Title: Length-Based Approach to Assess Yellowfin Tuna (*Thunnus albacares*) in the Marine Waters of Tanzania

Authors: *Mathew O. Silas*[*1], *Rushingisha George*[2], *Masumbuko Semba*[3], *Tumu Mussa*[1], *Saleh Yahya*[1]

[1]*Deep Sea Fishing Authority (DSFA), Fumba, Zanzibar, Tanzania*

[2]*Tanzania Fisheries Research Institute (TAFIRI), Dar Es Salaam, Tanzania*

[3]*Nelson Mandela African Institution of Science and Technology, Arusha, Tanzania*

**Corresponding author: mathew.silas@dsfa.go.tz*

Abstract

Yellowfin tuna (*Thunnus albacares*) is an economically and ecologically important species exploited within the United Republic of Tanzania's Exclusive Economic Zone (EEZ). However, assessment efforts are constrained by data limitations common in tropical tuna fisheries. This study employed length-based approaches, specifically the Length-Based Spawning Potential Ratio (LB-SPR) models, to assess the status of yellowfin stocks using length-frequency data collected in 2024. Fork lengths of sampled individuals ranged from 42 to 150 cm, with seasonal size shifts indicating clear recruitment pulses. The estimated length at 50% maturity (L_{50}) was 92.3 cm, lower than global references but consistent with the expected maturity range for the species, between 78 and 158. Growth parameter estimates included an asymptotic length (L_∞) of 161.3 cm, a growth coefficient (K) of 0.10 year^{-1}, and a natural mortality rate (M) of 0.14 year^{-1}. Selectivity analysis revealed that fishing gears capture individuals at a size (SL_{50} = 59.5 cm) substantially smaller than the size at maturity, indicating significant fishing pressure on juveniles. The LB-SPR analysis yielded a spawning potential ratio of 0.29, which is below the precautionary (0.40) and the critical (0.30) but relatively above the critical (0.2) reference points. This SPR, combined with the fishing-to-natural mortality ratio (F/M = 0.8), suggests moderate fishing pressure. These findings highlight an unsustainable exploitation pattern driven by the high capture of immature fish. We recommend implementing size-based management measures, such as minimum size limits or gear modifications, to reduce juvenile mortality and rebuild the spawning stock. This study demonstrates the practical use of length-based methods for data-limited fisheries and provides actionable insights for the sustainable management of yellowfin tuna in Tanzania.

Keywords: Yellowfin tuna, stock assessment, data-limited fisheries, Length-Based Spawning Potential Ratio (LB-SPR), overfishing

1. Introduction

Tropical tunas are among the most valuable fish species in the world, sustaining livelihoods, driving trade, and contributing to food security across ocean basins. In the Indian Ocean, yellowfin tuna (*Thunnus albacares*), bigeye tuna (*Thunnus obesus*), and skipjack tuna (*Katsuwonus pelamis*) are particularly important, forming the backbone of both industrial and small-scale fisheries (1). In the United Republic of Tanzania (URT), these fisheries are a cornerstone of the national blue economy, a source of income, foreign revenue, and employment while linking local fishing communities to global seafood markets (2).

Yet, despite their importance, detailed knowledge of tuna stocks in Tanzania's marine waters remains limited. Most regional stock assessments are coordinated through the Indian Ocean Tuna Commission (IOTC) and rely on basin-wide datasets. These assessments show that yellowfin tuna, in particular, is overfished and subject to continued overfishing (3). However, such large-scale analyses often mask local dynamics and make it difficult for countries like Tanzania to understand their contribution to fishing pressure or design management tailored to national waters. This creates a gap; while tuna is vital to Tanzania's economy and food security, the science needed to manage them sustainably is still developing. Long-term time series of catch and effort data are sparse, and biological information is often drawn from studies in other parts of the Indian Ocean. In such data-limited contexts, alternative approaches are essential.

