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**Developing an age structured projection model for bigeye tuna (*Thunnus obesus*) in the Indian Ocean**

(*Draft*)

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## Introduction

Population projection model can be used to evaluate possible effects of harvest scenarios on age-structured population over a given time horizon. This paper presented a simple age structured projection model for bigeye tuna (BET; *Thunnus obesus*) in the Indian Ocean. The model was developed using the formal fishery program Age Structured Projection Model (AGEPRO; NOAA Fisheries Toolbox 2011; Brodziak, 2009). The model was single stock based and sexes combined. Primary outputs of the AGEPRO include time series of spawning biomass, recruitment, and catch under different population dynamics assumptions and harvest scenarios. The BET stock was projected for 30 years from the beginning of 2008, on a yearly base.

## Biology

The biological parameter assumptions were selected based on recent stock assessments of BET in the Indian Ocean. The weight-at-age data (Table 1) was calculated using the equation ($W=3.661\times10^{-5}\ L^{2.901}$) as in Shono et al. (2009). Maturity-at-age (Table 2) was converted by maturity-at-length ($M_a = \frac{1}{1+e^{-0.25\times(L-110.888)}}$) used in Shono et al. (2009) by von Bertalanffy growth model of Stéquert and Conand (2004). Natural mortality assumptions were also used as in Shono et al. (2009) for both sexes: $M$=0.8 for ages 0 and 1, and $M$=0.4 for age ≥ 2 (Table 3). Proportion of total mortality that occurs before spawning was assumed to be 0.6. Age specific selectivity assumed for BET was shown in Table 4. All these biological parameters were assumed to be deterministic (error free) in the current projection analysis.

## Initial population

The initial stock abundance (stock number in the beginning of 2008) for BET was approximately calculated based on the recent estimates in Shono et al. (2009), showing in Table 5. It was expected that estimate of initial abundance will be improved on this year’s Working Party meeting, based on the most reliable stock assessments by participants.

**Stock recruitment relationship**

Beverton-Holt stock-recruitment model (B-H model) with lognormal error was assumed for Indian Ocean BET which was also adopted in recent stock assessments (e.g. Kolody et al. 2010). $R_0$ = 81,064,400 (number of fish) and $SSB_0$= 1,716,600,000 (kg) from Shono et al. (2009) were assumed to be the virgin recruits and spawning stock biomass. $R_0$ and $SSB_0$ were used to calculate $\alpha$ and $\beta$ parameter values for the B-H model (Francis, 1992.) under three steepness assumptions: steepness = 0.7, 0.8, and 0.9, respectively (Table 6).

**Uncertainty**

Three elements of uncertainty can be considered in AGEPRO: recruitment, initial population size, and natural mortality. Recruitment is defined as the number of age 0 fish entering the modeled population at the beginning of each year in the time horizon. For the current BET model, uncertainty was only considered for recruitment with a variance of 0.1 for the recruitment deviation.

**Harvest scenarios**

Fishing mortality rate and yield were two harvest control variables to be evaluated for the Indian Ocean BET stock. We selected maximum sustainable yield (MSY) related management quantities estimated in recent stock assessments for BET projection. A fishing mortality in correspondence with MSY ($F_{MSY}$) was assumed to be the potential harvest strategy implementing on the stock each year from 2008 to 2037 under different steepness assumptions for the B-H model. $F_{MSY}$ =0.29 was adopted based on an estimate by Shono et al. (2009). MSY=183000 t and 89000 t estimated by Shono et al. (2009) were two yield based harvest control variables to be examined for the BET stock. No time varying effects were considered for both the fishing mortality and yield strategies (i.e. constant over the projection time).

**Projection results**

The projection outputs were shown in Figure 1 – Figure 5. Under assumptions of steepness = 0.9 and 0.8, the BET stock can recover to the level of MSY in a few years, although it resulted in decreases in spawning stock biomass and yield (Figure 1 and 2). Under assumptions of steepness = 0.7, the BET stock will basically go down all the way from 2008 to 2037(Figure 3).

**References**

Brodziak, J. 2009. AGEPRO User Guide (Version 3.3).

Francis, R.I.C.C., 1992. Use of risk analysis to assess fishery management strategies: a case study using orange roughy (Hoplostethus atlanticus) on the Chatham Rise, New Zealand. Can. J. Fish. Aquat. Sci. 49, 922-930.

