STOCK ASSESSMENT OF BIGEYE TUNA (*THUNNUS OBESUS*) IN THE INDIAN OCEAN BASED ON THE VIRTUAL POPULATION ANALYSIS (VPA)

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ABSTRACT

This paper attempted the stock assessment of bigeye tuna in the Indian Ocean based on an age-structured analysis. The catch-at-age method of analysis known as ADAPT was used to estimate the age-specific population numbers using a catch-at-age matrix and an age-specific abundance index based on the Japanese longline CPUE. Under a given M vector (0.8 for age 0-1 and 0.4 for age 2+), results show that the total population (biomass) has been gradually increasing from 2.7 million (1970) to 4.5 million t (1990), After 1990, the total biomass sharply decreased to 3.3 million t (1994). Recruitment had been gradually increasing from 20 million (1970) to 40 million fish (1998). However, the recruitment has been sharply decreasing from 40million (1998) to 15 million fish (1992), but showed an increase to 21-23 million in 1993-94. Spawning biomass has been gradually increasing from 174,000t to 373,000t during 1970-92 and then from 1992, it decreased sharply to 114,000t in 1994. Exploitation rate has been gradually increasing from 5.1% to 13.9% during 1970-91 and then as from 1991, it sharply increased to 31% in 1994. It was concluded that population estimates were comparable to those in those in the Atlantic Ocean, and they are likely to be reasonable estimates.

INTRODUCTION

Strengthening tuna management role is one of the key tasks for the newly established Indian Ocean Tuna Commission (IOTC). Hence, the stock assessment will become the essential work for the successful management because it provides the basic information for its decision process. As bigeye tuna (BET) is highlighted in the first tropical tuna working party meeting of the IOTC, we attempted the ADAPT type of VPA to assess the Indian Ocean BET stock. VPA was applied because age based stock assessment has been recommended for BET in the Indian Ocean (e.g., Stobberup *et al* 1998 and others). We assume that the Indian Ocean BET is single stock.

REVIEW OF THE AGE STRUCTURED MODELS (MODIFIED FROM STOBBERUP ET AL, 1997)

Age structured models have also been applied in the assessment of bigeye in the Indian Ocean, although not recently. A preliminary yield-per-recruit analysis of the bigeye stock for the 1962-1985 period indicated that higher yields could be obtained only by increasing *F* for fish of ages greater than 2 years (Marsac and Hallier 1987). It was noted that, while the purse-seine fishery targeted 0- to 3-year-old bigeye, the longline fishery targeted 2- to 8-year-olds. Marsac and Hallier concluded that, since the purse-seine catch was low, this would not have an important effect on the longline fishery. However, the present purse-seine catches of bigeye are roughly 40%, by weight, of the longline catches, so the effect could now be important.

Another age-structured model, based on the ADAPT framework, was applied for practically the same period by Miyabe (1988). The catch at age was estimated by the slicing method using a length-age relationship for the Pacific Ocean (Suda and Kume 1967). After a decline in CPUE at the initial stages of the fishery, the standardized CPUE was considered stable, which was assumed to be the result of older fish being the primary targets of the longline fishery (Koido and Miyabe 1987). At that time, the catches of bigeye by purse seiners were estimated to be only 2,000 tons.

Although the results of the two studies which employed age-structured models were similar and complementary, they differed in explaining the CPUE trend. In both studies it was concluded that recruitment was relatively stable, and since most of fish taken were older ones, the standardized CPUE was also stable. Nevertheless, while Miyabe (1988) indicated that the rise in CPUE in 1977 was due to greater abundance of bigeye, Marsac and Hallier (1987) indicated that this was largely due to the deployment of deep longlining gear which increased the catchability of bigeye. A recent study by Okamoto and Miyabe (1996), using general linear models to standardize effort indicates that there was, in fact, an increase in CPUE in about 1977, which cannot be completely explained, by an increase in the deployment of deep longline gear. The most recent study on CPUE analyses by Okamoto and Miyabe (1998) showed the standardized CPUE trend of the Japanese LL fisheries (all age combined) from 1975-97 have been gradually decreasing.

INFORMATION

Following information were used to conduct the VPA :

- Catch-at-age matrix (Nishida, 1999)
- Abundance index (Okamoto and Miyabe, 1998)
- Database from NRIFSF of Japan for Japanese catch and size/weight data of longline (LL)

ESTIMATION OF AGE SPECIFIC ABUNDANCE INDEX

Okamoto and Miyabe (1998) estimated the abundance index by the GLM (standardized Japanese LL CPUE: all age pooled). Using MULTIFAN, the abundance index was separated into from age 2 to age 8+. The estimation method is explained as follows and Box 1 summarizes the estimation procedures.