Length-based methods provide one such solution. Models like the Length-Based Spawning Potential Ratio (LB-SPR) use length-frequency data, which is easier and more practical to collect in data-poor settings to estimate growth parameters, maturity, mortality, and spawning potential (4, 5). These approaches have been applied to yellowfin tuna in other parts of the Indian Ocean, such as the Oman Sea (6) and Southeast Asia (7). Still, their use in our region remains scarce. The present study addresses this gap by applying LB-SPR models to yellowfin tuna sampled in the Tanzanian marine waters. The objectives were threefold: (i) to estimate biological and exploitation reference points such as size at maturity, growth, and mortality; (ii) to assess the current stock status of yellowfin tuna using length-based indicators; and (iii) to provide evidence that can guide management measures at the national level. By grounding the analysis in Tanzania's own data, this work aims to strengthen national capacity for tuna stock assessment and contribute to regional efforts to ensure the sustainability of Indian Ocean tunas.

2. Methodology

2.1. Study Area

This assessment was conducted in the marine waters of the United Republic of Tanzania (URT), located along the western Indian Ocean between latitudes 1° and 11°48'S and longitudes 38°23' and 45°14'E (Figure *1*). Tanzania's maritime jurisdiction encompasses a 1,424 km coastline, territorial waters of approximately 64,000 km², and an Exclusive Economic Zone (EEZ) extending over 223,000 km², constituting the primary study area. These waters form part of the broader Western Indian Ocean (WIO) seascape and support highly diverse ecological systems and productive fisheries. The country's oceanography is strongly influenced by a reversing monsoon system that regulates environmental conditions and fisheries productivity. The northeast (NE) monsoon, prevailing from October to March, is generally characterised by calmer seas, weak winds, and warm surface waters.

In contrast, the southeast (SE) monsoon, which occurs from May to September, is characterised by stronger winds, cooler surface temperatures, and rougher seas (Richmond, 1995). These alternating seasons also govern the strength and direction of the East African Coastal Current (EACC), which flows northward along the coast and plays a central role in shaping local circulation patterns. Seasonal variability drives important oceanographic processes, including localised upwelling events in the Pemba Channel (8). Such upwelling enhances primary productivity, supporting rich pelagic and demersal fish assemblages critical for artisanal and industrial fisheries (9, 10). In addition to these dynamic physical drivers, the Tanzanian seascape encompasses a mosaic of ecological habitats—coral reefs, seagrass beds, mangroves, sandy beaches, and deep-water ecosystems—which sustain coastal livelihoods, biodiversity, and national food security.

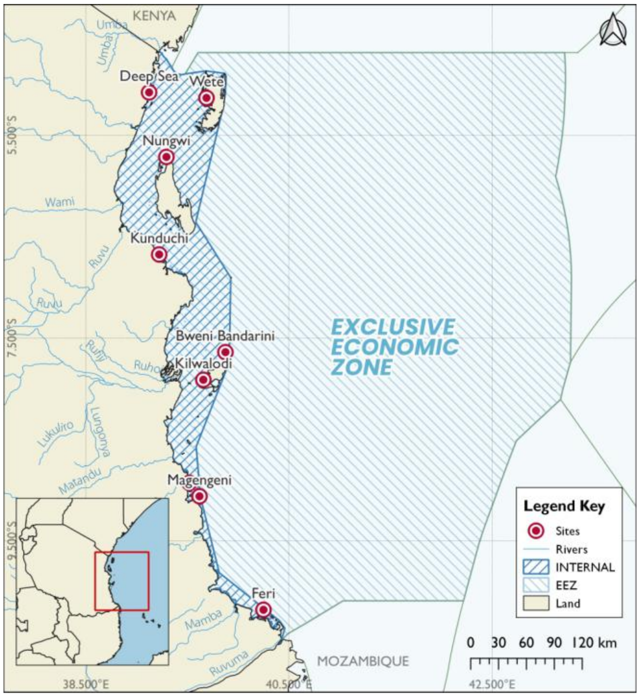

Figure 1: Monitoring stations for tuna and tuna-like species across the coastal waters of the United Republic of Tanzania and EEZ.

2.1.1. Data Collection

Length-frequency data for yellowfin Tuna were collected throughout 2024 from artisanal (small-scale) and industrial fisheries operating within Tanzanian waters. The sampling effort was primarily concentrated in neritic zones frequently accessed by artisanal fishers, with comparatively limited data obtained from industrial vessels operating farther offshore within the Exclusive Economic Zone (EEZ). This distribution of sampling sites reflects the existing monitoring framework, which is focused on coastal landing stations due to logistical accessibility. Consequently, while the dataset reliably represents nearshore catch composition, offshore fishery components may be underrepresented, typically consisting of larger individuals. Fork length (FL, cm) measurements were taken for all sampled individuals using a standard measuring board to the nearest centimetre. The collected data were subsequently analysed to examine the size structure of the population, assess cohort development, and identify potential recruitment patterns within Tanzanian waters.

