Preliminary Age and Growth of Bigeye Tuna, *Thunnus obesus* (Lowe, 1839) from the Northeastern Indian Ocean

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ABSTRACT

The present study provides preliminary information on age and growth for bigeye tuna, *Thunnus obesus* (Lowe, 1839) caught in the northeastern Indian Ocean. Two hundred and ten (210) individuals (size range: 41.0–188.5 cm fork length, FL) were collected from Phuket port, Thailand. High correlations were found (r>0.95) among head length, length to first dorsal fin and fork length. Age determined in 69 fish (size range: 41.0 to 137.1 cm FL) ranged between 133 and 1,530 days. Length and age data were fitted to the von Bertalanffy, Logistic and Gompertz growth models. The lowest sum of squares was obtained from the Logistic model, for which the asymptotic length was 180.49 cm FL, growth coefficient was 0.72 year^{-1}, and theoretical age at size equal to zero was 1.95 years. These findings serve as a baseline for further use in assessment of the status of bigeye tuna stocks in the Indian Ocean.

Keywords: Daily growth increments von Bertalanffy, Gompertz, Logistic, Otolith

INTRODUCTION

The bigeye tuna, *Thunnus obesus* (Lowe, 1839) is a large epi- and meso-pelagic fish commonly found in all tropical and subtropical oceans and is widely distributed across all marine waters between 45ºN and 40ºS except the Mediterranean (Froese and Pauly, 2019). This tuna can attain a maximum size of 2.5 m in total length (TL) (IUCN, 2016). Among other tropical tunas, the bigeye tuna has the lowest dissolved oxygen tolerance and lowest water temperature preference (between 11 and 15 °C); hence, they inhabit deeper parts of the water column during the day and move upward to the surface in the nighttime (Holland *et al*., 1990; Brill, 1994). Currently, there is growing evidence that the stocks of bigeye tuna worldwide have been heavily exploited and that their rate of harvest is either near or beyond maximum sustainable yield levels. Consequently, this species has been placed on the “red list” of vulnerable species by the IUCN (Duarte-Neto *et al*., 2012; IUCN, 2016).

In the Indian Ocean, the primary fishing ground for this tuna is the western portion, while the Eastern Indian Ocean is secondary; harvest is by commercial purse seines and longlines. Total catches of bigeye tuna in the Indian Ocean increased steadily from around 20,000 tonnes in the 1970s to over 150,000 tonnes by the late 1990s, but then

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have dropped since 2007 and were recently recorded at 94,218 tonnes in 2018 (IOTC, 2020). In the Eastern Indian Ocean, landings of bigeye tuna at the primary landing site (Phuket port, Thailand) fluctuated greatly, peaking at 34,032 tonnes in 1993 and then declining afterward (IOTC, 2020). Consequently, in recent years, some of the bigeye tuna fleets in the Eastern Indian Ocean have moved south to target albacore (IOTC, 2020).

To develop a sustainable and appropriate fishery management plan from a stock assessment perspective, it is necessary to have accurate and reliable age and growth information for the species in the target stock. Duarte-Neto *et al*. (2012) mentioned that even within a single bigeye tuna population in the Atlantic Ocean, different environmental factors across the distribution area contributed to differences in population parameters. Studies on growth of bigeye tuna began in the 1950s by analyzing modal progression from either length frequency data or tagging data and by counting annuli from scales (Lehodey *et al*., 1999; Sun *et al*., 2001). However, age estimates based on these sources of data are often uncertain. In the case of length frequency data, a lack of small-sized fish due to gear selectivity is problematic, while scale deformities create difficulty in validation of scale increments for annuli counting (Lehodey *et al*., 1999; Miyabe, 2001; Sun *et al*., 2001). As an alternative, counting the growth increments of inner calcified tissues, such as otoliths or vertebrae, is considered accurate if the age-determining method has been validated (Beamish and McFarlane, 1983). Recent works applying the use of daily otolith rings of tunas have confirmed that this method can provide reliable age and growth results (Lehodey *et al*., 1999; Stequert and Conand, 2004; Farley *et al*., 2006).

The bigeye tuna is already subject to a number of conservation and management measures adopted by the Indian Ocean Tuna Commission, in particular Resolution 14/02 for the conservation and management of tropical tuna stocks in the IOTC area of competence (IOTC, 2016). This study, therefore, aims to (1) describe relationships of bigeye tuna body size measurements, and (2) make preliminary estimates of length at age and growth parameters of bigeye tuna in the northeastern Indian Ocean,which can be used as baseline information for sustaining the stock in the future.