Catch-at-size

Catch-at-size by quarter and sub-area were initially estimated using the Japanese longline catch and size data. Sub-areas were needed because the size frequency distributions (catch-at-size, hence age compositions) were heterogeneous by sub-area. Five sub-areas were established (Fig. 2).

Sample sizes of the Japanese size frequency data (1970-96) by year, quarter and sub-area were investigated. If sample sizes were not enough (less than 150) in some quarter and sub-area, neighboring size data (next sub-area or next quarter) were substituted. Then, catch-at-size by quarter, sub-area and 2 cm interval were estimated by multiplying the total catch (in number) by compositions of the size frequency distribution.

BOX 1

Procedures to estimate age specific abundance index

Japanese size frequency distribution
by year, quarter and sub-area (*)

? compositions of size frequency distribution

? catch-at-size = (composition of size frequency distribution) x (total catch in number) by year, quarter and sub-area

? catch-at-size by year and quarter

? MULTIFAN

? Age compositions by year and quarter

? Annual age composition

? Age specific abundance index

= (annual age compositions) x (abundance index : all ages pooled) (**)

Note (*) : If there are not enough sample sizes in the size frequency distribution, neighboring size distribution (in terms of time and sub-area) is substituted.

Note (**) :The abundance index (all ages pooled) is from Okamoto and Miyabe (1998)

Age compositions

Moving average was applied to smooth the frequency distributions because some Japanese size frequency data include 5-cm interval information. Then, size frequency distribution by quarter was computed by pooling those of all sub-areas. Then, using MULTIFAN, annual size frequency distribution were converted to age composition, In MULTIFAN, K, sizes of the initial and last age (1 and 8+ respectively) were fixed to get the estimations smoothly. It was assumed that there were no age 0 fish caught by the Japanese LL. Finally, annual estimated age compositions were estimated by computing average quarterly compositions (Table 1).

Table 1 Estimated annual age composition of the Japanese LL fisheries based on the MULTIFAN analyses

YR	A1	A2	A3	A4	A5	A6	A7+
70	0.00	0.05	0.34	0.39	0.18	0.02	0.00
71	0.00	0.12	0.34	0.35	0.16	0.03	0.00
72	0.00	0.05	0.39	0.35	0.18	0.03	0.00
73	0.00	0.00	0.35	0.41	0.20	0.03	0.00
74	0.00	0.03	0.23	0.45	0.25	0.04	0.00
75	0.00	0.07	0.22	0.40	0.26	0.05	0.00
76	0.00	0.17	0.31	0.29	0.17	0.05	0.00
77	0.00	0.03	0.27	0.46	0.18	0.06	0.00
78	0.00	0.02	0.28	0.46	0.21	0.03	0.00
79	0.00	0.12	0.27	0.39	0.20	0.03	0.00
80	0.00	0.10	0.34	0.40	0.15	0.01	0.00
81	0.00	0.14	0.37	0.36	0.12	0.02	0.00
82	0.00	0.07	0.36	0.39	0.14	0.02	0.00
83	0.00	0.12	0.35	0.38	0.14	0.02	0.00
84	0.01	0.08	0.38	0.31	0.15	0.05	0.01
85	0.01	0.10	0.45	0.29	0.12	0.04	0.00
86	0.01	0.11	0.43	0.32	0.10	0.04	0.01
87	0.00	0.06	0.37	0.41	0.12	0.04	0.00
88	0.00	0.07	0.38	0.37	0.12	0.04	0.01
89	0.01	0.10	0.36	0.34	0.15	0.05	0.00
90	0.00	0.06	0.41	0.38	0.10	0.04	0.01
91	0.00	0.06	0.32	0.45	0.14	0.02	0.01
92	0.00	0.06	0.39	0.35	0.17	0.03	0.00
93	0.00	0.01	0.27	0.51	0.12	0.06	0.02
94	0.00	0.01	0.27	0.34	0.25	0.12	0.01
95	0.01	0.04	0.16	0.25	0.34	0.15	0.04
96	0.00	0.05	0.40	0.31	0.14	0.07	0.03

(3) Age specific abundance index

By multiplying the age compositions by the abundance index (all age pooled) by Okamoto and Miyabe (1998), age specific abundance index were evaluated for age 2-7+. We did not used ages 0-1 data because they were not fully exploited. Table 2 and Fig 2 shows the results. For ages 2-4, decreasing trends have been observed after 1987, but in 1996, the indices for ages 2-3 suddenly increased. For age 5-6, the trends have been stable in recent years, but jumped in 1995.

