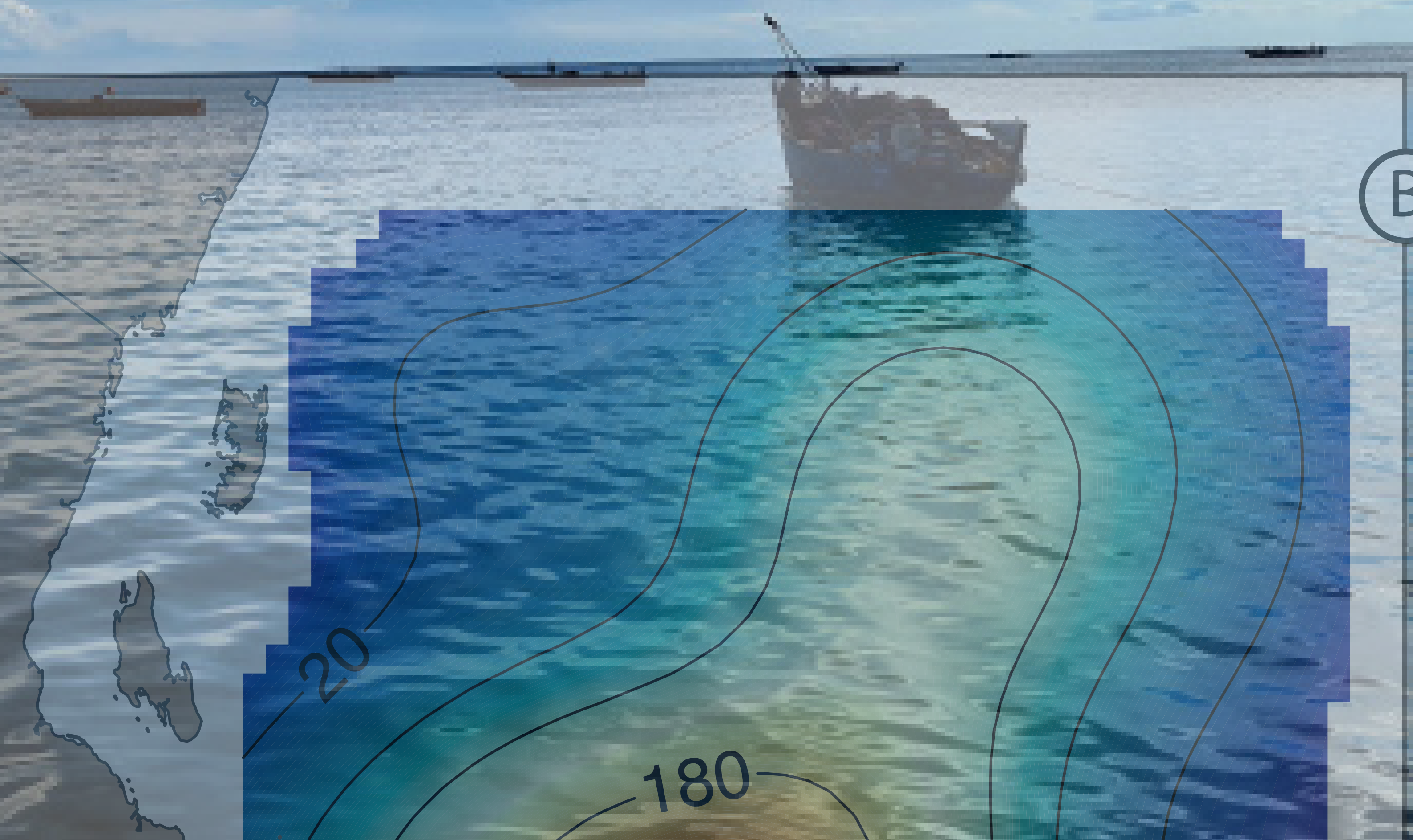
REPORT ON TUNA STOCK

A Case of Bigeye and Yellowfin Tuna in the Exclusive Economic Zone of the United Republic of Tanzania



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Preface

Effective management of marine resources is a top priority for coastal states with extensive Exclusive Economic Zones (EEZs) such as Tanzania. This report assesses the stock status of bigeye and yellowfin tuna in the Tanzania's EEZ. Acknowledging the challenges posed by limited long-term data, the report employs data-poor methods to comprehensively evaluate the stocks of bigeye and yellowfin tuna stocks. The analysis demonstrates how valuable insights can be derived from limited data to support sustainable fisheries management.

The report was motivated by Tanzania's commitment to advancing its blue economy agenda. By effectively understanding and managing its tuna resources, Tanzania can enhance its economic prospects while ensuring the long-term sustainability of these crucial marine species. The report's findings and recommendations are intended to provide guidance for policymakers, fisheries managers, researchers, and stakeholders in making well-informed decisions that balance economic development with ecological conservation.

It is hoped that this report will serve as a valuable resource for those involved in the fisheries sector and contribute to broaden efforts in sustainable ocean governance. Through ongoing research, collaboration, and adherence to best practices, Tanzania can fully unlock the potential of its EEZ, benefiting both the nation's economy and the health of its marine ecosystems. This report is based on collaborative effort involving the Tanzania Fisheries Research Institute (TAFIRI), Zanzibar Fisheries and Marine Resources Research Institute (ZAFIRI), Deep Sea Fishing Authority (DSFA), and the Nelson Mandela African Institution of Science and Technology (NM-AIST).

Executive Summary

Tanzania is about 36% water, a resource that is critical to the socio-economic development of the country. However, the fisheries sector in Tanzania is mainly small-scale and artisanal in nature, where 95% of the total fish production is generated by artisanal fishers. Despite marine waters occupying about 30% of the country's surface area, its contribution to fish production is less than 15% of the total fish landings vis-a-vis more than 85% contribution by inland freshwater fisheries. The marine landings, however, poorly represent the EEZ data because the fishing is mainly done by distant water fishing nations, which buy fishing licenses and keep data under their flag states. Thus, there is very little knowledge about the EEZ fish resources. Therefore, the tuna stock assessment report offers a thorough examination of the economic viability and sustainability of bigeye and yellowfin tuna stocks in Tanzania's EEZ using methods suitable for limited data. Carried out by the Tanzania Fisheries Research Institute (TAFIRI), Zanzibar Fisheries and Marine Resources Research Institute (ZAFIRI), Deep Sea Fishing Authority (DSFA), and the Nelson Mandela African Institution of Science and Technology (NM-AIST), this research addresses the significant lack of long-term, reliable fisheries data and puts forward suggestions for a sustainable management plan.

The stock status of bigeye (Thunnus obesus) and yellowfin tuna (Thunnus albacares) was assessed using the Length-Based Spawning Potential Ratio (LBSPR) model. The length frequency data for the two species used in the assessment was collected from the neritic and EEZ waters, which were collected by Tanzania Fisheries Research Institute (TAFIRI) and the Deep Sea Fishing Authority (DSFA), respectively. The neritic tuna length data were collected from the Kunduchi, Deep sea (Tanga), Wete (Pemba), and Shangani (Mtwara) landing sites, while the EEZ data were collected by distant water fishing vessels and through the observer program under the DSFA. The EEZ data were therefore collected from the three hotspots of fishing in the EEZ which include off Pemba Island in the northern, between Unguja and Mafia Islands in the middle, and off Mtwara in the southern sections of the Tanzania EEZ. The analysis therefore covered more than 5% of the Tanzania EEZ. The analysis established 15 biological, exploitation and stock reference points to serve as baseline for assessing fish stock health.

The main findings show that bigeye and yellowfin tuna stocks in Tanzania's EEZ hold considerable economic promise, with estimated stock biomass of 1,029,471,661 metric tonnes for bigeye tuna and 530,640,160 metric tonnes for yellowfin tuna. While the current fishing pressure is not at levels that would endanger the stock sizes, indicating a healthy population status, the results indicate that majority of these species are caught before reaching maturity, which calls for precautionary fisheries management practices to ensure long-term sustainability.

