Standardization of CPUE for yellowfin tuna caught by Taiwanese longline fishery in the Indian Ocean using generalized linear model

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INTRODUCTION

Yellowfin tuna is one of the most important target species for Taiwanese far seas tuna longline fishery operates in the Indian Ocean. The fishery was commenced in the northern and eastern Indian Ocean in the mid 1950's. The catches of this fishery mainly consisted of yellowfin tuna during late 1960's to early 1970's, and then changed to albacore in the mid 1970's, and to bigeye tuna since 1980's as super cold freezer were developed and equipped in larger new-built vessels. The catches of yellowfin tuna substantially increased during mid 1980's to early 1990's, especially for 1992 and 1993. For recent years, the catches of yellowfin tuna fluctuated at the level of late 1980's and early 1990's.

In this report, the standardization of CPUE for yellowfin tuna caught by Taiwanese longline fishery in the Indian Ocean is carried out using generalized liner model (GLM). Environmental factors have been included in the model this year. Updated data of 2000 and new data of 2001-2003 were used in the calculation.

MATERIALS AND METHODS

Catch and effort data aggregated by $5^\circ \times 5^\circ$ square area and month from 1967 to 2003 for Taiwanese longline fishery operated in the Indian Ocean are used to standardize the CPUE of yellowfin tuna. Environment information including the size of area, the sea surface temperature, mixed layer depth and southern oscillation index are provided by National Research Institute of Far Seas Fisheries, Japan.

In this analysis, GLM is used to model the logarithm of the nominal CPUE (defined as the number of fish per 1,000 hooks). The main effects considered in this analysis are year, season, area (as recommended in 2002 WPTT6, Fig. 1) and CPUEs for albacore and bigeye tunas (categorized as 5 levels). The interactions for the main effects are also included into the model.

$$\log(CPUE + c) = \mu + Y + M + A + ALB + BET + SST + MLD + \text{Interactions} + \varepsilon$$

where	$CPUE$	is the nominal CPUE of yellowfin tuna,
	c	is the constant value (i.e. 0.1),
	μ	is the intercept,
	Y	is the effect of year,
	M	is the effect of month,
	A	is the effect of fishing area,
	ALB	is the effect related to the CPUE of albacore tuna,
	BET	is the effect related to the CPUE of bigeye tuna,
	SST	is the effect of sea surface temperature,
	MLD	is the effect of mixed layer depth,
	Interactions	is the interactions between main effects,
	ε	is the error term, $\varepsilon \sim N(0, \sigma^2)$.

Akaike's Information Criterion (AIC) is used to select among alternative models of which the one with the lowest value of AIC is selected as the "best" model. The GLM analyses were conducted using R version 2.0.1 (The R Development Core Team, 2004). The standardized CPUE were then computed from the adjusted means (least square means) of the estimates of the year effects.

Annual abundance index is estimated by the following equation:

$$I_i = \sum_{j=1}^{N_j} w_j \cdot CPUE_{i,j}$$

where	I_i	is the abundance index in year i,
	w_j	is the weight for the size of area j,
	N_j	is the number of are$a$,
	$CPUE_{i,j}$	is the standardized CPUE in year i and and area j.

Due to the availability of data and the character of Taiwanese longline fishery, three options are selected for analyses.

Option 1: fit the model to whole data sets.

Option 2: fit the model but exclude the interaction of $A*MLD$ to whole data sets because of the missing data of MLD in Area3.

Option 3: fit the model to the data sets in main Taiwanese fishing ground for yellowfin tuna (i.e. Area 1, 2 and 5).

