STOCK ASSESSMENT OF BIGEYE TUNA (*THUNNUS OBESUS*) RESOURCES IN THE INDIAN OCEAN BY THE AGE STRUCTURED PRODUCTION MODEL (ASPM) ANALYSES

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ABSTRACT

Following recommendations made in the ad hoc method working group meeting in France in April, we attempted the age-structured production model (ASPM) analyses for the bigeye stock assessment. As a result of various runs under various scenarios, we selected two base cases which were likely two extremes under the current uncertain situation. The pessimistic base case (Run 1) provided MSY=83,000 and F(ratio)=0.88, while for the optimistic one (Run 3), MSY= 149,000 tons and F(ratio)=0.35. Considering the current sharp decrease of the longline CPUE and the sharp increase of the catch by both purse seine and longline fisheries, we consider the current stock status is close to Run 1. Thus, we suggest that the catch should be decreased from the current level (143,000 tons) to the MSY level (83,000 tons) of Run 1 as the minimum level.

INTRODUCTION

We attempt to assess the bigeye tuna (BET) resources using the age-structure production model (ASPM) as this approach was recommended for the BST stock assessment in the recent IOTC ad hoc working party meeting on methods held in IRD, Sète, France 23-27, April, 2001 (Anonymous, 2001).

Input data of the ASPM analyses

We used the ASPM software developed by Victor Restrepo (1997) called as ASPMS (stochastic version of ASPM). We attempted 3 base case runs and 6 additional reference case runs to check sensitivity as shown in the first half part of Table 1. Input data of the ASPM (biological, CPUE and fisheries) are explained as follows:

Biological inputs

ASPM requires 4 types of age-specific biological inputs, i.e., weights at the beginning and the mid year, natural mortality (M) and the fecundity. We used 9 age classes from age 0-8+. These inputs are obtained as follows:

Weight-at-age

Weight-at-age in the beginning and the mid year are estimated based on the following growth equations and the length-weight relationship.

- L-W relationship

For fork length < 80 cm : $W = (2.74 \times 10^{-5}) l^{2.908}$ Poreeyanond (1994) (Indian Ocean)

For 80cm <=fork length: $W = (3.661 \times 10^{-5}) l^{2.90182}$ Nakamura and Uchiyama (1966) (Pacific Ocean)

- Growth equation by Tankevich (1982)

Females: $L_{t(cm)} = 209.8\left(1-e^{-0.171[t-(-0.86)]}\right)$

Males : $L_{t(cm)} = 423.0\left(1-e^{-0.058[t-(-1.773)]}\right)$

We used the female equation for age < 3.5 and the average of both equations for 3.5 <=age

Resultant age-weight key

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Age	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5
(kg)	0.7	1.6	4.1	6.3	14.0	18.1	25.9	31.2	40.9	47.1	58.0	64.9	76.8	84.2	96.8	104.5	138.8	146.8

NATURAL MORTALITY (M)

We assume that 0.8 for age 0-1 and 0.4 for age 2 or older.

FECUNDITY

We assume that fecundity is proportional the body weight at the middle of each age and also assume 0 fecundity for age 0-2 and 50% of fecundity for age 3 as below:

Age	0	1	2	3	4	5	6	7	8
Fecundity (in tons)	0	0	0	0.0156	0.0471	0.0649	0.0842	0.1045	0.1468

SELECTIVITY

Miyabe *et al* (2001) estimated age specific selectivity vectors for LL and PS. For the LL, three different selectivity vectors were estimated for three time periods (1955-76, 1977-91 and 1992-99). For PS, one selectivity vector for log & free school fisheries combined was estimated. We used these selectivity vectors except for the one for PS (Runs 4-6). In these three runs, we used log-based selectivity vectors, which were estimated based on F values available in the VPA results by Nishida and Takeuchi (1999).

CPUE (1955-99)

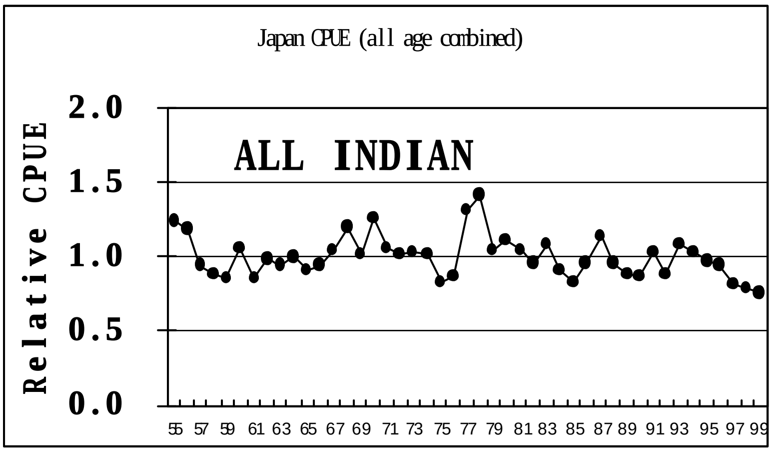
We use various Japanese and Taiwanese CPUE as specified in Table 1, which were estimated by Okamoto *et al* (2001) available in the other document in this meeting (IOTC/WPTT/01/21) and Hsu *et al* (2001) (IOTC/WPTT/01/04), respectively. Fig. 1 shows the trends of various CPUE series used in the ASPM analyses. For Runs 3,6 and 9, we omitted Japanese CPUE (age 6-8+) because the CPUE trend seems to be too flat, which is unlikely, realistic (see Okamoto *et al*, 2001 for detail discussion). As the Japanese CPUE included the year and area interaction, the missing data problems occurred for the data from 1952-54 when the bigeye tuna fishing grounds were limited in the eastern Indian Ocean and not fully expanded to the entire Indian Ocean. Thus, we used the 45 years of the data from 1955-99.

