J. Fish. Soc. Taiwan, **28**(4): 329-338

A New Assessment Approach Using Fuzzy Surplus Production Model to Evaluate the Albacore Stock in the Indian Ocean

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(Received, November 9, 2001; Accetped, December 17, 2001)

ABSTRACT

Albacore is one of the important temperate and productive species. Since 1970s, Taiwan has been the leading nation exploiting the species using longline in the Indian Ocean (about 85% total annual catch). For assessing the stock status, a traditional Schaefer surplus production model and a fuzzy surplus production model are used for this purpose. Daily catch and effort data extracted from logbooks from 1979 to 1997 of Taiwan tuna longline fishery is used to derive the abundance index that is standardized by the general linear model with year, month, subarea and target species factors. The annual catches from longline and surface gears were used to fit these production models. The results show that a standardized abundance index was obtained with fluctuated stably in a high level from 1979 to 1987 then decreased from 1988 to 1995, and increased after 1995. The maximum sustainable yield (MSY) estimated by Schaefer production model is 27,717 mt. The MSY estimated by fuzzy surplus production model ranged from 25,728 to 30,651 mt with increasing vagueness and point estimated at 27,248 mt. Since 1992, the catches have been far below MSY, indicating that the stock may be under exploited status and an optimistic projection with a current catch level may be resulted from the increasing abundance index trend and catch level under MSY.

***Key words**: Albacore, Schaefer surplus production model, fuzzy surplus production model, Maximum sustainable yield (MSY)*

INTRODUCTION

Albacore (*Thunnus alalunga*) is one of the important temperate and productive species (Nakamura, 1969). Since 1970s Taiwan has been the leading nation exploiting the species using tuna longline that mainly targets on the adult fish and gillnet from 1986 to 1992 that mainly targets on the young fish in the Indian Ocean (Chang, 1993; Hsu, 1993; Lee and Liu, 1995). Hence Taiwan's landing occupies more than 80% annually. Though the target species has been shifted to the tropical tuna species for sashimi, the landings of albacore in the Indian Ocean by Taiwan tuna longline (TLL) fishery still excess the half of the total Indian albacore landings (Table 1).

Schaefer surplus production model has often been used to provide the management criterion, e.g. maximum sustainable yield (MSY), for its easy calculation and simple data requirement (Hilborn and Walter, 1992). There are many studies of the variation of Schaefer surplus production models that have been done for the albacore in the Indian Ocean. Different MSYs were obtained by given various shape parameter (m), data set covered, and different states (Table 2). Those devia-

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Table 1. The estimated yearly catch statistics by gear of albacore in the Indian Ocean.

year	Total catch	LL(wt)[1]	SURF(wt)[2]	TLL[3]	JLL[3]	TGN[3]	TLLW[4]	TGNW[4]
1979	16211	16211	0	14023	266	0	14.21	
1980	12045	12045	0	9974	487	0	14.24	
1981	13309	13309	0	11205	1381	0	14.54	
1982	25393	23354	2039	21930	932	0	14.22	
1983	19341	19327	14	16958	1263	0	14.29	
1984	16429	15931	498	13932	0	0	13.26	
1985	10436	9110	1326	6155	721	721	13.67	9.81
1986	29228	13631	15597	11052	15176	15176	14.55	9.81
1987	29317	16872	12445	13137	1641	12179	14.39	9.81
1988	28522	13618	14904	11048	1171	14441	13.33	9.81
1989	25564	10965	14599	7097	776	14357	13.68	9.81
1990	32790	11313	21477	5756	1066	21142	14.00	9.38
1991	29235	17935	11300	13102	830	9001	14.36	8.03
1992	19184	14537	4647	11103	1040	1322	12.56	8.94
1993	16880	15514	1366	11890	895		14.40	
1994	20635	17998	2637	14407	1487		15.47	
1995	20129	18784	1345	14209	2043		14.72	
1996	28305	26697	1608	16930	2388		14.43	
1997	27233	25159	2074	15204	2870		13.61	

Data source was referred from IOTC data summary (in FISHSTAT).

1. LL: long line fishery. The unit is mt.
2. SURF: surface fishery that includes bait boat, gill net, hand line, purse seine, troll line. The unit is mt.
3. TLL: long line catch by Taiwan. JLL: long line catch by Japan. TGN: gill net catch by Taiwan.
4. TLLW and TGNW: the annual average weight in kg of TLL and TGN. TLLW is computed from logbook data and TGN can bereferred from Table 5 of Lee and Liu (1995).

tions may come from the sampling and system error (Beers, 1962). All of those previous studies were dealing with the sampling error rather than the system error.

