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Stock Assessment and Sustainable Potential of Skipjack Tuna (*Katsuwonus pelamis*) in Sibolga Waters for Optimized Fishing Practices

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ABSTRACT

The uncontrolled fishing of skipjack tuna (*Katsuwonus pelamis*) without recruitment efforts has led to stock degradation and unstable abundance due to excessive pressure. This study aims to estimate the sustainable potential of skipjack tuna by calculating Catch per Unit Effort (CPUE), assessing Maximum Sustainable Yield (MSY), and determining Total Allowable Catch (TAC). The research was conducted at PPN Sibolga and utilized survey-based data collection and surplus production analysis using the Schaefer model. The findings indicate that standardized CPUE in 2018 was 0.639 tons/trip, increased to 0.764 tons/trip in 2019, dropped to 0.527 tons/trip in 2020 and 0.506 tons/trip in 2021, and returned to 0.639 tons/trip in 2022. Purse seines were identified as the primary fishing gear. The Schaefer model estimated CMSY at 8,699.7 tons, classifying the fishery as fully exploited. FMSY was calculated at 5,447 trips, with annual efforts consistently exceeding this threshold, indicating overfishing. The TAC was set at 6,959.7 tons. Management strategies should regulate fishing efforts, enforce gear specifications, and implement science-based fisheries policies to prevent further degradation. Aligning fishing activities with sustainable thresholds will support skipjack tuna stocks' recovery and long-term productivity. These findings underline the importance of adaptive management and collaboration to sustain marine ecosystems and protect livelihoods.

Keywords: CPUE, MSY, TAC, skipjack tuna sustainability

1. INTRODUCTION

The Nusantara Fisheries Port (PPN) Sibolga plays a crucial role in supporting fishing activities along the western coast of North Sumatra, particularly as a central hub for the landing of skipjack tuna (*Katsuwonus pelamis*). According to Pasaribu et al. (2024), skipjack tuna production at PPN Sibolga during the 2017–2022 period exhibited fluctuations, with a significant decline in 2022 attributed to extreme weather conditions. Furthermore, Sudrajat et al. (2022) indicated that the area's exploitation rate of skipjack tuna resources had reached 120%, signaling an over-exploited status that necessitates serious management attention. Pulungan (2019) also highlighted that the Catch per Unit Effort (CPUE) value for skipjack tuna at PPN Sibolga fluctuated between 2011 and 2016, reflecting fishing effort and stock availability variability. These findings underscore the importance of implementing sustainable fishing practices and effective resource management strategies to ensure the long-term sustainability of skipjack tuna populations in Sibolga waters.

Fishing activities at the Nusantara Fisheries Port (PPN) Sibolga are predominantly carried out using purse seine fishing gear, locally called *jaring tongkol*. This fishing gear is categorized into two types based on the target catch: small pelagic purse seine and large pelagic purse seine. The selection of purse seine is aligned with the fisheries potential in the Indian Ocean, particularly in Fisheries Management Area (WPP) 572, which is abundant with species such as skipjack tuna (*Katsuwonus pelamis*), frigate tuna (*Euthynnus affinis*), yellowfin tuna (*Thunnus albacares*), Indian mackerel (*Rastrelliger kanagurta*), and skipjack tuna (*Decapterus macarellus*). Among these species, skipjack tuna is one of the primary catches landed at PPN Sibolga.

According to Simanjuntak et al. (2024), purse seine fishing grounds in Sibolga waters are mostly located beyond 12 nautical miles, following prevailing fisheries management regulations. Additionally, a study by Widiyastuti et al. (2020) revealed that skipjack tuna caught in the Indian Ocean, including those landed at PPN Sibolga, exhibit a negative allometric growth pattern, indicating that their length growth is more dominant than their weight increase. These findings emphasize the need for sustainable fishing practices to maintain stock availability and long-term productivity in Sibolga waters.