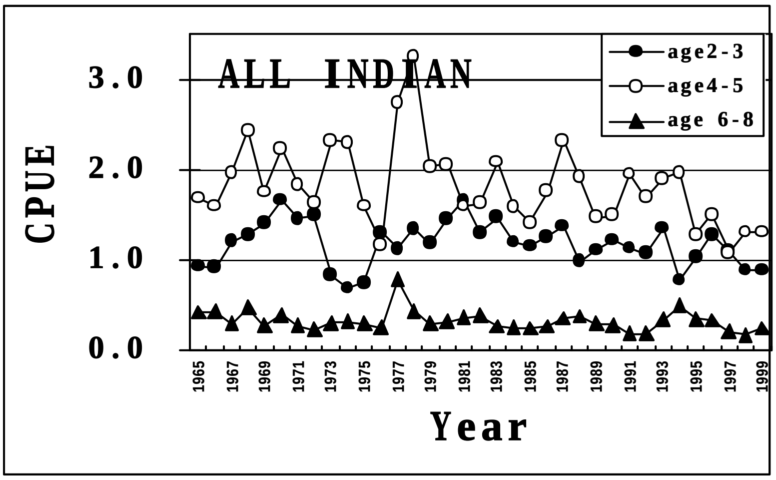
CATCH (1955-99)

The bigeye catch by gear type were obtained from the IOTC database. Table 2 and Fig. 2 show catch (in MT) by two types of fisheries, i.e., surface (mainly PS) and midwater (mainly LL). The catch data were available from 1952-99. But as the CPUE data were used from 1955-99, the catch data were also adjusted for the same period.

Table 1 Nine types of ASPM runs and their results

Run no.	1	2	3	4	5	6	7	8	9
type	Base cases			Reference cases (sensitivity)					
INPUT DATA									
Catch	LL (All) & PS (log & free combined)								
Biological information	Growth: Tankevich (1982), LW: Poreeyanond (1994) & Nakamura/Uchiyama (1966), M: 0.8 (age 0-1) and 0.4 (age 2 or older)								
Area	Indian Ocean						Tropical area		
Selectivity	LL (3types) & PS (log/free combined) (Miyabe et al, 2001)			**LL (3 types) & PS(log)(*)** (*) Based on Nishida & Takeuchi (1999)			LL (3types) & PS (log/free combined) (Miyabe et al, 2001)		
S-R	Beverton-Holt model (stochastic option)								
CPUE (Japan) inc. Y*A & env. factors (1955-99) (Okamoto et al, 2001)	All ages Pooled	1955-64 (all ages) 1965-99 age 2-3 age 4-5 age 6-8+	1955-64 (all ages) 1965-99 age 2-3 age 4-5 ~~age6-8+~~	All ages Pooled	1955-64 (all ages) 1965-99 age 2-3 age 4-5 age6-8+	1955-64 (all ages) 1965-99 age 2-3 age 4-5 ~~age6-8+~~	All ages Pooled	1955-64 (all ages) 1965-99 age 2-3 age 4-5 age 6-8+	1955-64 (all ages) 1965-99 age 2-3 age 4-5 ~~age 6-8+~~
CPUE(Taiwan) (1979-95) (Hsu, 2001)	All ages pooled (model 3: Indian Ocean)						All ages pooled (model 4: tropical area)		
RESULTS									
MSY (tons)	82,854	16,559 (too low)	148,743	77,006	126,570	68,288	(Not converged)	4,296,080 (too large)	453,039 (too large)
Virgin biomass (million tons)	0.68	4.6	1.28	0.99	1.71	0.88		1,198 (too large)	9.46
-ln (likelihood)	-146.63	(Not considered)	-171.57	-146.06	-183.32	-146.70		(Not considered)	(Not considered)
BIC	-95.16		-123.55	- 94.02	-132.03	-73.81			
Steepness	0.99		0.96	0.99	0.99	0.99			
F(ratio)= F1999/F(MSY)	0.88= 0.93/1.06		0.35= 0.35/0.99	1.12= 0.55/0.49	0.53= 0.29/0.55	1.47= 0.69/0.47			
B ratio(SSB)= B1999/B(MSY) (million tons)	2.07= 0.31/0.15		2.34= 0.68/0.29	2.00= 0.50/0.25	2.61= 1.07/0.41	1.77= 0.39/0.22			
B ratio(total)= B1999/B(total) (million tons)	____= 0.43/___		___= 0.88/___	___= 0.60/___	___= 1.25/___	___= 0.46/___			
B1 ratio = B1999/B(1955) (million tons)	0.57= 0.43/0.75		0.56= 0.88/1.56	0.52= 0.60/1.15	0.56= 1.25/2.22	0.44= 0.46/1.05			
DECISION (na: not accepted)									
	Selected as base Case	na	**Selected as base case**	na	na	Na	na	na	na





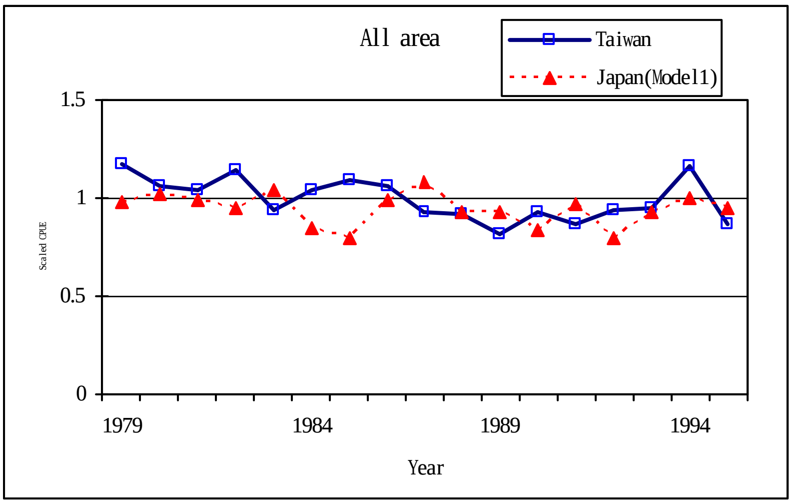


Fig. 1 Trends of standardized CPUE series applied in the ASPM analyses.