2.1.2. Analytical Framework

Given the data-limited nature of tuna fisheries in Tanzania, a length-based analytical approach was adopted. The Length-Based Spawning Potential Ratio (LB-SPR) model was used to estimate biological reference points, assess stock status, and infer exploitation levels using length-frequency data. LB-SPR models are particularly suitable for data-poor fisheries as they rely on easily obtainable size composition data to infer growth, mortality, selectivity, and reproductive potential. This approach has been successfully applied to *T. albacares* in other parts of the Indian Ocean, such as the Oman Sea, and was adapted here to reflect local conditions. The analysis focused on three main objectives: i) estimation of biological and exploitation reference points for

T. albacares in Tanzanian waters; ii) evaluation of stock status using length-based indicators, including the Spawning Potential Ratio (SPR), and iii) generation of evidence-based recommendations to guide national management and conservation measures.

2.1.3. Estimation of Biological and Exploitation Parameters

The LB-SPR model was used to estimate key biological and exploitation parameters, summarised in Table *2* of the manuscript. Logistic models were fitted to the length-frequency data to assess growth, maturity, and selectivity parameters.

2.1.4. Maturity Parameters

The length at 50% sexual maturity (L_{50}) was estimated using a logistic regression model fitted to the maturity data derived from sampled individuals. This model describes the probability of maturity as a function of fork length (FL), allowing for the estimation of the length at which half of the population reaches sexual maturity. Similarly, the length at 95% maturity (L_{95}) was derived to indicate the size at which nearly all individuals are mature. Corresponding ages at maturity (t_{50} and t_{95}) were estimated using established growth parameters for Thunnus albacares. These maturity parameters were then compared with published global ranges to evaluate the representativeness of the Tanzanian population relative to other tropical Yellowfin Tuna stocks.

2.1.5. Selectivity Parameters

Fishing gear selectivity was analysed using a logistic model to estimate the probability of capture as a function of fish length. The model provided estimates for the length at 50% selection (SL_{50}) and 95% selection (SL_{95}), representing the sizes at which half and nearly all individuals, respectively, become vulnerable to fishing gear. Comparison of selectivity parameters with maturity estimates (L_{50} and L_{95}) was used to assess the extent to which fishing activities target immature versus mature individuals. This analysis is essential for evaluating the size composition of the catch and understanding the potential implications of current fishing practices on the sustainability of the stock.

2.1.6. Growth and Mortality Parameters

Growth and mortality parameters were estimated using the Length-Based Spawning Potential Ratio (LB-SPR) model framework. Based on the von Bertalanffy growth function, the model applies length-frequency data to estimate key life-history parameters, including the asymptotic length ($L\infty$) and the growth coefficient (K). The ratio of natural mortality to the growth coefficient (M/K) was used to infer the natural mortality rate (M). In contrast, total mortality (Z) was derived from the observed length structure of the population. These parameters provide the biological foundation for assessing population dynamics, determining exploitation rates, and evaluating stock resilience under different fishing pressures.

2.1.7. Stock Status Indicators

The key stock status indicators derived from the LB-SPR model were used to evaluate the sustainability and reproductive potential of the Yellowfin Tuna fishery. The fishing-to-natural mortality ratio (F/M) provided insight into the fishing intensity relative to natural losses, suggesting whether the stock is experiencing low, moderate, or high pressure, warranting management consideration. The Spawning Potential Ratio (SPR) reflected the proportion of spawning biomass remaining in the population compared to an unfished state, and a reduced SPR implies diminished reproductive capacity and potential risks to long-term sustainability if fishing levels are not adjusted. Yield and biomass estimates offered a measure of the fishery's productivity and the status of the spawning stock biomass relative to harvest levels, informing management on the biological limits. However, since the analysis largely represents the neritic or nearshore component of the fishery with limited inclusion of industrial fleet data, these results should be interpreted as indicative of coastal fishing dynamics rather than the overall stock status across the entire Exclusive Economic Zone (EEZ).