System error is always ignored in the statistical model for its complexity resulted from the model assumptions for example the ideal stock, the unchanged environment, and the constant catchability coefficient etc. Generally, the system is always represented by the model parameters. The fuzzy linear regression model (Tanaka *et al*, 1982; Sakawa and Yano, 1992) was adopted in this study to resolve the system error. In this study, therefore, the objective was to currently assess the Indian albacore stock using (1) the Schaefer surplus production model incorporated the measurement error and (2) the fuzzy surplus production model incorporated system errors by setting parameters as fuzzy numbers. Finally the results obtained from both models were compared to depict the influence of measurement error and system error.

MATERIALS AND METHODS

The daily logbook data of Taiwan longline (TLL) fishery and the adjusted catch per unit effort (ACPUE) series of Taiwan gillnet (TGN) fishery were used for both fisheries contributed to most of the landings of albacore in the Indian Ocean (Table 3.1). The daily logbook data of Taiwan tuna longline (TLL) fishery from 1979 to 1997 was currently verified and provided by the Overseas Fisheries Development Council of the Republic of China (OFDC). The ACPUE series of

Table 2. Maximum sustainable yield (MSY) of albacore in the Indian Ocean estimated using production model by different authors after 1985. The MSY estimated by the PRODFIT were compared under the situation of k=4, and m=0, 1, and 2.

Authors	Data set covered	Program	MSY	m	MSY*
Shiohama (1985)	1952-1982	PRODFIT	15.4-20.5	0	20.5
Huang *et al.* (1986)	1963-1984	PRODFIT	16.6-17.7	0	17.1
Shiohama (1986)	1952-1984	PRODFIT	14.8-22.0	0	22.0
Lee and Liu (1988a)	1962-1986	PRODFIT	16.0-19.1	1	16.0
Lee and Liu (1988b)	1967-1986	PRODFIT	16.7-22.1	2	16.7
Shiohama (1988)	1952-1986	PRODFIT	16.0-17.6	0	17.6
Liu and Lee (1990)	1962-1986	PRODFIT	15.8-	1	16.0
Hsu and Liu (1990)	1962-1988	PRODFIT	17.5-21.8	0	21.8
Chang (1993)	1955-1990	PRODFIT	21.4-25.9	0	21.5
Chang (1993)	1967-1990	MUGEPROD	-	-	18.4
Chang and Hsu (1993)	1967-1990	ASPIC	-	-	13.6
Hsu (1995)	1967-1992	ASPM	-	-	24.2
Chen (1998)	1979-1996	Schaefer	-	2	30.5
Ma (1999)	1960-1996	ASPM	-	-	17.0
This study (2001)	1979-1997	SLSPM		2	27.7
This study (2001)	1979-1998	FLSPM	8-53	2	25.7-30.6

* : The unit is 10^3 mt.

TGN from 1986 to 1992 can be referred from Lee and Liu (1995). The catch statistics by gears of albacore in the Indian Ocean was referred from the data summary of Indian Ocean tuna commission (IOTC).

Before building the models, the data should be properly transformed into the needing variables in order to meet the model assumptions. There are three main steps to follow:

First: Standardized the ACPUE of TLL fishery

The daily logbook data was processed to obtain the nominal catch per unit effort (NCPUE) series after fuzzy synthesis (Fig. 1) for the structure change of TLL fishery (Wang, 2001). Then NCPUE series was standardized by general linear model (GLM) to obtain ACPUE series and to represent the abundance of the stock. ACPUE series of TGN is also adjusted by GLM (Lee and Liu, 1995). The method of GLM can be referred from Nelder and Wedderburn (1972). The model is listed as follow:

$$ln(NCPUE+\eta) = \mu + Y_i + M_j + A_k + S_l + \varepsilon_{ijkl}, \quad (1)$$

where ln is the natural logarithm operator; η is a constant for avoiding the zero value of NCPUE, setting to 10% of the grand mean of NCPUE (μ); Y_i is the year effect, i =1979, …, 1997; M_j is the month effect, j = 1, …, 12; A_k is the fishing area effect, k=1,2,3 to indicate that the area of k=3 was located between 10°S and 25°S, the area of k=1 is northerly to 10°S and the area of k=2 is southerly to 25°S; S_l is the target species effect, l = 1, …, 5 are for the percentage of albacore with 20% interval, respectively. The percentage of albacore is defined as albacore catch in number in total catches in number of albacore, bigeye tuna and yellowfin tuna; and ε is the error term with N.I.D.(μ, σ).

