UPDATED STANDARDIZED CPUE OF BIGEYE CAUGHT BY THE JAPANESE LONGLINE FISHERY IN THE INDIAN OCEAN, AND STOCK ASSESSMENT BY PRODUCTION MODEL

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INTRODUCTION

Bigeye tuna is one of Thunnus species and is distributed in tropical to temperate waters. Juvenile and young fish often form pure or mixed schools with other tunas near the sea surface, where they are exploited by surface fisheries such as purse seine. On the other hand, adults inhabit deeper water, at or just beneath the thermocline, than other tunas (Suda *et. al,.* 1969), and are mostly caught by longline gear.

According to longline catch records, bigeye tuna in the Indian Ocean are distributed north of 40°S (Figure 1). This area overlaps widely with that of yellowfin in the tropical area, and partly with that of southern bluefin tuna in the temperate area south of 30°S. Therefore, the longline effort is not necessarily directed toward bigeye tuna.

In the late 1970s, there were some changes in the number of branches per basket used in longline operations. Before 1977 most Japanese longline vessels used basket sets each of which included from five to eight branches (Table 1), while later more branches per basket (from nine to thirteen) became common (up to about fifty percent in early 1980s). The latter basket sets are called "deep type", and attempt to improve CPUE for bigeye tuna by increasing the depth of the hooks over the traditional setting. The positive effects on catch rate for bigeye were confirmed (Suzuki, 1977; Koido, 1985).

Because of this, when CPUE is to be used as an abundance index, nominal CPUE should be adjusted for these effects. In this paper, CPUEs were standardized up to 1994 by using the general linear model (GLM) technique.

Moreover, Aspic (A Surplus Production Model Incorporating Covariates) analysis, developed by Prager (1994), was applied to assess stock status of bigeye tuna.

MATERIALS AND METHODS

Standardization of CPUE

Data used

The Japanese longline catch and effort statistics up to 1994 were used (1994 data are preliminary). There are two sets of data: one is data from 1975 to 1994, aggregated by month, 5° square, and the number of branch lines per basket (branch line data), and the other is data from 1952 to 1976, aggregated by month and 5° square, but without branch line data.

Figure 1*. Geographical distribution of the catch number of bigeye caught by Japanese longline fisheries in the Indian Ocean from 1990 - 1994.*