3. Results

3.1.Length frequency

Analysis of the length composition of Yellowfin Tuna catches in 2024 reveals clear seasonal shifts in the population's size. The sampled population, with fork lengths ranging from approximately 42 cm to 150 cm, showed a distinct progression of size groups, or cohorts, throughout the year (Figure 3.1). Catches in the first half of the year were characterized by larger individuals (90-114 cm). A significant recruitment event was observed in August, marked by a strong pulse of smaller fish centred around 66 cm. This cohort demonstrated clear growth, becoming the dominant size class at 78-90 cm by November. Tracking this modal progression is essential for understanding the stock's recruitment patterns and growth dynamics.

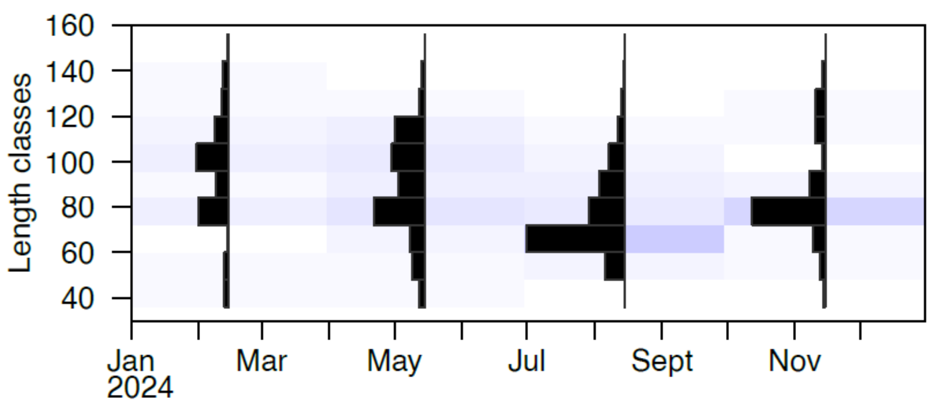

Figure 2: Length frequency of yellowfin tuna over twelve months of 2024

3.2.Juvenile and adult

The best fit measured length and weight of yellowfin tuna resulted in the clear separation of sample individuals into juvenile and adult (Figure *3*a), an important parameter for estimating the length at first maturity (L50). The study estimated the L50 of yellowfin tuna to be 92.3 cm, with more than 84% of the yellowfin individuals correlating well with the model fit (Figure *3*b). The R2 value of 0.84 signifies a strong goodness-of-fit for the logistic model. This means that approximately 84% of the variation in maturity status (juvenile vs. adult, see Table *1*) can be explained by the fork length of the Yellowfin Tuna. Although the estimated L50 of 91.2 cm in this study is lower than the median length of 103.3 cm reported in FishBase, it is within the maturity range of 78 and 158 cm (FishBase, 2023a).

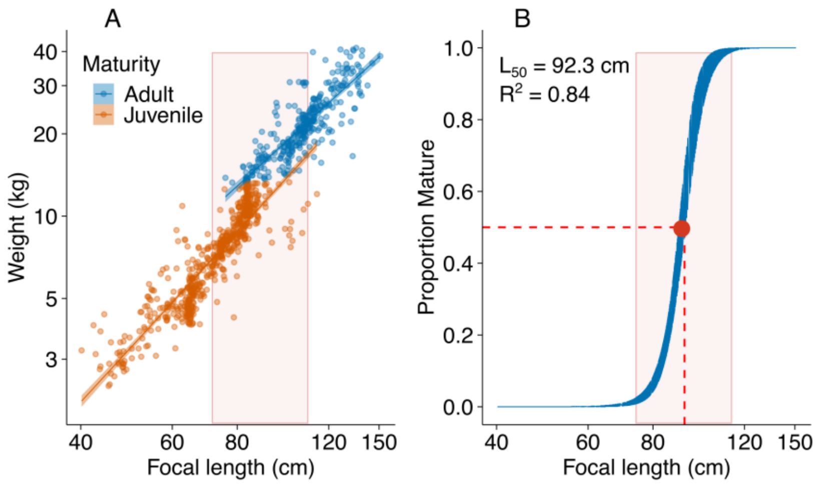

Figure 3: Length and weight information with a) Juvenile and adults and b) Maturity ogive

Table 1: Yellowfin tuna parameters derived from the logistic models

Table 3.1: Yellowfin tuna parameters derived from the logistic models

	Ogive Parameters			
Model	A[1]	B[2]	L_{50}	R^2
Original	-23.07	0.25	92.39	0.84
Bootstrap (Median)	-23.28	0.25	92.36	-

[1]A for Intercept of the logistic curve.