MATERIALS AND METHODS

Source of sample and measurement

A sample of 210 bigeye tuna was collected from Phuket port, Thailand between April 1999 and May 2003; all were caught in the northeastern Indian Ocean between 5ºN to 10ºS and between 80ºE to 95ºE. All individuals were measured for head length (HL, cm), length to first dorsal fin (LD1, cm) and fork length (FL, cm).

Age determination

For age determination, a sub-sample of 69 individuals was randomly selected, with a size range of 41.0 to 137.1 cm FL. Otoliths were carefully removed using forceps and separated from the otolithic membrane by brush, cleaned with water and ethanol, then stored in labeled plastic vials. The otolith samples were embedded in polyester resin, and cut into thin slices by using a low-speed ISOMET saw (Buehler Company). Each slice was attached to a glass slide with thermoplastic glue, ground with wet sandpaper (800 and 1200 grit) and polished with lapping film until the primordium was exposed. Details of otolith preparation in tunas are described in Secor *et al*. (2014). Otolith microincrements (daily growth rings) were counted three times along the long axis of the polished sections under a compound light microscope (1,000x; Stequert and Conand, 2004) by a trained reader who had no information of fish size.

Data analyses

Relationships among length measurements (n = 210 individuals) were examined by linear regression analysis. The coefficient of variation and average percent error (APE; Equation 1 and 2) were calculated to compare the reproducibility of the three readings as

$$APE = \frac{\sum_{j=1}^{n} APEj}{n} \quad \text{-------- (1)}$$

$$APE_j = 100 \times \frac{\sum_{i=1}^{r} \frac{|x_{ij}-x_j|}{x_j}}{n} \quad \text{-------- (2)}$$

where APEj = the average percent error for the j^{th} fish; x_{ij} = the i^{th} age estimate of the j^{th} fish; x_j = the mean age estimate for the j^{th} fish; r = the number of times that each fish was aged; and n = the number of aged fish in the sample (Campana, 2001).

To determine growth parameters, the obtained length and age data were further fitted to the von Bertalanffy (Equation 3; von Bertalanffy, 1938), Logistic (Equation 4; Ricker, 1975) and Gompertz (Equation 5; Gompertz, 1825) growth models, respectively, by using non-linear least squares estimation;

$$L_t = L_\infty \left(1 - e^{-K(t-t_0)}\right) \quad \text{-------- (3)}$$

$$L_t = L_\infty \left(1 + e^{-K(t-t_0)}\right)^{-1} \quad \text{-------- (4)}$$

$$L_t = L_\infty \, e^{-e^{-K(t-t_0)}} \quad \text{-------- (5)}$$

where L_t is the predicted length (cm) at age t, L_∞ is the asymptotic length (cm), K is a relative growth coefficient parameter, and t_0 is the theoretical age at size equal to zero. Suitability of a model for fitting the length at age data was tested by the sum of square error (SSE). All data analyses were conducted by using Package FSA (Ogle *et al*., 2020) in the program R (R Development Core Team, 2019).

RESULTS

A sample of 210 individual bigeye tuna was collected, with sizes ranging between 41.0 and 188.5 cm FL. Most were less than 100 cm FL (Figure 1). Positive linear trends and high correlations (r>0.95, Table 1; Figure 2) were found among length measurements, indicating that all measured dimensions of bigeye tuna increased proportionally.

The otoliths from 69 fish were successfully extracted and prepared for age reading. The range in size of these fish was 41.0 to 137.1 cm FL (Figure 1) and the daily ring counts ranged between 133 and 1,530 days (Figure 3). The coefficient of variation and APE values were 4.48 % and 2.82 %, respectively, indicating that the age estimates (from 3 counts) were precise and reliable.