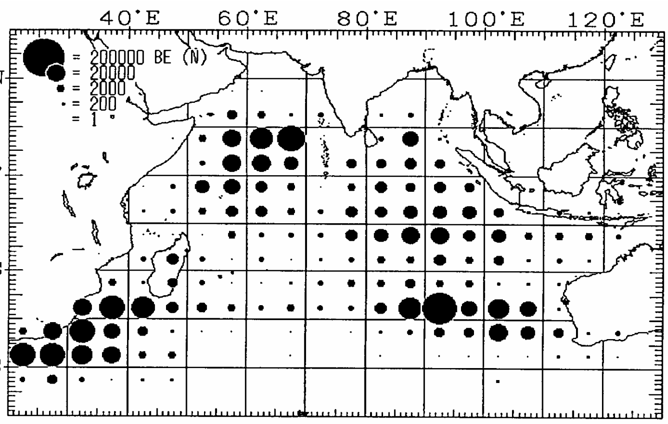


***Table 1**. Number of hooks (*1000), by year and by the number of branches per basket*

Year	BR4	BR5	BR6	BR7	BR8	BR9	BR10	BR11	BR12	BR13	BR14	BR15	BR16	BR17	BR18	BR19	BR20	BR21
75	672	16,818	11,972	1,739	789	588	273	442	243	0	0	0	0	0	0	0	0	0
76	451	12,863	5,674	589	272	368	9	143	63	0	0	0	0	0	0	0	0	0
77	19	9,033	3,716	307	528	591	451	686	739	0	0	0	0	0	0	0	0	0
78	36	9,041	5,591	1,566	255	2,970	3,253	2,441	2,531	1,682	96	42	0	0	0	0	0	0
79	4	5,737	5,998	1,584	422	1,395	1,903	1,290	1,265	296	0	0	0	0	0	0	0	0
80	0	5,871	7,000	1,705	1,013	2,125	2,356	2,127	915	339	0	0	0	0	0	0	0	0
81	19	7,014	9,335	3,587	794	1,981	5,541	3,246	738	42	0	0	0	0	0	0	0	0
82	67	10,146	9,329	2,560	223	1,623	6,675	7,673	2,280	469	0	0	0	0	0	0	0	0
83	0	5,755	10,767	3,172	460	1,159	5,595	11,801	5,097	2,364	112	0	0	0	0	0	0	0
84	28	5,611	14,367	3,875	800	341	6,404	9,808	6,066	1,723	218	0	0	0	0	0	0	0
85	19	1,624	17,083	6,841	678	706	7,318	12,886	7,819	2,325	97	211	0	0	0	0	0	0
86	0	2,296	19,247	5,414	674	446	4,113	9,987	6,771	3,149	302	354	0	0	0	0	0	0
87	0	1,237	18,031	9,030	1,009	454	1,174	6,264	10,561	2,201	410	418	0	0	0	0	0	0
88	0	798	12,762	4,988	943	700	1,777	3,705	11,431	2,176	44	543	0	0	0	0	0	0
89	0	173	15,195	2,832	732	303	2,463	1,709	6,447	1,594	164	765	0	27	0	0	0	0
90	0	732	8,492	6,174	995	108	2,394	1,176	4,445	4,340	372	527	168	188	26	0	0	0
91	0	311	9,732	6,928	1,822	686	898	1,304	3,033	3,569	1,188	424	111	57	413	0	36	0
92	7	409	15,251	6,735	1,997	659	1,582	595	2,058	2,118	293	767	82	257	584	36	720	0
93	0	211	8,590	6,696	2,111	610	3,281	730	2,032	870	685	106	290	707	319	0	1,668	283
94	2	10	4,813	8,145	4,538	2,796	7,148	920	1,873	1,666	299	683	617	380	1,582	247	1,405	548

Model configuration

The distribution of CPUE for bigeye in Indian Ocean is shown in Figure 2. Considering this distribution, the main