	..Surface fisheries (mainly PS)	Midwater fisheries (mainly LL)
1952	0	702
1953	0	1778
1954	0	4627
1955	0	5860
1956	0	9482
1957	0	7271
1958	0	6407
1959	0	5706
1960	0	9754
1961	0	9146
1962	0	14169
1963	0	9064
1964	0	14000
1965	0	15600
1966	0	17527
1967	0	23310
1968	0	34551
1969	0	27757
1970	81	24832
1971	51	20381
1972	58	18759
1973	130	15667
1974	124	26163
1975	100	35654
1976	142	27297
1977	160	33785
1978	124	48146
1979	133	32793
1980	125	33704
1981	241	34276
1982	220	43019
1983	780	47293
1984	4395	36493
1985	7480	41685
1986	11112	45231
1987	13832	49185
1988	17290	54471
1989	12751	49546
1990	13109	54899
1991	16172	51884
1992	11623	52701
1993	16389	76084
1994	19328	76112
1995	28933	86541
1996	25146	97788
1997	34344	97349
1998	27963	111070
1999	38889	104533

Table 2 Nominal catch data of the surface (mainly PS) and midwater (mainly LL) fisheries (in MT) ………. (tons)

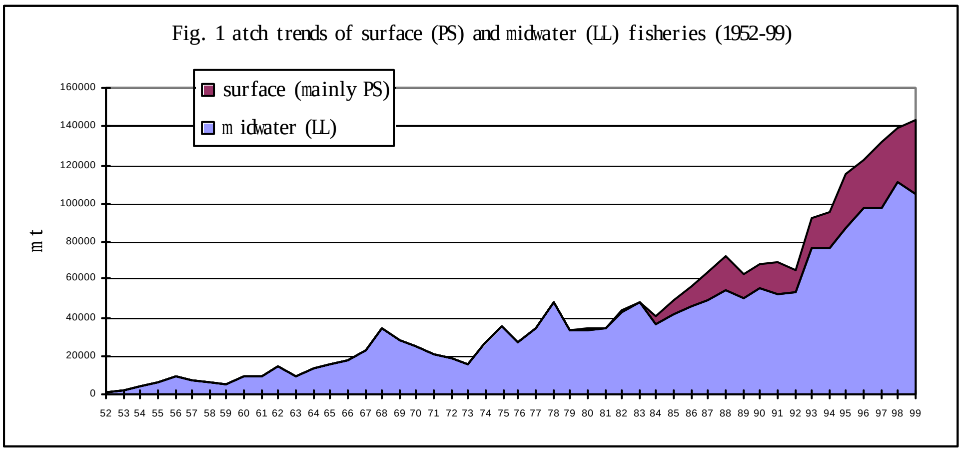
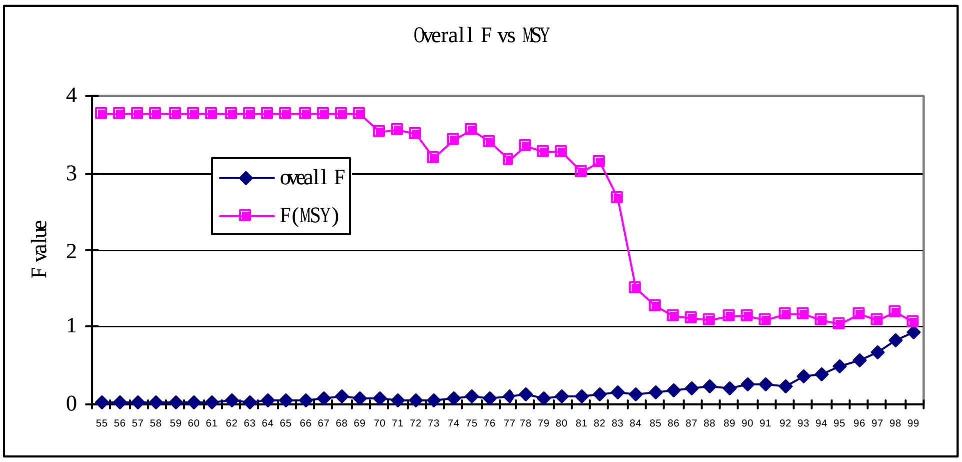


Fig. 2 Trends of the surface (PS) and midwater (LL) catch (in MT)

Run 1………….



…………….Run 3

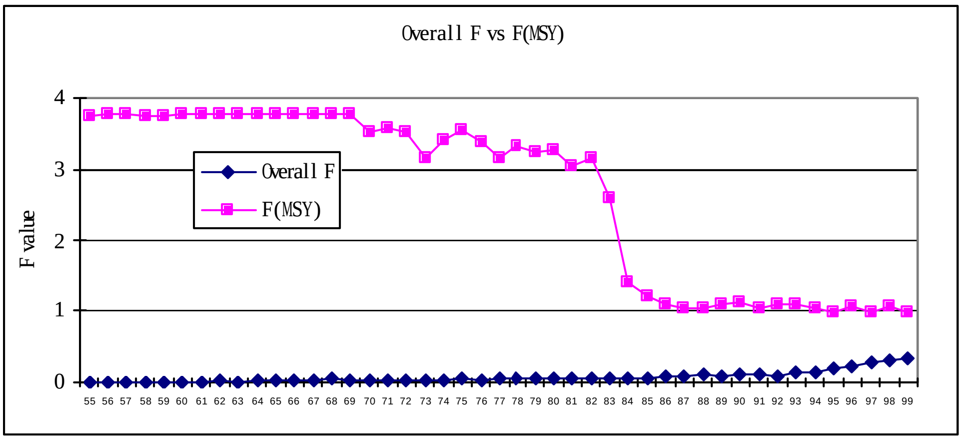


Fig.3 Overall F vs. F (MSY)

RESULTS OF THE ASPM ANALYSES

Table 1 (latter half part) shows the results of the ASPM analyses. Because we considered Runs 4-9 as the reference cases and will not use as base cases, we evaluate results of three base cases (Runs 1-3). As Run 2 provided too low MSY level which is unrealistic, we will not accept Run 2 as the base case. As a result, we will use Runs 1 & 3 as the base case. Various types of results of Runs 1 and 3 were depicted in Figs. 3–13.

