Sustainable utilization of hilsa fish (*Tenualosa ilisha*) resources in Labuhanbatu waters, North Sumatra Province, Indonesia: A bioeconomic analysis

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Abstract. Hilsa fish (*Tenualosa ilisha*) can be found in two locations in Indonesia: Labuhanbatu (North Sumatra) and Bengkalis (Riau). The continued existence of *T. ilisha* is increasingly imperiled by the practice of overfishing. This study aims to analyze the optimization of *T. ilisha* resources within the Labuhanbatu region. The research methodology employed consists of secondary data analysis. The investigation was carried out between July and December 2022, specifically within the Sei Barumun area of Labuhanbatu. The utilized dataset comprises time series data spanning from 2014 to 2021, encompassing catch fish data and the number of fishing trips, which were sourced from the Department of Marine and Fisheries of Labuhanbatu Regency. Data analysis was executed through the application of the Gordon-Schaefer bioeconomic model, alongside utilization and fishing capacity computations. The outcomes of the resource utilization optimization analysis reveal that *T. ilisha* in Labuhanbatu have undergone overexploitation. In the context of optimized catch levels and reduced costs, the scenario yielding the maximum economic yield (MEY) results in greater profitability compared to the scenario based on the maximum sustainable yield (MSY). However, within the framework of the open-access fishing scenario characterized by heightened fishing efforts, catch levels and revenue decline significantly, culminating in an absence of profitability. This underscores the unsustainability of open-access fishing practices in Labuhanbatu and underscores the potential for resource depletion. Furthermore, the utilization capacity estimated at 81% signals a state of overexploitation, where the rate of exploitation surpasses the MSY threshold. Additionally, a fishing capacity of 128% signifies that production capacity has reached its maximum limit.
Key Words: fishing capacity, maximum economic yield, maximum sustainable yield, overexploitation, utilization capacity.

Introduction. North Sumatra Province, with a total area of 181860.65 km^2, consists of 71680.68 km^2 of land area, while the rest is water (Nainggolan et al 2019). The province has a vast coastal region with significant potential for fisheries and marine resources (Rumondang et al 2019). The fisheries and marine potential of North Sumatra originate from approximately 100000 ha of offshore aquaculture, 81372.84 ha of freshwater aquaculture, 20000 ha of pond aquaculture, and 155797 ha of public waters (Arrazy & Primadini 2021). There is a region along the east coast of North Sumatra, known as Labuhanbatu Regency. This region is geographically positioned at 1°41'-2°44'N latitude and 99°33'-100°22'E longitude, covering a land area of approximately 2561.38 km^2. Within the confines of Labuhanbatu, one prominent water body is the Barumun River, also referred to as Sei Barumun. This river is located in the Panai Hulu District and directly discharges its waters into the Strait of Malacca (CBSLR 2020). The local community has historically relied on the Barumun River both for transportation and as a prime fishing ground for hilsa fishes (Siregar 2018).

There are three species of *Tenualosa* in Indonesia, including *Tenualosa macrura* in the waters of Muara Bengkalis (Riau), *Tenualosa ilisha* in Labuhanbatu (North Sumatra), and *Tenualosa toli* in Pemangkat (Borneo) (Hossain et al 2019). These fishes are distributed in several regions of Asia and the Middle East (Hashemi et al 2010; Karim et al 2019). They are anadromous species found in freshwater, brackish water, along coastlines, and the sea (Hossain et al 2014). The hilsa fishes belong to the pelagic fishes group in the Clupeidae family, commonly known as herrings in Europe. In Asia, five hilsa fish species have been described: *T. ilisha*, *T. macrura*, *T. toli*, *T. reevesii*, and *T. thibaudeaui*.

T. ilisha is one of the iconic species in Labuhanbatu and is the primary target of local fishermen (MMAF 2016). This is due to its high market value, which is 15.96 USD kg^{-1}, and dried fish eggs can be sold for up to 159.60 USD kg^{-1}. The *T. ilisha* population in the waters of Labuhanbatu has experienced a substantial decline over the years, primarily attributable to intensive fishing practices. This includes the targeted harvesting of mature individuals to procure their eggs for commercial purposes (Efizon et al 2012; Jihad et al 2014).

The decision of the Minister of Marine Affairs and Fisheries of the Republic of Indonesia Number 43/KEPMEN-KP/2016 regarding the Designation of Limited Protection Status for Hilsa Fish (*T. ilisha*), states as follows: (1) the prohibition of catching *T. ilisha* during the spawning period for six days during the transition from the dark moon phase to the bright moon phase (5 to 10 of the Hijri calendar) from January to April each year, and (2) the prohibition of catching *T. ilisha* during the spawning period for six days during the transition from the bright moon phase to the dark moon phase (20 to 25 of the Hijri calendar) from January to April each year. This regulation further establishes the distribution area of *T. ilisha* along the fish spawning route to ensure the preservation of its population.