***Figure 2**. Geographical distribution of CPUE for bigeye by Japanese longline fisheries in the Indian Ocean.*

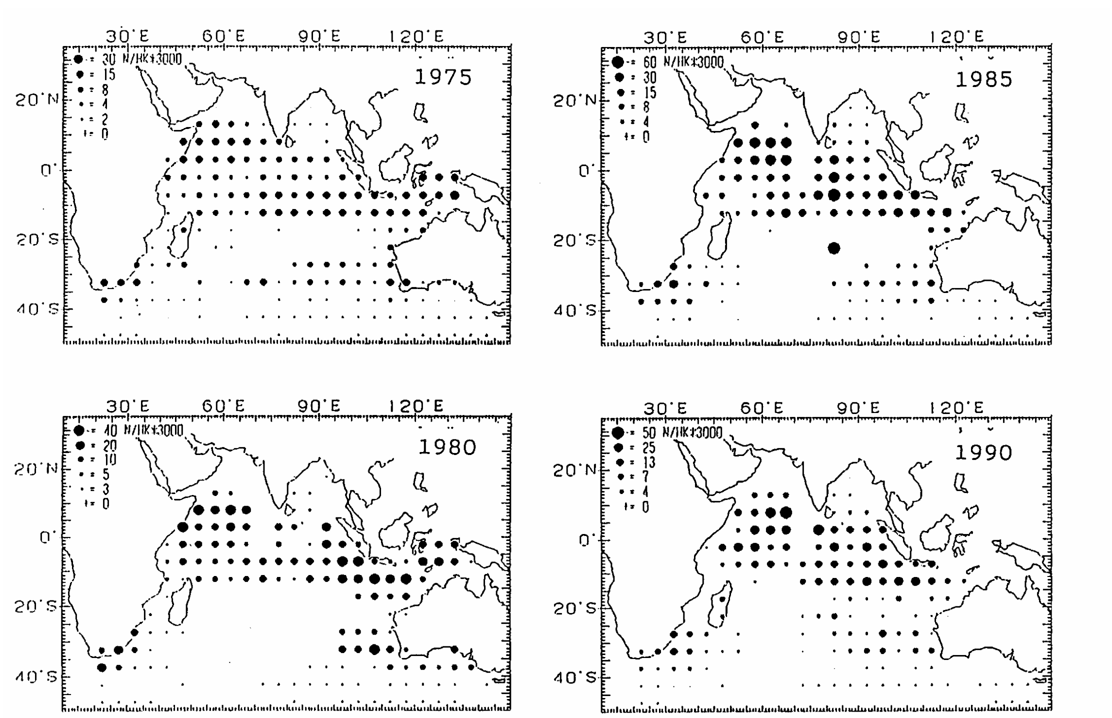


Table 2.. **Classification of CPUE of other tuna species (SBT: southern bluefin, ALB: albacore, YFT: yellowfin), swordfish (SWD), and billfish (BIL) for GLM analysis.**

CPUE rank	*SPECIES* *SBT*	*ALB*	*YFT*	*SWD*	*BIL*
1	0	0	0	0	0
2	0-2.01	0-0.93	0-4.13	0-0.71	0-0.68
3	2.01-4.66	0.93-3.93	4.13-11.83	0.71-1.35	0.68-1.62
4	4.77-8.11	3.93-10.66	11.83-24.66	1.35-2.39	1.62-3.23
5	8.11-	10.66-	24.66-	2.39-	3.23

fishing grounds were divided into six areas for analysis (Figure 3).

To include the effect of the number of branches in the model, the numbers of branches per basket were divided into 4 classes (class 1: 4-7, class 2: 8-11, class 3: 12-15, class 4: 16-21).

In setting classes of CPUE for other species (SBT: southern bluefin tuna; ALB: albacore; YF: yellowfin tuna; SWD: swordfish; and BIL: billfish), zero CPUE was set as class 1, and others were separated into four classes depending on the magnitude of CPUE so that each class included 25% of total observations (Table 2), thus five CPUE classes were prepared for each species).

The model used for GLM analysis was the following.

$$\text{Log}\,(CPUE_{ijkl}+1.0) = f\hat{E} + Y_{(i)} + Q_{(j)} + A_{(k)} + G_{(l)} + Others_{(m\,.)} + INT_{(n\,.)} + e_{(ijkl\,)}$$

Where

Log:	natural logarithm,
CPUE:	catch in number of bigeye per 3000 hooks,
$f\hat{E}$:	overall mean,
$Y_{(i)}$:	effect of year,
$Q_{(j)}$:	effect of fishing season (quarter),
$A_{(k)}$:	effect of area,
$G_{(l)}$:	effect of gear type (branch line number class)
$Others_{(m\,.)}$:	CPUE of other tunas, swordfish and billfish,
$INT_{(n\,.)}$:	interaction term between fishing season and area,
$e_{(ijkl\,)}$:	error term.

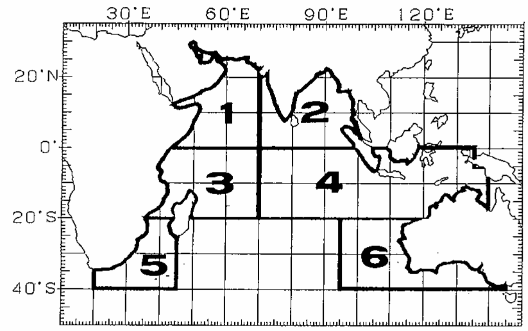
GLM analysis was done separately, using the two data sets described above, 1952-76 (without branch data) and 1975-1994 (including branch data).

ASPIC analysis

Stock structure

There is not enough information to determine the stock structure in the Indian Ocean. The relationship of fish between the Indian Ocean and other oceans is not known. In this paper, a single stock for the whole Indian Ocean was assumed.