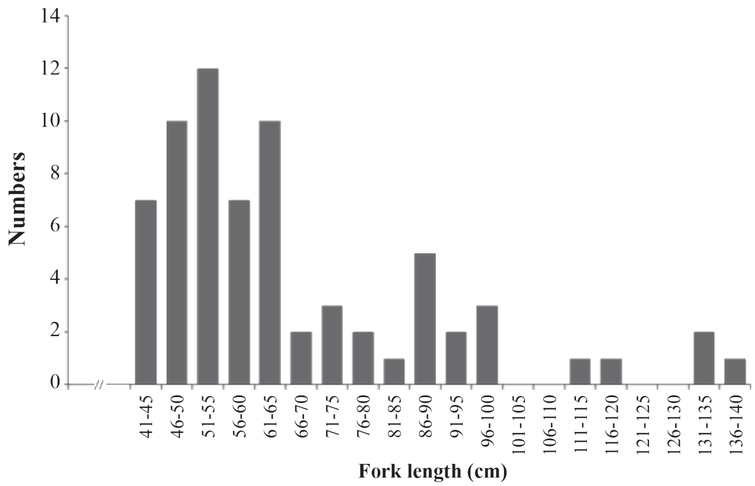

Figure 1. Size distribution of bigeye tuna collected by commercial fishing in the northeastern Indian Ocean and used for age determination in this study.

Table 1. Length-length relationships and regression coefficients of bigeye tuna individuals sampled from the northeastern Indian Ocean.

Length parameters	Intercept (SE)	Slope (SE)	Residual mean square	r^2
FL *vs* LD1	-15.25 (3.15)	3.65 (0.09)	56.77	0.894
LD1 *vs* HL	2.34 (0.64)	0.98 (0.02)	2.472	0.931
FL *vs* HL	-11.89 (2.90)	3.73 (0.08)	51.0	0.904

Note: FL: fork length; LD1: length to first dorsal fin; HL: head length

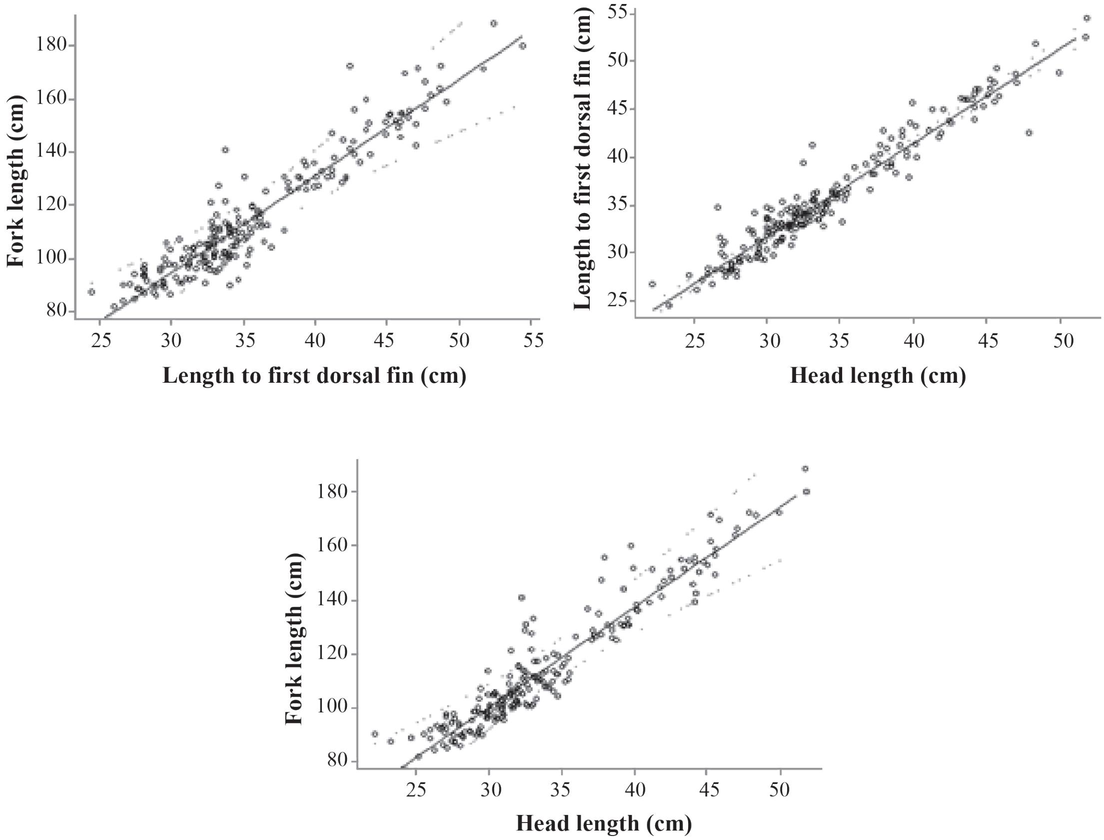

Figure 2. Scatter plots and regression lines among length measurements of bigeye tuna individuals sampled from the northeastern Indian Ocean.