The inadequate implementation of fishing regulations for skipjack tuna in the Indian Ocean, particularly in the Sibolga region, is primarily caused by limited information regarding the exploitation rate of this fishery resource. If this situation is not promptly addressed through prudent management measures, overexploitation exceeding the Maximum Sustainable Yield (MSY) of skipjack tuna will likely occur. Previous studies have estimated the sustainable potential of skipjack tuna in various locations, such as at the Nusantara Fisheries Port (PPN) Sibolga, North Sumatra (Pasaribu et al., 2024), and in the waters around Nias Island, where the catch is landed at PPN Sibolga (Sudrajat et al., 2022). However, similar studies assessing the CPUE (Catch Per Unit Effort) and MSY of skipjack tuna in Sibolga waters remain limited. Therefore, this research aims to estimate the CPUE, determine the MSY, and establish the allowable catch limit (JTB) for skipjack tuna landed at PPN Sibolga, supporting sustainable fisheries management in the region.

2. RESEARCH METHOD

Time and Place

The research was conducted from June to December 2024 at the Nusantara Fisheries Port (PPN) Sibolga, located on Jalan Jenderal Gatot Subroto, Pondok Batu Village, Sarudik District, Central Tapanuli Regency, North Sumatra. This location was chosen due to its strategic position as one of the primary fish landing ports in the Indian Ocean fisheries management area (WPP 572). PPN Sibolga serves as a crucial hub for fishing activities, particularly for skipjack tuna and other pelagic fish species. The port's infrastructure, facilities, and high fishing activity levels make it an ideal site for studying sustainable fisheries management practices.

Method

This research mainly focuses on skipjack tuna that landed at the Nusantara Fisheries Port (PPN) Sibolga. Data collected during the study were explicitly aligned with the research objectives to ensure accuracy and relevance. The primary data used in this study included catch records, fishing effort data, and observations directly from landing activities at PPN Sibolga. However, the research predominantly relied on **secondary data** from official statistical reports and documents published by relevant fisheries authorities and management institutions. These secondary data provided time-series information on skipjack tuna landings, fishing efforts, and catch per unit effort (CPUE), serving as the foundation for assessing the sustainable potential (MSY) and allowable catch limit (JTB) of skipjack tuna in Sibolga waters.

Data Collection

This research applied a quantitative descriptive method designed to systematically and structurally describe the characteristics of the skipjack tuna and its fishery. Descriptive research focuses on uncovering facts by presenting data comprehensively and in detail, enabling a deeper understanding of the subject under study (Sugiyono, 2013). The data collection utilized a literature review method, sourcing secondary data from time-series records of skipjack tuna landings reported in statistical and annual publications by the Nusantara Fisheries Port (PPN) Sibolga. These records covered five years (2018–2022), providing valuable insights into trends in catch volumes, fishing efforts, and stock dynamics. Using this approach, the study aimed to analyze the sustainable potential (MSY) and allowable catch limits (JTB) for skipjack tuna, contributing to sustainable fishing practices in Sibolga waters.

Data Analysis

The data analysis in this study was tailored to align with the research objectives. For the first objective, the Catch Per Unit Effort (CPUE) analysis was applied to evaluate fishing effort efficiency and resource availability of skipjack tuna. The surplus production analysis was conducted using the Schaefer model for the second objective. This model was chosen to calculate the Maximum Sustainable Yield (MSY), including CMSY (catch-based MSY), EMSY (effort-based MSY), and the Allowable Catch Limit (JTB). The Schaefer model was selected because its calculations and analyses are considered more accurate than other models, making it highly reliable for estimating the sustainable exploitation levels of fish stocks. This approach ensures that the analysis effectively supports sustainable fisheries management in Sibolga waters.

Analysis of Catch per Unit Effort (CPUE)

Catch per Unit Effort (CPUE) can be calculated by dividing the total catch by the fishing effort. This measure is a key indicator of the abundance of fish stocks and the efficiency of fishing activities. According to the formula proposed by Sparre & Venema (1998), the calculation is expressed as:

$$CPUEi=Ci/fi$$

Description:

CPUEi	:	Catch per unit effort at time i
CiC	:	Total catch at time i
fif	:	A fishing effort at a time i

The skipjack tuna landed at PPN Sibolga is captured using various types of fishing gear, each with different levels of efficiency and effectiveness. To ensure consistency in data analysis and comparisons, it is essential to standardize fishing efforts. This standardization process assumes that the catch from any specific fishing gear is comparable to that of a standardized fishing gear. The Fishing Power Index (FPI) is used to determine the relative efficiency of a particular gear type compared to the standardized gear. The FPI is calculated using the following formula:

$$FPI = \frac{\text{Catch from standard gear}}{\text{Catch from specific gear}}$$

Description:

FPI	:	Fishing Power Index, representing the relative efficiency of a gear type.
Catch from specific gear	:	The total catch obtained using the specific fishing gear being evaluated.
Catch from standard gear	:	The expected catch from the standardized fishing gear under similar conditions.