Run 1 Run 3

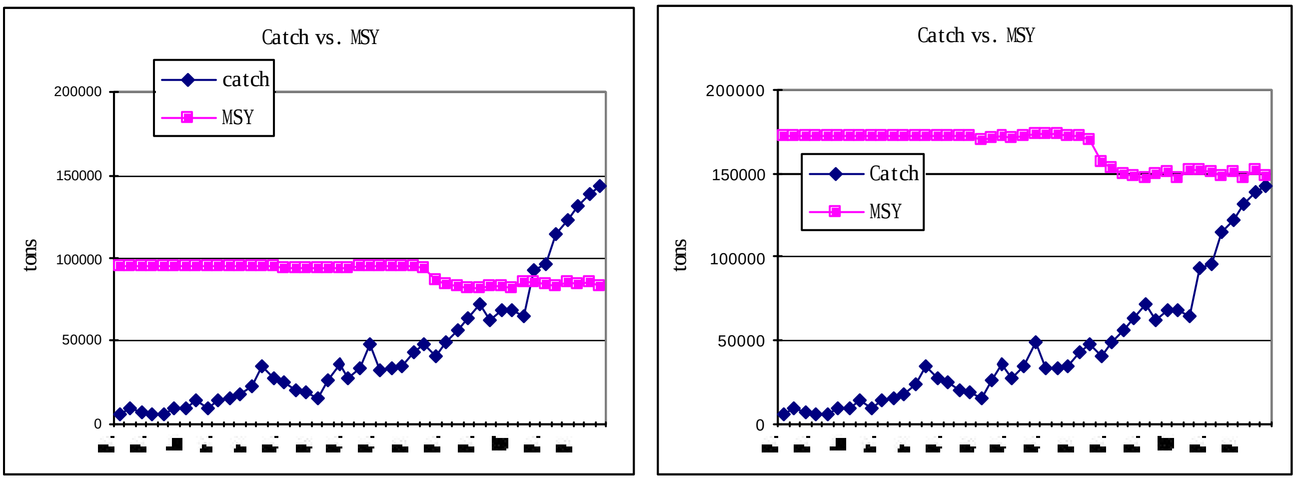


Fig. 4 Catch vs. MSY

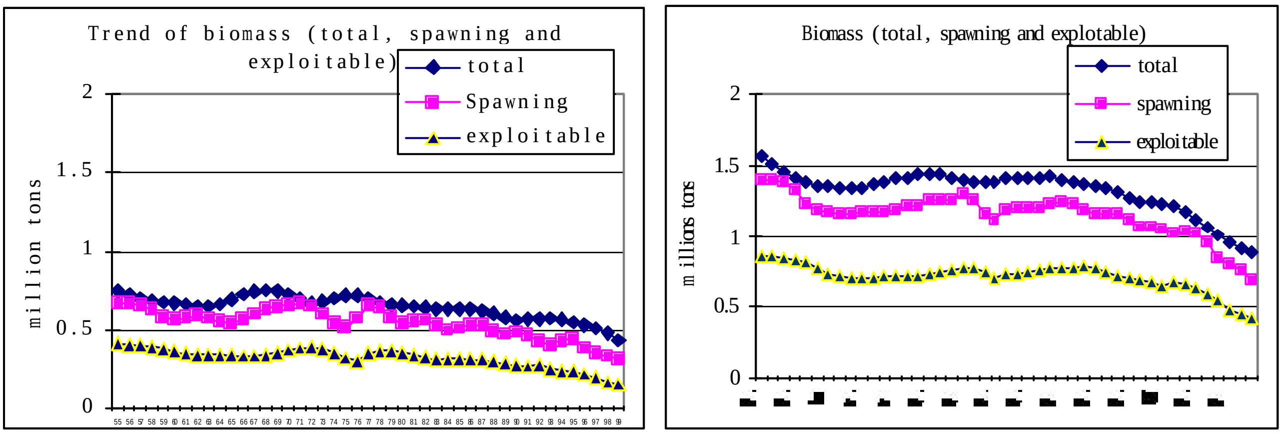


Fig. 5 Trends of biomass (total, spawning and exploitable)

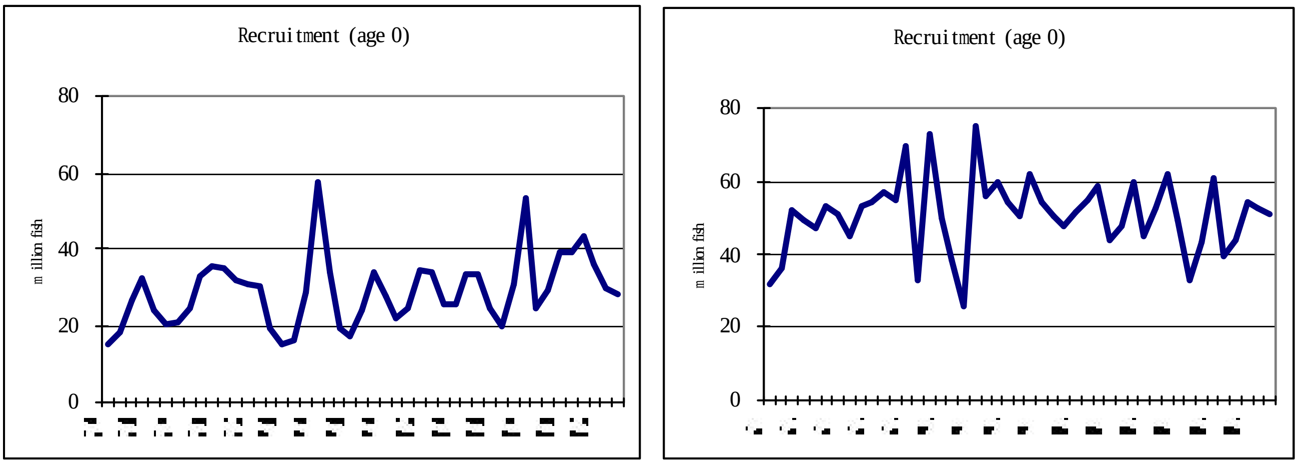


Fig. 6 Trends of the recruitment abundance (million fish)

