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Stock assessment of bigeye tuna (*Thunnus obesus*) in the Indian Ocean based on a tuned VPA analysis

(*Draft*)

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Introduction

Catch-at-age data are key information in current fisheries stock assessment for exploited commercial populations. Broadly speaking, there are two approaches to incorporate catch-at-age information in fisheries stock assessments: virtual population analysis (VPA) and statistical catch-at-age analysis (SCAA) (Butterworth and Rademeyer, 2008). They are generally characterized based on how they link the population dynamics models to the data. SCAAs are known as forward-projecting approaches as they start with an initial population in the past and work forward in time, whereas VPAs are basically backward-projecting approaches that start with the current population and work backwards. A significant difference between VPAs and SCAAs is that VPA models treat catch as "given" or known exactly, whereas SCAA often treat the catch as data needing to be fit (rather than assumed known without error).

Stock assessments of bigeye tuna (BET) in the Indian Ocean in recent years were conducted using forward-projecting based models such as Stock Synthesis (Shono et al., 2009; Kolody and Herrera, 2010). VPA based assessment for Indian Ocean BET was conducted more than ten years ago (Nishida and Takeuchi, 1999). Updated catch data in the passed 10 years for bigeye tuna facilitated an age-structured population analysis using VPA based methods. In this paper, we presented a preliminary assessment for the bigeye tuna in the Indian Ocean (1950-2008) using VPA/ADAPT (NOAA Fisheries Toolbox, 2011). The main objective of this paper is to compare the outputs of VPA analysis under different assumptions for plus age class. We assume that the Indian Ocean BET is single stock based on a recent genetic study (Chiang et al., 2008).

Material and methods

Catch-at-age data

Catch-at-age data covering years from 1950 to 2008 in IOTC database for tropical tuna species were used for VPA/ADAPT analysis (for datasets detail, see Herrera and Pierre, 2009). The model was on a yearly base so catch by quarter with all fisheries combined were aggregated into catch by year. Two age-structure scenarios about plus age class were assumed, i.e., age-structure covering age class 0-9+ (Base case) and age-structure covering age classes 0-18+ (Alternative case). The catch-at-age matrices for the two cases were shown in Table 1 and 2, respectively.

Biological assumptions

W-L relationship for sexes combined ($W=3.661\times10^{-5}\ L^{2.901}$) was used as in Shono et al. (2009). The von Bertalanffy growth parameters (L_{inf}=169.06 (cm, FL), K=0.32, t_0=-0.34) for sexes combined from Stéquert and Conand (2004) was used to calculate length-at-age data for catch. See Figure 1 and 2 for model curves.

Weight-at-age data of catch was converted from length-at-age data of catch by W-L relationship without error considered. The weight-at-age data of stock (stock on Jan. 1st each year) and weigh-at-age data of spawning stock were calculated from weight-at-age data of catch using Rivard weighting procedure (see VPA/ADAPT Version 3.0 Reference Manual).

Maturity-at-length model ($M_a(L)=\frac{1}{1+e^{-0.25\times(L-110.888)}}$) was adopted as in Shono et al. (2009). Maturity-at-length data (proportion of fish mature at length) was converted into maturity-at-age (proportion of fish mature at age) using von Bertalanffy growth model of Stéquert and Conand (2004). See Figure 3 for model curve.

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 $\geq$ 2. Both proportion of natural mortality that occurs before spawning and proportion of fishing mortality that occurs before spawning were assumed to be 0.6.

Abundance index

Two abundance indices standardized from the nominal CPUE (catch in number per 1000 hooks) of the Japanese longline fishery by GLM model (Okamoto et al. 2009) were used to tune the VPA model for parameter estimation. One was the index of tropical area and the other was the index of the whole Indian Ocean. The two indices were equally weighted. The abundance indices covered the time period 1960-2008 with all age classes pooled. Age-specific abundance index was calculated using abundance index of all ages pooled multiplied by age compositions. The age composition was calculated using catch-at-age vector for each year. This calculation was conducted automatically inside the software. Ages 0-1 data were not used because they were usually not fully exploited by the longline fishery (Nishida and Takeuchi, 1999), therefore, abundance index coving ages of 2-9+ were used for the Base case and ages of 2-18+ for the Alternative case.

Terminal quantities calculations

Fully-recruited fishing mortality in the terminal year (F_{FULL}) was estimated using classic method in which F_{FULL} is determined by the fishing mortalities of fully-recruited age classes, excluding the oldest true age. The partial recruitments in the terminal year for ages 0-1 were set at 0.1 and 0.3, respectively, and for ages 2-18+ were all set at 1.

The fishing mortality at oldest age class (age 9+ and age 18+ for Base case and Alternative case, respectively) in the terminal year was calculated by the product of F_{FULL} and the partial recruitment in that age class. The fishing mortality at oldest true age class (age 8 and age 17 for Base case and Alternative case, respectively) in the terminal year was computed as the arithmetic average of fishing mortalities over an assumed range of fully-recruited age classes (ages 5-7 and ages 14-16 for Base case and Alternative case, respectively). The ratio of fishing mortality at oldest age class to fishing mortality at oldest true age class for each year was set to be 1 for both cases.

Model run with retrospective analysis

The VPA was tuned by non-linear least squares (NLS) algorithms which search a set of parameters to minimize the objective function. The objective function was defined as the total of sum of square of differences between abundance indices predicted by the model and abundance indices obtained from standardized Japanese longline CPUEs (observed values).

Retrospective analysis was performed by successively removing the last year of survey and catch data and re-running the NLS algorithm. Retrospective analyses are typically conducted for the most recent 5 years or so. The calculation engine is re-initialized for each retrospective analysis. Results of the retrospective analysis were compared with the original NLS solution. For the current BET model, the year 2003 was selected as the last year in retrospective analysis.