Due to the rampant overexploitation of *T. ilisha* in Labuhanbatu waters, the current state of the fishery necessitates a thorough analysis of resource utilization optimization. Therefore, this research aims to analyze the optimization of the utilization of *T. ilisha* resources in the waters of Labuhanbatu following the implementation of the Minister of Marine Affairs and Fisheries Decree No. 43/KEPMEN-KP/2016, which has been in effect since August 2016. Moreover, the objective of this study is to provide valuable insights to stakeholders with the intention of improving the well-being of *T. ilisha* fishermen, particularly through the implementation of effective fish catch regulations.

Material and Method

Research site. This research was conducted from July to December 2022 in the waters of Sei Barumun, located in Panai Hulu and Panai Tengah Districts, Labuhanbatu Regency, North Sumatra Province, Indonesia.

Research method. The research method used is secondary data analysis. In this study, the data sources are the *T. ilisha* catch and fishing trips targeting *T. ilisha* by fishermen from 2014 to 2021. The data were obtained from the Department of Marine and Fisheries of Labuhanbatu Regency.

Catch per unit effort (CPUE). CPUE is a method used to determine the average annual production of marine fisheries. The changes in fish production in a specific area can be observed through CPUE results (Sibagariang et al 2011). To calculate the CPUE for *T. ilisha*, the total catch (in tons per year) is divided by the total fishing effort (Noija et al 2014). The formula for CPUE is the following:

$$CPUE=Catch/Effort$$

Optimizing the utilization of T. ilisha resources. The optimization analysis of *T. ilisha* resource utilization in Labuhanbatu waters was conducted using the Gordon-Schaefer bioeconomic model approach (Gordon 1954; Schaefer 1954). The bioeconomic analysis involved estimating biological parameters and economic parameters of maximum sustainable yield (MSY) and maximum economic yield (MEY). MSY serves as a fundamental reference point for the management of fisheries resources, aimed at ensuring their utilization without leading to population depletion, thereby maintaining the fishery resource at a sustainable level. MSY quantifies the maximum annual catch that the fishery can sustainably harvest (Widodo & Suadi 2006). The concept of MSY is based on a simplistic population model of the fish species considered as a whole. Furthermore, MSY serves as an important management parameter within fisheries resource assessment, as emphasized by Listiyani et al (2017). These biological parameters were obtained through regression analysis. The economic parameters, which include the output price (p) per ton of fishery resource production and the input cost (c) of daily fishing activities at sea, were estimated (Piliana et al 2016). Table 1 presents the bioeconomic formula proposed by Gordon-Schaefer.

Table 1

Bioeconomic model formula of Gordon-Schaefer

Variable	*Maximum sustainable yield*	*Maximum economic yield*	*Open access fishing*
Biomass (X)	$\frac{K}{2}$	$(\frac{K}{2})\ X\ (1+\frac{c}{pqK})$	$\frac{c}{pq}$
Catch (h)	$\frac{Kr}{4}$	$(\frac{Kr}{4})\ X\ (1+\frac{c}{pqK})\ X\ (1+\frac{c}{pqK})$	$(\frac{Rc}{pq})\ X\ (1-\frac{c}{pqK})$
Effort (E)	$\frac{r}{2q}$	$(\frac{r}{2q})\ X\ (1-\frac{c}{pqK})$	$(\frac{r}{q})\ X\ (1-\frac{c}{pqK})$
Rent/ Profit (π)	$(p.h_{MSY})-(c.E_{MSY})$	$(p.h_{MEY}) - (c.E_{MEY})$	$(p.h_{OA}) - (c.E_{OA})$

Note: K - carrying capacity; r - intrinsic growth rate; c - catch cost; p - fish price; q - catch coefficient.

Utilization and fishing capacities. Utilization capacity refers to the amount or percentage value that indicates the utilization of fish resources. According to Collette & Nauen (1983), the potential utilization of fish resources allowed to be caught is up to 80% of the MSY. Similarly, the Indonesian government also mandated the total allowable catch (TAC) of Indonesian potential fish resources for around 80% of the sustainable potential or equal to 10.03 million tonnes per year (Irschlinger & Tipping 2023; Gokkon 2023). According to Sparre & Venema (1999), the utilization capacity is expressed as a percentage (%) and can be calculated using the following formula:

$$UCi=(Ci/MSY)X100$$

Where: UC_i - the utilization capacity in the i-th year; C_i - the catch yield in the i-th year; MSY - maximum sustainable yield.

Fishing capacities are the ability of a vessel or fleet of vessels to catch fish (Reid et al 2003). The fishing capacity is also expressed as a percentage (%) and calculated using the following formula:

$$FC_i=(f_i/f_{opt})x100$$

Where: FC_i - the fishing capacity in the i-th year; f_i - total effort in the i-th year; f_{opt} - total optimum effort.

Results

***T. ilisha* catch**. The fishing activities targeting *T. ilisha* in the waters of Labuhanbatu are predominantly traditional in nature, characterized by the frequent use of non-motorized and small motorized boats. Fishermen typically employ gill nets with a mesh size of 10.16 cm to capture the fish. Figure 1 illustrates the *T. ilisha* catch data spanning from 2014 to 2021.