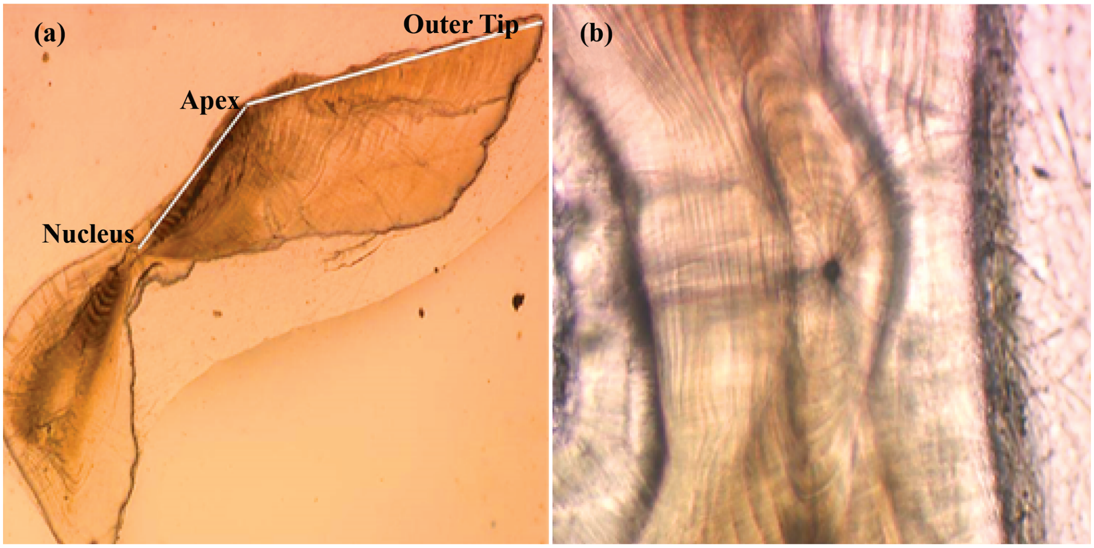

Figure 3. Sectioned otolith of bigeye tuna under light microscope (a = 100×; b = 1,000×).

The estimated asymptotic length (L_∞) and curvature parameter of growth coefficient (K) were estimated to be between 142.09 and 241.84 cm FL, and 0.35 and 0.72 year^{-1}, respectively. The estimated t_0 showed a wide range, between -0.05 and 1.95 years. The average growth performance index for bigeye tuna in this study was 4.34±0.04. From the three growth model equations (Table 2), the lowest sum of square errors was from the Logistic model, which implied that it fit the obtained length and age data in this study better than the other models. Thus the growth equation for bigeye tuna in the northeastern Indian Ocean can be expressed as

$$L_t = 180.49\left(1 + e^{-0.72(t-1.98)}\right)^{-1} \text{ -------- } (6)$$

From Equation 6, it can be estimated that the bigeye tuna in this stock reach about 50 cm FL in the first year and take about 15 years to attain asymptotic length.

length and

Table 2. Estimated growth parameters of three growth models for bigeye tuna from the northeastern Indian Ocean.

Growth model	L_∞ (cm FL)	K (year^{-1})	t_0 (year)	SSE	ø’
von Bertalanffy	142.09	0.55	-0.05	968.0	968.0
Logistic	180.49	0.72	1.98	136.2	136.2
Gompertz	241.84	0.35	1.95	141.4	141.4

Note: The performance index (ø’) was calculated as log K + 2log(L_∞) (Munro and Pauly, 1983)

DISCUSSION

The northeastern Indian Ocean is one of the main fishing grounds for bigeye tuna. A trend of over-exploitation of the species in this region is evident by the high proportion of immature sized fish in the catches observed in this study; the typical landing size at Phuket port presently ranges between 30 and 190 cm FL (Nootmorn, *personal observation*). Nootmorn (2004) reported that the 50 % maturity of this population occurs at about 100 cm TL, which is within the same range for bigeye tuna reported elsewhere in the world, between 95 and 120 cm FL (Zhu *et al*., 2011; Farley *et al*., 2017). Highly positive linear correlations among body dimensions of tunas and other fishes in Osteichthyes are common, since they exhibit isometric growth, in which every dimension increases proportionally as the fish grows (Froese and Pauly, 2019).