RESULTS AND DISCUSSION

Forward stepwise selection based the value of the AIC statistics is used to select a “best” model. Table 1 shows the ANOVA table for full model for Option 1 and 2. Table 2 shows the ANOVA table for the selected model for Option 1. The selected model included main effects with interactions between main effects is selected as the final model:

$$\begin{aligned}\log(CPUE+c) = {} & \mu + Y + M + A + ALB + BET + SST + MLD + Y*A \\ & + A*BET + A*ALB + M*A + A*SST + M*SST \\ & + M*BET + A*MLD + M*MLD + SST*MLD \\ & + ALB*SST + M*ALB + \varepsilon\end{aligned}$$

The final model explained 54.78% of the variance in raw CPUE records. The selected model for Option 2 is the same model for Option 1 but excluded the interaction of *A*MLD*. Table 3 shows the ANOVA table for Option 2. The model for Option 2 explained 54.72% of the variance.

The effect of SST is not statistically significant for Option 3 as examining the main effects and is not incorporated into sequential analyses (Table 4). This might be owing to that the studied area has been limited to tropical area. The selected model for Option 3 is as follow:

$$\begin{aligned}\log(CPUE+c) = {} & \mu + Y + M + A + ALB + BET + MLD + Y*A \\ & + A*BET + A*ALB + M*A + M*BET \\ & + ALB*BET + A*MLD + A*MLD\end{aligned}$$

The final model explained 39.33% of the variance. Table 5 shows the ANOVA table for Option 3. The statistics for the model indicate that the effects of model are highly statistically significant ($p < 0.01$) for three options.

The distribution of the standardized residuals for three options is concentrated between -1 and 1 and does not appear to differ much from those expected under the normal distribution (Fig. 2). The normal probability plot shows slight divergences for tails (Fig. 2), the standardized residuals, however, conform adequately to the normal distribution.

The nominal CPUE and standardized CPUEs obtained from the three options for yellowfin tuna caught by Taiwanese longline fishery in the Indian Ocean are shown in Fig. 3. The nominal CPUE fluctuated substantially in the 1970’s, then remained stable during 1979-1985, fluctuated during 1985-1993, decreased slightly during 1994-2000, and increased again thereafter.

For the options, the standardized CPUE roughly followed the pattern of nominal CPUE and revealed a high values before early 1970's and stabilized thereafter for almost 30 years. For Option 1, there were two peaks noted however in 1977 and 1988 within the 30 years. In 1977, the nominal CPUE was also higher than adjacent years, and the high standardized CPUE was mainly contributed by Area 1 and 3. However, in 1988, the nominal CPUE was not so conspicuous. The high standardized CPUE of this year was dominantly contributed by Area3. For Option 2, the peak of standardized CPUE in 1988 was not obvious and the trend of standardized CPUE was relative stable since 1980's. Comparatively, the standardized CPUE of Option 3 revealed a much more stable pattern than Option 2 and 3, especially for 1977 and 1988. From the results, the unusual large catch of Taiwanese longline fishery in Area 3 and the missing data of MLD in Area 3 have shown significant impact on standardization of CPUE.

Abundance indices for all the options are shown in Fig. 4. Approximately, the trends of abundance indices are similar to that of standardized CPUE. For Option 1 and 2, the abundance indices of 1988 were still higher than adjacent years. The unusual high value was mainly contributed by the value in Area 3. By contrast, obviously high values of 1977 and 1988 were not represented for Option 3.

Based on the results of the analyses, the stock status of yellowfin tuna in the Indian Ocean should remain to be stable for recent years. However, this is a preliminary suggestion from the catch and effort information of Taiwanese longline fishery. More investigations related to the stock of yellowfin tuna in the Indian Ocean are necessary to assess the status of this population.

Table 1. ANOVA table for the full model for Option 1 and 2.