Second: Combine the effort of TLL and TGN fisheries

The ACPUE series of TLL and TGN fisheries were combined to represent the

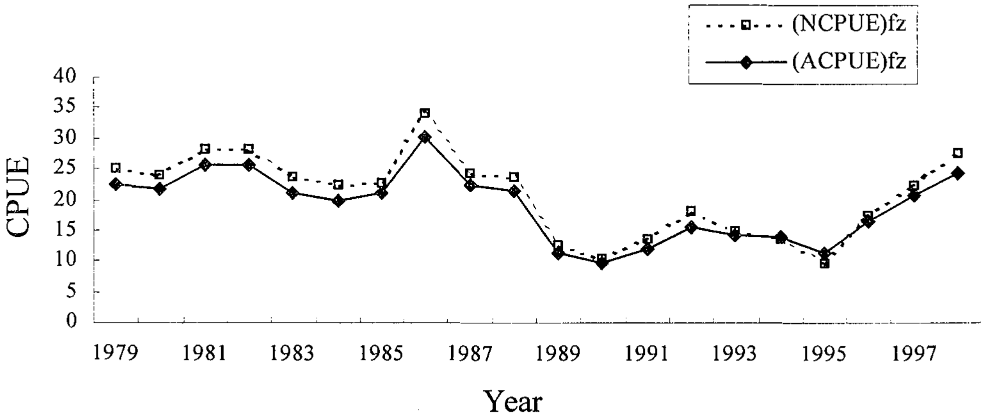

Fig. 1. Nominal (NCPUE) and standardized (ACPUE) catch per unit effort of Indian albacore stock by Taiwanese longline fishery from 1979 to 1997, in which the nominal catch per unit effort were classified into regular and deep fishing type directed by fuzzy synthesis method, and then standardized by general linear model.

stock abundance of albacore in the Indian for the different gear efficiencies. Because the ACPUE series of longline and surface fisheries were assumed to be represented by those of TLL and TGN fisheries, respectively, for the similar size distribution of the caught fish, the combined method is a weighting average of the two centralized ACPUE series by the weight of catch ratios of longline and surface fishery, respectively (Table 1). The relative ACPUE series was calculated from the above weighting average method. Then the effective effort series was calculated by the annual catch statistics divided by the relative ACPUE series. The details of this method can be referred from Sparre *et al.* (1989).

Third: Build the surplus production model

Schaefer surplus production mode is built as a simple linear relationship between ACPUE (Y_i) and effective fishing effort (X_i) with measurement error:

$$Y_i = a+bX_i+\varepsilon_i \quad (2)$$

The parameters of intercept (a) and slope (b) were estimated by maximum likelihood, then the maximum sustainable yield (MSY) can be obtained by the estimated intercept and the slope.

The fuzzy surplus production model is also a linear relationship between ACPUE and effective fishing effort, but with the parameters of fuzzy numbers:

$$Y_i = \tilde{a} + \tilde{b}X_i . \quad (3)$$

The dependent variable is also a fuzzy number by the extension principle (Klir and Yuan, 1992). So, the relative ACPUE (dependent variable) was transformed into the fuzzy number by setting its center and width from the mean and the half of the 95% confidence interval of the relative ACPUE series.

The parameters of fuzzy surplus production model were estimated by the linear programming. A constraint was given that the widest interval among the observations should be smaller than that of the model estimates and the degree of vagueness should be the smallest. The objective function is then the sum of the width of the parameter of fuzzy number that required a minimum value. The MSY of fuzzy surplus production model was calculated from the estimated parameters by fuzzy operator (Klir and Yuan, 1995). Then we can compare the estimated MSYs obtained from the estimates of Schaefer surplus production model and fuzzy surplus production model.

RESULTS AND DISCUSSION

The final model of GLM was selected by R^2 and mean square error (MSE) (Table 3) and about 40% of variation was explained by the model. Figure 1 shows that ACPUE and NCPUE series of TLL are in the similar trend. ACPUE series are smoother and smaller than that of the NCPUE series excepting two larger points in 1994 and 1995.

The general linear model can only explain about 41% variation (Table 3) with factors used in the present analysis; therefore, the discrepancies between ACPUE and NCPUE of Taiwanese longline fishery were not significant. Probably, some additional factors never used herein, such as environmental factors can improve the abundance index estimation.