[2]B for slope of the logistic curve.

3.3.Biological and Exploitation Reference Points

Table *2* summarises the biological and exploitation reference points of Yellowfin Tuna. The L50 value of 91.8 indicates that, on average, yellowfin tuna reach 50% sexual maturity at a fork length of 92.3 cm. This is a key biological reference point used to assess the reproductive capacity of the stock and can inform management measures such as minimum size limits. The estimated asymptotic length ($Linf$) for Yellowfin Tuna is 161.28 cm, with a relatively low growth coefficient (K) of 0.10 year^{-1} (Table *2*). This suggests that Yellowfin Tuna grow to a large size but approach this maximum size more slowly than species like Skipjack. The natural mortality-to-growth coefficient ratio (M/K) was estimated to be 1.43. Given K = 0.10 year-1, the natural mortality rate (M) can be inferred as approximately 0.143 year^{-1} (M = 1.43 × 0.10). The total mortality rate (Z) was estimated at 0.27 year^{-1}.

Table 2: Estimated biological and exploitation reference points for Yellowfin Tuna

Parameter	Value	Description
Biological		
L_{inf} (cm)	161.3	Asymptotic length, theoretical maximum length fish can reach.
K (year-1)	0.1	Von Bertalanffy growth coefficient
M/K Ratio	1.4	Ratio of natural mortality (M) to the growth coefficient (K).
L_{50} (cm)	92.3	Length at which 50% of the fish are sexually mature.
L_{95} (cm)	103.4	Length at which 95% of the fish are sexually mature.
Z (year-1)	0.3	Total mortality rate (Z = F + M).
t_{50} (years)	4.6	Age at which 50% of the fish are sexually mature.
Exploitation		
t_{95} (years)	6.2	Age at which 95% of the fish are sexually mature.
SL_{50} (cm)	59.5	Length at which 50% of the fish are vulnerable to the fishing gear.
SL_{95} (cm)	74.2	Length at which 95% of the fish are vulnerable to the fishing gear.
F/M Ratio	0.8	Ratio of fishing mortality to natural mortality

3.4.Growth and Mortality

The estimated asymptotic length ($Linf$) for Yellowfin Tuna is 161.28 cm, with a relatively low growth coefficient (K) of 0.10 year-1 (Table *2*). This suggests that Yellowfin Tuna grow to a large size but approach this maximum size more slowly than species like Skipjack. The natural mortality-to-growth coefficient ratio (M/K) was estimated to be 1.43. Given K = 0.10 year^{-1}, the natural mortality rate (M) can be inferred as approximately 0.143 year-1 (M = 1.43 × 0.10). The total mortality rate (Z) was estimated at 0.27 year^{-1}.

3.5.Maturity and Selectivity

Yellowfin Tuna are estimated to reach 50% maturity ($L50$) at a fork length of 92.29 cm (corresponding to an age, $t50$, of 4.61 years) and 95% maturity ($L95$) at 103.36 cm (age $t95$ of 6.16 years). The fishing gear selectivity indicates that 50% of individuals are selected ($SL50$) at 59.52 cm, and 95% are selected ($SL95$) at 74.20 cm. This is a critical finding, as $SL50$ is substantially lower than $L50$, indicating that most Yellowfin Tuna catches consist of immature individuals. This practice can significantly impair the reproductive capacity of individuals.

3.6.Fishing, Spawning, Yield, and Biomass

3.6.1. Fishing Pressure

The ratio of fishing mortality to natural mortality (F/M) is 0.80. This value suggests that fishing mortality is somewhat less than natural mortality. While an F/M ratio below 1.0 is generally preferred, its interpretation must be combined with other indicators like SPR.

3.6.2. Spawning Potential Ratio (SPR)

The Spawning Potential Ratio (SPR) is estimated at 0.29. This indicates that the current spawning stock biomass is only 29% of what it would be in an unfished state. This SPR value is below the commonly used precautionary reference point of 0.40 (40%) and near the critical limit of 0.30 (30%), which often triggers strong management action. An SPR of 0.29 suggests the Yellowfin Tuna stock is likely overfished and at a high risk of recruitment impairment.