Source	Df	SS	MS	F-value	P-value
Model	413	17776	43.04	48.17	0.0000***
Error	16359	14617	0.89		
Total	16772	32393			

Source	Df	SS	MS	F-value	P-value
Y	35	6089.3	174.00	194.71	0.0000***
M	11	300.7	27.30	30.59	0.0000***
A	4	7850.6	1962.70	2196.56	0.0000***
ALB	4	716.1	179.00	200.36	0.0000***
BET	4	148.6	37.20	41.58	0.0000***
SST	1	237.2	237.20	265.44	0.0000***
MLD	1	8.9	8.90	9.96	0.0016**
Y*A	126	1122.3	8.90	9.97	0.0000***
A*BET	16	392.5	24.50	27.46	0.0000***
A*ALB	16	288.1	18.00	20.16	0.0000***
M*A	44	221.3	5.00	5.63	0.0000***
A*SST	4	87.6	21.90	24.52	0.0000***
M*SST	11	38.4	3.50	3.91	0.0000***
M*BET	44	92.1	2.10	2.34	0.0000***
A*MLD	4	17.5	4.40	4.89	0.0006***
M*MLD	11	29.1	2.60	2.96	0.0006***
SST*MLD	1	13.9	13.90	15.53	0.0001***
ALB*SST	4	11.5	2.90	3.20	0.0122*
M*ALB	44	78.1	1.80	1.99	0.0001***
ALB*BET	16	24.4	1.50	1.71	0.0384*
BET*MLD	4	4.1	1.00	1.15	0.3296
BET*SST	4	2.2	0.60	0.63	0.6415
ALB*MLD	4	1.7	0.40	0.48	0.7531

Table 2. ANOVA table of the selected model for Option 1.

Source	Df	SS	MS	F-value	P-value
Model	385	17744	46.09	51.56	0.0000***
Error	16387	14649	0.89		
Total	16772	32393			

Source	Df	SS	MS	F-value	P-value
Y	35	6089.3	174.00	194.61	0.0000***
M	11	300.7	27.30	30.58	0.0000***
A	4	7850.6	1962.70	2195.45	0.0000***
ALB	4	716.1	179.00	200.26	0.0000***
BET	4	148.6	37.20	41.56	0.0000***
SST	1	237.2	237.20	265.30	0.0000***
MLD	1	8.9	8.90	9.95	0.0016**
Y*A	126	1122.3	8.90	9.96	0.0000***
A*BET	16	392.5	24.50	27.44	0.0000***
A*ALB	16	288.1	18.00	20.15	0.0000***
M*A	44	221.3	5.00	5.63	0.0000***
A*SST	4	87.6	21.90	24.51	0.0000***
M*SST	11	38.4	3.50	3.91	0.0000***
M*BET	44	92.1	2.10	2.34	0.0000***
A*MLD	4	17.5	4.40	4.88	0.0006***
M*MLD	11	29.1	2.60	2.96	0.0006***
SST*MLD	1	13.9	13.90	15.52	0.0001***
ALB*SST	4	11.5	2.90	3.20	0.0123*
M*ALB	44	78.1	1.80	1.99	0.0001***

Table 3. ANOVA table of the selected model for Option 2.

Source	Df	SS	MS	F-value	P-value
Model	381	17725	46.52	51.99	0.0000***
Error	16391	14668	0.89		
Total	16772	32393			

Source	Df	SS	MS	F-value	P-value
Y	35	6089.3	174	194.4101	0.0000***
M	11	300.7	27.3	30.545	0.0000***
A	4	7850.6	1962.7	2193.1397	0.0000***
ALB	4	716.1	179	200.0472	0.0000***
BET	4	148.6	37.2	41.5193	0.0000***
SST	1	237.2	237.2	265.0237	0.0000***
MLD	1	8.9	8.9	9.944	0.0016**
Y*A	126	1122.3	8.9	9.9531	0.0000***
A*BET	16	392.5	24.5	27.4127	0.0000***
A*ALB	16	288.1	18	20.1243	0.0000***
M*A	44	221.3	5	5.6206	0.0000***
A*SST	4	87.6	21.9	24.4795	0.0000***
M*SST	11	38.4	3.5	3.902	0.0000***
M*BET	44	92.1	2.1	2.3379	0.0000***
M*MLD	11	23.4	2.1	2.3799	0.0061**
SST*MLD	1	17	17	19.0315	0.0000***
ALB*SST	4	12	3	3.3653	0.0092**
M*ALB	44	78.5	1.8	1.9936	0.0001***

Table 4. ANOVA table of the full model for Option 3.