Figure 2 shows ACPUE series of Taiwanese longline fishery and Taiwanese gillnet fishery and the relative ACPUE series of albacore in the Indian Ocean. Because of the heavier weight of longline fishery than that of the surface fishery, the relative ACPUE series looks much alike the trend of Taiwanese lonling fishery.

Table 3. The ANOVA of the general linear model(GLM) with fyzzy synthesis of the logbook data.

Source	DF	Sum of square	Mean qauare	F value
(A)				
Model	35	26088	745	2194
Error	110778	37637	0.34	
Corrected Total	110813	63726		
Year	18	3824	212	625
Month	11	403	37	108
Area by season	2	2214	1107	3259
Target species	4	12246	3061	9011
R^2	C.V.	RMSE	CPUE Mean	
0.41	19.75	0.58	2.95	

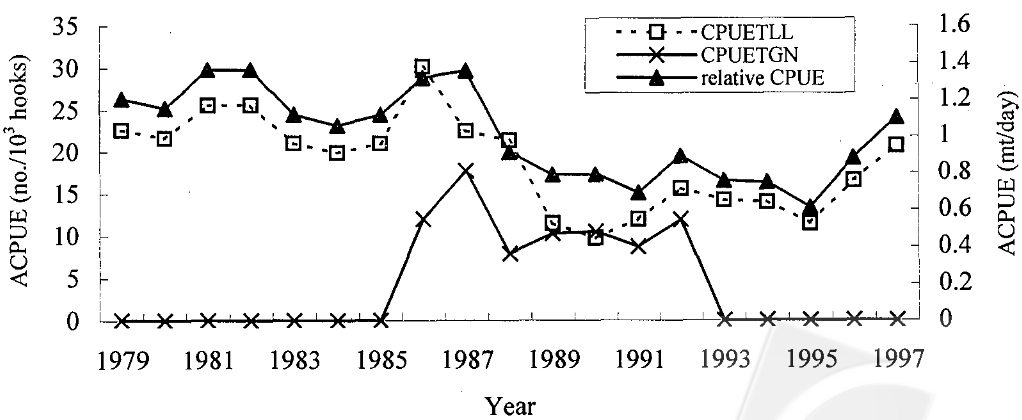

Fig. 2. Standardized catch per unit effort of Indian albacore stock for Taiwanese longline fishery (CPUETLL), Taiwanese gillnet fishery (CPUETGN) and the relative catch per unit effort (relative CPUE) trends from 1979 to 1997, which was computed from CPUETLL and CPUETGN as described in the text.

The estimated parameters and MSY of Schaefer surplus production model are listed in Table 4. MSY of Schaefer surplus production model is 28,000 mt, which is a level higher than those estimated previously (Table 2). The estimated parameters and MSY of fuzzy surplus production mdoel at different α-level are listed in Table 5. The MSY of fuzzy surplus production model is a fuzzy number. The center of it ranges from 27,000 to 51,000 mt with decreasing α -level (increasing vagueness). The width of it ranges from 0 to 23,000 mt with decreasing α-level. The estimated slope of fuzzy surplus production mdoel is a crisp value with the width equals to zero. It's somewhat steeper than that of Schaefer surplus production model. The estimated relative ACPUE of Schaefer surplus production model is in Figure 3. The estimated relative ACPUE of fuzzy surplus production model is in Figure 4. Figure 4 is a three dimensions plot for considering different α-level. There are unreasonable negative values of the lower extreme values at α under 0.3 in 1990 and 1991 (Figure 4). The confidence interval of Schaefer surplus production model is about the similar range at 0.4 α-level of fuzzy surplus production model.

The stock status is optimistic from the results of the present study. In viewing ACPUE series of the study stock (Figure 2), the abundance index fluctuated stably in a high level from 1979 to 1987; further decreased sharply to low level from 1988 to 1995; then increased from 1996 onward. Though a sharp decline trend of ACPUE of Taiwanese longline fishery may be resulted from heavy gillnet fishing from 1983 to 1992, the current result cannot reveal this situation, perhaps Beverton and Holt equation (Beverton and Holt, 1956; King, 1995) may be suitable to estimate the mortality for both fisheries, which targeted different sizes of fish. Afterward the heavy fishing period, the ACPUE showed an increasing trend from 1995. This may indicate that the stock seems possibly recovery after ban of gillnet fishery in 1993

Table 4. The parameters of Schaefer surplus production model estimated from relative ACPUE and effective fishing effort of Indian albacore from 1979 to 1997.

intercept	slope	R^2	MSY(10^3 mt)
1.44374548	-1.88E-05	0.53	28

Table 5. The fuzzy center (m) and width (c) of MSY, intercept and slope of fuzzy surplus production model.

