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Age and Growth Estimation of Bigeye Tuna, *Thunnus obesus* (Lowe, 1839) in the Eastern Indian Ocean Deduced from Otolith Microstructure

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ABSTRACT

Age-based stock assessment of globally important species, like bigeye tuna *Thunnus obesus* (Lowe, 1839), is urgently required to develop appropriate management plans for fisheries sustainability. This study aimed to estimate age and growth parameters using annual increments count of sectioned-otoliths, which effectively employed for age determination of tunas. Samples were collected from Indonesian tuna longline catch landed in the Port of Benoa from March until December 2017. Multi-models were employed to obtain robust growth parameters, and Akaike Information Criterion (AIC) was relied for the best fit model selection among those evaluated. Growth band formation was validated using marginal analysis (MI), indicating that one ring is deposited yearly and slow growth peaked during July (Australian winter). The von Bertalanffy growth model was selected as the best model fitting growth parameters from raw age data, as expressed as L_t = 183.49 (1-$e^{-0.134(t+2.991)}$). Large variances in growth were detected at the same age, with the oldest age of 15. Over 50% of fish in the Indonesian catch were <5 years old, that may have implications for fisheries sustainability.

1. Introduction

Bigeye tuna or BET (*Thunnus obesus* Lowe 1839) is a commercial target species of tunas commonly found in all tropical and subtropical waters in 3 major oceans, i.e., the Atlantic, Indian, and Pacific Oceans. The species is widely distributed between approximately 45°N and 40°S except in the Mediterranean Sea (Cayré *et al.* 1993; Collette and Nauen 1983; Farley *et al.* 2006). Compared to other tropical tunas, BET has the lowest dissolved oxygen tolerance and preferred water temperatures, ranging between 11 and 15°C. Consequently, they spent the day in the deeper water column and migrated vertically to the surface at night (Brill 1994; Holland *et al.* 1990). Adult fish can grow to be 2.5 m in total length (TL) and are targeted by tuna longline fleets (Polidoro *et al.* 2016), while small or immature fish (<90 cm FL) are caught mainly by purse seine (Sun *et al.* 2001).

In the Indian Ocean (IO), BET stock constituted a single panmictic population (Chiang *et al.* 2008; Clear *et al.* 2020; Diaz-Arce *et al.* 2020), with the Western Indian Ocean (WIO) and Eastern Indian Ocean (EIO) defined as the principal and secondary fishing ground (Nootmorn *et al.* 2021). BET catches increased gradually over time, rising from about 40,000 tons in the late 1980s to 170,000 tons in the middle of the 2000s. However, this catch history has declined since 2007 and was last recorded at 83,498 tons in 2020 (IOTC 2021). Among the top catchers, Indonesia has the highest contribution with an average catch of around 19,288 tons (23.1%) that was harvested during 2016-2020 from EIO, followed by Taiwan and China (15.7%), Spain, Seychelles, and Sri Lanka with

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portion by 16.9%, 13.6%, and 5.7%, respectively (IOTC 2021). The current stock assessment showed that BET stock is not overfished, although the average catch is just above the MSY level. However, it is subject to overfishing due to increasing fishing efforts, mainly dominated by purse seine. Evidence that depletion stock had also occurred in EIO when the CPUE as an abundance index (Campbell 2004; Maunder and Punt 2004) decreased in the last five years (Hartaty *et al.* 2019). These conditions raise global concern, so this species has been included on the IUCN's red list as vulnerable species (Duarte-Neto *et al.* 2012; Polidoro *et al.* 2016).

To ensure an effective management plan for BET sustainability, the Indian Ocean Tuna Commission (IOTC) adopted Resolution 14/02 to conserve and manage tropical tuna stocks in the IOTC area of competence (IOTC 2016). One fundamental component is strengthening the data collection system as a requirement to understand the current harvesting level of tuna stocks. Regarding accurate stock assessment, age-based growth modeling is substantial for estimating catch age structure, mortality, longevity, and age at maturity (Eveson *et al.* 2015; Farley *et al.* 2006; Sardenne *et al.* 2015). Numerous studies have concluded that counts of growth microstructures in sagittal otoliths can provide reliable age and growth estimation of tunas (Farley *et al.* 2006; Gunn *et al.* 2008; Ku *et al.* 2021). Otoliths are constituted primarily of calcium carbonate ($CaCO_3$) and a small quantity of organic matrix, which are deposited as daily and annual increments. Consequently, they are not reabsorbed and provide a permanent individual's record as the fish grows (Campana 2001).