Analysis of Maximum Sustainable Yield (MSY) and Allowable Catch Limit (JTB)

According to Wahyudi in Puspitha (2021), the sustainable potential (CMSY) using the Schaefer model begins with a simple linear regression equation: y=a−bxy = a - bxy=a−bx, where aaa is the intercept (constant), and bbb is the slope (gradient). In this equation, xxx represents fishing effort (E) by representing the catch per unit effort (CPUE), and it is the number of samples. After determining the parameters aaa and bbb, the equations for estimating the Maximum Sustainable Yield (CMSY) and Maximum Sustainable Effort (EMSY) are as follows:

$$E_{MSY} = a/2_b$$
$$C_{MSY} = a^2/4_b$$

Once the CMSY value is obtained, the Allowable Catch Limit (JTB) can be calculated using the formula: JTB=80%×CMSY

This method is widely used in fisheries science to assess the sustainable exploitation levels of fish stocks, ensuring ecological and economic balance.

3. RESULT AND DISCUSSION

CPUE of Skipjack Tuna Landed at PPN Sibolga

The fish landed at PPN Sibolga consist of various species, including demersal, pelagic, and reef-associated fish. Among these, skipjack tuna is one of the dominant pelagic species that frequently land at the port. As a highly valued resource, skipjack tuna plays a significant role in the fisheries industry in Sibolga. Over the past five years, the catch trends for skipjack tuna demonstrate its importance as a primary target species for local fishing fleets. These trends, as presented in Figure 1, provide critical insights into the stock dynamics and fishing patterns in Sibolga waters, highlighting the need for effective management to ensure the sustainability of this key fishery resource.

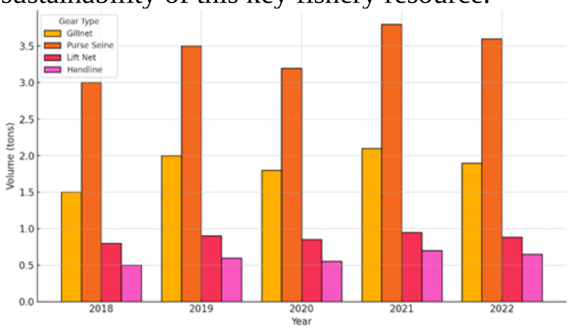

Figure 1. Skipjack tuna (*Katsuwonus pelamis*) landing volumes at PPN Sibolga from 2018 to 2022

Recent studies have provided valuable insights into the habitat characteristics and management strategies for skipjack tuna in Indonesian waters. Safruddin et al. (2022) utilized statistical models to identify key oceanographic parameters influencing skipjack tuna distribution during the Southeast Monsoon in the Bone Gulf, Indonesia. Their findings indicated that sea surface temperature, chlorophyll-a concentration, and water depth significantly affect skipjack tuna abundance, emphasizing the importance of these factors in fisheries management.

Zainuddin et al. (2023) also employed satellite-based ocean color and thermal signatures to define habitat hotspots and movement patterns for commercial skipjack tuna in Indonesia Fisheries Management Area 713. The study revealed that specific sea surface temperature ranges and chlorophyll-a concentration are associated with higher skipjack tuna catch rates, providing a scientific basis for identifying potential fishing zones.

Furthermore, Indonesia has been proactive in developing sustainable tuna fisheries management practices. In 2024, the country declared the "Year of Tuna," aiming to boost domestic demand and promote sustainable consumption of tuna species. This initiative is part of a broader effort to implement science-based policies and harvest strategies for tuna fisheries in Indonesia's archipelagic waters, ensuring the long-term sustainability of these vital resources. These studies and initiatives underscore the critical role of environmental factors in skipjack tuna distribution and the importance of implementing informed management strategies to sustain skipjack tuna populations in Indonesian waters.