α-level	(MSY)m	(MSY)c	(Intercept)m	(Intercept)c	(Slope)m	(Slope)c
0.1	51257	22506	1.642	0.718	2.62E-05	0.00E+00
0.2	45763	20006	1.642	0.638	2.62E-05	0.00E+00
0.3	41084	17505	1.642	0.559	2.62E-05	0.00E+00
0.4	37151	15004	1.642	0.479	2.62E-05	0.00E+00
0.5	33908	12503	1.642	0.399	2.62E-05	0.00E+00
0.6	31310	10003	1.642	0.319	2.62E-05	0.00E+00
0.7	29324	7502	1.642	0.239	2.62E-05	0.00E+00
0.8	27922	5001	1.642	0.160	2.62E-05	0.00E+00
0.9	27089	2501	1.642	0.080	2.62E-05	0.00E+00
1	26812	0	1.642	0.000	2.62E-05	0.00E+00

Note: The subscripts m and c mean the center and spread of a fuzzy number.
The unit of MSY is mt.

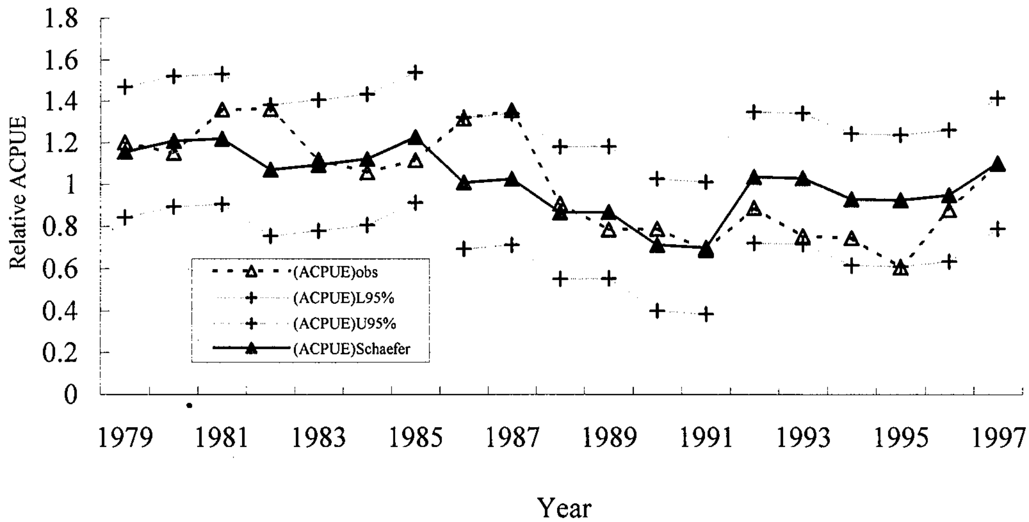

Fig. 3. The comparison between observed catch per unit effort and expected catch per unit effort estimated by Schaefer surplus production model for Indian albacore stock, in which the 95% confidence interval for expected series was depicted.