Even though the EIO is designated as one of BET's main fishing grounds, little is known about fish age and growth based on otolith examination. Consequently, there are obstacles to ensure that management measures are developed appropriately in this region. Several studies have reported otolith-based age and growth estimation of BET in the EIO (Farley *et al.* 2006; Nootmorn *et al.* 2021) that relied on 1999-2003 sampling activities. However, there are still high uncertainties due to possible changes in growth within that period, which may be affected by climate change, which can significantly impact the stock status. Therefore, this study aimed to estimate BET's age and growth parameters using sectioned-otoliths sampled from Indonesian tuna longline vessels. By counting the otolith's annual increments, we estimate age composition, length-at-age, and catch-at-age for management purposes. In addition, multi-models were employed to address growth parameter estimations uncertainty. Furthermore, these results contribute updated information as a baseline for stock assessment and help establish appropriate management and conservation of BET in the IO.

2. Materials and Methods

2.1. Samples Collection and Handling

BET samples were caught by Indonesian tuna longline vessels operating in the area between 0° and 34°S and 76° and 123°E or beyond the Indonesian Exclusive Economic Zone (EEZ) (Wujdi *et al.* 2015, 2016). A total of 4,451 BET were sampled between March and December 2017 by enumerators from the Port of Benoa, as the most extensive tuna landing base contributed over 85% of Indonesia's total tunas catch (Satria *et al.* 2011). The Research Institute for Tuna Fisheries (RITF), Ministry of Marine Affairs and Fisheries conducted the port-based monitoring program. This program is mandatory to implement the National Plan of Action (NPOA) for the sustainability of tunas, skipjack, and bonitos as established by the Decree of the Minister of Marine Affairs and Fisheries Number 107/KEPMEN-KP/2015. Biological parameters of each individual were recorded, including the length of caudal fork (LCF or FL) and dressed-body weight (DW) to the nearest centimeter (cm) and kilogram (kg), respectively. However, sex information was unavailable because all BET samples are being processed in the vessel, i.e., gills and stomach contents are removed to avoid bleeding and decaying when stored in the ship's hold.

Otoliths for age estimation were sampled randomly from processing factories. A total of 704 otoliths (sagittae) were extracted mainly as a pair by drilling the cranium part using a cordless drill diameter of 5/8 inch. After removing the cranium part, otoliths were removed carefully using fine forceps, rinsed with distilled water, and brushed to separate tissue membrane and blood, then placed in labeled plastic tubes (BEEM RB001 size 00) and dried at room temperature.

2.2. Samples Preparation Techniques

After being dried in the laboratory for 24 hours, we measured the length (OL) and weight (OW) of each undamaged otolith to the nearest 0.001 mm and 0.0001 g by using a stereo microscope (Leica M50) and digital balance (OHAUS Adventurer AX223), respectively. Otoliths from each individual were embedded in the mixture of polyester resin and hardener, dried in the oven at 55°C for 3-4 hours, then the 5x5 cm otolith block was produced. Otolith blocks were sectioned using GemMasta Sawing Machine GS10TS. Four transverse sections were produced serially, providing at least one section through the primordium precisely, as reflected as the starting point of fish growth. Transverse-sectioned otoliths were polished using 2000-grit sandpaper and 5-micron grit aluminum oxide paper using GemMasta Faceting Machine GF4 until the thickness of about 400–450 µm was produced. The sections with the highest contrast between growth zones, as the best for clarity and interpretability, were set on glass slides using synthetic resin (ENTELLAN™). Finally, otolith growth bands were photographed using a transmitted light-compound microscope (Leica M500) under 40x magnification. Remain specimens which not analyzed are deposited at RITF's Fish Aging Laboratory.

2.3. Otolith Reading

BET otolith microstructure reading was referred to guidebook for age determination of southern bluefin tuna or SBT (*Thunnus maccoyii*) and BET developed by CCSBT (2002) and Farley *et al.* (2006), respectively. In brief, the growth band consisted of an opaque and transparent zone that is seen along the long ventral arm of each transverse sectioned-sagittal otolith, thus forming a growth increment. The otolith edge was characterized as new opaque, narrow transparent, or broad transparent, referred to the criteria developed for Pacific bigeye tuna otoliths (Farley *et al.* 2017, 2020). The boundary from the opaque to transparent zone in the otolith's ventral arm was considered the final count for annual growth.

Otoliths were read twice by two trained readers without reference to biological measurements data, previous reading, and sampling date. The interval between these readings was conducted for at least after two months. If these two readings are agreed upon, this estimate was used as the final age (e.g., 1, 2, 3, and so on). However, if the readings varied, an additional reading was carried out with information from the earlier readings to determine a final estimation.

2.4. Decimal Age

The decimal age for each individual was calculated annually using the method advanced for age determination of bigeye and yellowfin tuna or YFT (Thunnus albacares) in the Indian and western Pacific oceans (Farley *et al.* 2020, 2021). First, each fish's age (in the year as a unit) was calculated at the completion of the first opaque zone. This step was carried out by correlating daily aging and otolith radius for paired otoliths. Second, the otolith's total number of whole annual increments was determined. A complete annual increment was defined as one opaque and transparent zone. Hence, it symbolizes one year of growth and is calculated as the total number of opaque zones minus one. Third, the period between the deposition of the last counted opaque zone and the time when the fish was captured was estimated. It was done by calculating the radius between the previous observed opaque zone to the otolith edge divided by the mean radius of increment estimated for each age group.