Skipjack tuna resource potential was estimated using annual production and fishing effort data collected over the past five years. The data on skipjack tuna landings and catch per trip indicate that purse seines were the most dominant fishing gear during this period. This dominance is attributed to the high number of purse seine units operating compared to other fishing gear types at PPN Sibolga. The extensive use of purse seines highlights their efficiency and capacity to target pelagic species like skipjack tuna, making them the primary fishing method in this region.

Fishing efforts targeting skipjack tuna in the western waters of North Sumatra (WPP 572) are relatively high, potentially leading to overfishing. One of the key factors contributing to the decline in skipjack tuna populations is the intensity of fishing efforts (trips). In addition to the number of trips, the CPUE is another crucial indicator. By analyzing and identifying CPUE trends, the productivity of different fishing gear types over a specific period can be assessed (Table 1).

The CPUE provides valuable insights into the efficiency of each fishing gear and the availability of skipjack tuna resources. High CPUE values indicate better productivity and stock abundance, while declining CPUE trends may signal overexploitation or reduced stock availability. The CPUE data for skipjack landed at PPN Sibolga from 2018 to 2022 reveal significant differences in the productivity of various fishing gear types. Purse seines exhibited the highest CPUE at 0.61243 tons per trip, making them the most efficient gear for targeting skipjack tuna in Sibolga waters. Handlines followed with a CPUE of 0.12357 tons per trip, indicating moderate efficiency, while lift nets recorded a lower CPUE of 0.08629 tons per trip. With a CPUE of only 0.00054 tons per trip, Gillnets showed the least productivity among the gear types.

The Fishing Power Index (FPI) further highlights the dominance of purse seines, with an FPI value of 1, significantly outperforming other gear types. These results emphasize the importance of purse seines in the skipjack tuna fishery but also raise concerns about the potential for overexploitation due to their high efficiency and widespread use. Effective management strategies are essential to ensure sustainable fishing practices and long-term stock health in Sibolga waters (Zainuddin et al., 2023; Safruddin et al., 2022). CPUE of Each Fishing Gear Landing Skipjack tuna at PPN Sibolga from 2018 to 2022.

Table 1. CPUE of each fishing gear landing skipjack tuna at PPN Sibolga from 2018 to 2022

Fishing Gear	Catch (Ton)	Effort (Trip)	CPUE (Ton/Trip)	FPI
Purse Seine	25260.3	41246	0.61243	1
Lift Net	1075.6	12465	0.08629	0.1409
Handline	594.9	4814	0.12357	0.2018
Gillnet	5.2	9635	0.00054	0.0009

The standardized trip effort data for skipjack tuna fishing at PPN Sibolga from 2018 to 2022 illustrates the dominant role of purse seine fishing gear in the region. Over the five years, purse seines consistently recorded the highest fishing effort, with trips ranging from 7,760 to 8,599 annually. This dominance underscores the effectiveness of purse seines in targeting pelagic species like skipjack tuna, which are a key resource in the fisheries sector of Sibolga waters.

Meanwhile, lift nets and handlines show considerably lower levels of fishing effort, reflecting their supplementary role in the fishery. With minimal annual trips (1–2 per year), Gillnets play a negligible role in skipjack tuna fishing. The standardized effort per trip, which combines data across all fishing gear types, remained relatively consistent, ranging from 8,379 to 9,112 trips annually. This stability indicates a steady fishing activity over the years, highlighting the importance of balancing fishing pressure and resource availability. High fishing effort, especially with purse seines, raises concerns about the potential overexploitation of skipjack tuna stocks, which could negatively impact the ecosystem and local livelihoods (Table 2).