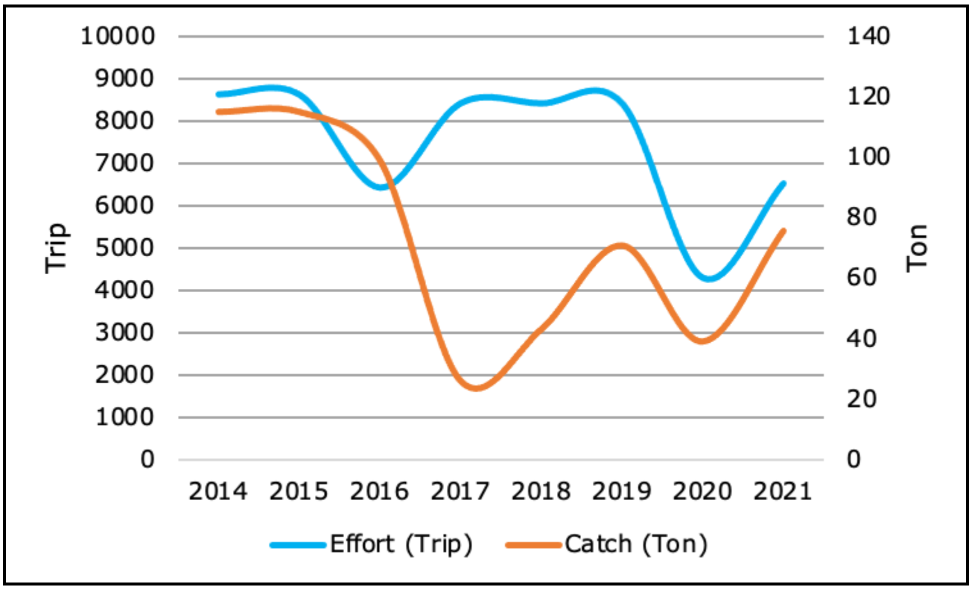

Figure 1. Hilsa fish (*Tenualosa ilisha*) catch in Labuhanbatu waters from 2014 to 2021 (Department of Marine and Fisheries of Labuhanbatu Regency 2022).

Catch per unit effort (CPUE). The CPUE values for *T. ilisha* are presented in Figure 2.

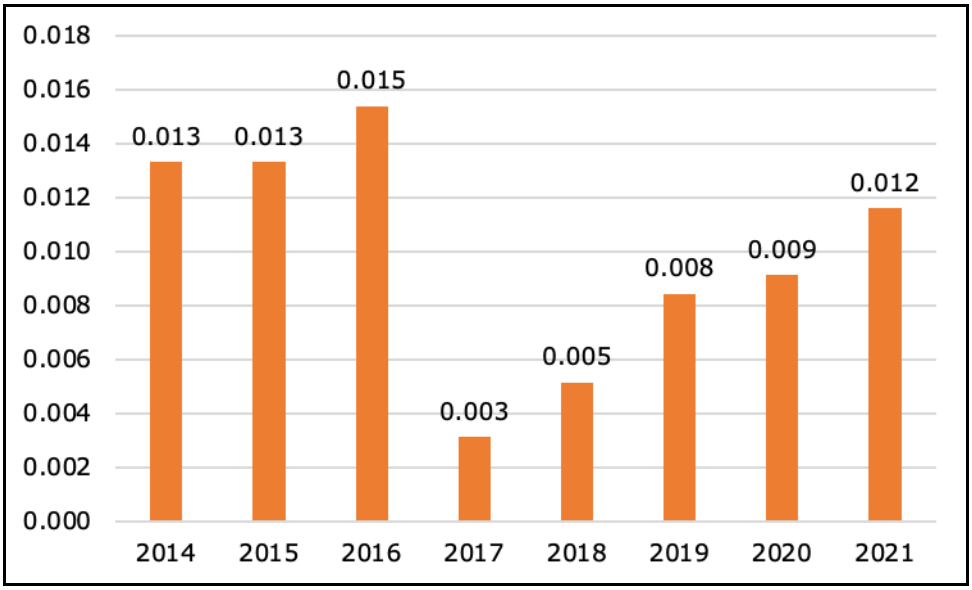

Figure 2. Hilsa fish (*Tenualosa ilisha*) CPUE values from 2014 to 2021 in the studied area.

Figure 2 illustrates fluctuations in the CPUE values. The average CPUE across the dataset is 0.001. The highest CPUE value, indicative of optimal fishing gear performance, is observed in 2016, reaching 0.015. In contrast, the lowest CPUE value, signaling reduced gear efficiency, occurs in 2017 at 0.003. The variations in CPUE values indicated annual fluctuations occurring in fish populations, which may be affected by various factors. They may occur as a result of increasing and decreasing the total efforts during the period, abundance of fish and possibility of climate-related factors (Budiasih & Dewi 2015; Vázquez-Prada 2014).

Optimization analysis of T. ilisha resources utilization. The specific MSY values calculated for *T. ilisha* resources in the Labuhanbatu waters are presented in Table 2.