2.5. Data Analysis

DRESSED-body weight (DW) measurement for each individual was calibrated using a conversion factor to estimate the total live weight (W) of gilled and gutted BET (IOTC 2005). In addition, we analyzed the relationship between FL and W to determine the relative growth of BET.

$$W = aFL^b$$

where *a* and *b* are constants

For each otolith, we measured the otolith radius (R), defined as the distance from the primordium to the otolith edge, and ring radius as the distance from the primordium to each opaque zone to the nearest 0.001 mm. The relationship between otolith length (OL) and FL was determined as a linear regression equation. To determine the periodicity of opaque zone formation and its frequency in a year, the marginal index (MI) was calculated based on an equation by Harris and Grossman (1985).

$$MI = \frac{R - r_n}{r_n - r_{n-1}}$$

R is the otolith radius at the otolith edge, r_n and r_{n-1} are the otolith radius at the outermost opaque zone and penultimate, respectively.

Age-bias plots were used to compare differences in age estimations between the two readers (Campana *et al.* 1995). The bias due to intra- and inter-reader inconsistency during otolith readings was examined to determine reading accuracy and consistency of age estimates by the average percentage error (APE) and coefficient of variation (CV) (Beamish and Fournier 1981; Campana *et al.* 1995; Campana 2001).

$$APE_j = 100\% \, x \, \frac{1}{R}\sum_{i=1}^{R}\frac{|X_{ij}-X_j|}{X_j}$$

$$CV_j = 100\% \, x \, \frac{\sqrt{\sum_{i=1}^{R}\frac{(X_{ij}-X_j)^2}{R-1}}}{X_j}$$

Where X_{ij} is the *i*-th age estimate of the *j*-th fish; X_j is the mean age estimate for the *j*-th fish; R is the number of times each fish was aged.

The estimated age data were further fitted using non-linear least squares estimation based on various growth functions i.e. the von Bertalanffy (von Bertalanffy 1938), the logistic (Ricker 1975), and the Gompertz (Gompertz 1825).

$$L_t \text{ von Bertalanffy} = L_\infty (1 - e^{-K(t - t0)}),$$
$$L_t \text{ Logistic} = L_\infty (1 + e^{-K(t - t0)})^{-1},$$
$$L_t \text{ Gompertz} = L_\infty e^{-e^{-K(t - t0)}},$$

Where L_t is the predicted length (cm) at age t, L_∞ is the asymptotic length (cm), K is a relative growth coefficient parameter (year^{-1}), and t_0 is the theoretical age (year) when size is equal to zero. The Akaike Information Criterion (AIC) was used to determine whether a model fit the length at age data (Duarte-Neto *et al.* 2012; Farley *et al.* 2020, 2021). The best fit model is based on the smallest AIC value. These calculations were done using the FSA (Ogle *et al.* 2020) and AICcmodavg (Mazerolle 2020) packages in R statistic software (R Core Team 2020). Furthermore, to compare intra-species growth from other oceans, the growth parameters (L_∞ and K) can be combined into a growth performance index (φ') based on the equation by Pauly and Munro (1984).

$$\varphi' = 2 \log L_\infty + \log K$$

3. Results

The relations between fork length (FL) and estimated-total weight (W) were described in an equation $W = 0.0000026FL^{2.968}$ ($R^2 = 0.972$) for combined gender (Figure 1A). Otolith length was found to be linearly related to fish length (Figure 1B; $R^2 = 0.705$), indicating that otoliths continue to grow permanently throughout fish life and that increment width are likely related to fish growth. Meanwhile, otolith weight and fish length were related curvilinearly as cubic polynomial fit (Figure 1C; $R^2 = 0.768$). This goodness of fit was relatively high, although heterogeneity was observed in the association between otolith length-weight and FL in fish exceeding 110 cm FL.

No significant difference was detected between the estimated ages from reader one and reader two readings. As required, the inter-reader APE and CV values between the readings showed 3.67% and 5.19%, respectively, indicating that age estimates were reliable. Reading consistency was demonstrated in interpreting growth bands on the otolith, although the clarity of increments varies greatly between samples. In general, opaque zones are deposited in a wide pattern, diffuse, and often consist of multiple transparent and opaque sub-annual bands, particularly at the first two or three growth bands representing the early stage of life (Figure 2). The following opaque zones are characteristically darker and more observable in older fish's otoliths. However, the radius between growth bands gradually narrows towards the otolith's edge. Consequently, overlapping opaque zones occurred more often, and age interpretation is more difficult to be attempted.