This analysis identified hotspots of longline and purse seine fisheries in the EEZ by both foreign and domestic fishing fleets in the EEZ. There were about 98% of fishing licenses issued to DWFN fleets. This underscores the necessity for Tanzania to strengthen its capacity for local deep-sea fishing operations. The study suggests that the government should intensify efforts to fully exploit these tuna stocks in order to maximize their economic advantages. Furthermore, it stresses the importance of an evidence-based research program to continually monitor stock status, gather genetic data, and analyze population dynamics, which will aid in establishing effective management practices and ensuring the sustainable utilization of these marine resources. This report offers valuable insights and practical recommendations to enhance the sustainable utilization of tuna resources in Tanzania's EEZ. The study concludes that the stocks of bigeye and yellowfin tuna in the EEZ are still viable with potential for expansion to provide economic benefit to the country. Understanding the status of these two species is critical for the Deep-Sea Fishing Authority (DSFA) in that it will enhance their decision-making on licensing and meeting their reporting obligations to IOTC. This study has also established 15 biological, exploitation and stock reference points which will serve as baseline for assessing fish stock health and informing future fisheries management strategies.

Acknowledgement

This work was funded by the Government of the United Republic of Tanzania. This report is a result of a collaborative effort between TAFIRI, ZAFIRI, DSFA and NM-AIST. The Zanzibar Fisheries and Marine Resources Research Institute (ZAFIRI), and the Deep Sea Fishing Authority (DSFA) are acknowledged for their invaluable contributions and unwavering support throughout the report generation process. Their expertise and assistance have greatly enriched the study's findings. Additionally, special recognition is extended to the Nelson Mandela African Institution of Science and Technology (NM-AIST) for their significant contribution to the report. Their involvement in data analysis and modeling of biological reference points and stock health has been particularly noteworthy and has added substantial value to the report findings.

Abbreviation

DSFA — Deep Sea Fishing Authority

EEZ — Exclusive Economic Zone

K — Growth Coefficient

LBSPR — Length-Based Spawning Potential Ratio

L_{50} — Length at 50% Maturity

L_{95} — Length at 95% Maturity

L_{inf} — Asymptotic Length

MK — Ratio of Natural Mortality to Growth Coefficient

NM-AIST — Nelson Mandela African Institution of Science and Technology

NOAA — National Oceanic and Atmospheric Administration

SL_{50} — Selection Length at 50%

SL_{95} — Selection Length at 95%

SPR — Spawning Potential Ratio

SSB — Spawning Stock Biomass

SSB_0 — Unfished Spawning Stock Biomass

t_{50} — Time at 50% Maturity

t_{95} — Time at 95% Maturity

TAFIRI — Tanzania Fisheries Research Institute

URT — United Republic of Tanzania

Yield — The total weight of fish harvestable

YPR — Yield Per Recruit

Z — Total Mortality Rate

ZAFIRI — Zanzibar Fisheries and Marine Resources Research Institute

“

1 INTRODUCTION

1.1 Background and rationale

The Tanzania fisheries catch data from 1950 to 2018 shows two peaks; one in 1990 at 417,018 and the second in 2007 with a total of 426,666 metric tons of fish, respectively (Figure 1). The fisheries sector in Tanzania is mainly small-scale and artisanal in nature, where 95% of the total fish production is generated by artisanal fishers. Despite marine waters occupying about 30% of the country's surface area, its contribution to fish production is less than 15% of the total fish landings vis-a-vis more than 85% contribution by inland freshwater fisheries. This is due to a fact that the fishery potential of the EEZ is mainly untapped, except the tuna and tuna-like species that are fished by distant water fishing nations.

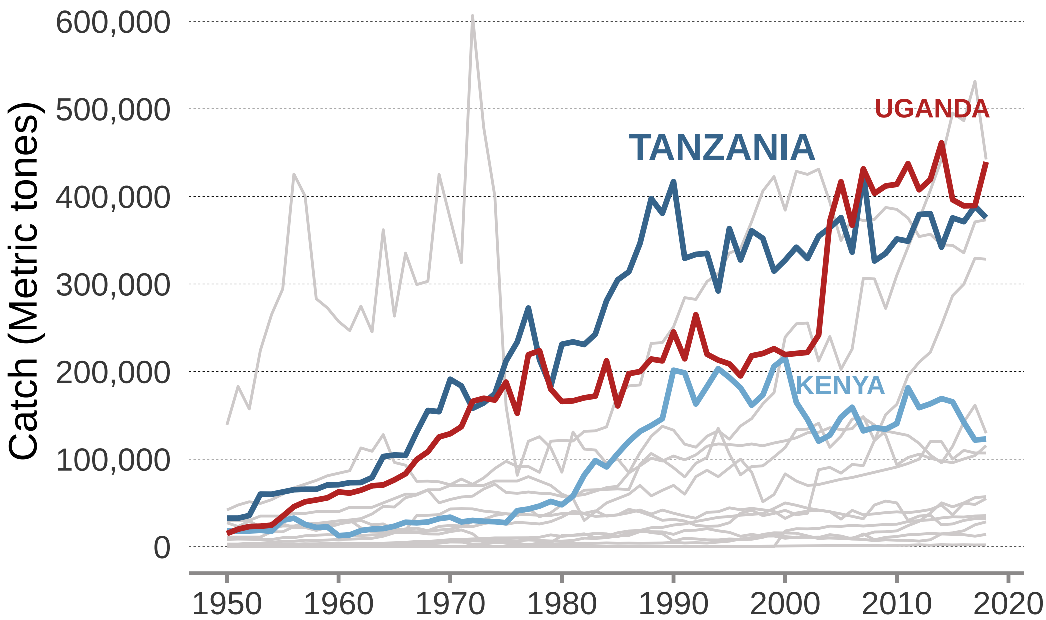

Figure 1: Total Capture Fisheries Landings in Selected African Countries relative to the landing data for Tanzania (Data source, FAO)

Despite remaining largely under-exploited (Thierry et al. 2021), the fisheries in the Exclusive Economic Zone (EEZ) of the United Republic of Tanzania (URT) also possess enormous potential that could contribute to the country's economy. This potential has driven both the Zanzibar and Tanzania Mainland governments to shift their fisheries focus towards the EEZ as a response to declining fish stocks in coastal waters. While local fishing capacity restricts overall activity in the EEZ, a significant portion of the fishing effort within the zone is carried out by licensed foreign vessels. For example, the Deep Sea Fishing Authority (DSFA), a government entity responsible for regulating fisheries in the deep sea, issued a total of 72 fishing licenses for the EEZ as of June 2024. These licenses included one for a domestic fishing vessel and 66 for foreign fishing vessels. The issuance of these licenses generated a revenue of 11.53 billion Tanzanian shillings (Budget Speech MLF, 2024). Bigeye tuna (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*) are economically valuable target species within the EEZ of the URT. Their high global demand translates to significant market value, making them a critical fishery resource. Although these fish species are exploited, but information about the stock status and biological and exploitation reference points, which are essential for their sustainable management is limited at national level. This places their stocks at high risk of depletion once fishing intensity is increased.

Sustainable fisheries management hinges on a thorough understanding of both stock status (Golden et al. 2016) and biological and exploitation reference points (Jackson et al. 2001). The reference points include various parameters such as total biomass, spawning biomass, fishing mortality rate, recruitment, and size and age distribution. Biological reference points serves as benchmarks for assessing the health and sustainability of fish stocks. These reference points, which include both target reference points and limit reference points, provide important information for setting and achieving sustainable fishing such as Maximum Sustainable Yield (MSY), which represent optimal stock that are allowable to harvest. These include Biomass Limit Reference Point, which provide thresholds to prevent the stock from collapse. The stock size for tuna and tuna-like species in the EEZ remain unknown. The major reason for limited information of the stock is contributed by lack of comprehensive and long-term data required for their estimation (Punt et al. (2021)). This phenomenon allow to train adopt technologies that will overcome the data challenge.

The data-poor methods offer alternative ways of assessing stock status when conventional stock assessment methods are not feasible. The methods rely on alternative sources of information and simplified models to estimate stock status and catch limits, providing quicker assessments and enabling prompt management actions. Additionally, data-poor methods allow for adaptive management strategies, where estimates and management measures can be adjusted as more data becomes available over time. Estimating the stock status and key reference points for bigeye and yellowfin tuna within EEZ faces a significant challenge; that is the lack of comprehensive and long-term monitoring data (Punt et al. (2021)). Long-term length-frequency, and catch and effort data, is essential for robust stock assessments, which are crucial for sustainable fisheries management. This data gap is caused, among other factors, by limited financial resources and capacity for data collection and processing. Inadequate funding and infrastructure for fisheries research and monitoring activities hinder effective data collection. The use of data-poor methods, thus, provide a in turn, has limited the implementation of sustainable fisheries management in the EEZ.