Kolody, D., Herrera, M. 2010. Exploration of Indian Ocean bigeye tuna stock assessment sensitivities 1952-2008 using Stock Synthesis. IOTC-2010-WPTT-04.

NOAA Fisheries Toolbox, 2011. Age Structured Projection Model (AGEPRO), Version 3.3.9. http://nft.nefsc.noaa.gov

Shono, H., Satoh, K., Okamoto, H., Nishida, T. 2009. Updated stock assessment for bigeye tuna in the Indian Ocean up to 2008 using Stock Synthesis III (SS3). IOTC-2009-WPTT-20.

Stéquert, B., Conand, F. 2004. Age and growth of bigeye tuna (*Thunnus obesus*) from the Western Indian Ocean. Cybium, 28: 163-170.

**Table 1 Weight-at-age used in the BET projection model in the Indian Ocean**

| Age (yr) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9+ |
|---|---|---|---|---|---|---|---|---|---|---|
| Weight (kg) | 0.1 | 5.0 | 16.6 | 31.4 | 46.3 | 59.6 | 70.7 | 79.6 | 86.4 | 91.6 |

**Table 2 Maturity-at-age used in the BET projection model in the Indian Ocean**

| Age (yr) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9+ |
|---|---|---|---|---|---|---|---|---|---|---|
| Proportion of maturity | 0 | 0 | 0 | 0.5 | 1 | 1 | 1 | 1 | 1 | 1 |

**Table 3 Natural mortality-at-age assumed in the BET projection model in the Indian Ocean**

| Age (yr) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9+ |
|---|---|---|---|---|---|---|---|---|---|---|
| M | 0.8 | 0.8 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |

**Table 4 Fishery selectivity-at-age assumed in the BET projection model in the Indian Ocean**

| Age (yr) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9+ |
|---|---|---|---|---|---|---|---|---|---|---|
| S | 0.2 | 0.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

**Table 5 Initial stock structure (stock number-at-age at the beginning of 2008) assumed in the BET projection model in the Indian Ocean**

| Age (yr) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9+ |
|---|---|---|---|---|---|---|---|---|---|---|
| Number (1000's fish) | 60674 | 9850 | 2944 | 5880 | 5444 | 2553 | 814 | 2201 | 72 | 74 |

**Table 6 Parameter values of B-H stock recruitment model used in the BET projection model in the Indian Ocean**

| | Steepness | | |
|---|---|---|---|
| | 0.7 | 0.8 | 0.9 |
| $\alpha$ | 90,792,128 | 86,468,693 | 83,380,526 |
| $\beta$ | 205,992,000 | 114,440,000 | 49,045,714 |

## Spawning stock biomass and catch trajectory with harvest scenarios

**Scenario #1**:

Constant fishing mortality equal to $F_{MSY}$ (=0.29, Shono et al. 2009), steepness=0.9

| Year | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | …. | 2037 |
|---|---|---|---|---|---|---|---|---|---|---|
| F | 0.29 | 0.29 | 0.29 | 0.29 | 0.29 | 0.29 | 0.29 | 0.29 | …. | 0.29 |