Characterization of otolith's growth bands was also evaluated quantitatively. The first transparent and opaque zone elapsed with a radius ranging between 0.26 and 1.017 mm. These gaps continue to be narrowed regularly as the fish's age becomes older over time, to only 0.039 mm in the oldest fish (Figure 3A). Although we had no samples from January or February, the marginal index (MI) value significantly varied all over the year (ANOVA, $p<0.05$). The MI had a sinusoidal pattern, with the highest value found in March, then decreased gradually until the lowest point in July, then grew again in the following months (Figure 3B). These findings suggested that transparent and opaque zones in otolith are formed once a year. The period of slow growth mainly

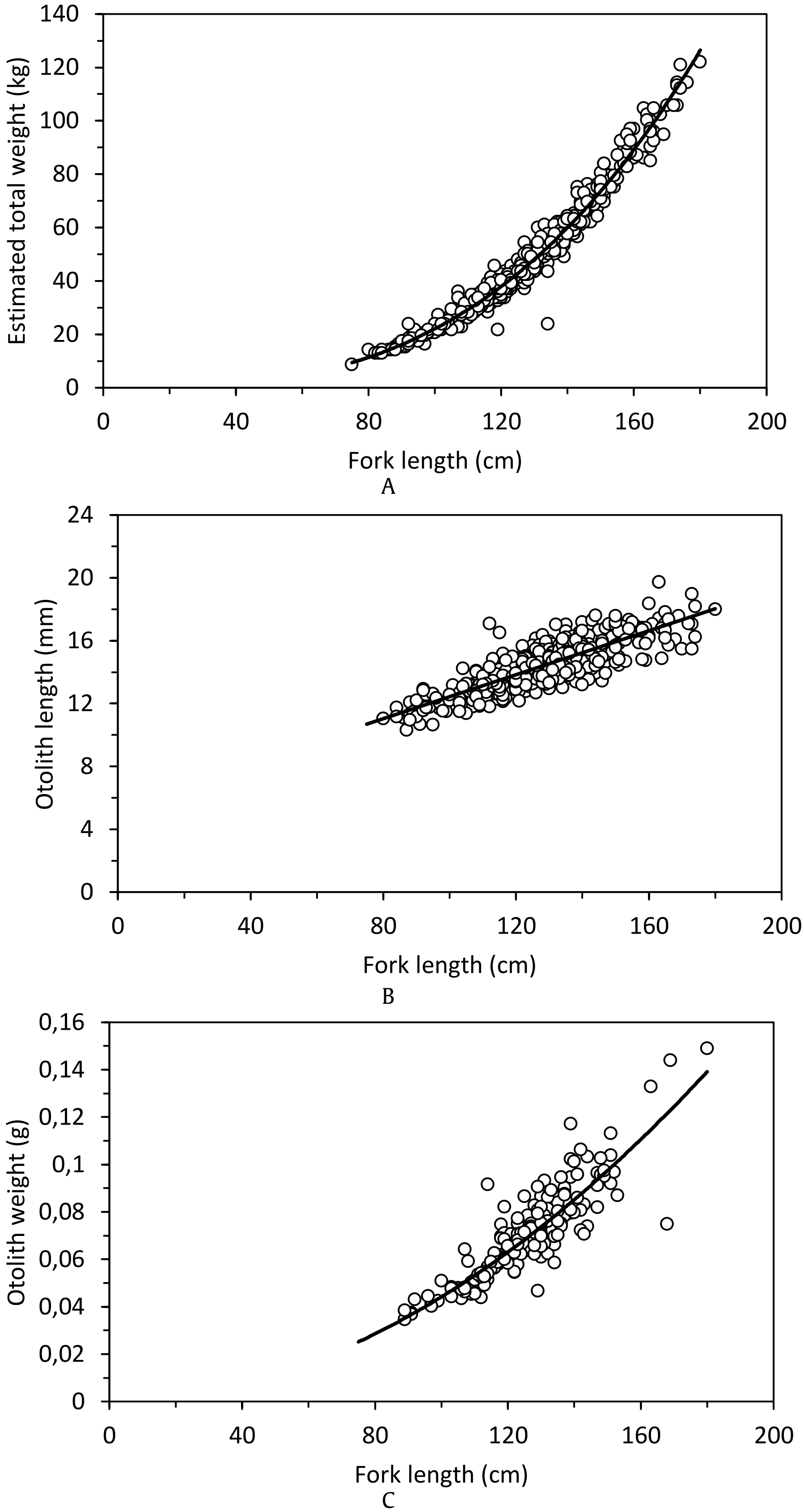


Figure 1. Relationship between otolith-and fork length (A), otolith weight and fork length (B), and fork length and total weight of BET (C) with otoliths used in the age determination