1.2 General objective

The general objective of this study is to document the stock status, establish biological reference points, and identify suitable fishing locations for yellowfin tuna and bigeye tuna in the EEZ. Specifically;

1. To establish biological and exploitation reference points for yellowfin tuna and bigeye tuna to guide sustainable fishing in the EEZ.

2. To evaluate yellowfin and bigeye tuna stock statu in the EEZ.

3. To identify and map areas with high fishing density for yellowfin and bigeye tuna within the EEZ.

To address these objectives, a comprehensive data set were collected and analysed to to obtain information on the biological parameters of the tuna population, such as their size distribution, growth rates, and overall biomass. By analyzing these parameters, we can gain insights of the health and sustainability of the tuna stock. The Zanzibar Fisheries Research Institute (ZAFIRI), the Tanzania Fisheries Research Institute (TAFIRI), and the Deep Sea Fishing Authority (DSFA) have collaborated to estimate the stock of commercial tuna and tuna like species in the EEZ. Therefore, this report presents key findings of the stocks for yellowfin and bigeye tuna across the geographical space of the EEZ. It also provides key biological and exploitation reference points for assessing the stock state of both yellowfin and bigeye tuna. Furthermore, the report present fishing intensity across the EEZ, an important information required to determine the fishing pressure and identify hotspot areas that need management interventions.

2 METHOD

2.1 Geographical Scope

This assignment used data collected in the Exclusive Economic Zone (EEZ) of the United Republic of Tanzania. This coastal and marine area is situated south of the Equator, between latitudes 1° and 11°48'S and longitude between 38°23' and 45°14'E. It is bordered by Kenya to the north and Mozambique to the south (Figure 2). The is endowed with unique oceanographic characteristics with major productive fishing ground of small and medium pelagic marine species like sardine, mackerel and tunas (Sekadende et al. 2020).

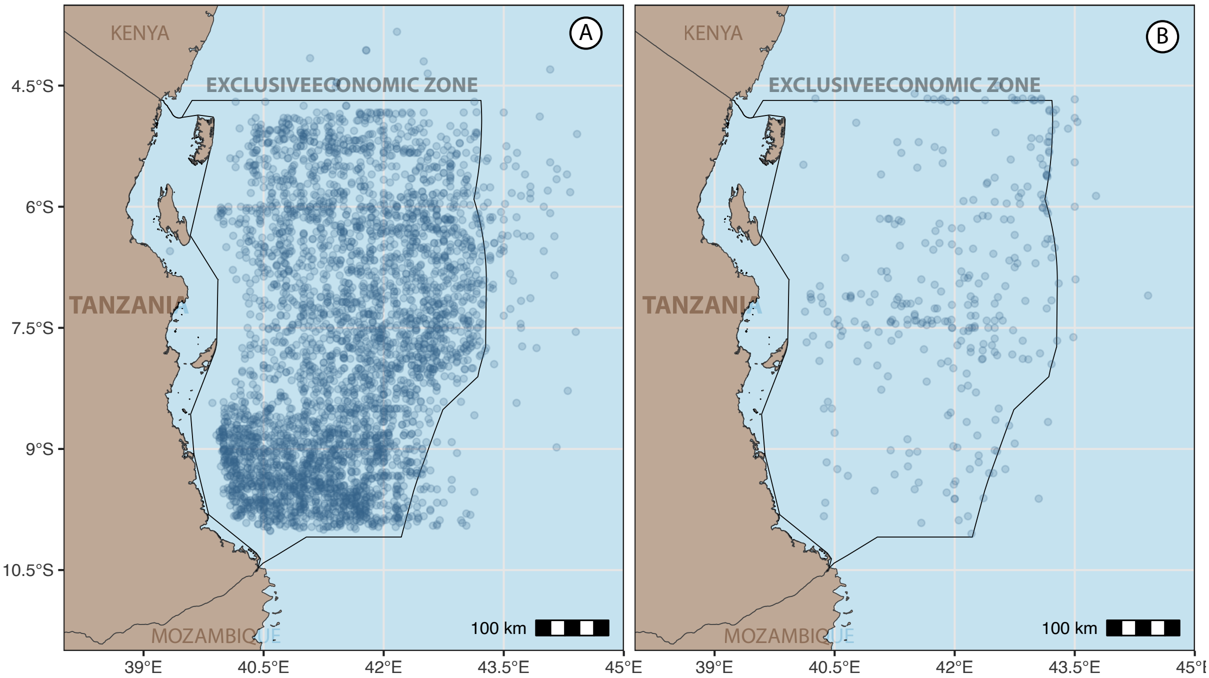

Figure 2: The distribution of fishing events across the EEZ water of the United Republic of Tanzania for a) longline and b) purse seine fishing gears. The dotted points are fishing events and the high intensity represent the high density of fishing events

The URT has an estimated coastline of 1,424 kilometers including the major islands of Pemba, Unguja and Mafa as well as other small islands. URT contains a continental shelf that extends from 2 to 80 kilometers based on geormorphology. This shelf covers an estimated 17,900 square kilometers confined in shallow coastal areas within 200 meters (Figure 3). Beyond the continental shelf lies the territorial sea, covering an estimate 64,000 square kilometers (Figure 3). EEZ extends 200 nautical miles from the coastline, encompassing a total area of 223,000 square kilometers (Figure 3).

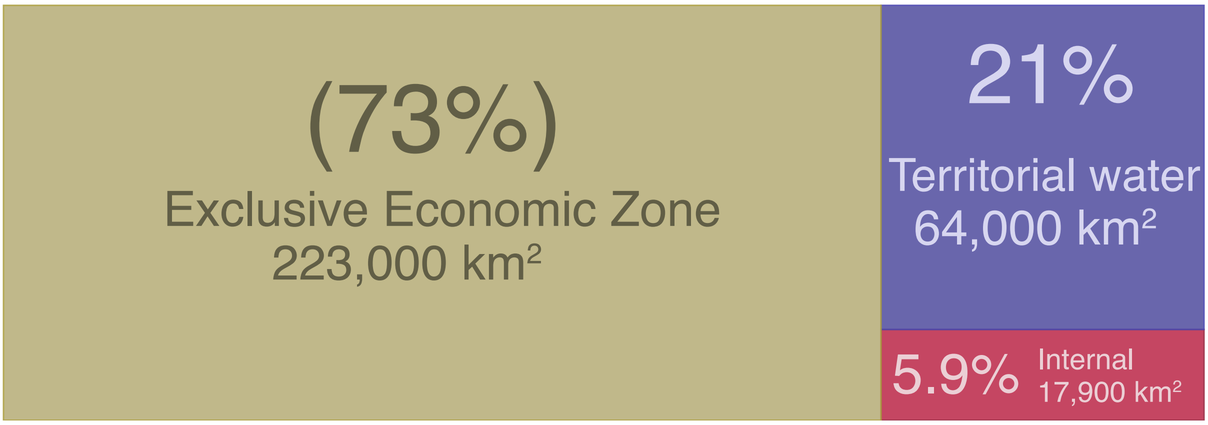

Figure 3: The Maritime of the United Republic of Tanzania. The size of the polygon area represent the size of the maritime zone.

The area experience distinct seasons that paves way to its local circulation and its unique oceanographic features including the presence of the western boundary East Africa Coastal Current that baths the channel throughout the year while flowing northward (Semba et al. 2019). Trade winds with unique phenomenon of reversing direction and changing magnitude to form the northeast (NE) and southeast (SE) monsoon winds (Richmond 1995). The NE monsoon winds often occurs from October through March and are characterized by warm surface waters, calm weather, a less energetic ocean current and the phenomenal upwelling events in the western part of the Pemba channel (Halo et al. 2020; Kyewalyanga et al. 2020). Unlike the NE monsoon season, the SE monsoon period often begins in May and ends in September. The SE season experiences strong winds, a more energetic EACC and cooler surface water.