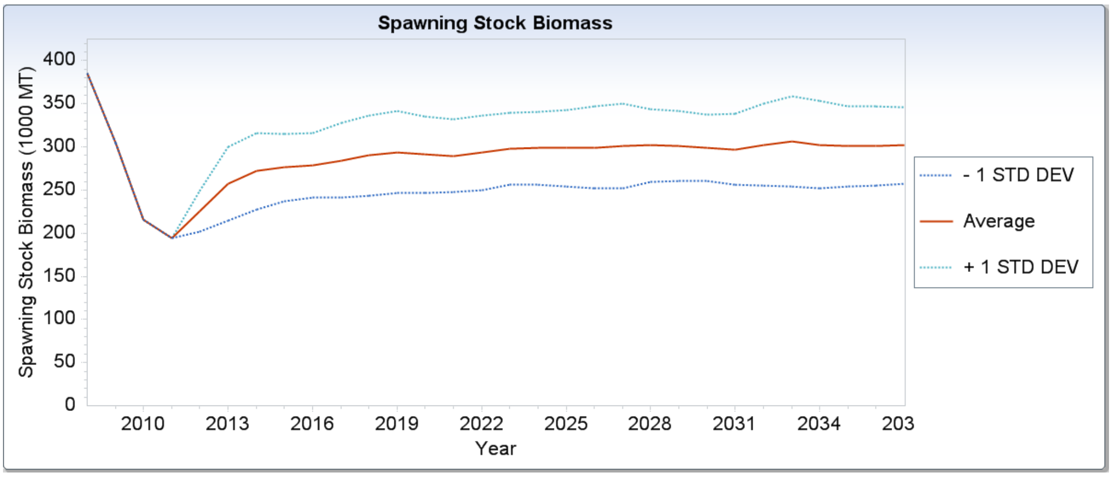


Figure 1 (a) Spawning stock biomass trajectory under Scenario # 1

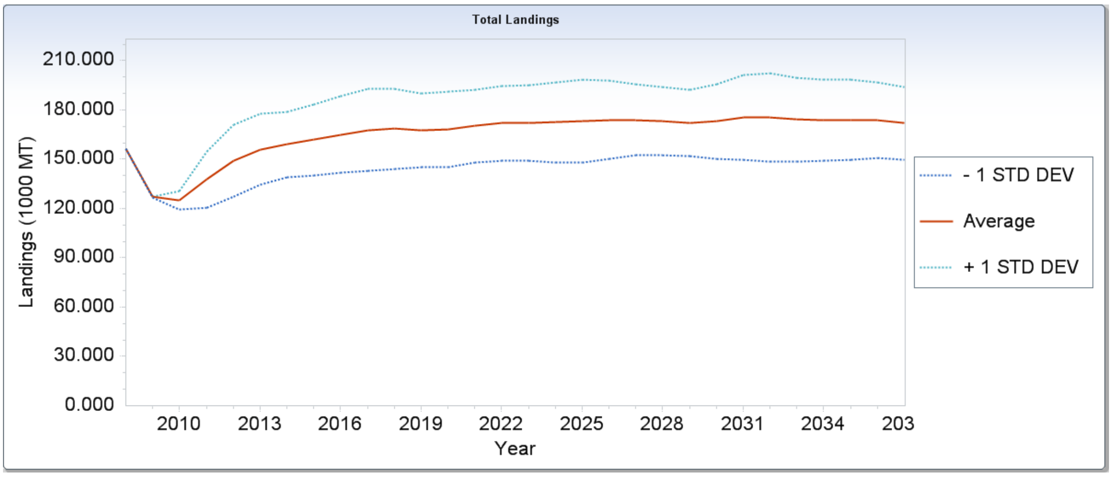


Figure 1 (b) Landing trajectory under Scenario # 1

**Scenario #2**:

Constant fishing mortality equal to $F_{MSY}$ (=0.29, Shono et al. 2009), steepness=0.8

| Year | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | …. | 2037 |
|---|---|---|---|---|---|---|---|---|---|---|
| F | 0.29 | 0.29 | 0.29 | 0.29 | 0.29 | 0.29 | 0.29 | 0.29 | …. | 0.29 |