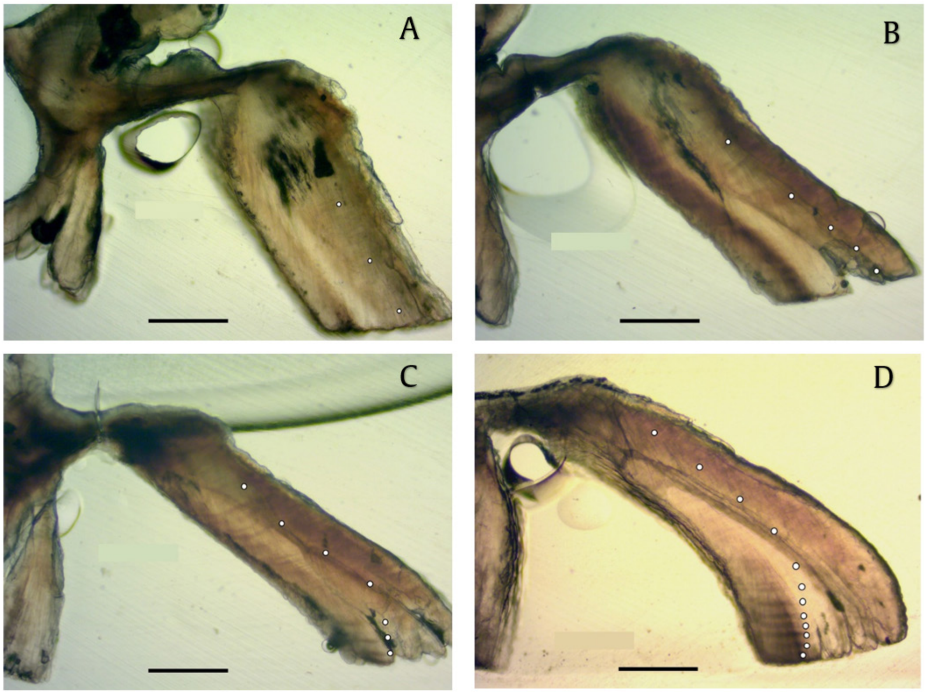


Figure 2. Photograph of transversely sectioned otolith (sagittae) of BET from a 114 cm FL (A), 139 cm FL (B), 146 cm FL (C), and 154 cm FL (D) viewed under transmitted light microscope. Annual age was estimated and marked by white circle along the ventral arm. Black scale bars represent 0.5 mm

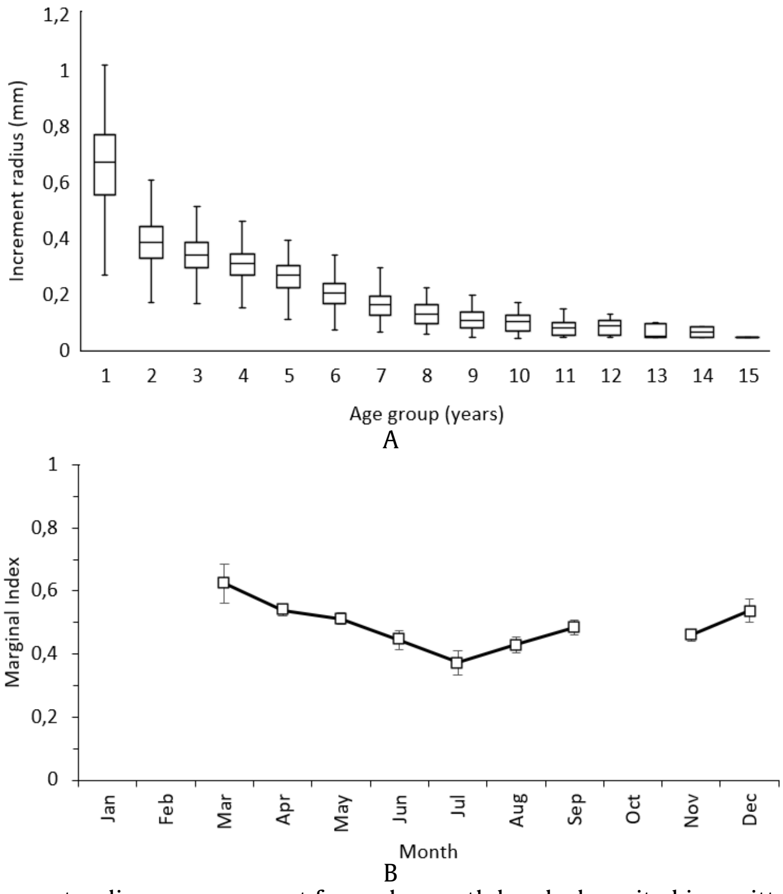


Figure 3. Box plot of increment radius measurement for each growth bands deposited in sagittae otolith of BET (A), and monthly mean variation of marginal index (MI) (B), error bars represent standard error (s.e.)

occurred in May and peaked in July, indicated by opaque zone formation. Meanwhile, fast growth is detected from August when MI increases gradually and is represented by transparent zone formation. Hence, annual growth bands were considered for BET.