Results and Discussion

Model fits

Both the Base case model and Alternative case model did not fit well to the CPUE time series. The model overestimated CPUEs for the years 1988-2008, while underestimated CPUEs for the years 1960-1985 (Figure 4, 5). This trend was consistent between the CPUEs from the tropical area and the CPUEs from the whole Indian Ocean. The main reason for the bad fits is most probably only abundance indices derived from longline fishery were used in VPA tuning. It will be useful if the abundance index from purse seine fishery is available because it covers ages 0-2, while longline fishery mostly cover ages $\geqq 2$. It is expected that more realistic and accurate assessment results can be obtained using these two abundance indices together for VPA tuning.

Stock status with retrospective pattern

The stock number estimate of BET showed an increase trend since 1950s, towards the years around 2000. After the years around 2000, the Base case resulted in declines in stock number and SSB estimates, while the Alternative case resulted in increases in these estimates (Figure 6a, b). The fishing mortality estimates showed fluctuations between 1955 and 2005 (Figure 6c). Differences existed in the estimates by Base case model and Alternative case model for stock number, spawning stock biomass, especially for fishing mortality (Figure 6a, b, c). This indicated that the assumption about age-structure of VPA model may have large impact on stock parameter estimates.

Retrospective pattern was examined for the estimates of spawning stock biomass (Figure 7) and fishing mortality (Figure 8). Retrospective errors had great impacts on the estimates of SSB and fishing mortality. However, the impacts showed quite different patterns between the Base case and Alternative case. For SSB, successively removing the data of last year resulted in underestimates of SSB in Base case, whereas overestimates of SSB in Alternative case. It is a contrary case for fishing mortality.

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Table 1 Catch-at-age of all BET fisheries in the Indian Ocean (1950-2008) (in thousands of fish) used for tuned VPA analysis (Base case)

age	0	1	2	3	4	5	6	7	8	9+
1950	0.04	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1951	0.26	1.41	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.00
1952	0.30	1.65	0.01	0.00	0.02	0.02	0.01	0.00	0.00	0.00
1953	0.32	2.63	6.50	12.34	10.49	4.69	1.45	0.31	0.05	0.01
1954	0.57	6.37	26.16	42.91	36.75	20.59	9.03	3.37	1.00	0.30
1955	0.72	9.02	36.50	59.92	51.76	29.05	12.83	4.98	1.76	0.69
1956	0.73	12.17	48.50	75.71	65.82	38.49	17.91	7.37	2.70	1.09
1957	34.53	14.44	50.83	75.04	62.00	34.73	15.53	6.06	2.09	1.01
1958	34.70	15.44	48.09	67.84	57.28	33.20	16.25	7.46	2.88	1.39
1959	34.51	12.77	41.81	59.04	49.60	28.60	13.51	5.74	2.03	0.88
1960	17.74	16.90	67.42	97.84	82.15	46.42	21.76	9.02	3.22	1.34
1961	26.48	16.40	61.80	91.13	77.46	43.88	20.35	7.94	2.48	0.97
1962	26.39	19.24	79.18	116.44	96.16	53.12	23.58	9.31	3.26	1.46
1963	26.15	16.10	61.15	88.39	69.85	36.74	15.93	6.14	2.07	0.88
1964	25.77	11.95	67.66	111.55	100.17	57.13	22.47	7.45	2.27	0.90
1965	17.40	20.91	81.85	114.13	97.33	57.81	26.85	11.23	4.35	2.16
1966	27.44	30.34	98.60	128.90	103.07	69.99	40.24	18.57	7.88	3.70
1967	29.40	14.68	119.14	160.29	133.31	72.86	29.73	9.72	2.94	1.01
1968	31.60	36.98	159.55	241.32	223.04	121.72	43.21	15.97	6.76	3.41
1969	32.56	44.40	183.20	220.88	153.13	76.43	33.77	11.12	3.03	1.14
1970	52.10	65.34	138.90	218.74	149.15	69.35	26.94	9.26	1.42	0.41
1971	28.73	45.88	109.92	131.81	123.11	71.86	29.00	8.42	2.40	1.61
1972	32.17	18.34	89.90	144.44	116.67	55.04	21.27	5.06	1.56	0.45
1973	68.13	9.98	48.40	122.25	93.99	52.15	22.06	8.33	3.27	0.94
1974	77.38	35.11	104.59	187.95	180.92	73.68	30.73	11.13	2.49	0.82
1975	66.58	141.10	216.69	221.94	174.26	115.39	45.22	15.44	4.85	3.27
1976	79.17	77.75	272.55	202.54	103.30	68.97	30.77	10.49	3.89	2.74
1977	88.24	45.42	121.54	198.60	158.91	90.93	63.37	39.65	10.59	2.72
1978	67.08	50.75	141.87	340.53	280.37	141.17	63.27	27.40	10.01	4.56
1979	73.64	74.21	166.43	262.64	175.55	78.27	29.80	12.33	4.38	3.88
1980	64.35	84.14	205.85	232.87	176.63	77.35	35.82	19.53	8.30	4.51
1981	130.12	90.73	210.97	224.54	162.68	87.71	40.46	19.28	6.77	4.48
1982	75.88	112.15	221.91	256.42	175.28	108.82	57.90	32.91	17.62	11.39
1983	116.51	158.12	253.55	323.10	243.82	124.26	56.66	24.04	12.04	10.54
1984	648.05	208.80	233.60	282.15	193.39	103.41	48.11	19.43	10.62	8.78
1985	1137.93	348.67	336.31	347.81	234.35	110.36	45.20	19.07	7.25	3.28

Table 1 Continued.