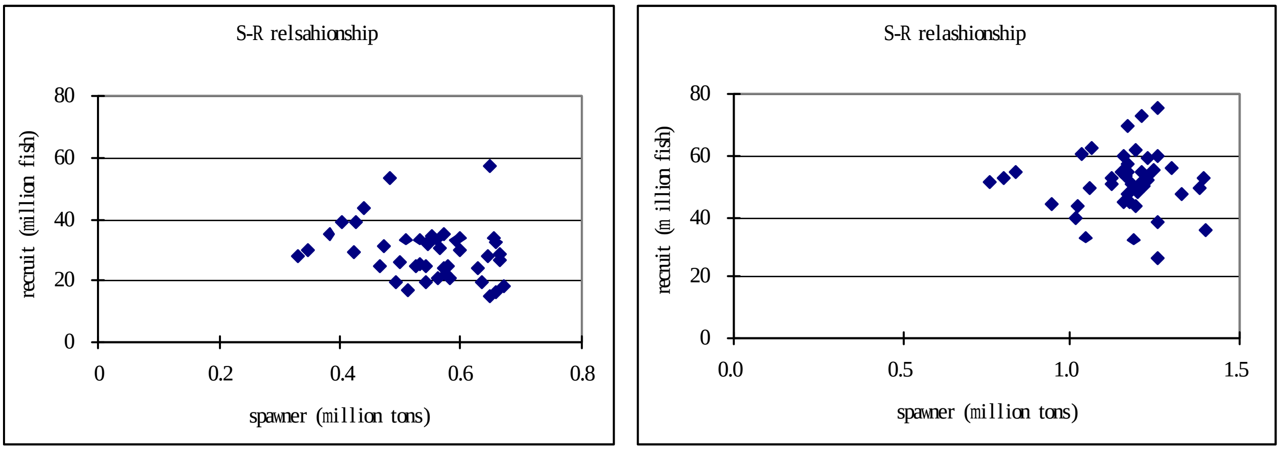


Fig. 7 Spawner-recruit relationship (Beverton-Holt model) (unit of recruitment: million fish)

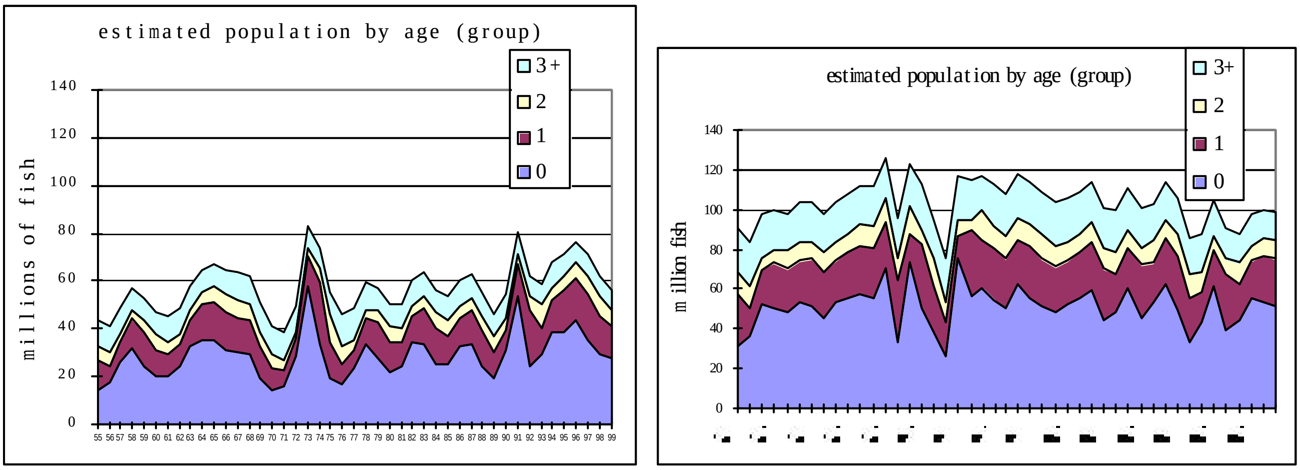


Fig. 8 Trends of estimated population by age (group) (I) (unit: million fish)

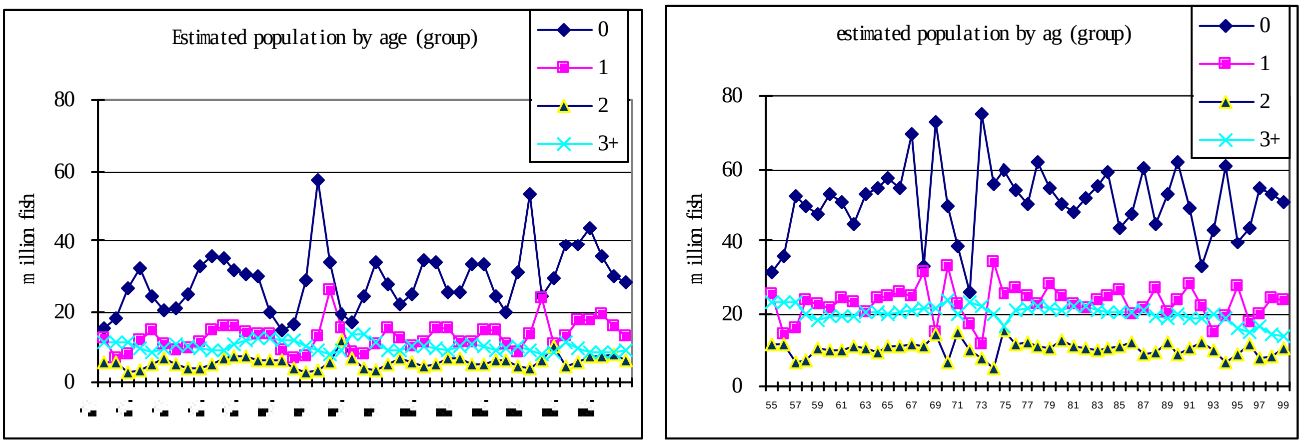
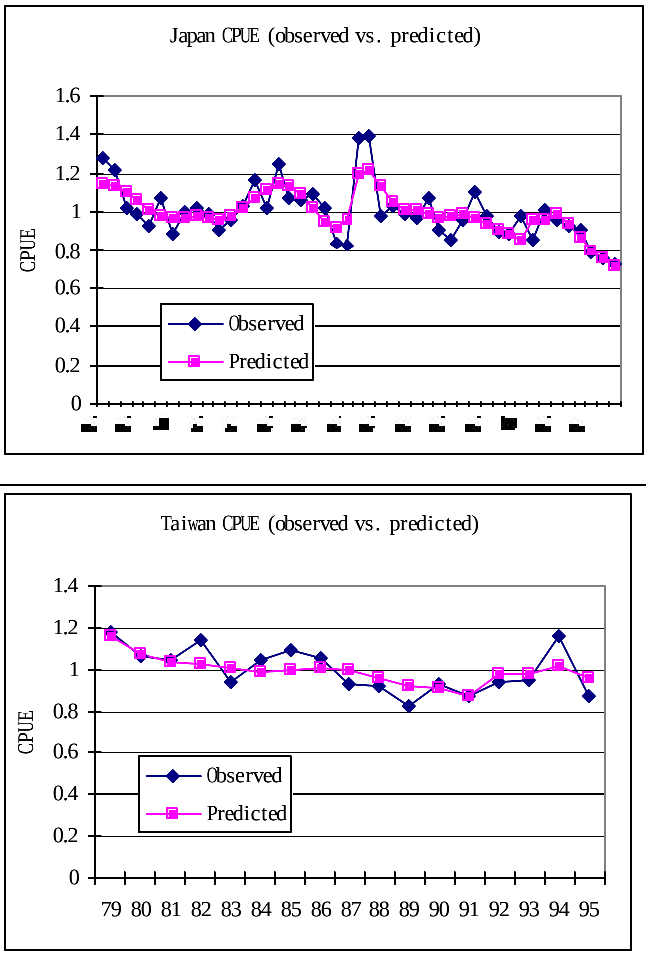