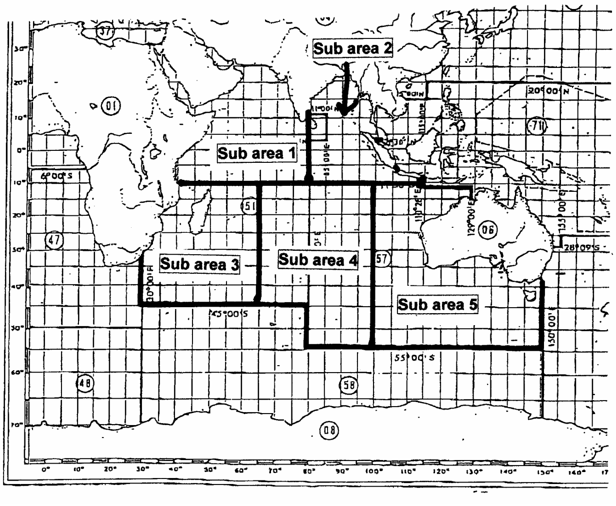

Fig. 2 Sub-area to estimate age compositions

Table 2 Estimated age-specific abundance indices based on the GLM analyses of the Japanese LL CPUE data

YR	A2	A3	A4	A5	A6	A7
70	0.34	2.21	2.53	1.18	0.15	0.00
71	0.65	1.80	1.82	0.86	0.13	0.00
72	0.28	2.43	2.18	1.13	0.19	0.00
73	0.02	2.13	2.52	1.25	0.20	0.00
74	0.18	1.38	2.67	1.47	0.22	0.00
75	0.38	1.14	2.08	1.32	0.23	0.00
76	1.02	1.86	1.72	0.99	0.27	0.00
77	0.24	2.57	4.33	1.71	0.59	0.02
78	0.16	2.52	4.18	1.92	0.30	0.02
79	0.81	1.86	2.74	1.37	0.18	0.00
80	0.68	2.37	2.79	1.03	0.07	0.00
81	0.92	2.44	2.41	0.77	0.10	0.00
82	0.48	2.60	2.81	1.02	0.16	0.02
83	0.88	2.66	2.88	1.05	0.15	0.00
84	0.44	1.99	1.66	0.77	0.28	0.11
85	0.55	2.60	1.65	0.71	0.20	0.01
86	0.76	3.02	2.27	0.69	0.25	0.04
87	0.51	3.06	3.33	0.95	0.29	0.00
88	0.48	2.63	2.56	0.81	0.29	0.05
89	0.62	2.24	2.10	0.92	0.28	0.02
90	0.38	2.48	2.30	0.58	0.24	0.03
91	0.31	1.71	2.41	0.76	0.12	0.05
92	0.32	1.98	1.76	0.87	0.13	0.01
93	0.06	1.30	2.41	0.59	0.30	0.11
94	0.03	1.20	1.54	1.11	0.54	0.03
95	0.18	0.76	1.20	1.65	0.70	0.30
96	0.23	1.77	1.37	0.62	0.29	0.16

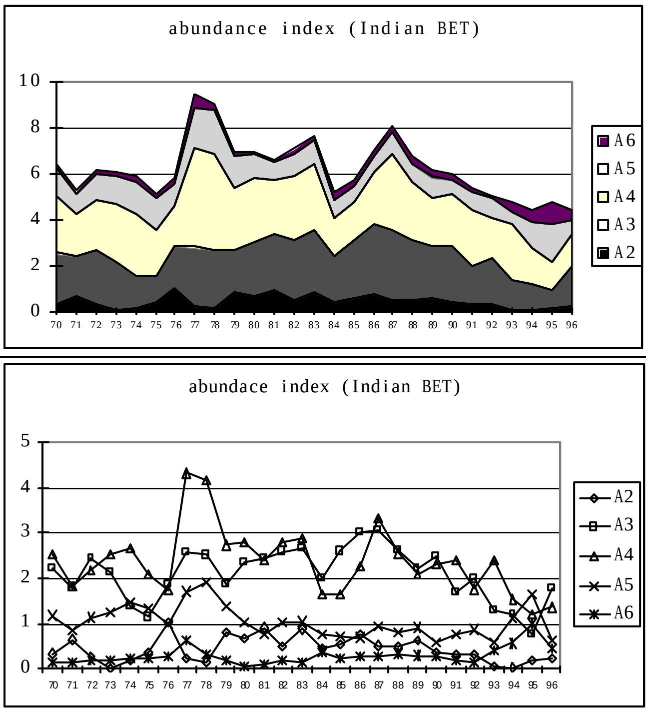

Fig. 2 Trend of estimated age specific abundance indices based on the GLM analyses of the Japanese LL data.