2.2 Data

To evaluate the stock of tuna in the Neritic and EEZ of the URT, data from various research initiatives, expeditions, and fishing activities were used. The neritic data were obtained from TAFIRI while the dataset for EEZ waters were gathered from DFSA. The neritic tuna length data were collected from the Kunduchi, Deep sea (Tanga), Wete (Pemba), and Shangani (Mtwara) landing sites, while the EEZ data were collected by distant water fishing vessels (DWFV) and through the observer program under the DSFA. The EEZ data were therefore collected from the three hotspots of fishing in the EEZ which include off Pemba Island in the northern, between Unguja and Mafia Islands in the middle, and off Mtwara in the southern sections of the Tanzania EEZ. The analysis therefore covered more than 5% of the Tanzania EEZ. The reason for combining these two dataset is because the EEZ dataset contains only adult individuals, while neritic dataset has a combination of juvenile and sub-adults. Therefore, these two dataset compliment and provided a continuum of population size from juveniles to adults, which is required for estimating population parameters. Figure 4 illustrate the process involved in collect, process, analyse, model data and present results as maps, tables and plots.

2.3 Stock estimation

We used the Length-Based Spawning Potential Ratio (LBSPR) model to assess the stock status based on length frequency data of bigeye and yellowfin from neritic and EEZ waters. The LBSPR was chosen for this analysis because is able to estimate fisheries stock from limited data – a situation where few data are available. The LBSPR models are equilibrium based (Hordyk 2021), and assume that the length composition data is representative of the exploited population at steady state. Because of limited data, LBSPR was deployed first to simulate the expected length composition and growth curve. Table 1 contains the key biological, exploitation and stock reference points that are used to estimate and understand the health of a particular fisheries. These parameters are then fitted to the model with the empirical length frequency data to estimate relative apical fishing mortality and spawning potential ratio. The LBSPR model requires biological and exploitation parameters to simulate length frequency data and predict an equilibrium size composition and the resulting level of Spawning potential ratio (SPR). The minimum required parameters are listed in Table 1.

Table 1: Biological and exploitation reference points and stock estimate parameters was used to assess the healthy stock of bigeye and yellowfin tuna

Reference point	Parameters	Description
Biological	Z	Total Mortality Rate
	K	Growth Coefficient
	MK	Ratio of Natural Mortality to Growth Coefficient
	t50	Time at 50% Maturity
	t95	Time at 95% Maturity
	L50	Length at 50% Maturity
	L95	Length at 95% Maturity
	Linf	Asymptotic Length
Exploitation	SL50	Selection Length at 50%
	SL95	Selection Length at 95%
Stock	SPR	Spawning Potential Ratio
	yield	The total weight of fish harvestable
	YPR	Yield Per Recruit
	SSB	Spawning Stock Biomass
	SSB0	Unfished Spawning Stock Biomass

2.3.1 Size at first maturity

Size at first maturity (L_{50}) describe the length at which 50 percent of the individuals fish caught are adults or with mature gonads. The size at 50% maturity (L_{50}) was estimated as the length at which a randomly chosen specimen has a 50% chance of being mature (Torrejon-Magallanes 2020). We used a morphometric instead of gonado somatic technique to estimate L_{50} of bigeye and yellowfin tuna because is robust in assessing the stock using the length-based-spawning potential ratio (LBSPR). In the regression analysis, the fork length is denoted as the explanatory variable and the classification of maturity (*juveniles* versus *adults*) is considered the response variable (*binomial*). The variables are fitted to a logit function in equation Equation 1 :

$$P_{CS} = \frac{1}{1 + e^{-(\hat{\beta}_0 + \hat{\beta}_1 \times X)}} \tag{1}$$

where PCS is the probability of an individual of being mature at a determinate X length. β_0 (intercept) and β_1 (slope) are parameters estimated. The L_{50} is calculated in equation Equation 2 :

$$L_{50} = -\frac{\hat{\beta}_0}{\hat{\beta}_1} \tag{2}$$

2.3.2 Length Converted Catch Curve

Life history parameters were determined from growth parameters (length asymptotic and growth coefficient), mortality and size at first maturity. Total mortality was estimated using the length–converted catch curve model. The selectivity parameters were estimated by the length-converted catch curve analysis with simultaneous estimation of the selection ogive. The construction of the catch curves requires information about growth parameters to estimate the relative age of the individuals. Here, growth parameters (L_∞ and K) of the von Bertlanffy growth equation (VBGE) were computed. Based on the growth parameters, the instantaneous natural mortality rate (M) was approximated by means of the empirical formula in equation Equation 3 :

$$M = 4.118K^{0.73}L_\infty - 0.33 \tag{3}$$

where K and L∞ are the growth parameters of the VBGE. By subtraction of M from Z, an estimate of the instantaneous fishing mortality rate (F) was estimated and an indicator of the exploitation rate was estimated as ($E = \frac{F}{Z}$).

2.3.3 Powell-Wetherall

A *Powell-Wetherall* method was used to estimate the instantaneous total mortality rate (Z) and the infinite length (L_∞) of the von Bertalanffy growth equation (Powell 1979; Wetherall, Polovina, and Ralston 1987). The Electronic LEngth Frequency ANalysis (ELEFAN) method was used to fitting the best growth curve, which allows the fitted curve through the maximum number of peaks of the length frequency distribution.With the aid of the best growth curve, the growth constant and asymptotic length (L_∞) were estimated. The von Bertalanffy growth equation was defined in equation Equation 4

$$L_t = L_\infty[1 - exp(-K(t - t_0))] \quad (4)$$

Where L_t is length at time t, L_∞, the asymptotic length, K, the growth coefficient and t_0, is the hypothetical time at which length is equal to zero. The t_0 value estimated using the empirical equation Equation 5

$$Log_{10}(-t_0) = -0.3922 - 0.2752 \times Log_{10} \times L_\infty - 1.038 \times Log_10 \times K \quad (5)$$

2.4 Data Analysis and Packages

The analytical workflow used in this report is presented in Figure 4. It illustrate key steps including gathering, organizing, analysis, modelling and plotting of reference points and stock parameters. To accomplish these key analytical steps, the R–a language version 4.5 (R Core Team 2020) was used. Several packages were used to generate a length frequency, compute biological references points and estimate exploitation parameters including TropFishR (Mildenberger, Taylor, and Wolff 2017), sizeMat (Torrejon-Magallanes 2020) and LBSPR (Hordyk 2019) packages. Other packages used for data management and analytic tasks includes **readr** (Wickham and Hester 2020) package for reading comma–separated files, **readxl** for Excel spreadsheets (Wickham and Bryan 2019), and **ncdf4** (Pierce 2019) for importing satellite data stored in NECDF file format and **sf** (Pebesma 2018) package for loading shapefile and simple feature files.

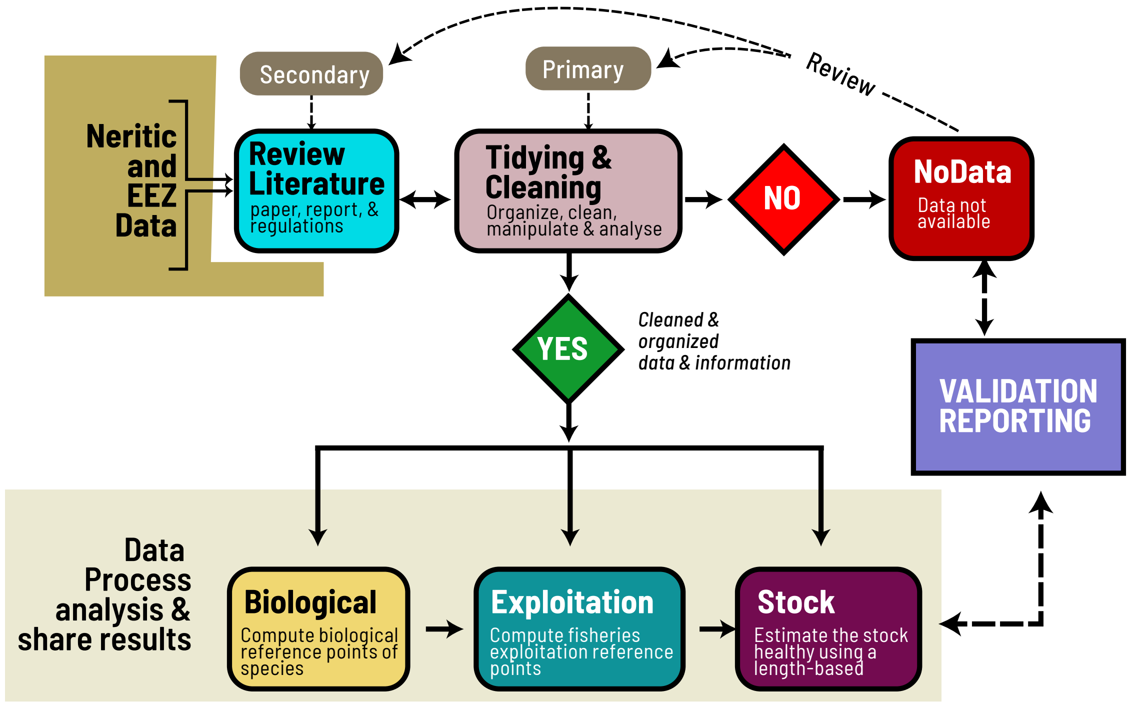

Figure 4: The conceptual diagram of key steps used to collect, organize, manipulate, analyse, model and plot length and weight relation as well as biological reference points and estimated stock of yellowfin and bigeye tuna