age	0	1	2	3	4	5	6	7	8	9+
1986	976.56	662.04	334.96	376.10	257.35	111.39	46.12	18.47	7.13	4.63
1987	1462.37	946.02	324.21	401.92	287.71	112.23	55.36	26.63	10.61	7.06
1988	2404.03	716.18	269.34	448.29	339.09	150.28	75.75	32.27	11.09	4.54
1989	2480.62	686.23	399.41	395.92	281.82	136.21	70.32	28.01	7.84	2.88
1990	1647.38	547.45	374.66	523.39	370.07	153.93	55.55	21.60	6.50	2.96
1991	1759.66	617.65	346.69	503.64	425.18	183.22	47.34	16.61	6.05	3.96
1992	1455.82	650.14	470.72	491.49	348.50	139.62	50.28	15.54	5.02	3.00
1993	2107.45	498.65	357.12	682.11	516.64	230.43	97.01	37.51	16.02	18.39
1994	2843.58	1010.47	468.45	588.08	471.39	277.69	130.60	41.16	16.94	11.90
1995	5029.83	1782.28	941.51	699.10	403.41	188.49	85.77	45.70	16.75	9.68
1996	3692.96	1099.32	773.33	859.23	521.01	207.58	107.40	57.87	25.98	16.13
1997	7116.24	1675.13	688.48	848.86	595.06	233.93	108.96	56.14	28.51	30.48
1998	3763.14	1407.75	1157.23	944.95	564.79	218.61	92.80	41.89	15.46	9.73
1999	6537.75	2309.27	1213.90	921.76	553.48	207.30	88.60	31.29	9.78	7.20
2000	4576.12	1421.00	1191.52	868.18	425.68	147.37	88.46	48.72	23.81	19.33
2001	4869.82	1118.00	1157.57	688.29	430.23	169.77	80.22	39.01	24.39	19.39
2002	6037.73	1237.12	770.27	949.21	621.67	229.12	85.32	41.74	23.56	19.98
2003	3134.38	825.42	590.73	844.17	679.14	280.49	95.77	45.98	18.52	8.99
2004	2776.14	1101.77	581.26	852.91	770.93	322.30	99.68	36.29	13.46	9.64
2005	2784.47	1024.77	336.51	634.44	654.03	317.51	120.04	44.93	18.22	17.41
2006	2294.68	1389.55	376.48	616.25	601.85	298.50	115.65	43.10	17.07	13.61
2007	4489.92	1011.17	357.61	686.41	657.58	312.56	116.12	35.47	11.90	10.70
2008	6067.40	985.00	294.36	588.01	544.41	255.31	81.41	22.10	7.17	7.44

Table 2 Catch-at-age of all BET fisheries in the Indian Ocean (1950-2008) (in thousands of fish) used for tuned VPA analysis (Alternative case)

age	0	1	2	3	4	5	6	7	8
1950	0.04	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1951	0.26	1.41	0.01	0.00	0.01	0.01	0.01	0.00	0.00
1952	0.30	1.65	0.01	0.00	0.02	0.02	0.01	0.00	0.00
1953	0.32	2.63	6.50	12.34	10.49	4.69	1.45	0.31	0.05
1954	0.57	6.37	26.16	42.91	36.75	20.59	9.03	3.37	1.00
1955	0.72	9.02	36.50	59.92	51.76	29.05	12.83	4.98	1.76
1956	0.73	12.17	48.50	75.71	65.82	38.49	17.91	7.37	2.70
1957	34.53	14.44	50.83	75.04	62.00	34.73	15.53	6.06	2.09
1958	34.70	15.44	48.09	67.84	57.28	33.20	16.25	7.46	2.88
1959	34.51	12.77	41.81	59.04	49.60	28.60	13.51	5.74	2.03
1960	17.74	16.90	67.42	97.84	82.15	46.42	21.76	9.02	3.22
1961	26.48	16.40	61.80	91.13	77.46	43.88	20.35	7.94	2.48
1962	26.39	19.24	79.18	116.44	96.16	53.12	23.58	9.31	3.26
1963	26.15	16.10	61.15	88.39	69.85	36.74	15.93	6.14	2.07
1964	25.77	11.95	67.66	111.55	100.17	57.13	22.47	7.45	2.27
1965	17.40	20.91	81.85	114.13	97.33	57.81	26.85	11.23	4.35
1966	27.44	30.34	98.60	128.90	103.07	69.99	40.24	18.57	7.88
1967	29.40	14.68	119.14	160.29	133.31	72.86	29.73	9.72	2.94
1968	31.60	36.98	159.55	241.32	223.04	121.72	43.21	15.97	6.76
1969	32.56	44.40	183.20	220.88	153.13	76.43	33.77	11.12	3.03
1970	52.10	65.34	138.90	218.74	149.15	69.35	26.94	9.26	1.42
1971	28.73	45.88	109.92	131.81	123.11	71.86	29.00	8.42	2.40
1972	32.17	18.34	89.90	144.44	116.67	55.04	21.27	5.06	1.56
1973	68.13	9.98	48.40	122.25	93.99	52.15	22.06	8.33	3.27
1974	77.38	35.11	104.59	187.95	180.92	73.68	30.73	11.13	2.49
1975	66.58	141.10	216.69	221.94	174.26	115.39	45.22	15.44	4.85
1976	79.17	77.75	272.55	202.54	103.30	68.97	30.77	10.49	3.89
1977	88.24	45.42	121.54	198.60	158.91	90.93	63.37	39.65	10.59
1978	67.08	50.75	141.87	340.53	280.37	141.17	63.27	27.40	10.01
1979	73.64	74.21	166.43	262.64	175.55	78.27	29.80	12.33	4.38
1980	64.35	84.14	205.85	232.87	176.63	77.35	35.82	19.53	8.30
1981	130.12	90.73	210.97	224.54	162.68	87.71	40.46	19.28	6.77
1982	75.88	112.15	221.91	256.42	175.28	108.82	57.90	32.91	17.62
1983	116.51	158.12	253.55	323.10	243.82	124.26	56.66	24.04	12.04
1984	648.05	208.80	233.60	282.15	193.39	103.41	48.11	19.43	10.62
1985	1137.93	348.67	336.31	347.81	234.35	110.36	45.20	19.07	7.25

Table 2 continued.