Figure 3. *Area division of main fishing ground of longline for CPUE analysis.*



Data used

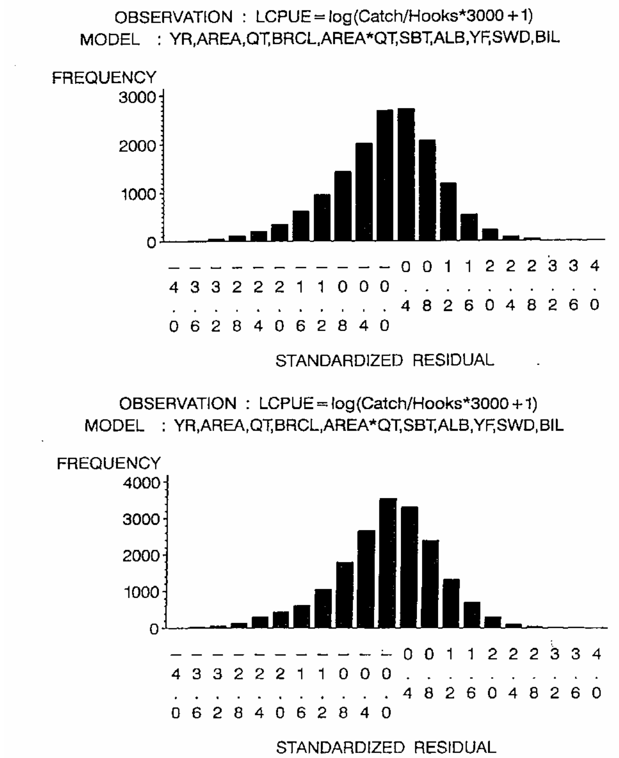
Catch in weight and effective fishing effort data or an abundance index are required for production model analysis. Abundance indices estimated in this paper are used.

Catch in weight by the fishery before 1983 were taken from Miyabe and Suzuki (1991). More recent data were obtained from IPTP (1995). Since 1994 figures are not available, 1993 statistics were carried over. These catches are tabulated in Table 3.

Fitting the ASPIC model

The surplus production model developed by Prager (1994) was applied to bigeye in the Indian Ocean. To create input data, four options were considered: catch (total or longline catch), treatment of abundance indices (combined or kept separate), with or without penalty of having a larger starting biomass (B1) than the maximum biomass (K), and years covered (excluding or including the developmental stage of the longline fishery, 1952-1960). The reasons for setting up two options for abundance indices are 1) the data sets are different (no information on gear before 1975), 2) to investigate the possibility of change in catchability through time. As already experienced in the case of Pacific bigeye (Miyabe 1994), the model itself failed to provide reasonable solutions when data for the developing stage of fishery were included. During the initial stage of the fishery, CPUE possibly overestimated the real abundance of the stock because it was as if fleets were exploiting a new stock every year as they entered new fishing grounds. To avoid this problem, runs excluding data between 1952 and 1960 were made. It is often found in the application of the ASPIC model that B1 tends to exceed K which is a really unrealistic situation. It

Figure 4. *Overall histograms of standardised residuals from the GLM models (upper: GLM 1952-1976 without the gear term, and lower: GLM 1975-1994 including gear term).*



is one of Prager's recommendations to give a penalty for B1>K under such circumstances.

Table 3. **Classification of CPUE of other tuna species (SBT: southern bluefin, ALB: albacore, YFT: yellowfin), swordfish (SWD), and billfish (BIL) for GLM analysis.**

Year	*LL*	*PS*	*Total*
52	1.5	-	1.5
53	3.6	-	3.6
54	8.0	-	8.0
55	10.3	-	10.3
56	14.0	-	14.0
57	13.3	-	13.3
58	12.8	-	12.8
59	10.4	-	10.4
60	17.0	-	17.0
61	15.5	-	15.5
62	19.9	-	19.9
63	14.1	-	14.1
64	18.6	-	18.6
65	19.4	-	19.4
66	25.6	-	25.6
67	25.6	-	25.6
68	37.8	-	37.8
69	27.2	-	27.2
70	23.2	-	23.2
71	21.7	-	21.7
72	17.7	-	17.7
73	15.1	-	15.1
74	26.4	-	26.4
75	38.6	-	38.6
76	27.3	-	27.3
77	35.8	-	35.8
78	54.8	0.0	54.8
79	33.9	0.0	33.9
80	32.0	0.0	32.0
81	32.0	0.0	32.0
82	41.1	0.1	41.2
83	48.3	0.3	48.6
84	36.8	2.5	39.3
85	41.9	3.9	45.8
86	44.6	5.6	50.2
87	48.9	6.0	54.9
88	51.5	7.2	58.7
89	40.5	9.3	49.8
90	48.0	8.1	56.1
91	35.8	17.0	52.8
92	34.9	10.5	45.4
93	54.9	12.9	67.8
94	54.9	12.9	67.8