Table 2. Standard effort (F) per trip for each fishing gear from 2018 to 2022

Year	Purse Seine	Lift Net	Handline	Gillnet	Standard Effort/Trip
2018	8266	400	227	2	8895
2019	7760	405	212	2	8379
2020	8521	388	201	2	9112
2021	8599	288	166	1	9054
2022	8100	276	164	1	8541

Studies have shown that effective management strategies are essential to ensure the sustainability of skipjack tuna fisheries. Ramlah et al. (2020) highlighted that continuous monitoring of CPUE and fishing efforts is crucial in assessing utilization rates and the health of skipjack tuna stocks. Zainuddin et al. (2024) emphasized using satellite-derived habitat modeling to identify optimal fishing zones, reducing unnecessary fishing efforts and promoting sustainability. Furthermore, Syamsuddin et al. (2017) demonstrated the importance of identifying pelagic habitat hotspots to optimize fishing practices and minimize ecological impacts. These findings reinforce the need for a science-based approach to managing fishing efforts and protecting skipjack tuna stocks in Sibolga waters.

The table presents data on skipjack tuna production, standardized fishing effort, and CPUE at PPN Sibolga from 2018 to 2022. Production volumes fluctuated, peaking at 6,404.5 tons in 2019 and dipping to 4,585.7 tons in 2021. Standardized fishing efforts remained relatively stable, ranging from 8,379 to 9,112 trips annually. CPUE values varied, the highest at 0.764 tons per trip in 2019 and the lowest at 0.506 tons per trip in 2021 (Table 3).

Table 3. Production volume, standard effort, and standard CPUE from 2018 to 2022

Year	Production (Ton)	Standard Effort (Trip)	CPUE (Standard) (Ton/Trip)	ln CPUE
2018	5683.8	8895	0.639	-0.448
2019	6404.5	8379	0.764	-0.269
2020	4805.5	9112	0.527	-0.64
2021	4585.7	9054	0.506	-0.68
2022	5456.5	8541	0.639	-0.448

Recent studies have emphasized the importance of understanding environmental factors influencing skipjack tuna distribution and abundance. For instance, Zainuddin et al. (2023) utilized satellite-based ocean color and thermal signatures to identify habitat hotspots for skipjack tuna in Indonesia's Fisheries Management Area 713, highlighting the species' preference for specific oceanographic conditions.

Maximum Sustainable Yield (MSY) and Allowable Catch Limit (ACL)

The estimation of the maximum sustainable yield (MSY) and the allowable catch limit (TAC) for skipjack tuna landed at PPN Sibolga between 2018 and 2022 is essential to ensure sustainable fisheries management in the region. Using the Schaefer surplus production model, the constant was calculated to be 3.1941, while the regression coefficient was -0.0003. These parameters, derived from the relationship between fishing effort and CPUE, indicate the model's capability to predict sustainable fishing levels effectively. The coefficient of determination (R^2) was found to be 0.83, meaning that 83% of the variability in CPUE can be explained by fishing effort, reflecting a strong and reliable correlation between these variables (Hasrun et al., 2021). This high R^2 value validates the Schaefer model's accuracy and highlights its applicability in managing skipjack tuna stocks sustainably. Nurgiyantoro et al. (2012) emphasized that the coefficient of determination measures the extent to which variations in the dependent variable CPUE are influenced by changes in the independent variable (effort), making this an important tool for fisheries assessment. By calculating MSY and TAC, managers can establish limits to prevent overfishing and ensure the long-term productivity of skipjack tuna stocks. Furthermore, the findings align with Pasaribu et al. (2024), who noted that using robust statistical models to evaluate skipjack tuna stock sustainability is critical for implementing science-based fisheries policies.

Such analyses underscore the importance of balancing fishing efforts with stock availability. The consistent monitoring and application of reliable models like Schaefer's can provide valuable insights for decision-makers, enabling them to develop adaptive strategies to mitigate overexploitation risks. These strategies are essential to protect skipjack tuna stocks, which are vital in supporting local livelihoods and the economic stability of fisheries-dependent communities in Sibolga.