Source	Df	SS	MS	F-value	P-value
Model	314	6579	20.95	24.72	0.0000***
Error	11418	9678	0.85		
Total	11732	16257			

Source	Df	SS	MS	F-value	P-value
Y	35	3716.7	106.2	125.2817	0.0000***
M	11	62.9	5.7	6.7479	0.0000***
A	2	887	443.5	523.2474	0.0000***
ALB	4	280.2	70.1	82.6459	0.0000***
BET	4	78.3	19.6	23.0989	0.0000***
SST	1	0.2	0.2	0.2051	0.6506
MLD	1	12.8	12.8	15.0774	0.0001***
Y*A	70	533.7	7.6	8.9944	0.0000***
A*BET	8	334	41.8	49.2615	0.0000***
A*ALB	8	174	21.7	25.6597	0.0000***
M*A	22	142.9	6.5	7.6637	0.0000***
A*SST	2	28.3	14.2	16.704	0.0000***
M*SST	11	24.4	2.2	2.6212	0.0024**
M*BET	44	112.7	2.6	3.0212	0.0000***
A*MLD	2	13.8	6.9	8.1654	0.0003***
M*MLD	11	19.6	1.8	2.1034	0.0170*
SST*MLD	1	5.5	5.5	6.4587	0.0111*
ALB*SST	4	26.3	6.6	7.7494	0.0000***
M*ALB	44	75.7	1.7	2.0298	0.0001***
ALB*BET	16	35.9	2.2	2.6491	0.0004***
BET*MLD	4	0.6	0.2	0.1888	0.9443
BET*SST	4	9.5	2.4	2.791	0.0248*
ALB*MLD	4	3.3	0.8	0.97	0.4225

Table 5. ANOVA table of the selected model for Option 3.

Source	Df	SS	MS	F-value	P-value
Model	231	6394	27.68	32.28	0.0000***
Error	11501	9863	0.86		
Total	11732	16257			

Source	Df	SS	MS	F-value	P-value
Y	35	3716.5	106.2	123.822	0.0000***
M	11	63	5.7	6.6737	0.0000***
A	2	887.2	443.6	517.2853	0.0000***
ALB	4	280.2	70.1	81.6945	0.0000***
BET	4	78.4	19.6	22.8457	0.0000***
MLD	1	11.8	11.8	13.7096	0.0002***
Y*A	70	534.4	7.6	8.9015	0.0000***
A*BET	8	331.6	41.5	48.3408	0.0000***
A*ALB	8	174.2	21.8	25.3964	0.0000***
M*A	22	138.7	6.3	7.3497	0.0000***
M*BET	44	109.9	2.5	2.9115	0.0000***
ALB*BET	16	43.6	2.7	3.1801	0.0000***
A*MLD	2	15.3	7.7	8.9225	0.0001***
ALB*MLD	4	9.2	2.3	2.6789	0.0300*