Table 2
Maximum sustainable yield of hilsa fish (*Tenualosa ilisha*) resources in Labuhanbatu waters

Parameter	*Maximum sustainable yield*
Catch (C)	89.69 tons
Effort (E)	5824 trips
Total revenue (TR)	1539101.08 USD
Total cost (TC)	703737.10 USD
Rent/Profit (π)	835363.99 USD

Based on the MSY calculation, the catch-MSY (CMSY) is determined to be 89.68 tons per year. Achieving this CMSY level requires the operation at an effort-MSY (EMSY) of 5824 trips per year. Based on the data, the total revenue (TR) amounts to 1539101.08 USD, while the total cost (TC) stands at 703737.10 USD, resulting in a profit of 835363.99 USD at the MSY level.

Meanwhile, MEY analysis assesses the highest achievable profit within a particular level of production. Should the catch surpass the MEY, profits will diminish. Consequently, excessive resource utilization can lead to economic losses for fishermen involved in fishing activities, as highlighted by Nasution et al (2018). The specific determination of MEY for *T. ilisha* resources in the Labuhanbatu waters is presented in Table 3.

Table 3
Maximum economic yield of hilsa fish (*Tenualosa ilisha*) resources in Labuhanbatu waters

Parameter	*Maximum economic yield*
Catch (C)	85.00 tons
Effort (E)	4493 trips
Total revenue (TR)	1458657.07 USD
Total cost (TC)	542849.06 USD
Rent/Profit (π)	915.808.00 USD

Based on the MEY calculation, the catch-MEY (CMEY) reaches 85 tons per year. *T. ilisha* fishing units can achieve this level of CMEY with an effort-MEY (EMEY) of 4493 trips per year. According to the data, the total revenue is 1458657.07 USD, and the total cost is 542849.06 USD, resulting in a profit of 915808.00 USD.

Based on Table 4, open access fishing, which involves unrestricted fishing, results in a lower catch level of 63.27 tons compared to MSY and MEY. In addition, open access fishing exhibits a higher effort level of 8985 trips per year. In contrast to profit in MSY and MEY, open access fishing generates a total revenue of 1085698.12 USD, which matches the total cost, resulting in no profit.

Table 4
Open access fishing of hilsa fish (*Tenualosa ilisha*) resources in Labuhanbatu waters

Parameter	*Open access fishing*
Catch (C)	63.27 tons
Effort (E)	8985 trips
Total revenue (TR)	1085698.12 USD
Total cost (TC)	1085698.12 USD
Rent/Profit (π)	0 USD

The values extracted from Tables 2, 3, and 4 carry substantial implications for the exploitation of *T. ilisha* resources. The strategies outlined in MSY and MEY underscore more sustainable fishing approaches, prioritizing the preservation of fish populations while optimizing economic gains. These strategies take into account the ecological boundaries of fish populations and are designed to mitigate the risk of overexploitation. Conversely, open-access fishing, characterized by the absence of regulations and constraints, holds the potential to result in overfishing and the depletion of *T. ilisha* resources. Furthermore, the MSY and MEY strategies generate higher rent/profit than open access fishing. This indicates that implementing sustainable and economically optimized fishing practices can lead to more significant financial gains in the long run. By aligning fishing efforts with the MSY or MEY levels, fishermen can enhance their economic well-being while safeguarding the *T. ilisha* population.

The interplay between fishing costs, revenue, and profit within fishery resources is depicted in Figure 3. As Figure 3 illustrates, revenue surpasses fishing costs, leading to significant profits for fishermen until the MEY point is reached. If fishing efforts persist beyond the MEY level, physical production may increase, but economic profits will decline. If fishing efforts persist further, they will eventually reach the break-even point.