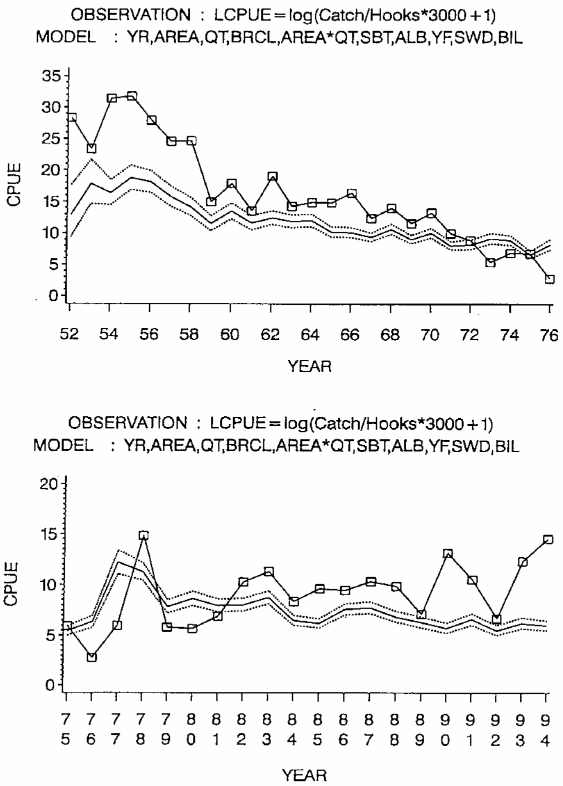
Table 4. Results of ANOVA from the General Linear Model for bigeye in the Indian Ocean

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F value	R-Sq.
GLM(1952-1976)					
Y +Q + A + Q * A + SBT + ALB + YFT + SWD + BIL					
Model	67	5441.9	1.22251	108.26	0.3202
Error	15397	11551.81	).75026	-	
Total	15464	16993.72	-	-	
GLM(1975-1994)					
Y +Q + A + Q * A + SBT + ALB + YFT + SWD + BIL					
Model	65	11757.15	30.8792	237.37	0.4488
Error	18949	4439.5443	0.762	-	
Total	19014	5196.6917	-	-	

Table 5. Results of F test of each effect term in GLM models, 1952-76 and 1975-94

Source	F value	Pr>F
GLM(1952-1976)		
YEAR	29.39	0.0001
AREA	190.4	0.0001
QUARTER	23.8	0.0001
AREA*QUARTER	15.52	0.0001
Southern bluefin	81.89	0.0001
Albacore	87.05	0.0001
Yellowfin	143.86	0.0001
Swordfish	151.26	0.0001
Billfish	110.66	0.0001
GLM(1975-1994)		
Source	F Value	Pr>F
YEAR	39.02	0.0001
AREA	259.32	0.0001
QUARTER	51.62	0.0001
GEAR	135.48	0.0001
AREA*QUARTER	38.19	0.0001
Southern bluefin	263.52	0.0001
Albacore	53.33	0.0001
Yellowfin	83.89	0.0001
Swordfish	230.44	0.0001
Billfish	100.09	0.0001

***Figure 5**. Annual change of relative CPUE (upper and lower broken line indicate 95% confidence limits) and nominal CPUE (solid line with square marker). Relative CPUE of upper and lower graphs are derived from GLM 1952-1976 and GLM 1975-1994.*



RESULTS AND DISCUSSION

Standardized CPUE

The final model and results of ANOVA are shown in Table 4. R^2 was about 0.320 (1952-1976, without gear effect) and 0.448 (1975-1994, including gear effect term). In one of the GLM analyses using data for 1952-1976 (GLM1952-1976), area, YF, SWD, and BIL showed large effect values (Table 5), while in the other GLM analysis using data for 1975-94 (GLM1975-1994), area, gear, SBT, SWD, and BIL showed large effects. Among these species, southern bluefin showed a negative correlation, while yellowfin, swordfish, and billfish showed positive correlations with bigeye tuna.