Other packages include **lubridate** (Grolemund and Wickham 2011) for dealing with date and group observations to monsoon seasons, **wior** package Semba and Peter (2020) was used to detect outlier observations from the datasets, **dplyr** (Wickham et al. 2021) for manipulating data, and **tidyr** (Wickham 2021) for organizing the file into a consistent format for subsequent analysis and mapping. The results from the analysis were summarized and presented in tables with **knitr** (Xie 2014) and **kableExtra** (Zhu 2021) packages while plotting and mapping was made with the **ggplot2** (Wickham 2016), and **ggstatsplot** (Patil 2021) and **metR** (Campitelli 2021) packages. **patchwork** (Pedersen 2020) was used to combine plots and export them in both PDF and PNG formats. The **Quarto** (Bauer and Landesvatter 2023) and **rmarkdown** (Xie, Dervieux, and Riederer 2020) packages were used for typesetting and compiling this report as $LATEX$ rendered to PDF document with **knitr** package (Xie 2014).

3 RESULTS & DISCUSSION

This section describes the key findings of reference points (biological, and exploitation), and standing stock as well as fishing intensity and catch variations across the EEZ of URT. It further discusses the implication of the findings on management and research priorities of these species in the EEZ. It is important to know that **skipjack**, though considered for this study, could not provide sufficient data and little data available failed to fit the model. Hence the section discusses **bigeye** and **yellofin** tuna metrics, biological and stock reference points and their implications for management and future research of these species in the EEZ of the URT.

3.1 Fish Size Distribution

A total of 6,072 individuals of fish, including 2,799 from EEZ and 3,273 individuals from neritic waters were analysed. Figure 5 shows that bigeye and yellowfin tuna caught in neritic waters (coastal zones) are generally smaller than those caught within the EEZ. This size difference is attributed to the different environmental conditions and resources available in neritic waters compared to the deeper, more open waters of the EEZ, which can affect the growth rates and maximum sizes of the tuna in these areas. Despite the typical trend of smaller sizes in neritic waters, there is an overlap in the size distributions of these tuna (Figure 5). This suggests that some individuals from neritic waters can grow to lengths comparable to those from the EEZ. Factors such as food availability, genetic variability, and movement patterns play a role in allowing some larger individuals to be found in coastal areas, even though the average size may be smaller there. Therefore, while most larger bigeye and yellowfin tuna are usually associated with the EEZ, larger specimens can still be occasionally encountered in neritic zones (Figure 5).

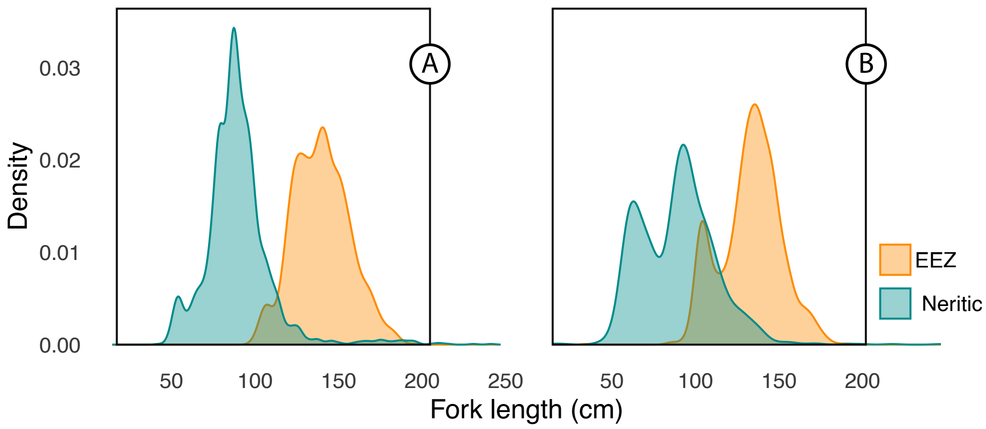

Figure 5: Density plot of fork length for a) bigeye and b) yellowfin tuna

3.2 Length and weight relationship

The relationship of length and weight of bigeye tuna was strong and positive (R^2 = 0.84) which implies that more than 84% of individuals fitted the liner model (Figure 6). Similarly, the relationship of length and weight of yellowfin tuna was also strong and positive (R^2 = 0.89).

Since the approach used is length-based model, the stronger the relationship of length and weight guarantees the high accuracy of the model and high prediction power of the fish stock. Therefore, since the relationship for both species modeled in this study is above 80 percent (Figure 6), the data is reliable for estimation of biological and exploitation reference points as well as prediction of standing stock.

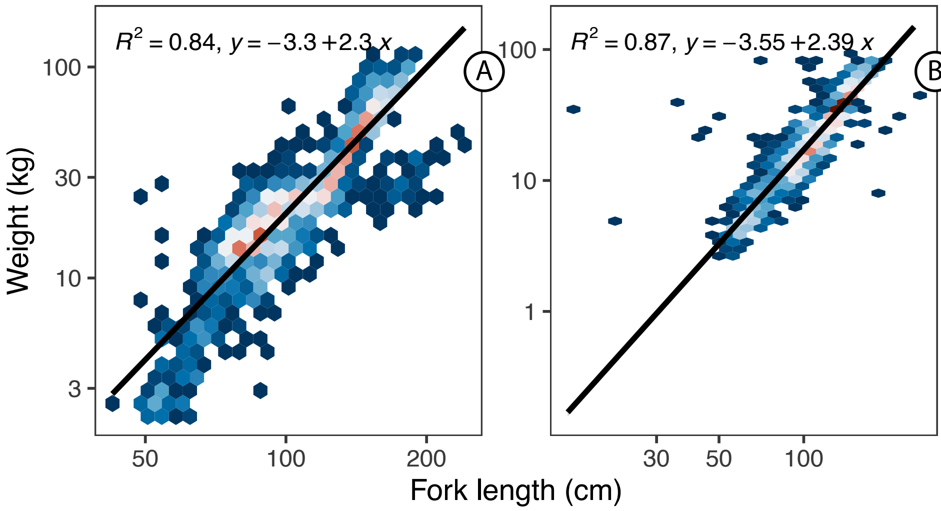

Figure 6: Length-weight relationship of a) bigeye and b) yellowfin tuna

3.3 Separate Juvenile and adults

Despite stronger relationship observed in Figure 6, for both bigeye and yellowfin tuna disaggregated data for adult and juvenile individual for both species revealed stronger relation for adult and weak for juveniles (Figure 7). The weak relationship observed in juveniles could be caused by data used being fisheries dependent, which is subject to targeting a specific size group of fish.