Fig. 9 Trends of estimated population by age (group) (II) (unit: million fish)



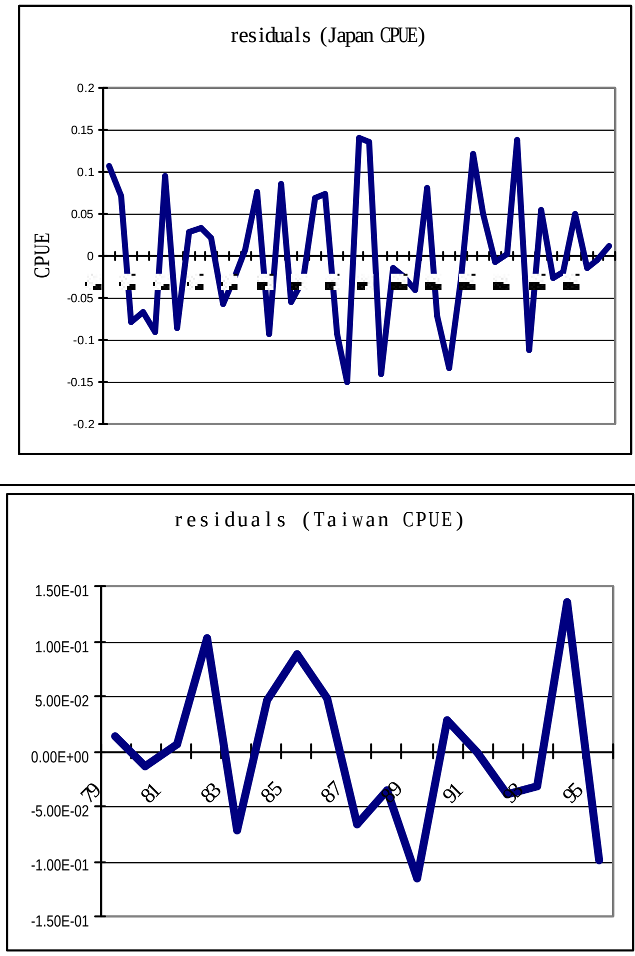
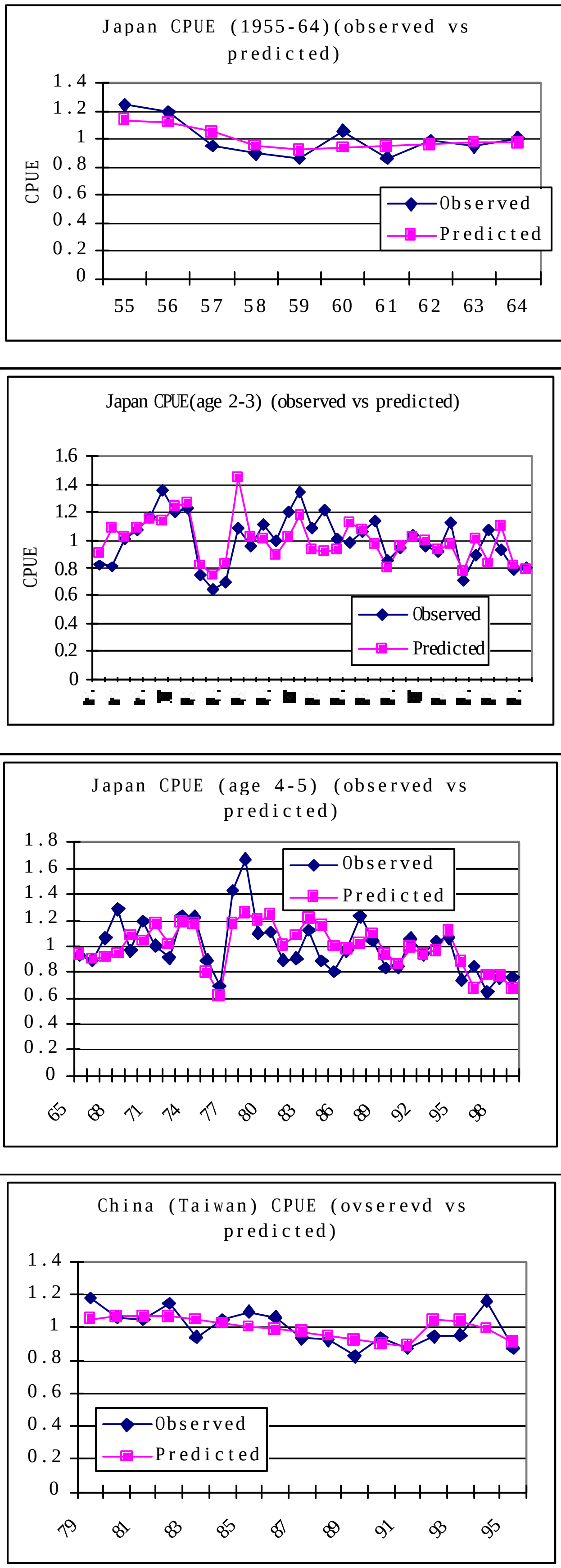