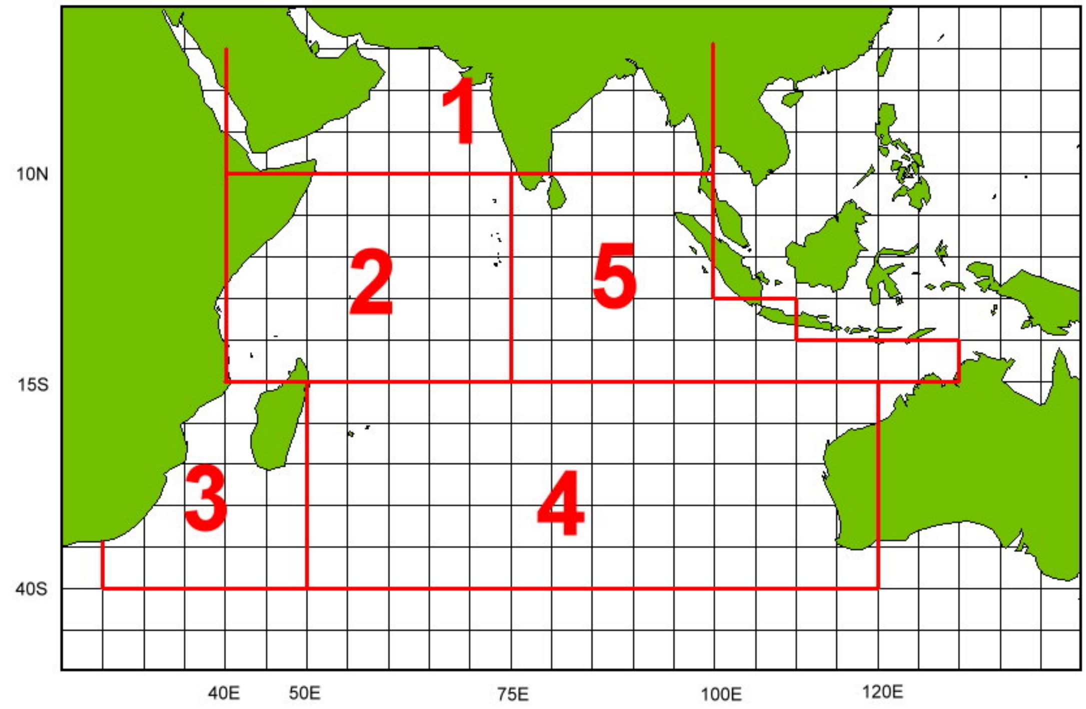


Fig. 1. Area stratification used fro the standardization of CPUE for yellowfin tuna in the Indian Ocean.