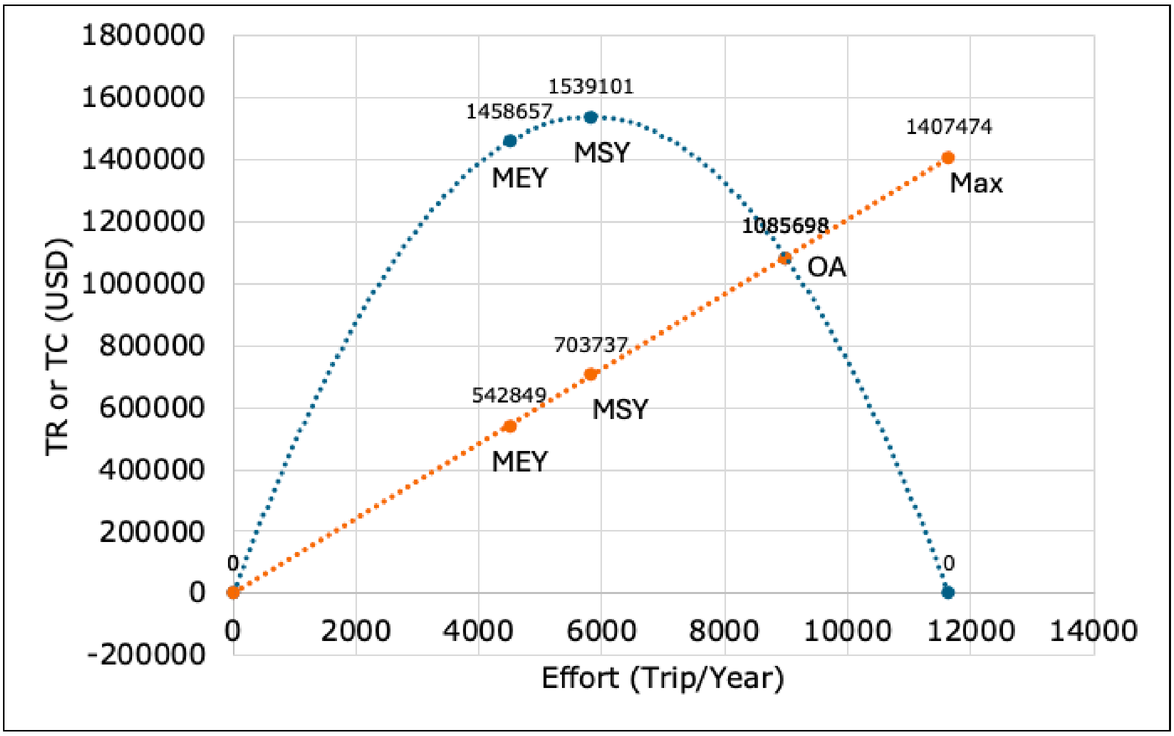

Figure 3. Bioeconomic equilibrium curve of hilsa fish (*Tenualosa ilisha*) in Labuhanbatu waters; TR - total revenue with blue dotted line; TC - total cost with orange dotted line.

Utilization and fishing capacities of T. ilisha resources. Figure 4 shows the utilization capacity of *T. ilisha*. Based on the data, the average capacity reaches 81%, which exceeds the allowed capacity of 80%.

Figure 4 provides an illustration of the fishing capacity pertaining to *T. ilisha*. The average annual fishing effort, spanning from 2014 to 2021, was 7474 trips. This signifies that the utilization of *T. ilisha* exceeds the fishing capacity, which represents the MSY. The average fishing capacity is determined to be 128%, indicating that the capacity level has surpassed its maximum capacity of 100%.

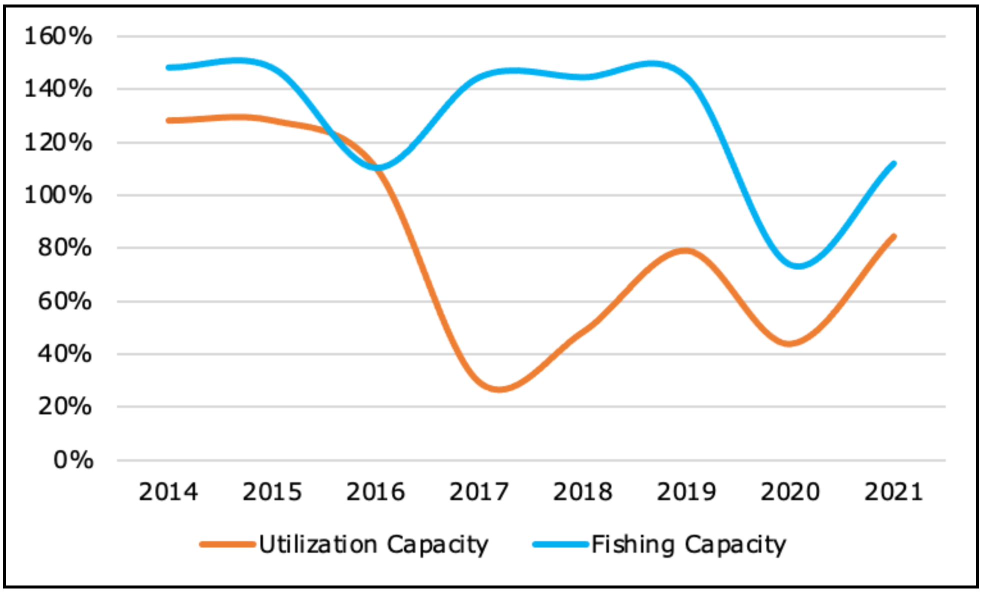

Figure 4. Utilization and fishing capacities of hilsa fish (*Tenualosa ilisha*) resources in Labuhanbatu waters.

Discussion. According to Law Number 31 of 2004 of the Republic of Indonesia concerning Fisheries, as amended by Law Number 45 of 2009, the management of fisheries aims to achieve not only economic benefits from fish resources, but also their long-term sustainability. This legislation confers authority upon the Minister of Maritime Affairs and Fisheries, which, among other responsibilities, has to identify potential fish resources, allocate fish resources, and establish allowable catch levels within the Indonesian Fisheries Management Area. In practice, the Minister receives recommendations from a national commission responsible for assessing fish resources, as outlined in Article 7 of Law Number 31/2004. The enforcement of laws focused on the sustainability of fish resources is essential to mitigate the adverse impacts of excessive fishing activities and habitat degradation. Consequently, the Minister of Maritime Affairs and Fisheries of the Republic of Indonesia issued Ministerial Decree Number 43/KEPMEN-KP/2016, designating Limited Protection Status for *T. ilisha* in the Barumun River, Labuhanbatu Regency, North Sumatra Province. This decree came into effect on August 2, 2016, under the authority of the Minister of Maritime Affairs and Fisheries of the Republic of Indonesia.