Fish age was possibly deduced from the micro-increment pattern along the preferred reading path. Sectioned otoliths were extracted from 704 individuals, sizing between 75.0 and 180.0 cm FL, showing evident growth bands in the otolith's ventral arm. BET's estimated age ranged from 1 to 15 years. The asymptotic length (L_∞), relative growth coefficient (K), theoretical age (t_0), Akaike Information Criterion (AIC), and growth performance index (φ') for three growth models are shown in Table 1. The three models (von Bertalanffy, Logistic, and Gompertz) showed comparable fits to the raw age data. However, if we relied on the AIC, the von Bertalanffy (VB) growth model was selected as the best fit among the models we examined. Thus, the length-at-age of BET can be estimated by following the formula $L_t = 183.49\ (1 - e^{-0.134(t+2.991)})$ and growth performance index was 3.655 (Figure 4). In our samples, the oldest fish was estimated to be 15 years old. However, the oldest fish was not the largest, as the highest mean length was 176 cm for fish between 11 and 13 years old.

Large variances of age were observed across all length classes, indicating that BET growth is highly varied, even for individuals at the same age (Figure 5A). For instance, fish that are two years old attained sizes ranging from 80-110 cm FL. BET can grow rapidly in its early years of life. Its catch by the Indonesian tuna longline fleet in 2017 mainly comprised young fish, dominated by the 3-to 4-year age classes (Figure 5B).

Table 1. Growth parameters estimates from fitting the von Bertalanffy, Logistic, and Gompertz models to the bigeye tuna (BET) length at age data with 95% confidence interval as written in parenthesis (n = 704)

	Growth model structure		
	von Bertalanffy	Logistic	Gompertz
L_∞	183.51 (176.45-192.51)	172.28 (167.72 - 177.90)	176.61 (171.44 - 183.02)
K	0.134 (0.11-0.15)	0.231 (0.21 - 0.25)	0.183 (0.16 - 0.20)
t_0	-2.991	1.374	-0.254
φ'	3.655	3.837	3.756
AIC	4555.24	4582.16	4568.85
ΔAIC	0.00	26.93	13.62

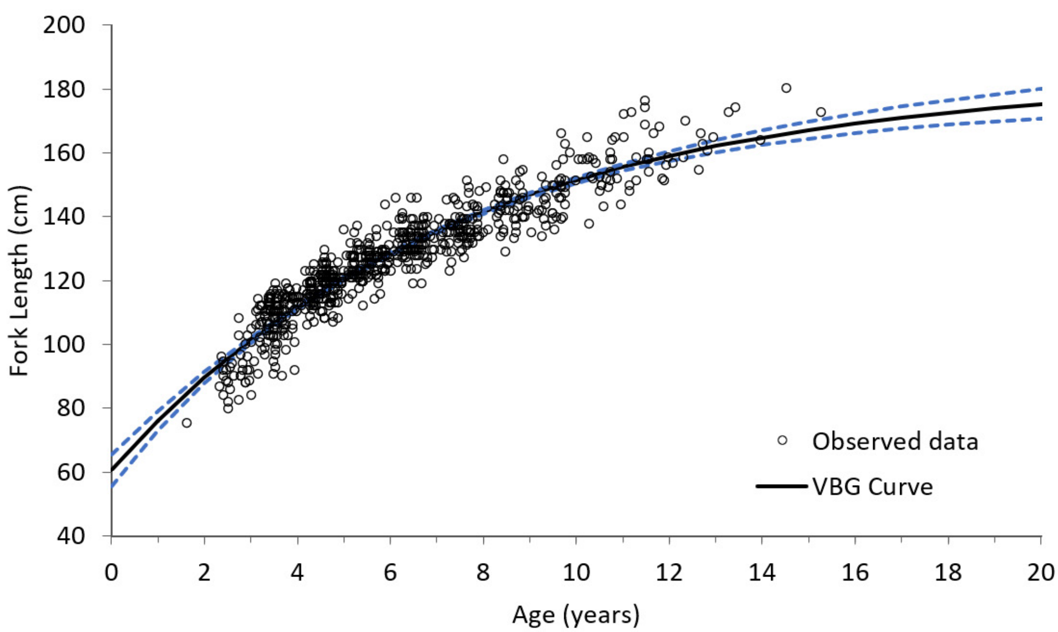
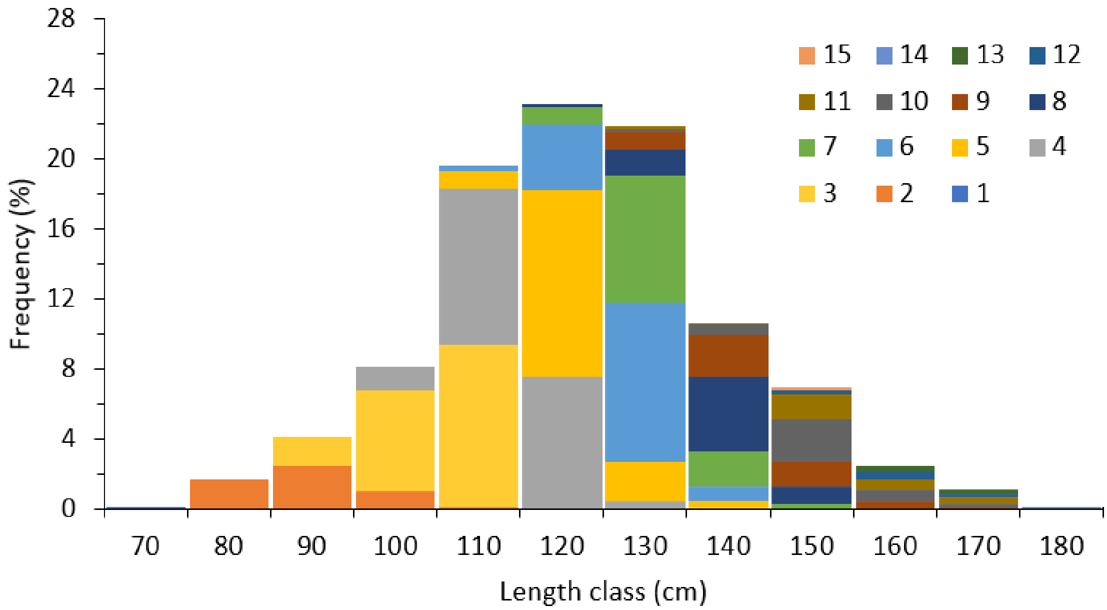