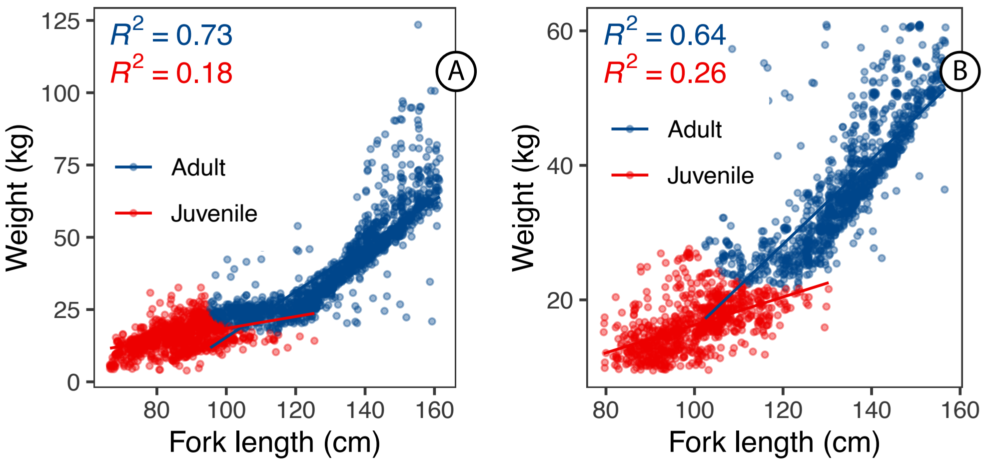

Figure 7: Length-weight relationship of juvenile and adult of (a) bigeye and (b) yellowfin tuna

Because of similarities of bigeye and yellowfin tuna, there is likelihood of misidentification of the juveniles individuals leading to weak and low correlations observed for bigeye (Figure 7 a) and yellowfin (Figure 7 b). The implication of weak relationship for juveniles is that there is a likelihood of either over or under estimating the length at first maturity for the modeled species. The weaker length-weight relationships in juveniles of both bigeye and yelowfin tuna could be attributed to two factors: First, data source bias. This study relied on fisheries-dependent data, which typically targets specific size groups of fish. This may result in a lack of representative data for the entire population, leading to a weaker length-weight relationship for that age class (Hordyk et al. 2014); second, species misidentification. Due to the similarities between juvenile bigeye tuna and yellowfin tuna, there is a risk that data collectors at landing sites may misidentify these species in the catch data.

The potential for misidentification of juvenile fish in the catch data could have introduced outliers, weakening the length-weight relationship for juveniles in both species . Bigeye tuna stand out from yellowfin tuna with their noticeably thicker and more robust bodies (Itano, 2005). Supporting our argument, Carreiro et al. (2023) reported a misidentification of species in 33% of the tuna individuals, involving a mix between bigeye tuna and yellowfin tuna, but not either of these species with skipjack tuna. The weak length-weight relationship observed in juvenile bigeye and yellowfin tuna presents a challenge for accurately estimating the length at first maturity in stock assessment models (Hordyk et al. 2014). Consequently, there is a likelihood of either overestimating or underestimating the length at first maturity for the modeled species. Inaccurate estimates of length at first maturity can lead to miscalculations of spawning potential ratio and ultimately, unreliable stock assessments in the modelled species (Hordyk et al. 2014).

3.4 Length at first maturity

One of the key biological reference points used in estimating fisheries population dynamics is length at first maturity. In this study, length at first maturity for bigeye was 100.8 cm (Figure 8 a) while for yellowfin tuna was 114.4 cm (Figure 8 b). The length at first maturity found in this study align with those from FishBase. For instance, FishBase reported that bigeye mature at a length between 100 cm to 125 cm, with a mean length of 112.5cm (Froese 2005), this study found that bigeye mature at 100.8 cm (Figure 8 a) which is within the range (Froese 2005). Similarly, yellowfin mature at a length between 78 cm to 158 cim, with a mean length of 103.3cm, this study also found yellowfin mature at 114.4 cm (Figure 8 4), which is within the range (Froese 2005). The agreement of the length at maturity in this study with those in FishBase provide assurance of the reliability of the length-based approach in estimating biological and exploitation reference points as well as stock size.

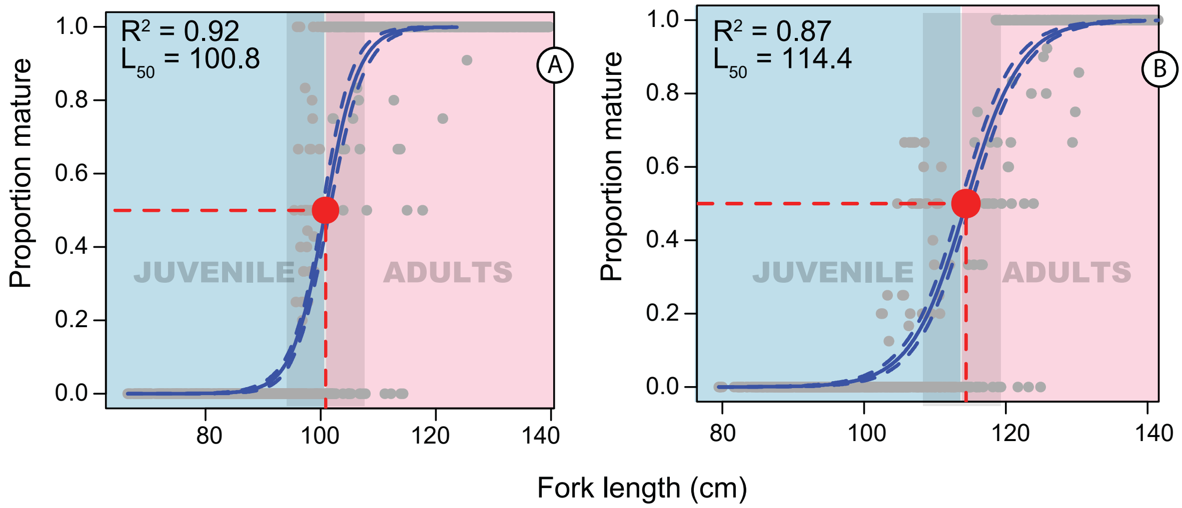

Figure 8: Length at first maturity for (a) bigeye and (b) yellowfin tuna

3.5 Estimated stocks

Biological and exploitation reference points of bigeye and yellowfin tuna are required for effective management of tuna fishery in the territorial and EEZ of Tanzania. Although, this study found the total mortality rate (Z) for bigeye tuna was 0.51, which is relatively high contributed by natural and fishing mortality (Table 2). But, the combined natural mortality and growth coefficient (MK) for bigeye is 0.97 (Table 2), suggesting a balanced relationship between natural mortality and growth. The growth coefficient (K) is 0.42, suggests quick growth of bigeye tuna (Table 2). That attain 50% (L_{50}) maturity at 100.72 cm, and 95% (L_{95}) maturity at 108.40 cm, with an asymptotic length (L_{inf}) of 161.23 cm (Table 2). This size of maturity, indicate that bigeye matures at relative early age. For instance, 50% (t_{50}) of bigeye mature at 1.42 years, and 95% (t_{95}) at 1.60 years (Table 2). However, the length at which 50% (SL_{50}) of bigeye are caught is 72.32 cm, and 95% (SL_{95}) is 78.87 cm. This imply bigeye are caught at relative smaller size before reaching maturity at 100.72 cm (Table 2).

Table 2: Biological and exploitation reference points and stock estimates for bigeye and yellowfin tuna in the coastal and marine waters of URT

Parameters		Species	
Reference point	Parameters	Bigeye	Yellowfin
	Z	0.51	0.35
	K	0.42	0.28
	MK	0.97	1.10
	t50	1.42	2.93
	t95	1.60	3.51
	L50	100.72	114.24

Biological Parameters		Species	
Reference point	Parameters	Bigeye	Yellowfin
	L95	108.40	124.40
	Linf	161.23	156.21
	SL50	72.32	87.51
Exploitation	SL95	78.87	97.69
	SPR	0.14	0.13
	yield	1,029,471,661.00	530,640,160.00
Stock	YPR	376,192.00	279,284.00
	SSB	375,533,574.00	134,666,432.00
	SSB0	967,853.00	549,297.00

Despite bigeye being fished at relatively small size than size at maturity, yet the stock is still viable with a spawning potential ratio (SPR) of 0.14 (Figure 9 a), indicating that the current fishing levels are significantly low to affect stock size (Table 1 and Figure 9 b). With a potential yield of 1,029,471,661 tones (Table 2), the yield per recruit (YPR) is also 376,192, suggesting that each individual bigeye tuna contributes significantly to the overall catch (Figure 5b). Figure 5b shows the spawning stock biomass (SSB) for bigeye tuna was 375,533,574 tones (Table 2), indicating the high reproductive biomass in the population.