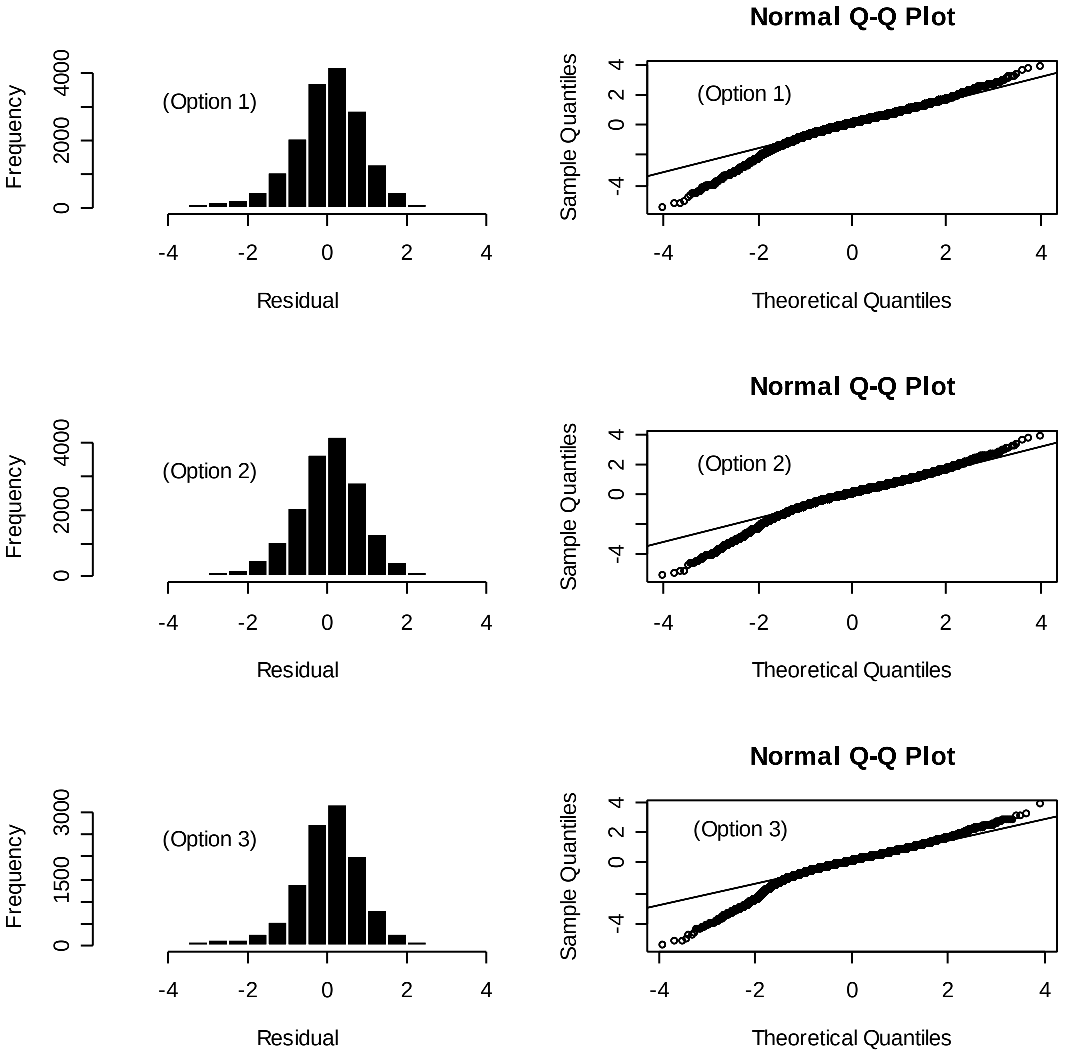
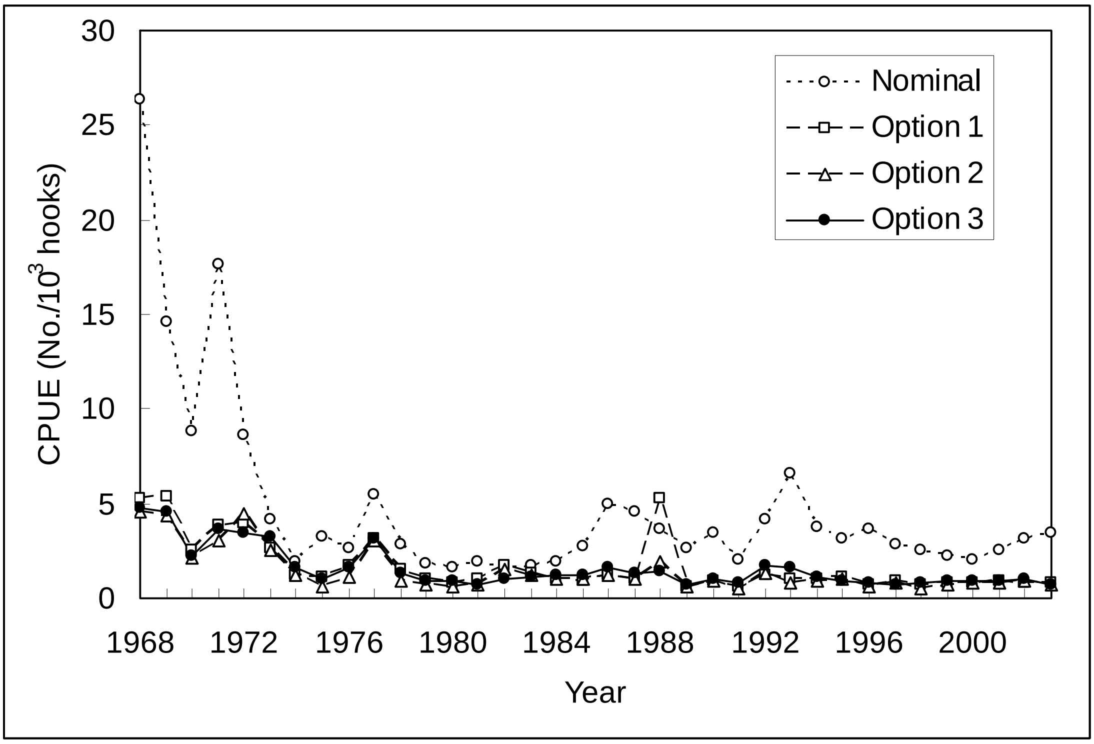


