be maintained, so that the fish does not become extinct and that economic

benefits can continue to be enjoyed by future generations. Data from scientific research are essential for managing policies. Bioeconomic data on *T. ilisha* may be of use in management and conservation measures for the Barumun River. Mustafa (2020) stated that research is essential to support government programs. Data related to research results is critical in terms of biology, ecology, habitat, pollution, and ecosystems, which can be useful in an effort to support the life of *T. ilisha* in its natural habitat.

MSY and F_{MSY}. MSY and F_{MSY} calculations are based on the values of a and b, where a was 4.2 and b was -0.0046. The MSY value obtained is 959.93 kg year^{-1} and the F_{MSY} value is 456.82 trips.

Based on the Schaefer formula, F_{MSY} exceeded the optimal value, because the average annual trips in 2017-2021 was 416 trips year^{-1}. MSY and F_{MSY} interpretations are presented in Figure 2.

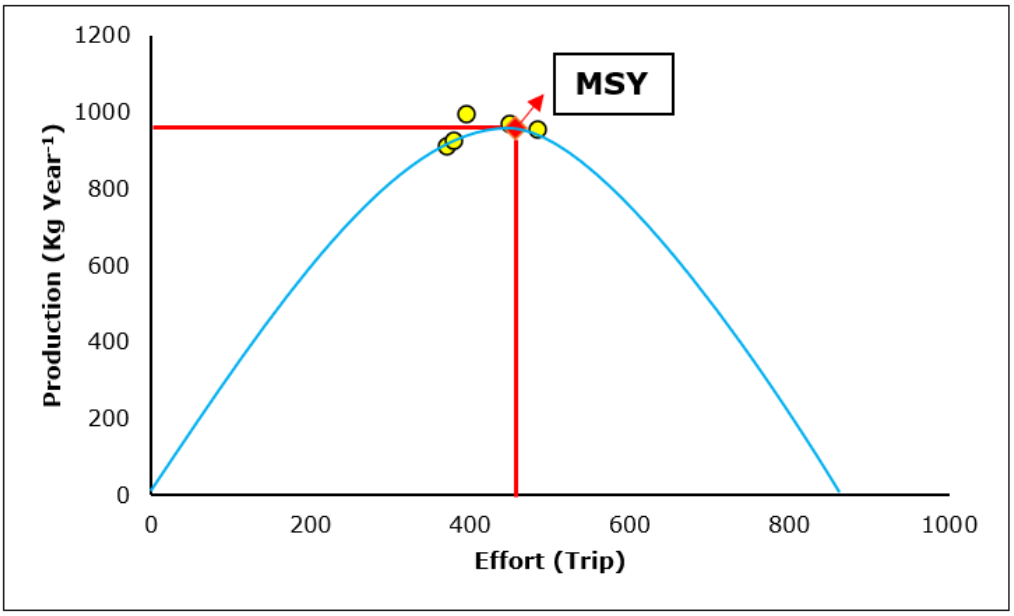

Figure 2. Maximum sustainable yield (MSY) of *Tenualosa ilisha* on Barumun river for five years.

Based on the analysis results, the MSY value of *T. ilisha* in the Barumun River was 959.93 kg year^{-1}. The application of the MSY and F_{MSY} concepts in fisheries management aims to achieve a balance between the utilization of fish resources and their sustainability. Therefore, the potential of the resource is maintained. The analysis results can be used to evaluate the future capture of *T. ilisha* in the Barumun River. According to Hermawan et al (2020), a 5-year data collection for MSY calculation is intended to be used as a recommendation in determining the threshold between resource balance and fish production. Mohamed & Qasim (2014) analyzed the population dynamics of *T. ilisha* in the Iraqi sea waters. The study's results indicated that the maximum yield per recruitment could be achieved at 0.72, while the current exploitation ratio was 0.67. The MSY level in the study exceeded the existing potential, resulting in a 50% reduction in biomass.

Maximum economic yield. The MEY value based on the statistical analysis results can be seen in Table 3.