Over the past five years, the Maximum Sustainable Yield (MSY) analysis for skipjack tuna landed at PPN Sibolga indicates a CMSY value of 8,699.7 tons and an FMSY value of 5,447 trips/efforts. Based on annual production data from 2018 to 2022, the production volumes remain below the CMSY value. However, the status of this fishery is categorized as fully exploited, as the Total Allowable Catch (TAC), calculated at 6,959.7 tons, is nearly equal to the annual production, particularly in 2019, which recorded the highest production volume. This situation highlights the urgent need for effective management and stricter monitoring of fishing efforts to prevent exceeding the TAC limit. Hosseini et al. (2018) emphasize that proper fisheries management includes adjusting fishing efforts based on stock assessments, implementing science-based fisheries policies, and intensifying monitoring of fishing activities. These measures aim to ensure the sustainability of skipjack tuna stocks in the western waters of Sumatra (WPP 572), safeguarding against stock depletion that could adversely impact the marine ecosystem and the livelihoods of local communities.

The current production status of skipjack tuna in PPN Sibolga is classified as fully exploited. However, when comparing the FMSY value, which is calculated at 5,447 trips/efforts, with the actual fishing efforts conducted between 2018 and 2022, it becomes evident that the fishery has entered an overfishing phase. During this period, all annual effort values exceeded the FMSY threshold. Even in 2019, which recorded the lowest effort at 8,379 trips, the figure was significantly above the FMSY (Abdullah et al., 2021). These findings highlight the urgent need for stricter monitoring and practical fisheries management to regulate fishing activities and prevent stock depletion. One recommended strategy is implementing measurable fisheries policies to align fishing efforts with sustainable limits (Hakim et al., 2022). These policies would help reduce fishing pressure and mitigate the risk of stock degradation. Adaptive management, grounded in scientific stock assessments, is essential to ensure the long-term productivity and sustainability of skipjack tuna resources in Sibolga waters, safeguarding dependent communities' ecosystems and livelihoods.

The Maximum Sustainable Yield (MSY) approach has traditionally been used to manage fishery resources based on biological factors (Waileruny, 2014). This biological model provides transparent information about overfishing, offering valuable insights into the sustainability of fish stocks. MSY is a crucial benchmark for determining the optimal fishing effort and maximum catch levels. The MSY formula is considered valid when the slope, or by value, is negative, indicating that an increase in fishing effort causes a decline in CPUE. This relationship highlights the importance of controlling fishing activities to prevent excessive exploitation and maintain the sustainability of skipjack tuna stocks in PPN Sibolga (Utami et al., 2012).

Various fishing gears used to catch

skipjack tuna at PPN Sibolga demonstrate significant exploitation levels of this species. Total catch and fishing effort are crucial data for evaluating and managing fisheries sustainably. CPUE is a key indicator for assessing stock utilization and abundance in a specific area. According to Karnauskas & Babcock (2012), CPUE analysis is highly relevant for monitoring fish population dynamics and determining exploitation levels. Over the years, a decline in CPUE values indicates excessive pressure on fish stocks, potentially reducing resource availability in their habitat. Therefore, controlling the frequency and intensity of fishing is essential to ensure

The management of fisheries resources plays a crucial role in ensuring the sustainability of fish stocks, including skipjack tuna, a primary target species at PPN Sibolga. One key approach to achieving this is regulating the mesh size of fishing gear. Such regulations are vital to prevent the capture of undersized fish, thereby preserving fish populations and supporting sustainable fisheries (Adel et al., 2016). Additionally, setting proper specifications for fishing gear designed for skipjack tuna ensures effective fishing practices while minimizing the risk of resource depletion in marine ecosystems (Mallawa et al., 2014). Implementing strict rules on gear specifications safeguards fish stocks and enhances fishing operations' safety and efficiency. Input control in fisheries management, mainly through gear specification regulations, is a strategic measure to support the sustainability of marine ecosystems and the long-term viability of capture fisheries at PPN Sibolga (Jamal et al., 2011).

4. CONCLUSION

The study on skipjack tuna fisheries at PPN Sibolga from 2018 to 2022 has revealed critical insights into the status of the fishery, highlighting challenges and proposing sustainable management strategies to address overfishing and resource sustainability. Skipjack tuna, a significant regional economic resource, is currently categorized as fully exploited. While production volumes remain below the calculated Maximum Sustainable Yield (MSY) of 8,699.7 tons, fishing efforts have consistently surpassed the sustainable threshold (FMSY) of 5,447 trips annually. This indicates that overfishing is occurring in terms of effort, posing risks to stock health and long-term resource availability.

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