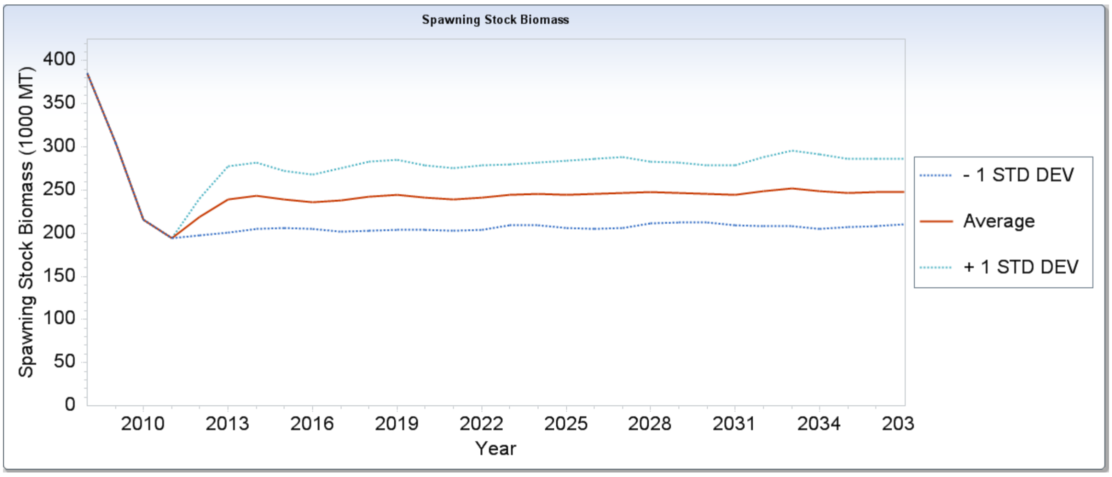


Figure 2 (a) Spawning stock biomass trajectory under Scenario # 2

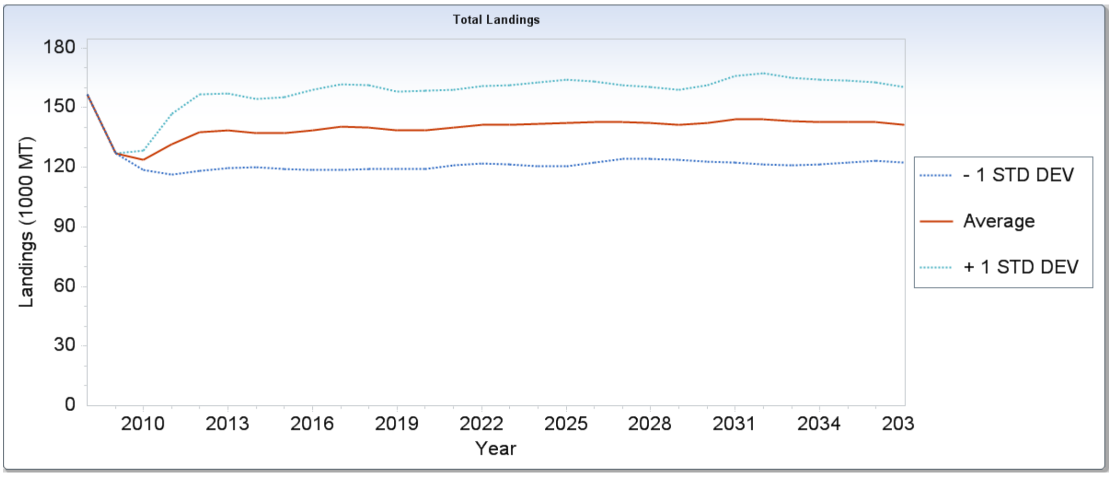


Figure 2 (b) Landing trajectory under Scenario # 2

**Scenario #3**:

Constant fishing mortality equal to $F_{MSY}$ (=0.29, Shono et al. 2009), steepness=0.7

| Year | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | …. | 2037 |
|---|---|---|---|---|---|---|---|---|---|---|
| F | 0.29 | 0.29 | 0.29 | 0.29 | 0.29 | 0.29 | 0.29 | 0.29 | …. | 0.29 |


Figure 3 (a) Spawning stock biomass trajectory under Scenario # 3

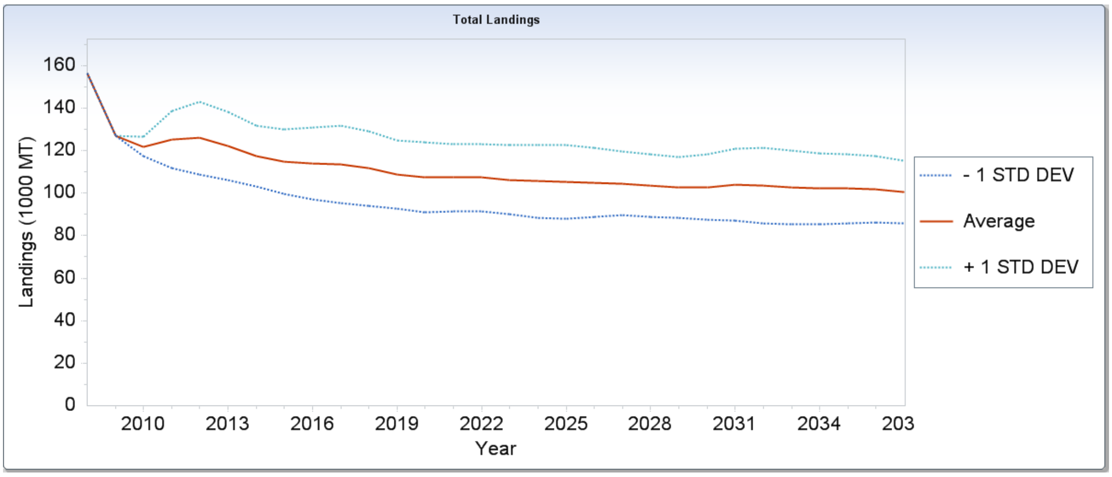


Figure 3 (b) Landing trajectory under Scenario # 3

**Scenario #4**:

Deterministic constant catch using MSY (=183000t), steepness=0.9

| Year | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | …. | 2037 |
|---|---|---|---|---|---|---|---|---|
| Catch (t) | 183000 | 183000 | 183000 | 183000 | 183000 | 183000 | …. | 183000 |