According to Siregar et al (2020), the exploitation of the *T. ilisha* in Labuhanbatu waters has been carried out intensively for an extended period. The *T. ilisha* population was abundant in the 1960s, but started to decline in the 1970s and significantly decreased in the 1980s, as reflected in fishermen catch. Particularly in the Barumun River, which serves as a primary spawning and breeding area for *T. ilisha*, there has been a notable deterioration in the environmental quality of their habitat. The simultaneous occurrence of high exploitation rates and habitat degradation has resulted in the overall degradation of *T. ilisha* resources in the Labuhanbatu waters.

In implementing the Minister of Marine Affairs and Fisheries Decree No. 43 of 2016, continuous supervision and monitoring are necessary to raise awareness among fishermen who rely on open-net fishing, particularly regarding the importance of sustainable practices for future generations. A persuasive approach and increased knowledge about the importance of sustaining open-net fishing in nature are needed. One solution for fishermen dependent on open-net fishing is providing alternative livelihood support. For instance, the Coastal and Marine Resources Management Center in Padang has already assisted six fishermen groups in Teluk Sentosa Village, Sei Merdeka Village, and Telaga Suka Village by providing gillnets, since Gulamah fish (*Johnius belangerii*) is available year-round along the Barumun River (Siregar et al 2020).

This study clearly demonstrates that *T. ilisha* resources in the Labuhanbatu waters are experiencing overexploitation, as evidenced by fishing activities surpassing the MSY level. This suggests that resource utilization exceeds sustainable thresholds, even though fishing efforts are within the capacity. As Miah (2015) has emphasized, the sustainable management of marine living resources and the reduction of environmental impacts on mariculture are crucial considerations.

Economists have long argued that maximizing the economic benefits (MEY) of fisheries biomass is a management target (Grafton et al 2010). MEY represents a long-term equilibrium concept of the appropriate output level and effort to maximize economic profits from fishing activities (Dichmont et al 2010). Capturing fish at the MEY point provides maximum economic benefits for vessel owners and wages for workers dependent on profit-sharing systems. While economic rent from each value chain is considered, the highest rent remains at the MEY level. At this point, maximum benefits are obtained without disrupting the biological balance of fishery resources (Pascoe et al 2015).

In order to achieve MEY, fleet reductions are necessary to lower input demand and thus lower input costs to the fisheries. However, such measurement also potentially leads to other negative impacts include reduced consumption, income loss and employment loss in the fishery sector (Norman-López & Pascoe 2011). It is therefore crucial to carefully consider whether MEY is an appropriate management target, as it results in a high revenue and cost ratio. This scenario could imply that only a few vessels participate in the fishery, generating substantial profits from a shared resource. The increased profitability might also enable more significant investment, improving efficiency and catchability. Consequently, there may be pressure to increase fishing mortality rates and disregard downward quota revisions (Pilling et al 2008).

The results of optimizing the utilization of fishery resources in the waters of Labuhanbatu indicate that MSY management has reached an optimal level. If the most significant fish resources are left open, competition in this condition becomes uncontrolled, resulting in zero profit. Based on the rent obtained in MEY management, the rental value obtained is the highest compared to other conditions. Additionally, the highest stock of MSY-selected fish is produced in the waters. Therefore, the fishery resources that exist remain underwater in Labuhanbatu, obtained by static fishing structures, should be managed with MEY management. When reaching maximum production, fishermen should cease expanding their fishing activities to ensure resource sustainability and optimal utilization of biological resources.

The management recommendations for marine *T. ilisha* can effectively collaborate with the regulation mentioned. Firstly, providing alternate employment for fishermen during the off-fishing season aligns with the prohibition of catching *T. ilisha* during the designated spawning periods. This ensures that fishermen have alternative sources of income and reduces pressure on the *T. ilisha* population during critical reproductive periods. In addition, regulating industrial and artisanal fishing activities can be implemented by prohibiting catching *T. ilisha* during the specified spawning periods. This helps reduce overfishing and allows the fish to reproduce without disturbance, contributing to sustainable production.

The aim of regulations is to preserve the *T. ilisha* population. Research can concentrate on developing effective breeding techniques that support the natural reproductive process and contribute to replenishing the fish stock. Preventing indiscriminate exploitation of *T. ilisha* aligns with the regulation's objective of establishing limited protection status. The prohibition of dumping harmful chemicals helps to safeguard the environment and supports the overall preservation of the *T. ilisha* population. Additionally, improving the registration process for fishing vessels and gear complements the regulation's goal of ensuring the effective monitoring and management of fishing activities.