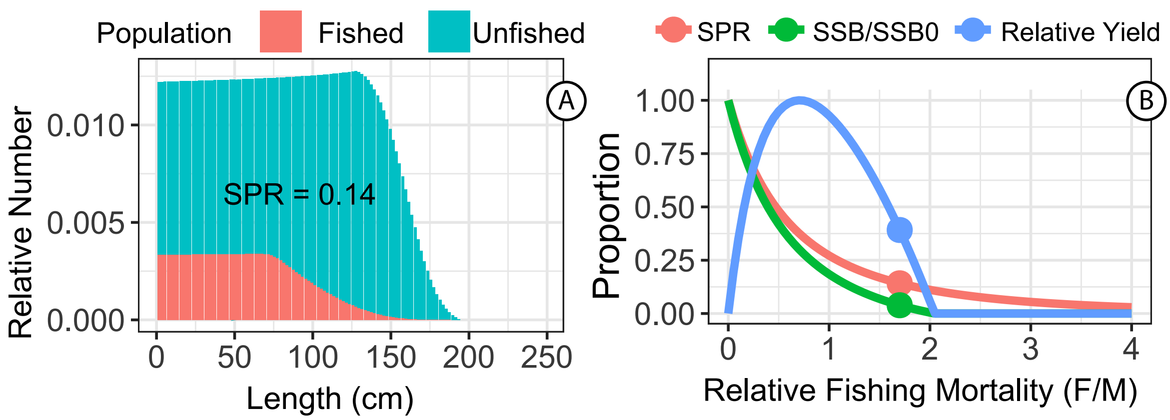

Figure 9: Length based model of (a) size structure of catch and expected unfished size and (b) relative yield curves as a function of relative fishing mortality of bigeye tuna

The total mortality rate (Z) for yellowfin tuna is 0.35 and growth coefficient (K) is 0.28. The combined natural mortality and growth coefficient (MK) of yelowfin tuna is 1.10 (Table 2), suggesting that natural mortality plays a more significant role relative to growth. The length at which 50% (L_{50}) of yellowfin maturity is 114.24 cm, and 95% (L_{95}) reaches maturity is 124.40 cm, with asymptotic length (L_{inf}) of 156.21 cm (Table 2). Yellowfin attain 50% (t_{50}) maturity at 2.93 years and 95% (t_{95}) at 3.51 years. Despite yelowfin matures at 114.24 cm at age of 2.93 years, but 50% (SL_{50}) is caught at 87.51 cm, and 95% (SL_{95}) at 97.69 cm (Table 2).

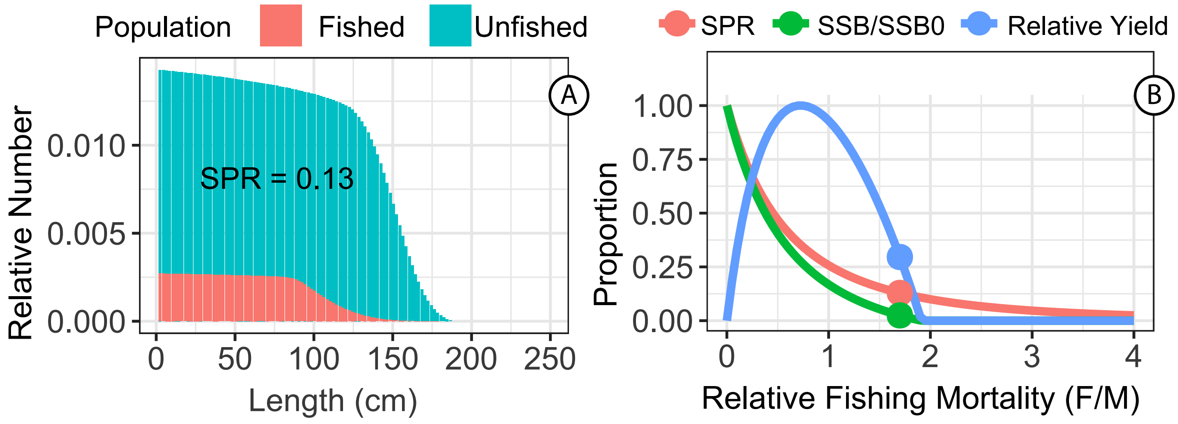

Figure 10: Length based model of (a) size structure of catch and expected unfished size and (b) relative yield curves as a function of relative fishing mortality of yellowfin tuna

The spawning potential ratio (SPR) for yellowfin tuna is 0.13, indicating that current fishing levels are significantly impacting the population's ability to replenish itself. The estimated yield, or total catch in numbers, for yellowfin tuna is 530,640,160 metric tonnes, showing a substantial level of fishing activity. The yield per recruit (YPR) is 279,284, indicating the contribution of each individual yellowfin tuna to the overall catch (Figure 10 b). The spawning stock biomass (SSB) for yellowfin tuna is 134,666,432 metric tonnes, reflecting the reproductive biomass available in the population (Figure 10 b). In the absence of fishing, the spawning stock biomass (SSB0) would be 549,297, highlighting the potential size of the population if fishing pressure were removed (Figure 10 b). These stock estimates emphasize the need for sustainable fishing practices to ensure the long-term viability of yellowfin tuna populations.

3.6 Fishing intensity

Monitoring fish catch and density distribution in space plays a crucial role in assessing the stability of fishing areas. By quantifying the fish caught and evaluating population density over time, it is possible to determine the sustainability of fishing practices. Tracking these metrics allows scientists to identify overfishing, underfishing, or sustainable fishing patterns. Implication High fish density and consistent or increasing catches indicate a healthy and sustainable fishing zone, while declines in these measures may signal overfishing or environmental issues. Analyzing seasonal and annual fluctuations, alongside long-term trends, enables precise management decisions regarding fishing quotas and habitat protection, ultimately ensuring the long-term stability of fishing areas.

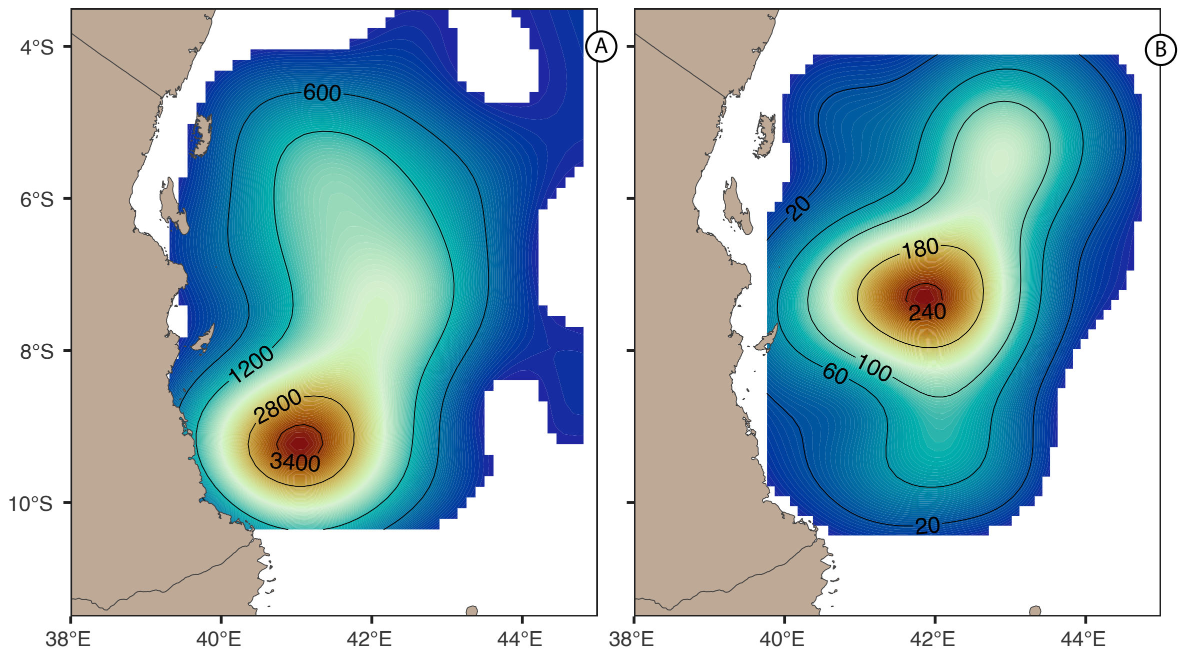

Figure 11: The density variation across the Exclusive Economic Zone of Tanzania for a) Longline and b) purse seine fishing vessels. The solid black lines are isobar of equal fishing efforts

The density of fishing effort vary across the EEZ by species. The density of longline (Figure 11 a) is relatively higher than purse seine (Figure 11 b). The density of longline is higher in the southern part of the EEZ and decrease toward the northern side of the country. This imply that distant fishing vessels concentrate in the offshore waters of Mtwara. In contrast, the fishing intensity of purse seine vary across with high fishing density in the middle section of the EEZ (Figure 11). Therefore, high intensity of fishing activity reveals that the two gears have different fishing grounds and hence the fishery can be optimized with this kind of fishing activities. It also provide important information of the hotspot areas that can be delineated and mapped for research activities.