Figure 4. The von Bertalanffy (VB) growth curve (black line) as the best model for fitting the raw length-at-age data of BET as indicated by the lowest AIC. Blue dash line represents 95% confidence interval



A

B

Figure 5. Age class composition in correspond to length class (A) and catch-at-age (B) of BET caught by Indonesian tuna longline in the eastern Indian Ocean

4. Discussion

The value of average percentage error (APE) and coefficient of variation (CV) among the two readers were relatively low. Not surprisingly, the accuracy of the reading is correlated to the confidence score when reading as a consequence of the clarity of each sample. The obvious growth band pattern resulted in a high readability score, and eventually, zero deviation was obtained among readers and vice versa. In the present study, when different readers made successive readings of the otoliths, 80.25% had zero deviation, and 18.75% inconsistencies were calculated with a difference of ±1 year, indicating a high degree of reading accuracy was obtained. The level of precision of readings above is coherent with the recommended reference point for reading precision, which is less than 10% for quality control

(Secor *et al.* 2014) or at most 5% for readings of long-lived species with a relatively difficult level of interpretation (Campana 2001; Morison *et al.* 1998).

Fish age determination is typically built by investigating the biological birthday, where calculating the monthly changes of the marginal index (MI) is defined as one method to validate it. This study validated growth band formation indirectly through MI analysis, indicating that growth bands are formed annually. As required, a sinusoidal cycle is characterized by attaining the lowest value of MI when a growth band is fully formed (Campana 2001; Lessa *et al.* 2006). This finding is relevant to previous studies, as the MI can be used to investigate the BET's birthday in the Indian Ocean (Farley *et al.* 2006), Pacific (Sun *et al.* 2001), and Atlantic (Duarte-Neto *et al.* 2012), therefore, annual growth was considered.

This current study also revealed that the periodicity of slow growth started in May and peaked in July when the MI value attained the lowest value, as reported in the previous studies (Duarte-Neto *et al.* 2012; Farley *et al.* 2006). In addition, these findings confirm the conception that July 1st can be used as the given birthday for fish that inhabit the waters of the southern hemisphere, if the species spawn all year round or the spawning season is not yet known, and January 1st for fishes in the northern hemisphere.

The BET's slow growth in the eastern Indian Ocean is related to the lowest sea surface temperature (SST) in southern Indonesia during June and August (Farley *et al.* 2006), also known as Australia's winter season. Low SST during winter also affected in slow growth of other tunas, such as southern bluefin tuna and albacore or ALB (*Thunnus alalunga*), which opaque zone formation during winter was also observed in these species (Eveson *et al.* 2004; Farley *et al.* 2013; Gunn *et al.* 2008). Furthermore, we compared the BET spawning season, which showed the highest gonad somatic index (GSI) in October (Faizah and Prisantoso 2010), indicating that opaque zone formation was not affected by spawning activities.

Since multi-models used in this study provide comparable support for describing species growth, the Akaike Information Criterion (AIC) was applied to perform robust parameter estimations and address the uncertainty associated with model selection. The authors consider the emergence of biased growth parameters if generated from only a single model. This is dangerous for stock status assessment, particularly for highly exploited species like BET (Duarte-Neto *et al.* 2012). The procedure of using the AIC in selecting a model is highly recommended due to its effectiveness in determining a cost-effective approximation model (Katsanevakis 2006). As a result, the von Bertalanffy (VB) growth model is selected as the best model for describing BET growth inferred from otolith microstructure.