age	0	1	2	3	4	5	6	7	8
1986	976.56	662.04	334.96	376.10	257.35	111.39	46.12	18.47	7.13
1987	1462.37	946.02	324.21	401.92	287.71	112.23	55.36	26.63	10.61
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1991	1759.66	617.65	346.69	503.64	425.18	183.22	47.34	16.61	6.05
1992	1455.82	650.14	470.72	491.49	348.50	139.62	50.28	15.54	5.02
1993	2107.45	498.65	357.12	682.11	516.64	230.43	97.01	37.51	16.02
1994	2843.58	1010.47	468.45	588.08	471.39	277.69	130.60	41.16	16.94
1995	5029.83	1782.28	941.51	699.10	403.41	188.49	85.77	45.70	16.75
1996	3692.96	1099.32	773.33	859.23	521.01	207.58	107.40	57.87	25.98
1997	7116.24	1675.13	688.48	848.86	595.06	233.93	108.96	56.14	28.51
1998	3763.14	1407.75	1157.23	944.95	564.79	218.61	92.80	41.89	15.46
1999	6537.75	2309.27	1213.90	921.76	553.48	207.30	88.60	31.29	9.78
2000	4576.12	1421.00	1191.52	868.18	425.68	147.37	88.46	48.72	23.81
2001	4869.82	1118.00	1157.57	688.29	430.23	169.77	80.22	39.01	24.39
2002	6037.73	1237.12	770.27	949.21	621.67	229.12	85.32	41.74	23.56
2003	3134.38	825.42	590.73	844.17	679.14	280.49	95.77	45.98	18.52
2004	2776.14	1101.77	581.26	852.91	770.93	322.30	99.68	36.29	13.46
2005	2784.47	1024.77	336.51	634.44	654.03	317.51	120.04	44.93	18.22
2006	2294.68	1389.55	376.48	616.25	601.85	298.50	115.65	43.10	17.07
2007	4489.92	1011.17	357.61	686.41	657.58	312.56	116.12	35.47	11.90
2008	6067.40	985.00	294.36	588.01	544.41	255.31	81.41	22.10	7.17

Table 2 continued.

age	9	10	11	12	13	14	15	16	17	18+
1950	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1951	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1952	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1953	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1954	0.24	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1955	0.52	0.14	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1956	0.82	0.22	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1957	0.70	0.24	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1958	0.97	0.33	0.08	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1959	0.64	0.19	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1960	0.99	0.27	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1961	0.69	0.20	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1962	1.00	0.33	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1963	0.58	0.21	0.08	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1964	0.61	0.22	0.07	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1965	1.49	0.53	0.13	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1966	2.66	0.69	0.13	0.02	0.04	0.11	0.05	0.01	0.00	0.00
1967	0.80	0.17	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1968	2.42	0.81	0.17	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1969	0.77	0.21	0.05	0.05	0.03	0.01	0.00	0.00	0.00	0.03
1970	0.25	0.13	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1971	0.86	0.50	0.17	0.05	0.02	0.00	0.00	0.00	0.00	0.00
1972	0.38	0.07	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1973	0.78	0.14	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1974	0.57	0.17	0.05	0.01	0.00	0.01	0.00	0.00	0.00	0.01
1975	1.52	0.93	0.33	0.04	0.02	0.01	0.00	0.00	0.00	0.43
1976	1.42	0.61	0.25	0.19	0.18	0.05	0.01	0.01	0.00	0.02
1977	1.52	0.63	0.42	0.08	0.03	0.01	0.01	0.01	0.00	0.02
1978	2.95	0.86	0.31	0.19	0.19	0.06	0.00	0.00	0.00	0.00
1979	1.69	1.21	0.68	0.17	0.10	0.03	0.00	0.00	0.00	0.00
1980	2.83	1.06	0.41	0.13	0.07	0.02	0.00	0.00	0.00	0.00
1981	2.24	1.20	0.63	0.25	0.12	0.03	0.00	0.00	0.00	0.02
1982	7.33	2.75	0.87	0.21	0.09	0.03	0.03	0.04	0.02	0.04
1983	5.90	2.63	1.29	0.43	0.13	0.06	0.04	0.03	0.01	0.02
1984	5.50	2.37	0.62	0.17	0.06	0.03	0.01	0.01	0.00	0.01
1985	2.16	0.73	0.24	0.07	0.02	0.01	0.00	0.00	0.00	0.05

Table 2 continued.

age	9	10	11	12	13	14	15	16	17	18+
1986	2.81	1.19	0.41	0.13	0.06	0.02	0.00	0.00	0.00	0.00
1987	4.14	1.36	1.03	0.42	0.06	0.03	0.01	0.00	0.00	0.00
1988	3.29	0.85	0.30	0.08	0.01	0.00	0.00	0.00	0.00	0.00
1989	2.01	0.57	0.21	0.07	0.01	0.00	0.00	0.00	0.00	0.01
1990	1.86	0.65	0.29	0.12	0.04	0.01	0.00	0.00	0.00	0.00
1991	2.64	1.08	0.18	0.02	0.02	0.01	0.00	0.00	0.00	0.01
1992	2.00	0.83	0.16	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1993	8.99	5.96	2.47	0.50	0.11	0.03	0.02	0.01	0.00	0.29
1994	7.52	2.36	0.88	0.59	0.23	0.09	0.08	0.07	0.03	0.07
1995	4.02	1.57	0.73	0.40	0.43	0.17	0.10	0.12	0.04	2.11
1996	9.98	3.27	1.06	0.63	0.53	0.17	0.11	0.14	0.05	0.21
1997	13.16	8.41	4.90	2.79	0.73	0.06	0.10	0.16	0.05	0.12
1998	5.92	2.36	0.97	0.34	0.12	0.02	0.00	0.00	0.00	0.01
1999	4.21	1.90	0.83	0.23	0.03	0.00	0.00	0.00	0.00	0.00
2000	11.60	5.49	1.70	0.34	0.08	0.08	0.04	0.01	0.00	0.00
2001	12.14	5.06	1.48	0.38	0.08	0.02	0.01	0.00	0.01	0.21
2002	11.25	5.19	2.61	0.71	0.10	0.02	0.01	0.00	0.00	0.09
2003	5.60	1.81	0.80	0.31	0.16	0.07	0.05	0.05	0.02	0.12
2004	4.66	2.08	1.14	0.56	0.31	0.18	0.14	0.14	0.05	0.38
2005	8.15	4.23	2.07	0.93	0.53	0.31	0.24	0.24	0.09	0.63
2006	7.17	3.56	1.39	0.49	0.34	0.20	0.11	0.09	0.03	0.23
2007	5.18	2.42	1.11	0.61	0.41	0.27	0.14	0.09	0.03	0.43
2008	3.36	1.82	0.94	0.47	0.28	0.18	0.11	0.08	0.03	0.18