CATCH-AT-AGE (CAA)

CAA estimated by Nishida (1999) was used. Table 3 and Fig. 3 show the trend of the CAA.

Table 3 Estimated catch-at-age matrix of all BET fisheries in the Indian Ocean (1970-96) (in millions of fish)

YR	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+	ALL
70	0.00	0.02	0.15	0.21	0.18	0.07	0.01	0.64
71	0.00	0.03	0.14	0.21	0.14	0.06	0.01	0.59
72	0.00	0.01	0.09	0.19	0.13	0.05	0.02	0.49
73	0.00	0.00	0.03	0.14	0.13	0.06	0.01	0.37
74	0.00	0.01	0.06	0.20	0.26	0.11	0.03	0.68
75	0.00	0.04	0.15	0.23	0.32	0.18	0.03	0.93
76	0.00	0.02	0.26	0.24	0.17	0.13	0.03	0.85
77	0.00	0.01	0.09	0.32	0.27	0.14	0.06	0.89
78	0.00	0.02	0.11	0.47	0.45	0.15	0.04	1.24
79	0.00	0.01	0.19	0.30	0.28	0.13	0.03	0.93
80	0.00	0.02	0.21	0.32	0.29	0.11	0.02	0.97
81	0.00	0.03	0.37	0.32	0.21	0.09	0.03	1.05
82	0.01	0.02	0.21	0.35	0.30	0.14	0.07	1.11
83	0.05	0.04	0.22	0.44	0.33	0.14	0.05	1.27
84	0.12	0.12	0.06	0.32	0.35	0.17	0.08	1.22
85	0.08	0.37	0.12	0.45	0.40	0.18	0.07	1.66
86	0.33	0.32	0.18	0.46	0.45	0.18	0.07	1.99
87	0.36	0.25	0.18	0.37	0.55	0.23	0.08	2.02
88	0.87	0.75	0.22	0.37	0.56	0.22	0.10	3.09
89	1.04	0.82	0.17	0.39	0.43	0.19	0.07	3.12
90	1.01	0.35	0.09	0.42	0.48	0.16	0.07	2.58
91	1.33	1.14	0.17	0.27	0.57	0.20	0.05	3.73
92	0.96	0.73	0.10	0.35	0.40	0.21	0.04	2.78
93	1.33	0.71	0.06	0.35	0.65	0.24	0.17	3.50
94	1.49	1.28	0.13	0.27	0.47	0.32	0.26	4.22
95	2.84	1.97	0.29	0.33	0.30	0.43	0.37	6.52
96	2.13	2.36	0.25	0.37	0.49	0.27	0.24	6.11

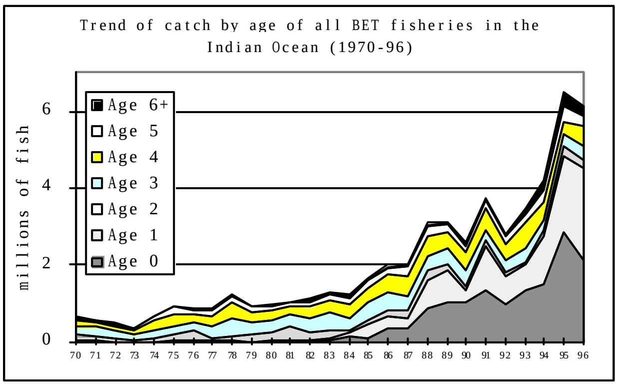

Fig 3. Trend of estimated annual age-specific catch of BET fisheries in the Indian Ocean (1970-96)

VPA

METHODS

Using the ADAPT type VPA, the analyses were conduced. Theoretical backgrounds to estimate parameters are described as follows:

Basic structure of VPA

Stock number of a certain age at a beginning of certain year, $N_{age,yr}$ and catch in number of that year $C_{age,yr}$ were determined by the following equations :

$N_{age+1,yr+1} = N_{age,yr}\exp(-(M_{age} + F_{age,yr}))$ for age = 0 to 5

$N_{6+,yr+1} = N_{5,yr}\exp(-(M_5 + F_{5,yr})) + N_{6+,yr}\exp(-(M_{6+} + F_{6+,yr}))$ for age = 6 or older (1)

$$C_{age,yr} = N_{age,yr}\frac{F_{age,yr}}{F_{age,yr} + M_{age}}\left\{1 - \exp\left(-\left(F_{age,yr} + M_{age}\right)\right)\right\} \quad (2)$$

where M_{age} and $F_{age,yr}$ are natural and fishing mortality rates and all fish of age 6 and older are aggregated into one age-group. Standard backward VPA was used for estimation of F for all age group other than plus group. F for age 2, 3, and 4 in 1996 as well as F for age 5 in 1977, 1986, 1992, 1993 and 1996 were estimated as parameters by minimizing the objective function described in the equation (6) on page 12. F for terminal age (age 5) between parameterized years was estimated using linear interpolation.