Fig. 2. Distributions of the standardized residuals and the normal probability plots for the standardization models fitted to the catch and effort data.



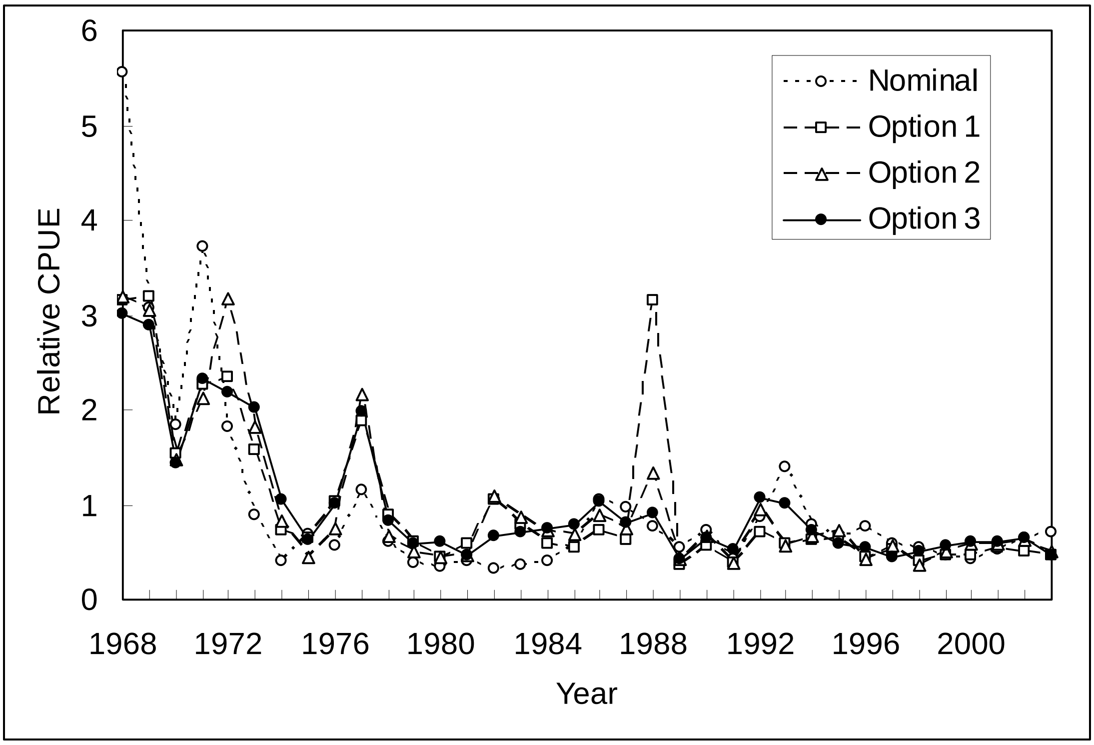


Fig. 3. Trends of nominal and standardized CPUE of yellowfin tuna caught by Taiwanese longline fishery in the Indian Ocean. Relative values are scaled to the average of estimates.