Conclusions. Research findings on the optimal utilization analysis of *T. ilisha* resources from 2014 to 2021 indicate that the *T. ilisha* in Labuhanbatu, North Sumatra Province, has been overexploited. This conclusion is based on bioeconomic analysis using the

Gordon-Schaefer model. A utilization capacity of 81% indicates overexploitation as it has exceeded the MSY level. Meanwhile, the fishing capacity stands at 128%, indicating that it already surpassed its maximum capacity of 100%. In light of this, it is advisable for the Labuhanbatu Regency Government to consider offering alternative livelihoods to *T. ilisha* fishermen. This measure can help reduce fishing activities and ensure the continued availability of *T. ilisha* in the waters of Labuhanbatu. Future research has the potential to make significant contributions to the sustainable management of *T. ilisha*. One crucial aspect is conducting a comprehensive stock assessment to gain precise insights into population dynamics, growth rates, and reproductive patterns. Such an assessment would be instrumental in determining the present status of *T. ilisha* stocks and informing appropriate management actions. Additionally, an environmental impact assessment would be valuable in evaluating the broader ramifications of overexploitation on the marine ecosystem, encompassing the effects on other fish species, biodiversity, and ecosystem dynamics. Assessing the socioeconomic impacts on local fishing communities, including economic dependencies, social implications, and alternative livelihood options, through a dedicated socioeconomic analysis is also essential. Exploring various policy and management strategies, such as implementing catch limits, gear restrictions, or establishing marine protected areas, would further guide effective conservation measures. Additionally, actively engaging stakeholders and comprehending their perspectives would enhance the decision-making processes associated with *T. ilisha* management. Moreover, investigating the potential impacts of climate change on *T. ilisha* populations would underscore the necessity of adopting adaptive management strategies to ensure their long-term survival.

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

References

Arrazy M., Primadini R., 2021 [The potential of the fisheries subsector in the provinces of Indonesia]. Bina Bangsa Ekonomika Journal 14:1-13. [In Indonesian].

Budiasih D., Dewi D. A. N., 2015 [CPUE and utilization rate of skipjack tuna (*Katsuwonus pelamis*) fisheries around Palabuhanratu Bay, Sukabumi Regency, West Java]. Agriekonomika 4:37-49. [In Indonesian].

Collette B. B., Nauen C. E., 1983 Vol. 2. Scombrids of the world: An annotated and illustrated catalogue of tunas, mackerels, bonitos, and related species known to date. FAO Species Catalogue, FAO Fisheries Synopsis No. 125, p. 140.

Dichmont C. M., Pascoe S., Kompas T., Punt A. E., Deng R., 2010 On implementing maximum economic yield in commercial fisheries. Proceedings of the National Academy of Sciences 107(1):16-21.

Efizon D., Djunaedi O. S., Dhahiyat Y., Koswara B., 2012 [Population abundance and exploitation rate of hilsa shad (*Tenualosa macrura*) in the waters of Bengkalis, Riau]. Hilsa Fisheries Periodical, 40(1):52-65. [In Indonesian].

Gordon H. S., 1954 The economic theory of a common-property resource: The fishery. Journal of Political Economy 62(2):124-142.

Grafton R. Q., Kompas T., Chu L., Che N., 2010 Maximum economic yield. Australian Journal of Agricultural and Resource Economics 54(3):273-280.

Hashemi S., Mohammadi G., Eskandary G., 2010 Population dynamics and stock assessment of hilsa shad, (*Tenualosa ilisha* Hamilton-Buchanan, 1822) in coastal waters of Iran (northwest of Persian Gulf). Australian Journal of Basic and Applied Sciences 4(12):5780-5786.