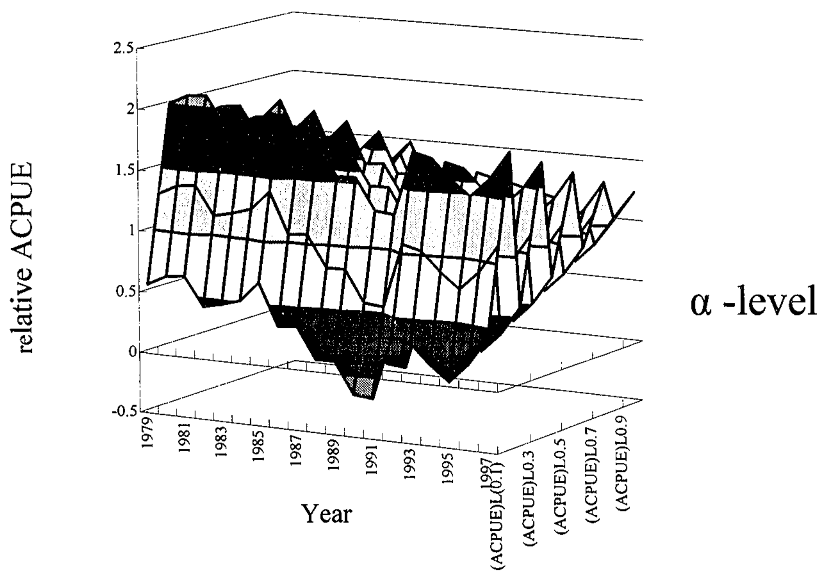

Fig. 4. The stereotype relationship among annual expected catch per unit effort estimated by fuzzy surplus production model with α -level for assessing Indian albacore stock from 1979 to 1997.

and a significant target shift of Taiwanese longline fleets (Wang *et al.*, 2001). This inference may be satisfactory to conclude the more reasonable estimation of MSY in the present study than others reported previously (Table 1).

The combination of fishing effort is a disadvantage in using surplus production models to assess a fish stock if the fish stock was exploited by different gears. The Indian albacore stock was fished by gillnet from 1983 to 1992, and by longline gear for the entire time series. Therefore, the fishing powers are different between both gears, in which the combined fishing effort made by catch proportion seemed not very appropriate, because the estimation may overshoot the gillnet fishing effort (Hsu, 1994). To overcome the drawback, age-structured population dynamic models may be useful for this purpose.

The stock status looks in a happy future according to the increasing trend of the relative ACPUE series. From Figure 2, the series may be divided into three stages, the first stage, from 1979 to 1987, the second stage, from 1988 to 1995, and the third stage, from 1996 to 1997. The first stage looks smoother and fluctuated stably in a higher level. The second stage decreases to another lower level and also fluctuated stably. The third stage looks in a increasing trend and increases sharply and nearly approaching to the lowest level of the first stage. Though a sharply decline of the ACPUE of Taiwanese longline fishery may be caused by the joint of the Taiwanese gillnet fishery. After several years (1993-1995), the ACPUE trend increases again after 1995. This may reveal that the recovery status of the stock for the decreasing pressure of Taiwanese longline fishery for the shift of target species and the ban of Taiwanese gillnet fishery that mainly caught the young fish. This can be shown by the increasing ratio of young fish in the fish size distribution of Taiwanese longline fishery (Wang *et al.*, 2001).

The impacts of measurement and system errors on the estimation of surplus production models were observed through the estimation of model fitting. The measurement and system errors always occur simultaneously, unfortunately, only the effort of system error was proved. Since the various ranges of model estimates in the present study (Figures 3 and 4), the fluctuation of the estimate was resulted by wide possible range of fuzzy surplus production model in a large proportion and by the vibration of Schaefer surplus production model in a small part. Hence, the different results may indicate that considering the effect of the system error in the estimation of production models is essential. On the other hand, the ability of the fuzzy surplus production model to quantify a fish stock can describe different degrees of impact of the system event resulted from the system error. However, the advance study may be worthy in the future for the topics of importance.

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印度洋長鰭鮪資源的模糊生產量模式評估分析

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(2001 年 11 月 9 日收件；2001 年 12 月 17 日接受)

長鰭鮪是重要的溫帶高產鮪類之一。自 1970 年代起，臺灣成為在印度洋使用鮪延繩釣漁具開發長鰭鮪的主要國家(產量約佔總印度洋年產量之 85%)。為評估印度洋長鰭鮪資源，傳統和模糊餘量生產模式被應用於評估分析。臺灣 1979 年至 1997 年每日報表資料，先經以年、月、小漁區和標的魚種等因子做泛線性模式法標準化後之單位努力漁獲量，被用來做為資源量指標。結果顯示時序列資源量指標在 1979 年至 1987 年間呈波動且穩定地處於高水準狀態，接著自 1988 年起下降至 1995 年後，又呈上升趨勢。經以傳統和模糊餘量生產模式分析結果顯示，最大持續生產量分別為 27,717 公噸及 27,248 公噸，模糊餘量生產模式估得之限界為 25,728 公噸和 30,651 公噸之間。這些估值都高於 1992 年以後的總年產量，顯示族群在低開發中，且因上升的資源量指標趨勢和遠低於最大持續生產量的漁獲水準，本資源在目前漁獲水準下應有樂觀的投射結果。

關鍵詞：長鰭鮪、傳統餘量生產模式、模糊餘量生產模式、最大持續生產量

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