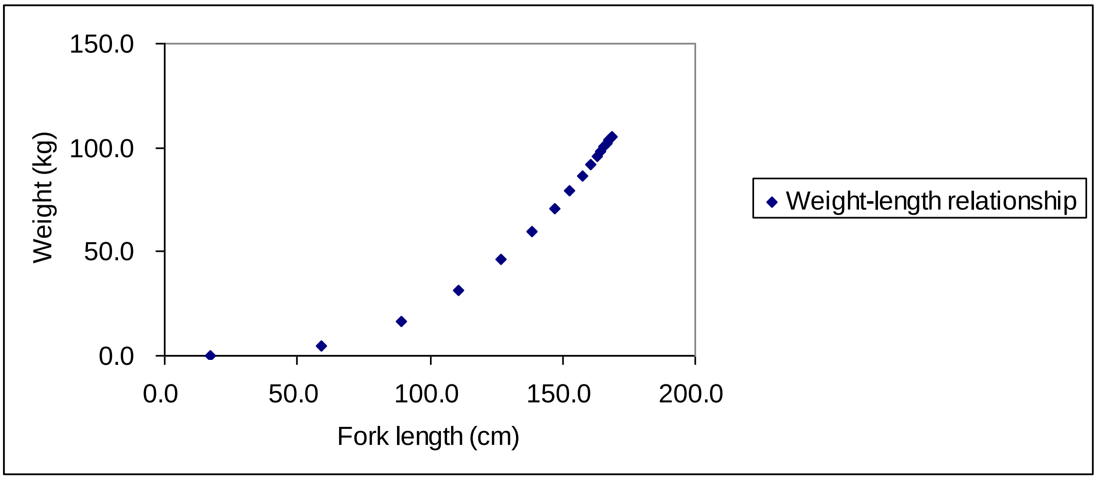

Figure 1 Weight-Length relationship used in Shone et al. (2009) for bigeye tuna in the Indian Ocean