According to the L_∞ and K obtained in this study, BET was categorized as slow growth and long-lived species. As required, the BET has a K value lesser than 1.0 year^{-1} (Sparre and Venema 1998) thus, it has similar characteristics among tunas (Farley *et al.* 2013; Gunn *et al.* 2008; Ku *et al.* 2021). We also compared the BET growth parameters with those of previous studies. Still, a comparison based on a single parameter (L_∞ or K only) can lead to misinterpretation. Therefore, estimated growth performance indexes (φ') were also provided to compare intra-species growth more effectively (Munro and Pauly 1983; Pauly 1979) (Table 2). Overall, minor differences are calculated for BET growth performance in the IO, which is mostly less than 4.00. The most contrast is estimated by Nootmorn *et al.* (2021), reporting a slightly higher value of φ' than the range (3.39 to 4.29) informed for other BET stocks elsewhere around the world (Froese and Pauly 2022).

The difference in growth performance was mainly due to the narrow-size range of sampled fish and deficiencies of otolith samples from large-sized fish (>100 cm FL). Not surprisingly, given that daily growth band reading was designed in the previous study, in contrast to this current study which applied direct

Table 2. Growth parameters and growth performance index estimated for the BET in the Indian Ocean

Indian Ocean zone	Method	Sex	L_∞ (cm)	K (years^{-1})	t_0 (years)	φ'	Author
Western	Otolith	Combined	169.06	0.32	-0.34	3.96	Stequert and Conand (2004)
Eastern	Otolith	Combined	178.41	0.18	-2.50	3.75	Farley *et al.* (2006)
Eastern	Length frequency	Combined	199.50	0.22	-0.45	3.94	Kurniawati *et al.* (2017)
Eastern	Otolith	Combined	180.49	0.72	1.98	4.37	Nootmorn *et al.* (2021)
Eastern	Otolith	Combined	183.59	0.13	-2.99	3.84	This study

aging by annual growth bands. Age determination based on daily increments is effectively applied to explain how rapidly the individual grows in the first few years of life, specifically during the first three years (Farley *et al.* 2006; William *et al.* 2013). Consequently, BET grows faster, as indicated by a relatively high coefficient (K = 0.72), and attained approximately 50 cm FL in the first year. Unfortunately, we could not describe rapid growth at the early phases of life due primarily to very few small-sized-and young-fish were used in this current study, as indicated by the lowest value of t_0 and followed by higher estimated length-at-age for very young fish (≤2-year age class).

Other studies also highlighted differences in growth estimations due to the aging methods employed (Brown 2005; Hallier *et al.* 2005). The comparison between length frequency-based techniques and hard-part structure was also provided (Table 2). Length-frequency analysis is frequently questioned due to subjectivity in starting point selection during modal progression analysis, leading to the overlap of length modes and unrealistic parameters produced (Lessa and Duarte-Neto 2004). Despite differences in L_∞ and K were observed, the resulting value of growth performance index (φ') is in the same range, as similar as observed in the WIO. These slight differences in growth performance support the hypothesis of a wide-range movement and high connectivity between populations of BET within the WIO and EIO. Therefore, a single unique BET stock in the IO is the most plausible as genetic examinations are evidenced by substantial mixing (Chiang *et al.* 2008; Diaz-Arce *et al.* 2020).

Our findings provide the age-length keys and estimated catch-at-age for BET from the Indian Ocean-Indonesian tuna longline catch. BET catch is dominated by about three and 4-year age classes, indicating relatively large recruitment of the 2013 and 2014 cohort to the biomass, respectively. We also highlighted that 5 to 10 age classes are still being captured, indicating that 2007 to 2012 cohorts are still available in the region and well recruited to the fisheries. This result suggests that most catches have spawned at least once before being caught by longline vessels. As noticed from previous studies, BET females in the IO attained their maturity size from 88 to 110 cm FL (Farley *et al.* 2006; Nootmorn 2004; Zhu *et al.* 2011).

Regardless growth parameters in this current study are combined without gender segregation, this study revealed essential biological parameters required for stock assessments and population modeling of BET in the IO and Indonesian waters. Counting annual increments of hard part structure for aging and employing multi-model inference demonstrated a robust estimation of growth parameters. These enabled a more precise estimate of stock status to be generated, in spite of most stock assessments for tropical tuna fisheries being derived by length frequency-based methods and tagged-recapture data to estimate age-based population parameters from commercial fisheries (Langley *et al.* 2009). Given that changes in fish growth rates can have important implications for the stock status, demographic data of exploited species such as length and age composition, sex ratio, and maturity should be monitored on a routine basis in the future. Comprehensive information was expected to improve scientific contribution for a better understanding of the recent changes in the life history of BET and to establish appropriate management measures for species sustainability and conservation.

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