Table 3

Maximum sustainable yield and maximum economic yield results

	MSY	*MEY*
Catch (C) (kg year^{-1})	959.93	905.59
Effort (F) (Trip)	456.82	348.12
Total revenue (TR) (USD)	9599.28	9055.98
Total cost (TC) (USD)	4568.15	3481.19
Profit (∏) (USD)	5031.13	5574.79

Utilization of *T. ilisha* resources in the MSY condition gave a profit of 5031.13 USD. MSY profit is lower than the MEY condition of 5574.79. The MSY provides the maximum level of production economically and is the optimum level of sustainable effort. The catches at MSY are greater than at MEY, but profits are lower, due to increased fishing effort. This condition illustrates the magnitude of the effort, which increases the required costs. The total cost obtained in MSY was higher than in MEY. The bioeconomic analysis results in this study are similar to those obtained by Susanto et al (2015) for *Oreochromis niloticus* in the Cirata Sukabumi Reservoir.

Bioeconomic model. The MSY and MEY points reference the *T. ilisha* fisheries management approach in Labuhanbatu Regency based on the 2017-2021 catch. The actual conditions are summarized in Figure 3.

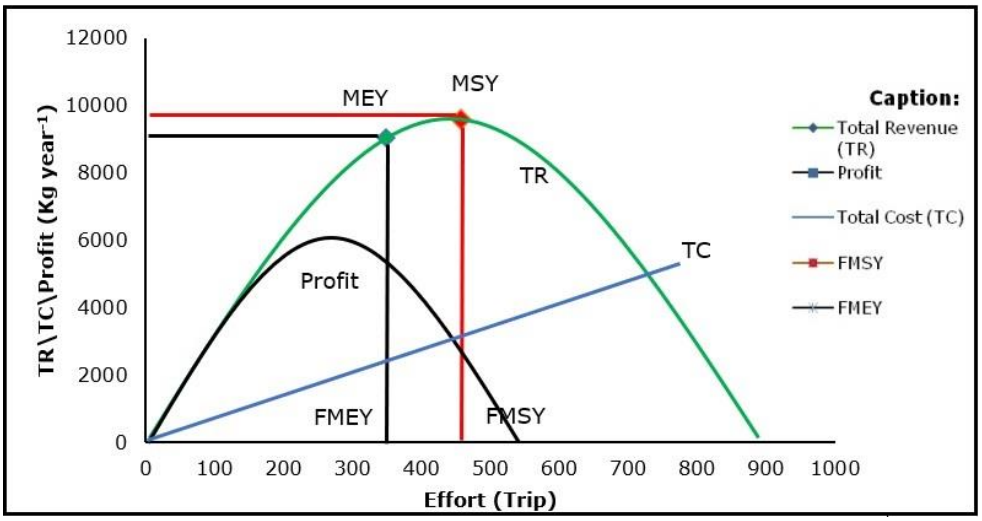

Figure 3. Bioeconomic Gordon-Schefer curve; TR - total revenue; TC - total cost; MSY - maximum sustainable yield; MEY - maximum economic yield; F_{MEY} – the value of sustainable optimum effort; F_{MSY} - the value of the sustainable economic catch.

The bioeconomic balance curve in Figure 3 may guide stakeholders in making policies in the management of *T. ilisha* catches in Labuhanbatu District. The calculation results using the Gordon-Schefer model for catching *T. ilisha* in the Barumun River have exceeded the optimal FMSY because the average annual trip yield (in 2017-2021) is 416 trips year^{-1}. Thus, there has been overfishing, which caused a decrease in the population of *T. ilisha* in the Barumun River. Hermawan et al (2020) explained that the first indicator of a decline in fish resources is a decline in CPUE values from year to year, where the annual production value exceeds the MSY point limit and the number of trips exceeds FMSY and FMEY. Furthermore, Gordon (1954) stated that economic overfishing would occur under uncontrolled management.

Conclusions. There has been overfishing of *T. ilisha* in the Barumun River, Indonesia. The management of catching *T. ilisha* in the Barumun River must be improved, and

contained in a regulation, so that the biological and economic benefits of *T. ilisha* can continue to be utilized. The data from this research may be used by related agencies in Labuhanbatu Regency for approaches to maintain the sustainability of *T. ilisha* fishery resources in Labuhanbatu Regency.

Conflict of Interest. The authors declare that there is no conflict of interest.

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