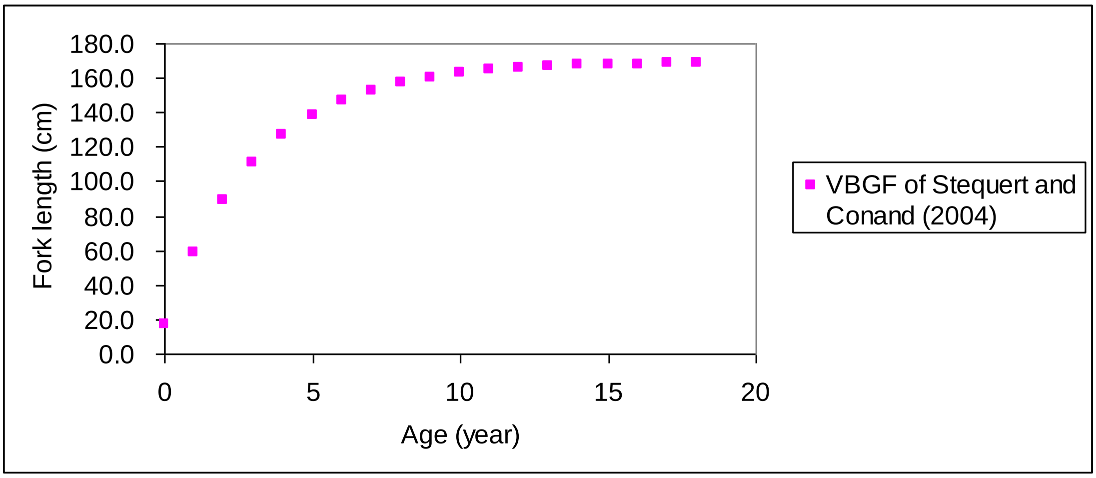

Figure 2 Von Bertalanffy growth model for bigeye tuna in the Indian Ocean

Figure 3 Maturity-at-age for bigeye tuna in the Indian Ocean

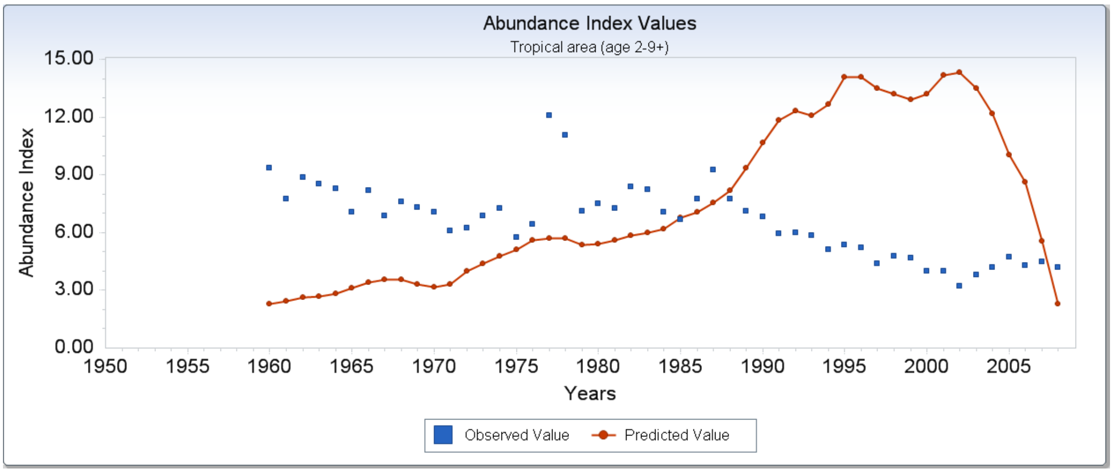

Figure 4 (a) Base case CPUE fits for tropical area

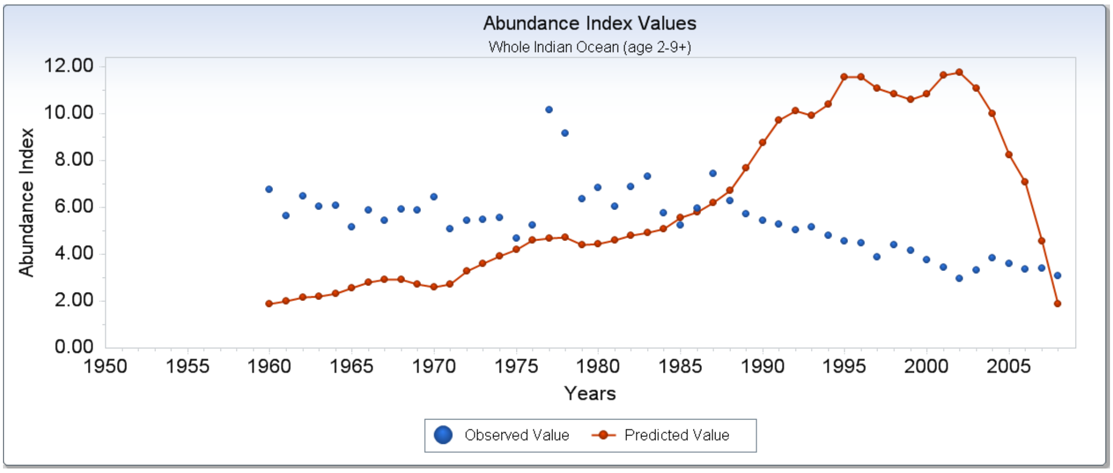

Figure 4 (b) Base case CPUE fits for the whole Indian Ocean

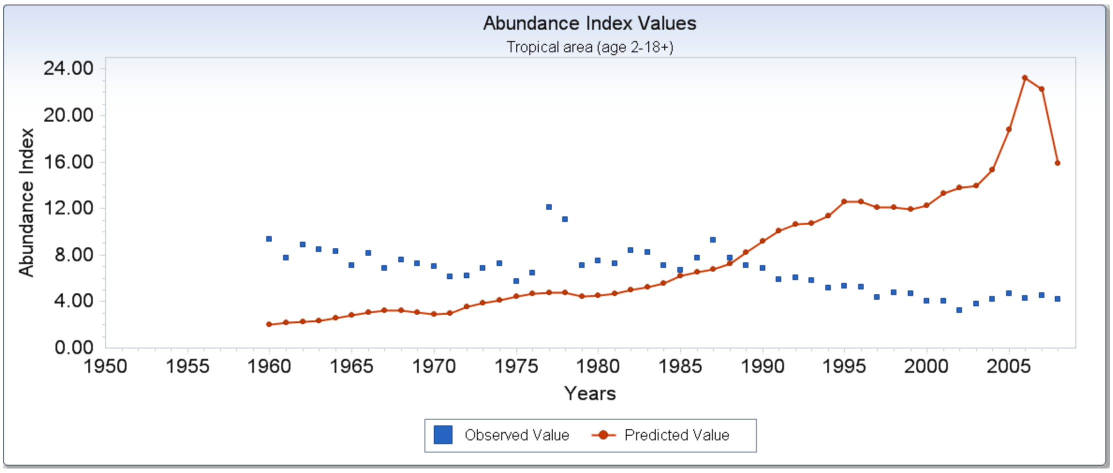

Figure 5 (a) Alternative case CPUE fits for tropical area

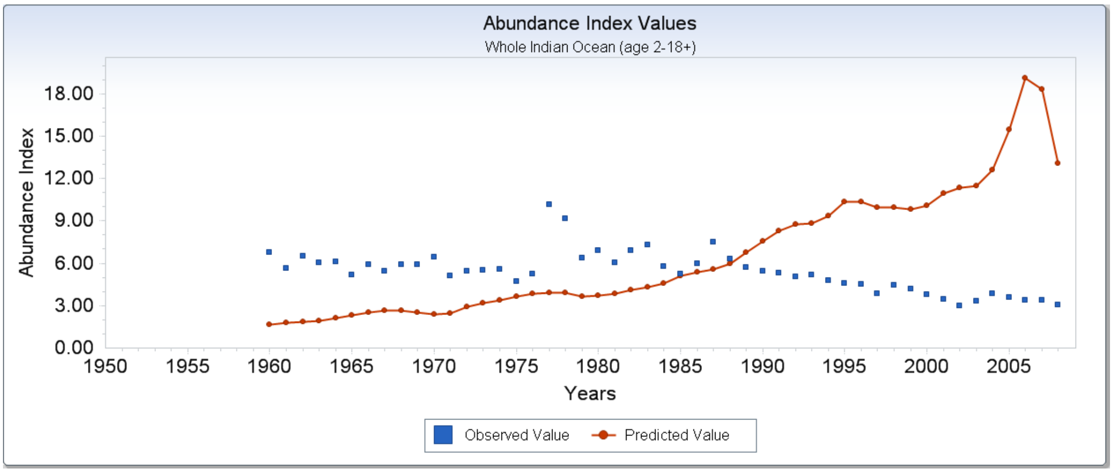