Tuning of VPA.

The VPA was adjusted to select a set of parameters to minimize the objective function. The objective function was defined as a total of sum of square of difference between predicted and observed values for the following components:

- abundance indices obtained from standardized CPUE of Japanese longline. - estimated observed catch (age 5)

Abundance indices from Japanese longline CPUE

It was assumed that stock number in a middle of year was proportional to relative abundance indices obtained from Japanese longline standardized CPUE with log-normal error structure. The population size in a middle of year was determined as a mean of population estimates at the beginning of that year and those at the beginning of the following year for a certain cohort.

$$Nmid_{age,yr} = \frac{1}{2}\left(N_{age,yr} + N_{age+1,yr+1}\right) \quad (4)$$

where $Nmid_{age,yr}$ and $N_{age,yr}$ correspond to the stock size of a certain age and year in a middle of year and at the beginning of year, respectively.

Parameter estimations

Seven indices were estimated for age 2, age 3, age 4, age 5 and age 6+. Indices for Age 0-1 were not used because they were not fully exploited by the LL. The objective function for each index was :

$$I = q \cdot \sum Nmid \cdot \exp(\varepsilon) \quad (5)$$

$$w\sum_{yr=1970}^{1996}\left(\log \hat{I} - \log I\right)^2 \quad (6)$$

where $\hat{I}$ corresponded to each abundance index and *w* was weight put to that index. Weight (w) was set as 1 for all ages.

F for age 2, 3, and 4 in 1996 as well as F for age 5 in 1977, 1986, 1992, 1993 and 1996 were estimated as parameters by minimizing the objective function described in the equation (6).

Parameter search and summary of input information

Parameter searches were conduced using the software developed by Ishizuka and Takeuchi, National Research Institute of Far Seas Fisheries (NRIFSF) of Japan. Input information is summarized in Table 4. VPA was conduced for two scenarios of M vectors as indicated in Table 4.

Table 4 Input information and options used in the VPA.

Input	Options	Used
Age range		0-6+
Year range		1970-96
Natural mortality	age specific	**(case 1)** ages 0 and 1: 0.8 ages 2 and above: 0.4 **(case 2)** ages 0 and 1: 2.0 ages 2 and above: 0.5
Weights at age	by year	refer to Table 5
No. of indices	1	Japanese LL standardized CPUE by GLM
Calculate max. likelihood replace iterative re weighting variances by index?		re-weighting was not used (only one index)
Objective functions	normal or log norma	log normal
For each index	time of year which index appears	mid

	biomass or number	both
catch-at-age		yearly
Terminal-year Fs to	choose among ages for which there is relative abundance info in terminal year	Age 5
	year period and initial F values	1996 1993 1992 1986 1977 0.3 0.1 0.1 0.1 0.1
F-ratios	yearly F-ratios of greatest age To that of next-greatest age	1.0 used for all cases, all years

Table 5 Age-Length-weight key

Age	L (cm)	W (kg)
0.0	35.014	0.995
0.5	47.890	2.334
1.0	60.001	4.445
1.5	71.402	7.367
2.0	82.144	13.168
2.5	92.273	18.447
3.0	101.832	24.554
3.5	110.857	31.417
4.0	119.388	38.962
4.5	127.457	47.116
5.0	135.097	55.808
5.5	142.334	64.973
6.0	149.196	74.551
6.5	155.707	84.485
7.0	161.891	94.727
7.5	167.767	105.232
8.0	173.356	115.959

RESULTS

Case 1

Results are summarized in Tables 6-7 and Figs 4-8.

Table 6 and Figs 4-5: Estimated population (in number) by age.

Table 6 & Fig. 4 (age 0-6+ for 1970-94) and Fig. 5 (age 2-6+ for 1970-96)

Table 7 : Estimated age specific F matrix.