Fig. 10 Observed and predicted CPUE (Run 1)   Fig. 11 Residual plots of Fig 10 (Run1)

- Japan (above) and Taiwan (below) --



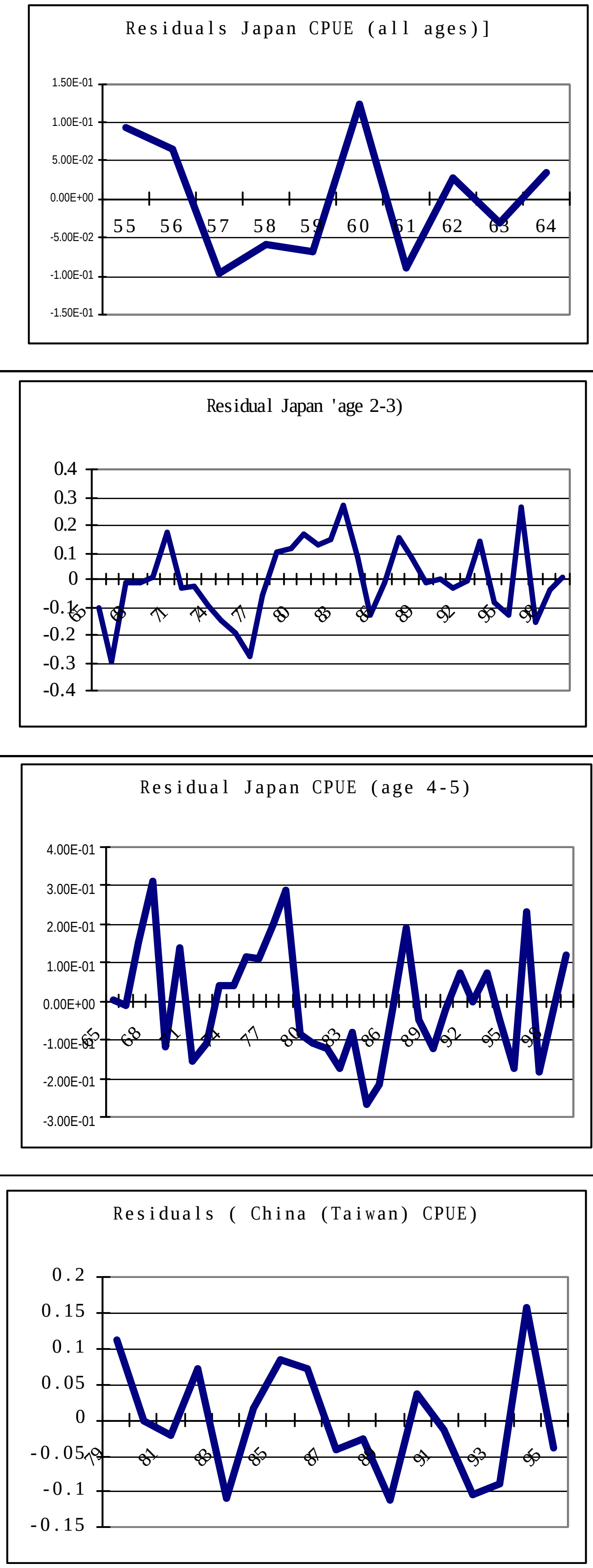


Fig. 12 Observed and predicted CPUE (Run3)   *Fig. 13 Residual plots of Fig 11 (Run 3).*

PROJECTIONS

Materials and methods

The projection of the spawning biomass and the total biomass after 2000 was analyzed using the results of two base cases of the ASPM analyses (Run 1 and Run 3), in order to observe behaviors of their future dynamics. In the projection analyses, we assume that the 1999 catch level was constantly exploited after 2000. Estimated spawning and total biomass before 2000, were extracted from the ASPM outputs. Annual recruitments from 2000-2017, were estimated by the Beverton-Holt stock-recruitment model, i.e.,

$$R = \frac{aS}{b+S}$$

, where

R: recruitment (number),

S: spawning stock biomass (tons),

a: maximum number of recruits produced (extracted from ASPM outputs),

b: spawning stock needed to produce the average recruitment

(extracted from ASPM output).

Biomass by age group from 2000-2017 was estimated by the following equations:

Age 1 – 7: $N_{t,y}=N_{t-1,y-1}*\exp(-M_{t-1})-C_{t-1,y-1}*\exp(-M_{t-1}/2)$

Age 8+: $N_{t,y}=N_{t-1,y-1}*\exp(-M_{t-1})+N_{t,y-1}*\exp(-M_{t})-C_{t-1,y-1}*\exp(-M_{t-1}/2)$

,where

$C_{t,y}$:catch in number of age t in year y,

$N_{t,y}$: biomass in number of age *t* in year *y*,

M_t : natural mortality at age *t (0.8 for age 0-1 and 0.4 for age 2 or older)*.

Total biomass and spawning stock biomass (SSB) were calculated as follows :

Total biomass: $$\sum_t (N_{t,y} * w_t)$$

SSB: $$\sum_t (N_{t,y} * w_t * S_t)$$

, where

w_t: average weight in kg at age t (at the mid year) (refer to page 2).

S_t: probability matured (0 for age 0-2, 0.5 for age 3 and 1 for age 4 or older)

Results

Results of the future projection are shown in Fig. 14. As for Run 1, if the 1999 catch level (143,000 MT) were continued, both spawning and total biomass would decline sharply and the spawning biomass at MSY would reach in 5 years (2005). Furthermore, the result indicates that the spawning biomass would be extincted by 2010. As for Run 3, the decline of biomass was resulted to be very slow. If the projection for Run 1 were realistic, the BET stock would be seriously affected in a short time, while if that for Run 3 were true, we would have the optimistic view on its status of stock. As a result of the projection analyses, we have two extreme situations on the current BET stock status in the Indian Ocean.