Figure 5 (b) Alternative case CPUE fits for the whole Indian Ocean

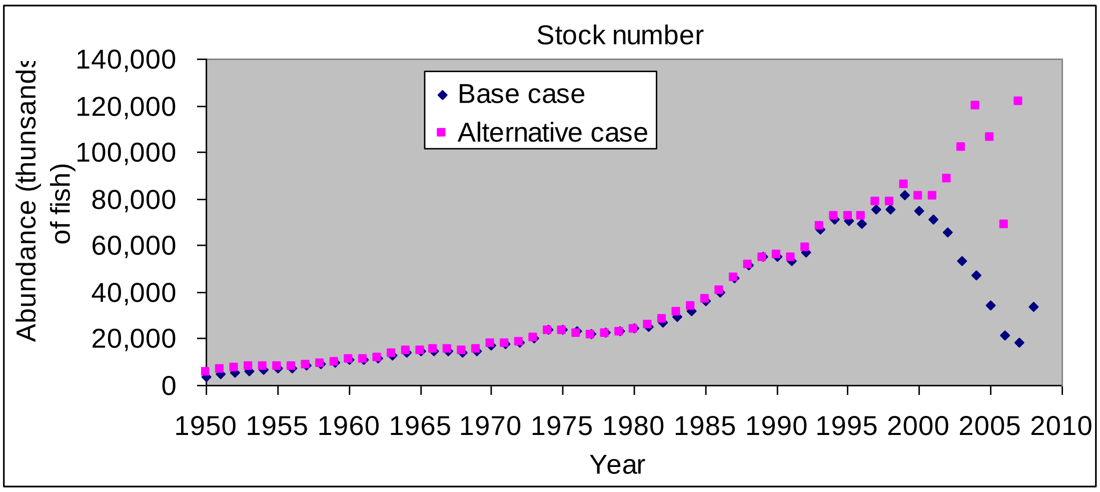

Figure 6 (a) Comparison of stock number estimated by tuned VPA under Base case and Alternative case

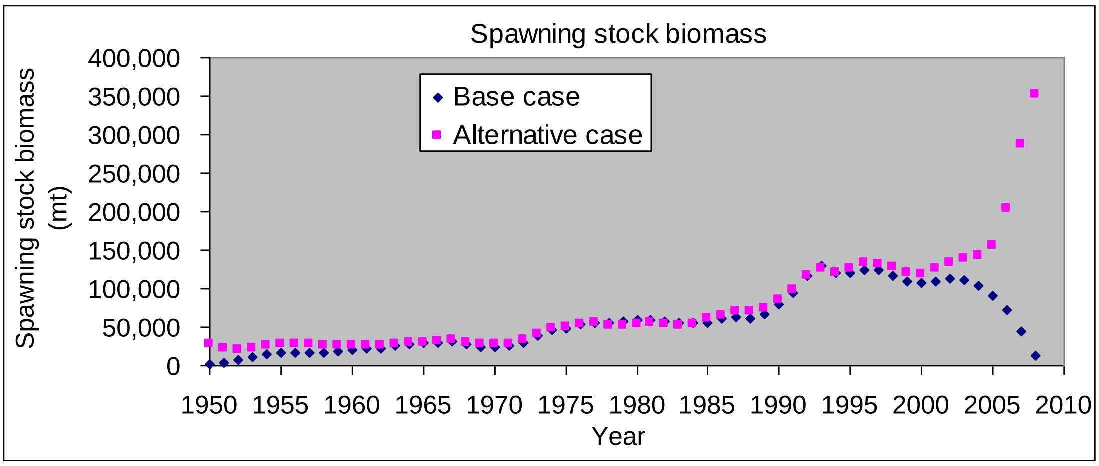

Figure 6 (b) Comparison of spawning stock biomass estimated by tuned VPA under Base case and Alternative case

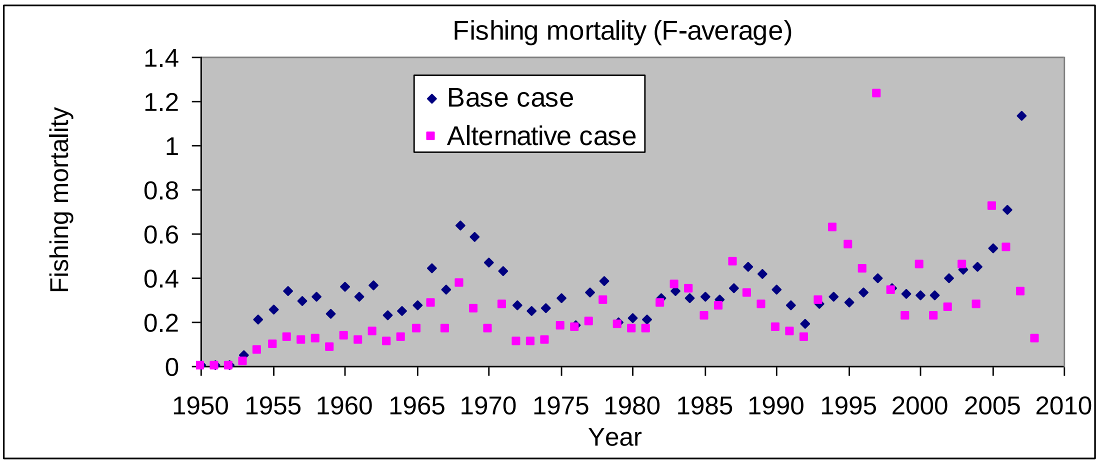

Figure 6 (c) Comparison of fishing mortality estimated by tuned VPA under Base case and Alternative case