Fig. 6: Trend of the estimated BET recruitment in the Indian Ocean based on the VPA

Fig. 7: Trend of the estimated BET population (age 0-2) based on the VPA

Fig. 8: Trend of the estimated BET spawning biomass based on the VPA

Fig. 9 : Trend of total biomass, spawning biomass and catch of BET based on the VPA

Fig. 10: Estimated exploitation rate of BET fisheries on the VPA

Table 6 Estimated population by age by age (in millions of fish)

Age	**0**	**1**	**2**	**3**	**4**	**5**	**6+**
70	19.5	6.8	3.3	1.4	1.2	0.6	0.8
71	18.2	8.7	3.0	2.1	0.8	0.7	0.9
72	11.5	8.2	3.9	1.9	1.2	0.4	1.0
73	18.1	5.2	3.7	2.5	1.1	0.7	0.9
74	27.4	8.2	2.3	2.4	1.6	0.7	1.0
75	27.2	12.3	3.7	1.5	1.5	0.9	1.0
76	24.0	12.2	5.5	2.3	0.8	0.7	1.1
77	18.8	10.8	5.5	3.5	1.4	0.4	1.1
78	21.3	8.4	4.8	3.6	2.1	0.7	0.8
79	21.4	9.6	3.8	3.2	2.0	1.0	0.9
80	22.0	9.6	4.3	2.4	1.9	1.1	1.1
81	20.6	9.9	4.3	2.7	1.3	1.0	1.4
82	25.0	9.2	4.4	2.6	1.5	0.7	1.5
83	24.7	11.2	4.1	2.8	1.4	0.8	1.4
84	26.0	11.1	5.0	2.6	1.5	0.7	1.3
85	22.0	11.6	4.9	3.3	1.5	0.7	1.1
86	29.7	9.8	5.0	3.2	1.9	0.7	1.1
87	40.4	13.1	4.2	3.2	1.8	0.9	1.0
88	31.0	17.9	5.7	2.7	1.8	0.7	1.0
89	26.5	13.4	7.6	3.7	1.5	0.8	0.9
90	24.1	11.2	5.5	4.9	2.1	0.7	0.9
91	15.8	10.2	4.8	3.6	3.0	1.1	0.9
92	13.5	6.2	3.8	3.1	2.2	1.5	1.1
93	21.4	5.5	2.3	2.5	1.8	1.1	1.5
94	23.2	8.7	2.0	1.5	1.4	0.7	1.5
95	0.0	9.4	3.1	1.2	0.8	0.6	1.0
96	0.0	0.0	3.0	1.8	0.6	0.3	0.4

Fig. 4 Trend of estimated BET population (age 0-6+) in the Indian Ocean based on the VPA (1970-96)

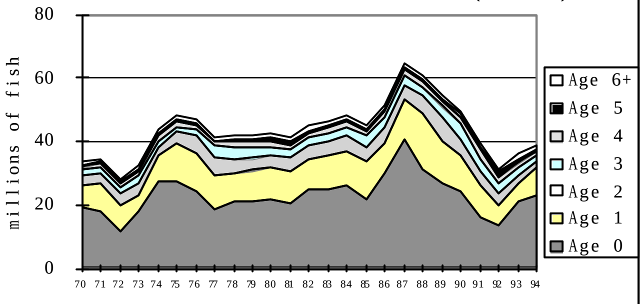

Fig 5 Trend of estimated BET population (age 2-6+) in the Indian Ocean (1970-96)

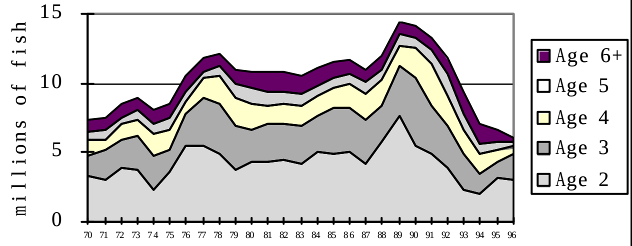

Fig. 6 Trend of estimated recruitment of BET in the Indian Ocean based on the VPA

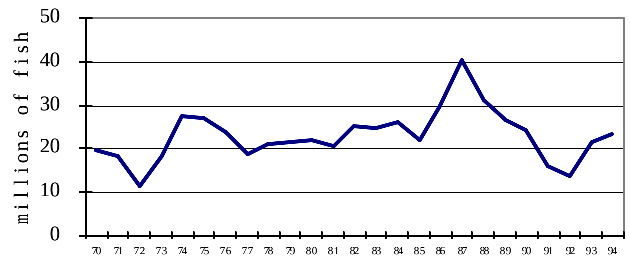

Fig 7 Trend of estimated BET population (age0-2) in the Indian Ocean based on the VPA