The distribution of overall residuals from the final model (Figure 4) seems to be not so far from the normal distribution, and to be acceptable. The standardized CPUE derived from the two GLM analyses, with the upper and lower 95% confidence limits, are shown in Figure 5 overlaying nominal CPUE. Comparing the standardized CPUE and nominal CPUE, both show a declining trend but nominal CPUE decreased much faster than standardized CPUE in GLM1952-1976. In contrast, GLM1975-1994 showed a stable or slightly decreasing trend, while an increasing trend was observed in nominal CPUE. If the two series are combined by setting the 1975 data point

Table 6. *Summary of the results of production model analysis (ASPIC) applied to bigeye tuna in the Indian Ocean.*

INPUT DATA				ESTIMATED PARAMETERS									
Catch	***Number of CPUE***	***Penalty for B1<K***	***Years covered***	***MSY***	***r***	***K***	***B1***	***B1R***	***q1***	***q2***	***SS***	***B-ratio***	***F-ratio***
Total	1	No	52-94	45	7.40E-02	2500	4800	3.9	5.80E-04	-	1.13	1.55	0.95
Total	2	No	52-94	4	5.70E-03	2500	27000	2.1	1.00E-04	1.40E-04	1.03	6.24	3.04
LL	1	No	52-94	46	5.80E-02	3100	6500	4.1	4.20E-04	-	1.14	1.72	0.69
LL	2	No	52-94	68	8.50E+00	32	39	2.4	6.00E-02	5.30E-02	2.08	1.44	0.56
Total	1	Yes	52-94	35	1.30E-01	1000	1100	2.2	1.80E-03	-	1.54	0.99	1.90
Total	2	Yes	52-94	32	1.20E-01	1100	1200	2.2	1.70E-03	1.90E-03	1.79	0.90	2.28
LL	1	Yes	52-94	33	1.60E-01	850	910	2.1	2.30E-03	-	1.49	1.02	1.58
LL	2	Yes	52-94	68	8.50E+00	32	32	2.0	6.00E-02	5.30E-02	2.08	1.43	0.56
Total	1	No	61-94	57	2.80E-01	812	942	2.3	2.00E-03	-	0.84	1.33	0.88
Total	2	No	61-94										
LL	1	No	61-94	34	7.30E-02	1865	1973	2.1	8.60E-04	-	0.88	1.39	1.15
LL	2	No	61-94	77	1.60E+01	20	133	1.3	8.10E-02	8.20E-02	1.08	1.54	0.46

MSY : maximum sustainable yield in 1000 MT
r : intrinsic rate of increase
K : maximum stock biomass (carrying capacity)
B1 : biomass at the beginning of the fishery
B1R : ratio of current biomass to B1
q1, q2 : catchability coefficients for fisheries 1 and 2
SS : value in the objective function
B-ratio : ratio of current biomass to B_{msy} (biomass which gives MSY). Value larger than 1.0 means that biomass is larger than Bmsy.
F-ratio : ratio of current fishing mortality rate (F) to F_{msy} (F which gives MSY). Value smaller than 1.0 means that F is lower than Fmsy.

equal to 1.0, the highest values (1954-1955), 1975, a peak (1977) in the 1970s, and current year (1994) are 2.8, 1.0, 2.2 and 1.1, respectively. This means current abundance is about 40% of the initial stock condition. These trends are similar to the past study by Miyabe and Suzuki (1991), especially for the early part of fishery. Standardized CPUE in this study showed much a quicker drop than in Hsu and Chang (1993), which also standardized the Japanese longline CPUE but did not include gear type. This fact suggests that the inclusion of information on gear (number of branch lines per basket) in GLM analysis is very important. At the same time, as the number of branch lines per basket has continued to increase (Table 1), it is essential to keep collecting this information in future.

Results of ASPIC fitting

In conclusion, the annual catch of bigeye in the Indian Ocean were about the level of the estimated MSYs except for the most recent two years (55 and 68 thousand MT for total longline and grand total, respectively). Since this increase of catch is attributable to the increased catch of the purse-seine fishery, whose catches are dominated by small-sized fish, it would take a couple of years to see the effect of purse-seine catch on longline catch. As the abundance indices for the most recent years are stable, it can be said that, at this moment, the bigeye stock in the Indian Ocean is also stable, although it has been extensively exploited. Careful monitoring of the stock status is highly recommended.

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