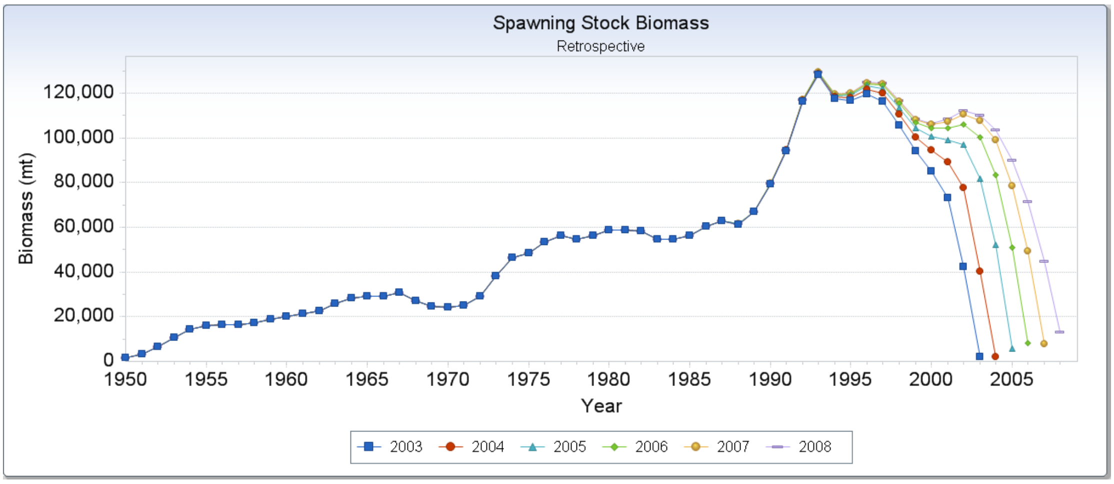

Figure 7 (a) Base case retrospective error for the spawning biomass estimates

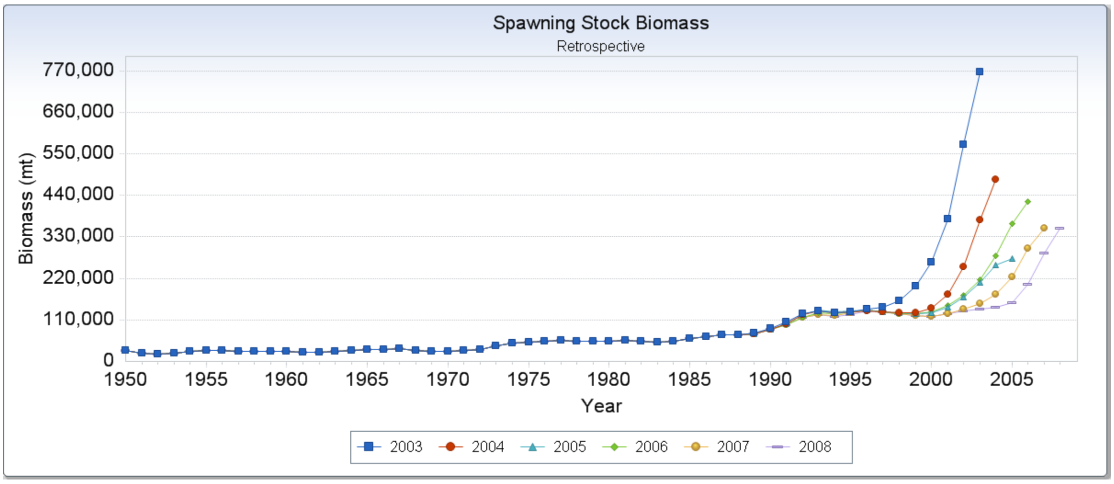

Figure 7 (b) Alternative case retrospective error for the spawning biomass estimates

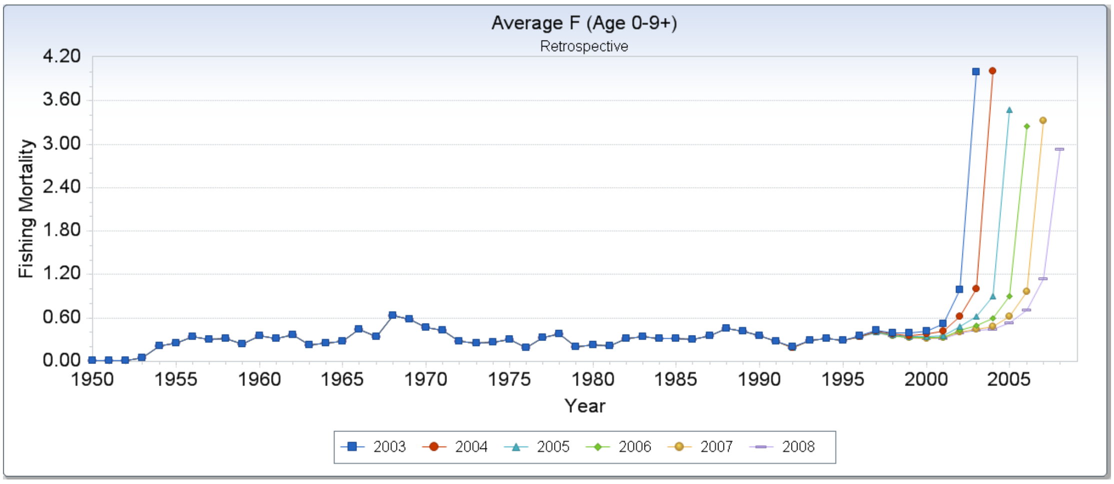

Figure 8 (a) Base case retrospective error for the fishing mortality estimates

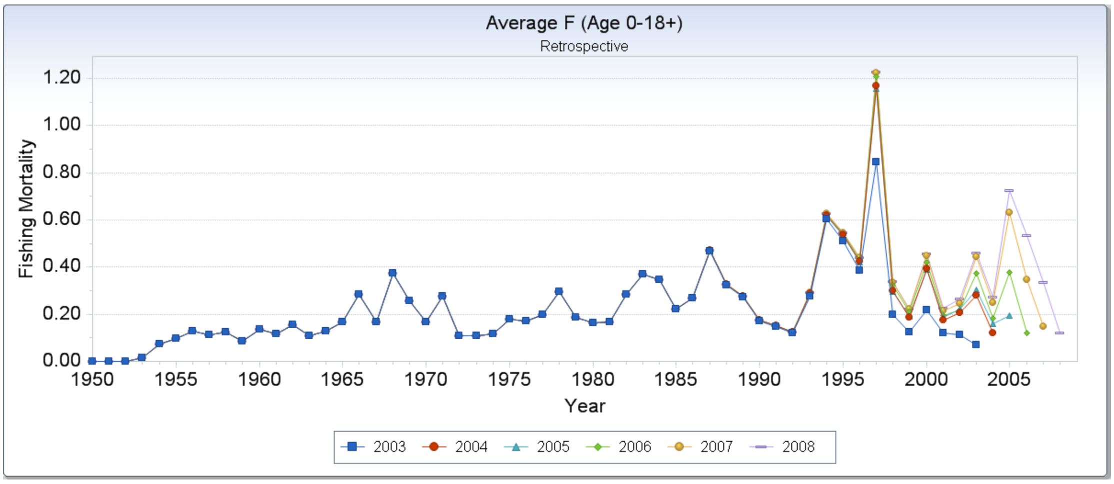

Figure 8 (b) Alternative case retrospective error for the fishing mortality estimates