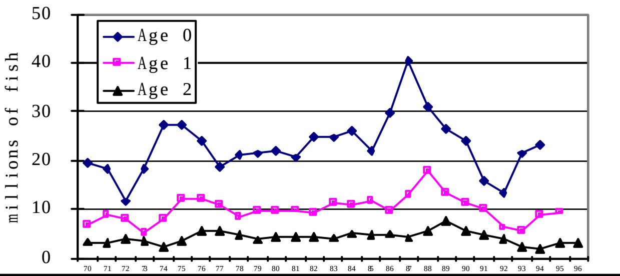

Fig. 8 Trend of total biomass, spawning biomass and catch of BET in the Indian Ocean based on the VPA

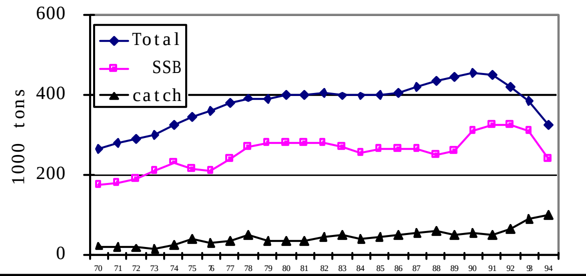

Fig. 9 Estimated exploitation rate of BET fisheries in the Indian Ocean based on the VPA

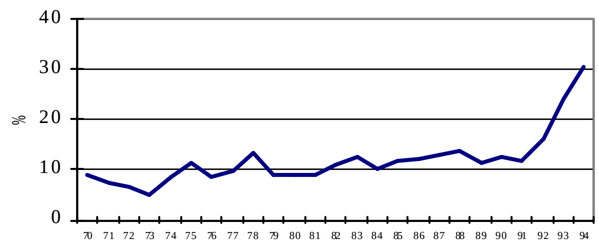

Fig. 10 Trend of estimated spawning BET biomass in the Indian Ocean based on the VPA

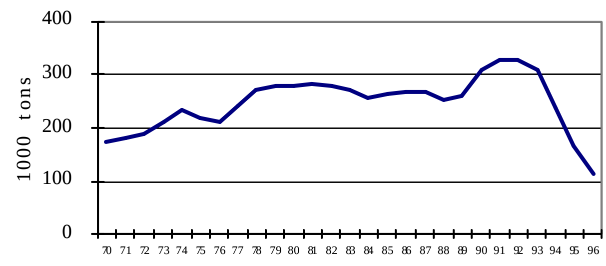

Table 7 Estimated F matrix by age and year

Age	0	1	2	3	4	5	6+
970	0.00	0.00	0.06	0.19	0.20	0.16	0.02
1971	0.00	0.00	0.06	0.13	0.25	0.11	0.02
1972	0.00	0.00	0.03	0.13	0.14	0.16	0.02
1973	0.00	0.00	0.01	0.07	0.15	0.10	0.01
1974	0.00	0.00	0.03	0.11	0.22	0.23	0.03
1975	0.00	0.00	0.05	0.20	0.30	0.28	0.04
1976	0.00	0.00	0.06	0.13	0.29	0.24	0.03
1977	0.00	0.00	0.02	0.12	0.27	0.53	0.07
1978	0.00	0.00	0.03	0.17	0.30	0.31	0.07
1979	0.00	0.00	0.06	0.12	0.18	0.17	0.04
1980	0.00	0.00	0.06	0.18	0.21	0.12	0.03
1981	0.00	0.00	0.11	0.16	0.21	0.11	0.02
1982	0.00	0.00	0.06	0.18	0.27	0.27	0.06
1983	0.00	0.01	0.07	0.21	0.32	0.23	0.05
1984	0.01	0.02	0.02	0.16	0.32	0.35	0.08
1985	0.01	0.05	0.03	0.18	0.38	0.35	0.08
1986	0.02	0.05	0.04	0.19	0.34	0.39	0.09
1987	0.01	0.03	0.05	0.15	0.46	0.37	0.11
1988	0.04	0.06	0.05	0.18	0.46	0.43	0.12
1989	0.06	0.09	0.03	0.14	0.43	0.36	0.10
1990	0.06	0.05	0.02	0.11	0.31	0.36	0.10
1991	0.13	0.17	0.04	0.10	0.26	0.26	0.08
1992	0.11	0.18	0.03	0.15	0.25	0.18	0.05
1993	0.09	0.21	0.03	0.18	0.57	0.29	0.14
1994	0.10	0.23	0.08	0.25	0.52	0.83	0.24
1995	0.00	0.35	0.12	0.38	0.59	2.05	0.59
1996	0.00	0.00	0.11	0.28	3.23	4.00	1.16

Summary of results (case 1)