The age determination error (APE and CV values) in this study is quite low and below a recommended level (less than 10 %) for quality control, i.e., indicating the consistency in age reading among readers (Secor *et al*., 2014). Although a validation of daily periodicity of growth increments for bigeye tuna was not conducted in this study, many previous studies have reported on the daily increments of tuna species, including the bigeye tuna (Farley *et al*., 2006; Duarte-Neto *et al*., 2012). However, there is a caution on age estimation of bigeye tuna by using otoliths since the daily periodicity may only be acceptable within the first three years for this species (Lehodey *et al*., 1999; Farley *et al*., 2006). Williams *et al*. (2013) reported that estimates of age from counts of annual increments were generally higher than those from counts of daily increments for all four tuna species (bigeye, yellowfin (*Thunnus albacares*), southern bluefin (*T. maccoyii*) and albacore (*T. alalunga*)), particularly for fish older than two years. Age estimation by reading daily rings instead of annual rings is recommended for the bigeye tuna because the first annual opaque zone is rarely deposited, which indicates that spawning does not control opaque-zone formation (Farley *et al*., 2006). Another hard part that could be used for age determination of bigeye tuna is the spine of the first dorsal fin. Nevertheless, it presents the same problem as the otoliths, i.e., sometimes the absence of the first annual growth mark (Stequert and Conand, 2004).

The estimated L_∞ is less than 200 cm FL, which is similar to the recently estimated L_∞ elsewhere, for example 168.99 and 178.41 cm FL in the western and eastern Indian Ocean, i.e., Australian region (Stequert and Conand, 2004; Farley *et al*., 2006), 158.1 cm FL in the central and western Pacific Ocean (Farley *et al*., 2017), and 222.42 cm TL in the Atlantic Ocean (Duarte-Neto *et al*., 2012). The ϕ' values calculated for bigeye tuna in this study are around 4.3, slightly higher than the range (3.39–4.29) reported for other stocks elsewhere in the world (Froese and Pauly, 2019). Growth of the bigeye tuna is most rapid in the first few years of life, and it can attain the size at maturity within two years (Stequert and Conand, 2004; Farley *et al*., 2006; 2017). Results from this study show that the bigeye tuna in the northeastern Indian Ocean can reach the size of approximately 200 cm FL at 15 years, which is similar to the western and eastern Indian Ocean stocks (Stequert and Conand, 2004; Farley *et al*., 2006). According to the estimated size and the findings by Miyabe (2001), it can be assumed that most of the catch from the purse seine fishery is less than one year old; meanwhile, selectivity by the longline fishery increases the mean age at capture (Miyabe, 2001). The theoretical age at length of zero was added to the growth models, rather than using only asymptotic length and curvature parameters, to reduce the bias in growth estimation. Biased growth estimates could have profound consequences for fisheries stock status (Pardo *et al*., 2013). However, for tagging-recapture data, the Logistic model and Gompertz model showed better fit to growth of the bigeye tuna in the Indian Ocean (Eveson and Million, 2008) and Atlantic Ocean (Hallier *et al*., 2005), respectively. Maunder *et al*. (2018) mentioned that the growth curve of bigeye tuna is simply linear for the youngest ages and then conforms to a logistic function when they grow older. Considering multiple growth models is very important when selecting the best model to describe fish growth, since it could be dangerous for a species with a high level of exploitation, such as bigeye tuna, if the stock status is assessed through biased growth parameters (Katsanevakis, 2006; Duarte-Neto *et al*., 2012).

CONCLUSION

Preliminary estimation of age and growth of the bigeye tuna in the northeastern Indian Ocean by using otolith daily rings is reported here. The major findings of the present study are: (1) the relationship among length measurements, and (2) preliminary estimates of length at age and growth parameters. Three growth models were applied, of which the Logistic model yielded the best fit to the obtained length and age data. Additional samples of large-sized bigeye tuna (over 200 cm FL) would allow more robust estimates and better explain growth variation. The findings can be further used for fisheries management to sustain and wisely exploit the bigeye tuna in the Indian Ocean.

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