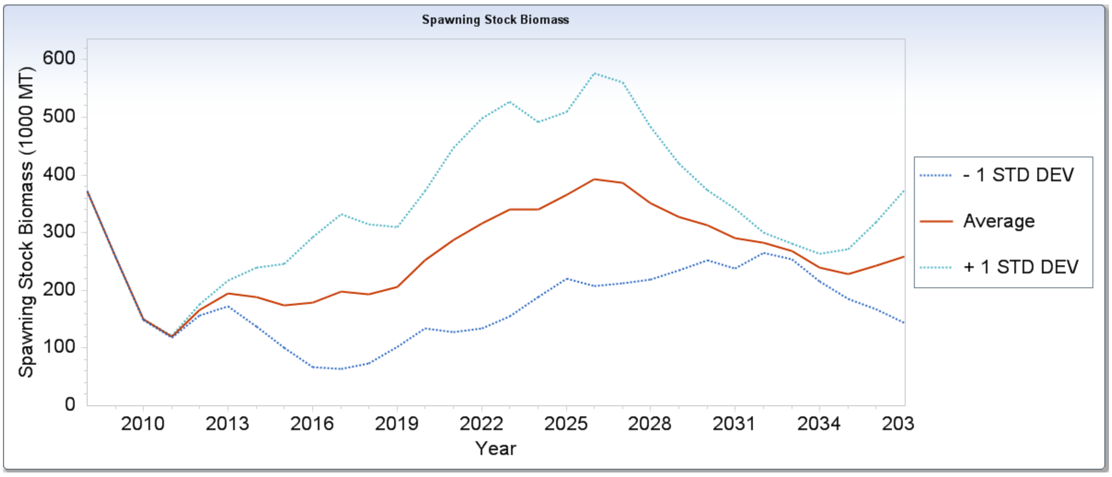


Figure 4 Spawning stock biomass trajectory under Scenario # 4

**Scenario #5**:

Deterministic constant catch using MSY (=89000t), steepness=0.7

| Year | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | …. | 2037 |
|---|---|---|---|---|---|---|---|---|
| Catch (t) | 89000 | 89000 | 89000 | 89000 | 89000 | 89000 | …. | 89000 |

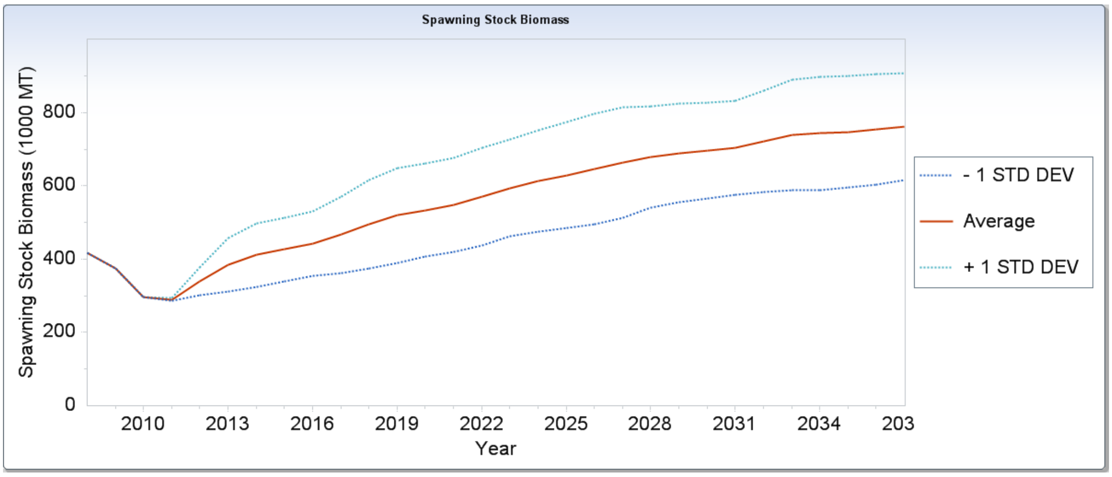


Figure 5 Spawning stock biomass trajectory under Scenario # 5