Based on the results obtained by the VPA analyses, although there was only one scenario, following findings are obtained:

- Total population (biomass) has been gradually increasing from 2.7 million ton (1970) to 4.5 million (1990). After 1990, total biomass sharply decreased to 3.3 millions tons (1994).
- Recruitment had been gradually increasing from 20 millions of fish (1970) to 40 (1988). However, the recruitment have been sharply decreasing from 40 millions of fish (1988) to 15 (1992), but it started to increase to 21-23 millions in 1993-94.
- Spawning biomass has been gradually increasing from 174 thousand tons to 327 during 1970-92, then from 1992; it sharply decreased to 114 thousand tons in 1994.
- Exploitation rate has been gradually increasing from 5.1% to 13.9 % during 1970-91, then from 1991, it sharply increased to 31 % in 1994.
- It was resulted that M vector (0.8 for age 0-1 and 0.4 for age 2 or older) provided reasonable population estimations.

Case 2

Results showed unrealistic and extremely large population size and trends. Thus, we decided not to present and discuss this case.

DISCUSSION

- Because the total BET catch (especially age 0-1) have been increasing since 1988 (Fig. 3), it is likely that population of spawning biomass (age 3+) started to decrease sharply from 1993 due to these sudden increase of high catches for age 0-1.
- Various VPA scenarios need to be examined to investigate the possible dynamics of the population trends. Due to time constraint, we could perform only two scenarios. But, the one of two resulted to be unrealistic. Possible scenario concerned are: (a) sensitivity of M vectors around the one used in this paper (0.8 for age 0-1 and 0.4 for age 2 or older), (b) age group 0-5+ and 0-7+, (c) years to be analyzed: 1980-96 (because of heterogeneity of q, catchability).
- In the MULTIFAN analyses to convert size frequency distribution to age composition, spawning season (or recruitment season) needed to be fixed because of the requirement of the MULTIFAN. Because BET spawning season vary by area and season, this factor needs to consider in the MULTIFAN analyses in the future.
- It was realized that LL did not fully exploit Age 2 BET. Thus, in the VPA, the abundance index for age 2 might not need to be included for turning.
- There is high F in recent years in ages 4-6+. We need to find the reason.
- Results of VPA by Miyabe (1988) and this study were compared. Miyabe’s population estimates are much lower than those of this study (about 1/10 lower). Miyabe’s study did not include the population of age 0. Thus, it is difficult to compare. In addition, Miyabe ‘s study did not yet include the large catch of the PS catch. Thus, the real dynamics may not be able to reflect in his analyses.

RECOMMENDATIONS

Technical recommendation

- If possible, sex based BET stock assessment is needed because growth, size frequency, LW, maturity is quite heterogeneous between sex.
- Results of this study need to be compared with those by different approach, in order to evaluate the status of the BET population in the Indian Ocean objectively.
- Further research, especially tagging experiments, would contribute to better understanding of natural mortality, migration and rates of exchange among various areas. These population parameters are crucial to assess the extent of interactions among fisheries and future effects of changes in exploitation patterns.

- Establish ecologically meaningful sub-areas (statistical areas) of BET to evaluate sample size of size frequency distributions and for GLM analyses.
- To analyze the tag recovery data of BET (1980-99) by JAMARC and also SKJ and YFT for the general recommendation.
- Review of LW data and growth equation for large BET caught by LL.
- In the MULTIFAN, seasonally and spawning is not concerned. Need some method.
- It will be useful if the abundance index based on PS is available beaver it covers aging 0-2 BET, while LL cover age 3-6+. Thus, it is expected that more realistic and accurate assessment can be conducted using these two abundance indices for VPA tuning

General recommendations

In general, interpretation of the results of stock assessment need to be explained in TWO ways, i.e., (a) very conservative way and (b) LESS conservative way. This is because at this stage, any stock assessment can not provide any satisfactory answers, as long as the commercial tuna fisheries data are used. Because IPTP/IOTC has been taking the rather conservative way in the past, the stock status have been reported as 'UNKNOWN' or 'UNCERTAIN', even there were some results of the assessments.

This caused problems that fisheries managers considered that tuna researchers in the region had been nothing or could not do anything. To avoid such mis-leading or mis-understanding, it is suggested that the status stock need to be explained in two ways, 'very conservative way' as in the past and 'less conservative way' if there are any possible answers (results) of the stock assessment. In the latter case, the shortcomings of the analyses needs to be noted , so that the readers can understand why results of the stock status are regarded as less conservative measure. By reporting in these two ways, rather objective and balanced picture can be obtained and the mis-understanding can be solved.

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