4 CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

The study concludes that the stocks of bigeye and yellowfin tuna in the EEZ are still viable with potential for expansion to provide economic benefit to the country. Understanding the status of these two species is critical for the Deep-Sea Fishing Authority (DSFA) in that it will enhance their decision-making on licensing and meeting their reporting obligations to IOTC. This study has also established 15 biological, exploitation and stock reference points that serve as baseline for assessing fish stock health and informing future fisheries management strategies. Furthermore, while the longline fishing intensity for both bigeye and yellowfin tuna is concentrated in the southern part, for purse seine it is at the center. These high intensity fishing areas serve as hotspots and hence coincides with zones of high catch rates. Therefore, the southern area of the EEZ serve as hotspot for longliners while the areas close to the center of the EEZ is most preferred by purse seiners. This information is relevant for marine spatial planning. This analysis, also, integrates data collected from artisanal fisheries thus widening the scope of tuna resources management in Tanzania and the region in general since there is a clear separation of adults and juvenile individuals caught from the EEZ and neritic waters, which necessitate the DSFA to pay extra attention to the neritic tuna fishery as it may be critical to maintaining a healthier offshore tuna resources. Finally, this analysis serves as precursor towards conducting a comprehensive ship-based stock assessment in the Tanzanian EEZ.

4.2 Recommendations

The findings of this study lead to the following recommendations, which aim to maximize the economic potential of bigeye and yellowfin tuna through sustainable fishing practices while ensuring their sustainable management.

1. Given the healthy stock size and low current fishing pressure, the government should explore opportunities for sustainable exploitation of the bigeye and yellowfin tuna fisheries in the Tanzanian EEZ to maximize their economic potential. This can be achieved through the following strategies:

    i. **Targeted investment in fishing infrastructure and technology**: Investment should focus in upgrading local fishing vessels and equipment. This will improve fishing efficiency, potentially allowing for increased sustainable catches of bigeye and yellowfin tuna. The overall impact will be to reduce fishing intensity in the neritic waters, thus allowing juvenile individuals to grow and recruit to the offshore fishery.

    ii. **Concentrate in identified zones with high catches within the EEZ**: Local fishing efforts should prioritize areas within the Tanzanian EEZ identified as having high catch potential to maximize sustainable bigeye and yellowfin tuna catches. This strategy should be implemented while adhering to responsible fishing practices to ensure long-term stock health.

iii. **Market development and diversification**: Analyze and potentially expand markets for bigeye and yellowfin tuna within the country and beyond to maximize economic and nutritional benefits from the fishery.

2. Given that the established biological and exploitation reference points and stock biomass serve as the foundation for sustainable management of bigeye and yellowfin tuna, implement a science-based management framework for the fisheries of these species in the Tanzanian EEZ. This can be achieved through the following strategies:

   i. **Regular stock assessments**: Conduct regular stock assessments using the reference points established to monitor the health of bigeye and yellowfin tuna stock.

   ii. **Adaptive harvest control rules**: Establish harvest control rules that adjust fishing quotas based on the status of the stocks as determined by the reference points. This ensures harvest levels remain sustainable and do not jeopardize future populations.

   iii. The Exclusive Economic Zone (EEZ) data is limited, only providing length and weight values for adult fish. To better represent bigeye and yellowfin tuna, data from coastal (neritic) areas was also included. Therefore, implementing a robust monitoring program that gathers both neritic and EEZ length and weight data will enhance the accuracy of the stock estimation model.

   iv. **Data collection improvement**: Strengthen data collection programs to ensure continued accuracy and comprehensiveness of information on catch, effort, and biological characteristics of bigeye, yellowfin and skipjack tuna. This should be accompanied by enhancing the capacity of local data collectors at selected landing sites, focusing on species identification and accurate measurement of lengths and weights. An electronic Catch Assessment system (eCAS) developed by TAFIRI should be used to collect and collate all data in the artisanal fishery.

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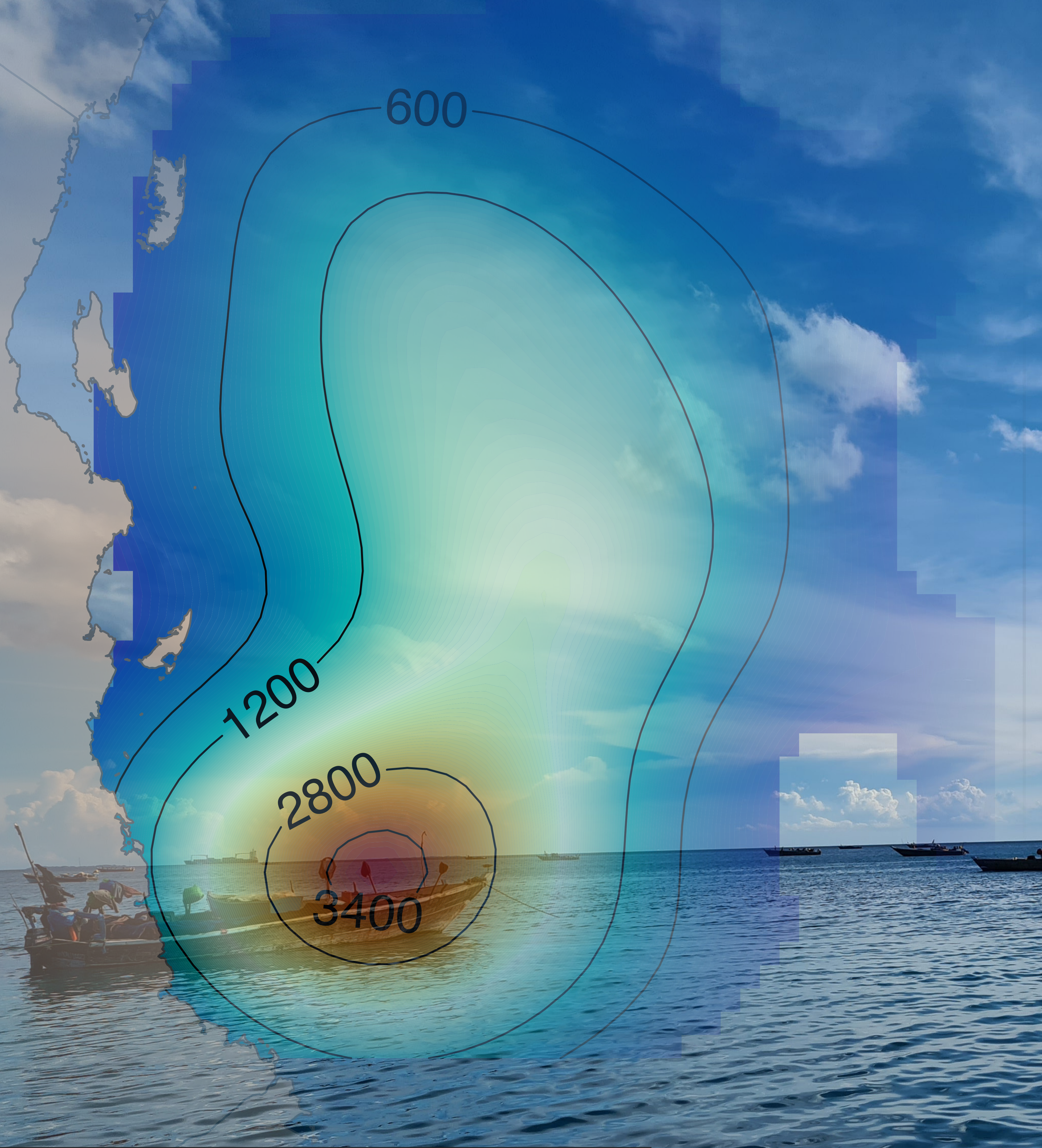

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