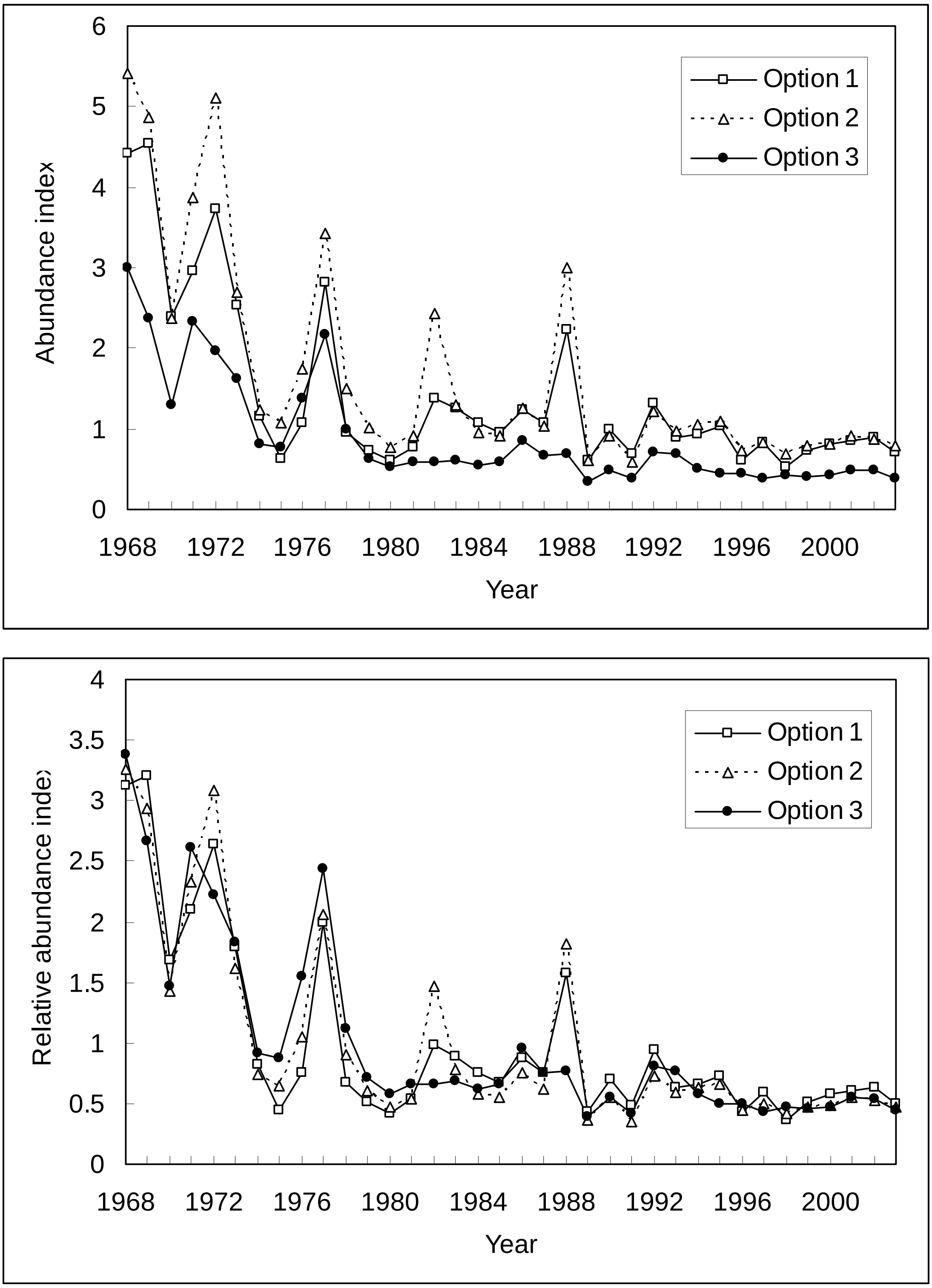


Fig. 4. Abundance index for yellowfin tuna in the Indian Ocean. Relative values are scaled to the average of estimates.