Table 3: Estimated stock metrics for Yellowfin Tuna.

Parameter	Value	Description
SPR	0.29	Spawning Potential Ratio
Yield (kg)	927,723,024	Estimated total annual yield from the fishery.
YPR (kg)	130,246	Yield Per Recruit, expected yield from an average recruit.
SSB (kg)	799,846,689	Current Spawning Stock Biomass.

3.6.3. Yield and Biomass

The estimated total annual yield from the fishery is very high (Figure 3.3), at approximately 927,723 metric tonnes. The Yield Per Recruit (YPR) is 130,246.10 kg/recruit. The current Spawning Stock Biomass (SSB) is estimated at 799,846 metric tonnes.

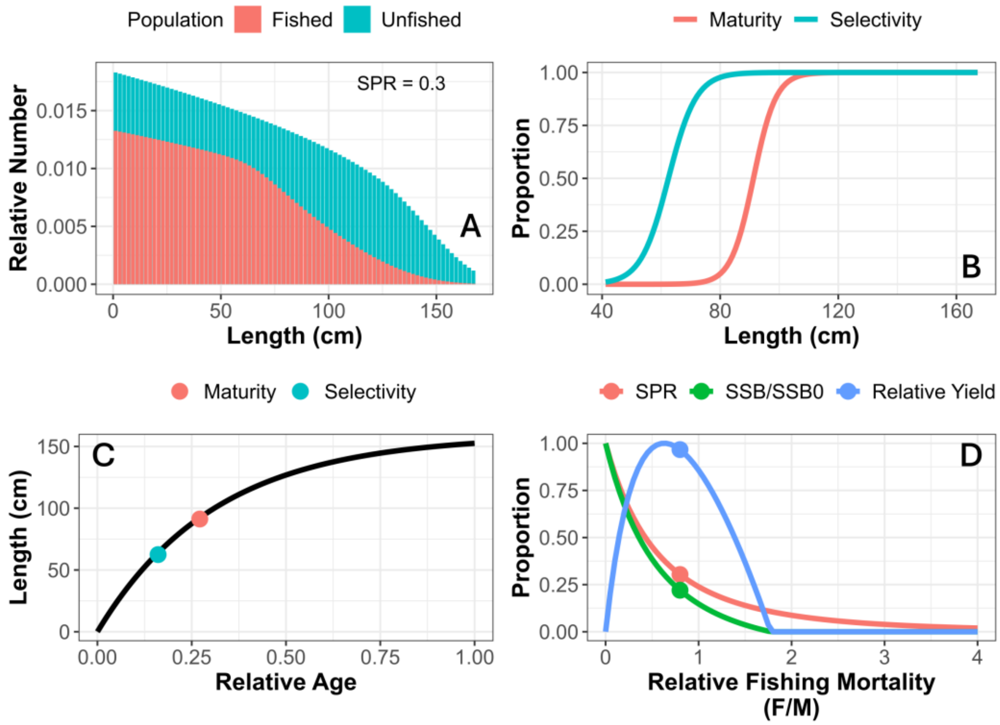

Figure 4: LB-SPR model outputs for yellowfin tuna. (A) length that 50% of individuals are matured and selected (B), relative number of fished and unfished fish in the stock

4. Discussion

4.1. Overview and Context

This study provides a critical, yet spatially constrained, assessment of Yellowfin Tuna (*Thunnus albacares*) in Tanzanian waters using a Length-Based approach. The model has provided a practical framework for estimating biological reference points and evaluating exploitation status using locally collected length-frequency data. It is important to frame these findings within the study's primary limitation: the data used are dominated by the nearshore, artisanal fishery, with only a limited contribution from industrial fleets that limit the dynamics of the offshore, industrial fleet. Consequently, the results offer a valuable snapshot of exploitation patterns in coastal zones but cannot be generalised to the entire Exclusive Economic Zone (EEZ) without significant caution. The estimated biological parameters, selectivity, and stock status indicators reflect the portion of the Yellowfin Tuna population accessible to small-scale fishers. The key conclusion from this nearshore perspective is a pattern of growth overfishing, where fishing pressure is concentrated on immature individuals, thereby compromising the local spawning potential. While this provides crucial insight for national management, it must be viewed as one component of a larger, more complex fishery that also includes industrial operations targeting different size classes.