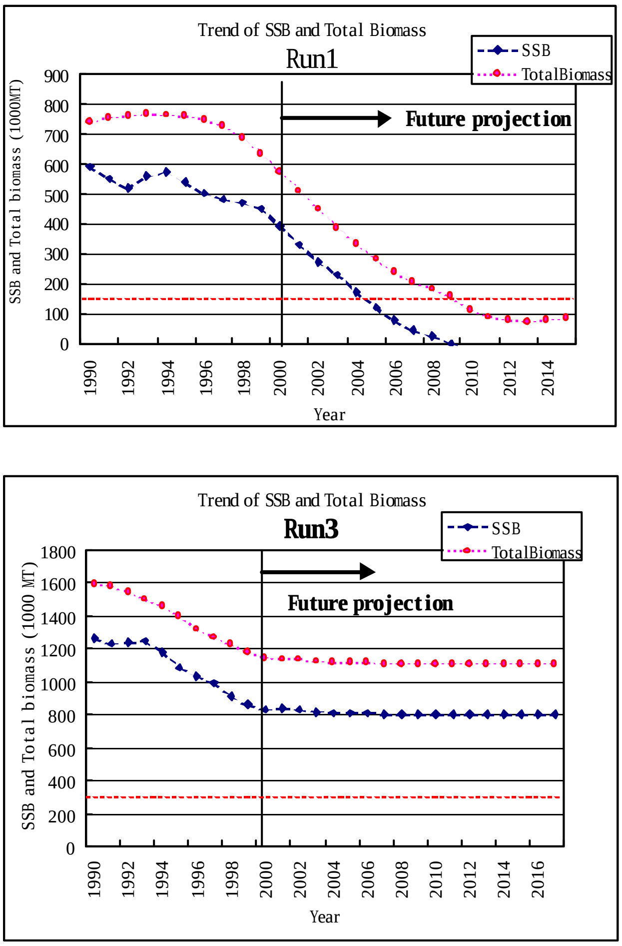


Fig. 14. Trends of projected total biomass and spawning stock biomass (SSB) (after 2000) based on the ASPM results and the Beverton-Holt stock recruitment model. (Note Horizontal broken lines indicate estimated spawning biomass level at the MSY)

DISCUSSION

Comparing the results of Runs 1 & 3, it is difficult to judge which Run is more realistic one. If we compare diagnostics of the fitness to the ASPM model (the residual analyses) (Fig. 11 for Run 1 and Fig. 13 for Run 3), Run 1 seems to show better fitness than that of Run 3. But, if we compare BIC, Run 3 is the better one. Thus, it might be not appropriate to select one final base case. Hence, we will examine both results of Run 1 & 3.

Results (Table 1 and Figs. 3-13) indicate large discrepancies between Run 1 and 3. For example, estimated MSY for Run1 is 83, 000 tons, while MSY for Run 3 is 149,000 tons. Another example is that there are large gaps in F ratios between two Runs, i.e., 0.88 (Run 1) and 0.33 (Run 3). Furthermore, the estimated population levels are almost twice difference between two Runs. Hence we can assume that these two base cases are two extreme boundaries of the current BET stock status in the Indian Ocean. In fact, the similar situation is also observed in the reference cases (Runs 4-6), i.e., the MSY ranges from 78,000 tons to 130,000 tons and twice difference of the estimated population levels. Thus, the two extreme boundary assumption is likely realistic.

These large discrepancies between two extremes are caused by uncertain elements such as (a) not enough biological (eg, LW) data which affect various age specific parameters, (b) inaccurate quality or unreported catch (for example the Indonesian catch, IUU catch etc), and (c) difficulty to estimate unbiased standardized CPUE due to the uncertain factors such as targeting problem, big jumps in 1978-79 etc., (d) super stabilized CPUE series (age 6-8+), and (e) heterogeneity of q (catchability) of PS & LL fisheries data occurred over the long-term fishing periods.

However, judging from the sharp decrease trends of the spawning biomass after 1992 observed in both Run 1 & 3 (Fig. 5) and also the sharp decrease of the LL CPUE (Fig. 1) after 1992, it is indicated that <u>the real stock status situation is most likely close to Run 1</u>. These sharp declines in the spawning biomass and LL CPUE are caused by the recent sharp increasing catch by both PS & LL after 1992. Furthermore, the projection results for Run 1, indicate that if the current catch level were continued, spawning biomass would become lower than its MSY level (150,000 tons) in four years, 2004 and will be extincted in 10 years by 2010. On the other hand, the projection result for Run3 dose not indicate any serious situation at all and shows the healthy BET stock status, as the its spawning biomass indicates the very gentle decrease trend even if the 1999 catch level were maintained.

However, in Run1, the recent catch level after 1993 exceed the MSY level (82,000 tons) for 7 consecutive years already, which indicate the serious over-fishing situation. As the real situation is considered to be close to Run 1, we can not support the optimistic situation as in Run 3 and need to conserve the BET stock.

As a conclusion, concerning uncertainties between Run 1 and Run 3 and considering the current situation being more likely close to the situation in Run1, it is wise to not exceed the current catch level (143,000 tons) and consider the optimum catch level to be between 83,000 tons (MSY level in Run 1) and 143,000 (current catch level) as the fundamental management advice.

ACKNOWLEDGEMENTS

We appreciate Dr Ziro Suzuki, Dr Yuji Uozumi and Mr Yukio Takeuchi (NRIFSF) who provided the constructive suggestions to improve this paper.

REFERENCES

ANONYMOUS (2001) Report of the IOTC ad hoc working party on methods, Sète, France 23-27, April, 2001: 20pp.

HSU, C-C., LEE, H-H., YEH, Y-M., AND LIU, H-C (2001) On targeting problem, partitioning fishing effort and estimating abundance index of bigeye tuna for Taiwanese longline fishery in the Indian Ocean, IOTC/WPTT/99/4: 23pp.

MIYABE, N. (2001) Estimation of selectivity at age for bigeye tuna in the Indian Ocean, IOTC/WPTT/01/20; 13pp.

NISHIDA, T. AND TAKEUCHI, Y. (1999) Stock assessment of bigeye tuna (Thunnus obesus) in the Indian Ocean based on the virtual population analysis, IOTC/WPTT/99/8: 23pp.

OKAMOTO, H., MIYABE, N., AND MATSUMOTO, T. (2001) GLM analyses for standardization of Japanese longline CPUE for bigeye tuna in the Indian Ocean applying environmental factors, IOTC/WPTT/01/21: 37pp.