Hossain M. S., Sarker S., Chowdhury S. R., Sharifuzzaman S. M., 2014 Discovering spawning ground of hilsa shad (*Tenualosa ilisha*) in the coastal waters of Bangladesh. Ecological Modelling 282:59-68.
Hossain M. S., Sharifuzzaman S. M., Rouf M. A., Pomeroy R. S., Hossain M. D., Chowdhury S. R., AftabUddin S., 2019 Tropical hilsa shad (*Tenualosa ilisha*): Biology, fishery and management. Fish and Fisheries 20(1):44-65.
Irschlinger T., Tipping A., 2023 Fisheries subsidies that contribute to overcapacity and overfishing: A review of key concepts and data. Available at: https://www.iisd.org/
Jihad S. S., Efizon D., Putra R. M., 2014 [Reproductive biology of the *Tenualosa ilisha* in Labuhanbatu Regency, Sumatra Utara Province]. Jurnal Online Mahasiswa 1:1-10. [In Indonesian].
Karim E., Liu Q., Sun M., Barman P. P., Hasan S. J., Hoq M. E., 2019 Assessing recent gradual upsurge of marine captured hilsa stock (*Tenualosa ilisha*) in Bangladesh. Aquaculture and Fisheries 4:156-165.
Listiyani A., Wijayanto D., Jayanto B. B., 2017 [Analysis of CPUE (catch per unit effort) and the utilization rate of lemuru (*Sardinella lemuru*) fisheries resources in the Bali strait waters]. Jurnal Perikanan Tangkap, 1(1):1-9. [In Indonesian].
Miah M. S., 2015 Climatic and anthropogenic factors changing spawning pattern and production zone of hilsa fishery in the Bay of Bengal. Weather and Climate Extremes 7:109-115.
Nainggolan H. L., Tampubolon J., Ginting A., 2019 [Analysis of the marine economic performance and directions for the development policy of marine tourism and maritime services in North Sumatra Province]. PT Alex Media Computindo, Jakarta, 269 p. [In Indonesian].
Nasution Y. S., Hendrik H., Warningsih T., 2018 [Analysis of the bioeconomy anchovies rice (*Stolephorus commersonii*) in Labuhanbatu District waters of North Sumatera Province]. Jurnal Perikanan dan Kelautan 23(2):38-46. [In Indonesian].
Noija D., Martasuganda S., Murdiyanto B., Taurusman A. A., 2014 [Potential and utilization rate of demersal fishery resources in the waters of Ambon Island, Maluku Province]. Jurnal Teknologi Perikanan dan Kelautan 5:55-64. [In Indonesian].
Norman-López A., Pascoe S., 2011 Net economic effects of achieving maximum economic yield in fisheries. Marine Policy 35(4):489-495.
Pascoe S., Vieira S., Thebaud O., 2015 Allocating repairs and maintenance costs to fixed or variable costs in fisheries bioeconomic models. Applied Economics Letters 22(2):127-131.
Piliana W. O., Kusumastanto T., Diniah, 2016 [Bioeconomic analysis and optimization of skipjack tuna resource management in the waters of Muna Regency, Southeast Sulawesi]. Marine Fisheries: Journal of Marine Fisheries Technology and Management 6(1):13-22. [In Indonesian].
Pilling G. M., Kell L. T., Hutton T., Bromley P. J., Tidd A. N., Bolle L. J., 2008 Can economic and biological management objectives be achieved by the use of MSY-based reference points? A North Sea plaice (*Pleuronectes platessa*) and sole (*Solea solea*) case study. ICES Journal of Marine Science 65(6):1069-1080.
Reid C., Squires D., Jeon Y., Rodwell L., Clarke R., 2003 An analysis of fishing capacity in the western and central pacific ocean tuna fishery and management implications. Marine Policy 27(6):449-469.
Rumondang R., Ariyanto D., Manurung H. P., 2019 [PPM (Participatory Planning and Management) in the "Kompak Bersama" grouper fish farmers group in Mesjid Lama village, Talawi Subdistrict, Batubara Regency]. In: Seminar Nasional Multi Disiplin Ilmu Universitas Asahan. [In Indonesian].
Schaefer M. B., 1954 Some aspects of the dynamics of populations important to the management of commercial marine fisheries. Bulletin of the Inter-American Tropical Tuna Commission 1(2):27-56.
Sibagariang O. P., Fauziyah, Agustriani F., 2011 [Analysis of the sustainable potential of longline tuna fisheries resources in Cilacap Regency, Central Java]. Maspari Journal: Marine Science Research 3(2):24-29. [In Indonesian].

Siregar A. M., Kuswardani R. A., Hasibuan S., 2020 [Analysis of the implementation of regulations on the designation of limited protection status for hilsa shad fish (*Tenualosa ilisha*)]. AGRISAINS: Jurnal Ilmiah Magister Agribisnis 2:10-25. [In Indonesian].
Siregar I. H. K., 2018 [Development of responsible fishing technology in the waters of Labuhanbatu Regency, North Sumatra Province]. Jurnal Perikanan dan Kelautan 23:57-68. [In Indonesian].
Sparre P., Venema S. C., 1999 Introduction to the study of tropical fish stocks. Fisheries Research and Development Center, Jakarta, 423 p.
Suharsono A., Mustofa A., Nuraini, Hizbulloh L., Bellmann C., Irschlinger T., Tolvanen S., 2021 Supporting marine fishing sustainably: A review of central and provincial government support for marine fisheries in Indonesia. Available at: https://www.iisd.org/system/files/2021-07/sustainable-marine-fisheries-indonesia-en.pdf Accessed 2024-04-04.
Vázquez-Prada G., 2014 Analyzing fish stocks dynamics using CPUE and PRCF: A new approach for the fishery management. Journal of Coastal Life Medicine 2(1):1-6.
Widodo J., Suadi, 2006 Marine fisheries resource management. University of Gadjah Mada Press, Yogyakarta, 252 p. [In Indonesian].
*** Central Bureau of Statistics of Labuhanbatu Regency, 2020 Labuhanratu Regency in Figures. [In Indonesian].
*** Department of Marine and Fisheries of Labuhanbatu Regency, 2022 Governmental institution performance report of the Labuhanbatu Regency in 2022. [In Indonesian].
*** Gokkon B., 2023 Indonesia delays enforcement of widely panned fisheries policy. Available at: https://news.mongabay.com/2023/12/indonesa-fisheries-quota-policy-sustainable-ministry-small-fishers/
*** Government of the Republic of Indonesia, 2004 Law Number 31 of 2004 concerning Fisheries. [In Indonesian].
*** Government of the Republic of Indonesia, 2009 Law Number 45 of 2009 concerning Amendments to Law Number 31 of 2004 concerning Fisheries. [In Indonesian].
*** Minister of Marine Affairs and Fisheries of the Republic of Indonesia, 2016 Decree No. 43/KEPMEN-KP/2016 concerning Designation of Limited Protection Status for the Hilsa Fish (*Tenualosa ilisha*). [In Indonesian].
*** MMAF, 2016 [National action plan for hilsa fish conservation]. Directorate of Marine Conservation and Biodiversity, Directorate General of Marine Spatial Planning, Ministry of Marine Affairs and Fisheries, Indonesia. [In Indonesian].

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