4.2. Interpretation of Biological and Growth Parameters

The estimated biological parameters reflect the life history of species accessible to nearshore waters. The asymptotic length ($L\infty$ = 161.3 cm) and growth coefficient (K = 0.10 $year^{-1}$) are consistent with a large, relatively slow-growing species. However, these estimates are derived from a dataset skewed towards smaller, younger fish. They may not fully represent the growth potential of individuals that migrate to offshore waters and evade coastal fishing pressure.

The length at 50% maturity (L_{50} = 92.3 cm) is a robust finding for the sampled population (R^2 = 0.84) and serves as a critical local benchmark. The clear recruitment pulse observed in August confirms that the nearshore areas function as important nursery or feeding grounds for juvenile and sub-adult cohorts. This observation underscores the ecological significance of these coastal zones and their vulnerability to fishing pressure.

4.3. Selectivity and Juvenile Exploitation

A major finding of this study is the pronounced severe mismatch between the size at first capture (Lc50 = 59.5 cm) and the size at maturity (L50 = 92.3 cm). This disparity confirms that the artisanal fishery, which provided the bulk of the data, predominantly captures immature fish. This practice, a classic sign of growth overfishing, directly impedes recruitment to the spawning stock by removing individuals before they can reproduce. The estimated selectivity curve is a direct reflection of the fishing methods (e.g., handlines, small longlines) and spatial distribution of the small-scale fleet. It is crucial to recognise that this selectivity pattern is not representative of the industrial fishery. Offshore longline and purse-seine fleets target larger, often mature Yellowfin Tuna and thus have a different, and currently unquantified, impact on the population structure. Therefore, the conclusions regarding juvenile exploitation are specific to the coastal fishery component.

4.4.Stock Status and Reproductive Potential

The Spawning Potential Ratio (SPR) of 0.29 is a stark indicator of the status of the stock as seen by the nearshore fishery. It implies that the current spawning biomass in these coastal waters is approximately 29% of its unfished level, falling below the precautionary threshold of 0.40 and near the critical limit of 0.30, suggesting a localised state of overfishing. The estimated total mortality ($Z = 0.26$ year^{-1}) and fishing-to-natural mortality ratio ($F/M = 0.80$) suggest moderate fishing pressure overall. However, when combined with the high capture of immature fish, the effect on reproductive output becomes severe. It is imperative to reiterate that this SPR value does not reflect the entire EEZ-wide stock. The unsampled offshore population, which likely contains a higher proportion of large, mature spawners, may have a healthier status. Therefore, while the current SPR provides a robust local indicator of fishing impacts in coastal zones, a more comprehensive understanding of EEZ-wide status requires integrated sampling incorporating industrial catch data.

4.5.Management Implications and Recommendations

Despite the study's limitations, the findings provide clear and actionable recommendations for managing Tanzania's artisanal Yellowfin Tuna fishery. The central management challenge is to mitigate growth overfishing in coastal waters. The following measures are recommended:

- Implement Size-Based Management: The pronounced gap between size at capture and size at maturity necessitates interventions. Establishing a minimum legal size limit, set at or near the L_{50} of 92.3 cm, would be the most direct tool to protect immature fish.
- Promote Gear Selectivity: Management should encourage or mandate the use of gear that avoids capturing smaller tunas. This could include regulations on hook size or promoting fishing techniques and areas that selectively target larger individuals.
- Strengthen Data Collection and Integration: This study's primary limitation—the lack of industrial fishery data—is also its most critical recommendation for future work. A comprehensive national stock assessment requires integrating data streams from both artisanal and industrial fleets. Establishing a robust observer program, enhancing port sampling for industrial vessels, and utilising electronic monitoring are essential steps to create a complete picture of the EEZ-wide stock structure and exploitation status.

5. Conclusion

This work successfully demonstrates the utility of length-based methods for providing rapid, policy-relevant advice in a data-limited context. However, it simultaneously highlights the urgent need to move beyond a spatially-limited view. By addressing the unsustainable capture of juveniles in the nearshore fishery and concurrently building a comprehensive, EEZ-wide monitoring framework, Tanzania can advance towards the sustainable management of its vital Yellowfin Tuna resources and better fulfill its regional conservation responsibilities.

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