CPUE Standardization of Indian Ocean Swordfish from Taiwanese Longline Fishery for Data up to 2002

Shui-Kai Chang[1] and Shyh-Jiun Wang[2]

INTRODUCTION

Taiwanese longline fishery in the Indian Ocean commenced in mid-1950s and targeted on yellowfin tuna in the beginning. Following the development of the fishery, two different operation patterns were currently established: The first targets on albacore (ALB) for canning and the other on tropical tuna species (bigeye, BET and yellowfin, YFT) for sashimi market (Chang and Liu, 2000; Chang, 2002). But, since 1990s, swordfish (SWO) has become a seasonal target species to some of the fleets, which have made the major portion (about 40-60%) of the overall catch in the Indian Ocean during recent decades (Figs. 1 and 2).

Besides of Taiwan, there were about 15 countries utilizing the Indian Ocean swordfish stock (IOTC, 2003) and made the overall catch increase three-folds from 10,000 tons before 1990s to 30,000 tons in 2002, with a peak of 40,000 tons in 1998 (Fig. 1). With the rapid increase of catch, significant decrease of catch rates in some regions was observed (IOTC, 2003). This observation and the recent increase of fleet size fishing for swordfish have caused concerns on the resource and therefore analysis on the stock status is required.

Historically most of the swordfish catch in the Indian Ocean was made by longline fisheries. Among the longline fishing nations, Taiwan (seasonal targeting fishery) and Japan (bycatch fishery) have the longest period of catch data series. And, Taiwanese data are of importance due to its targeting feature and the high-proportion to the total catch. Studies on CPUE standardization of Taiwanese data is thus important for understanding the stock status, but however is not straightforward because the data have confounded with many factors, especially the target-shifting effect. This paper performs several trials (runs) using the GLM approach on data series up to 2002 and provides

[1] Fisheries Agency, Council of Agriculture, Taipei, Taiwan

[2] Overseas Fisheries Development Council, Taipei, Taiwan

comparisons and discussions on the results, based on the similar studies performed during the 2003 meeting of the IOTC Working Party on Billfish (IOTC 2003).

MATERIAL AND METHODS

The data

The Taiwanese catch and effort data are compiled from logbooks and start from 1967 to 2002, with year 2002 being preliminary. For years of 1967-1978, only aggregated 5°x5° square monthly data are available, and from 1979 onwards, both original logbooks and aggregated data are available. The logbook data contain basic information on fishing time, area, hooks and catches of 14 species including major tunas (albacore, bigeye, yellowfin, bluefin tunas) and billfishes (swordfish and marlins). Only years after 1995 contain hooks per basket (HPB) information. These data were provided by the Overseas Fisheries Development Council of the Republic of China.

The data between 20°E and 30°E in the waters adjacent to South Africa has been included in the dataset for study.

The model

The statistical model used for standardization was GLM under lognormal error structure, with main factors of year (Y), quarter (Q), area (A), target (T), sea surface temperature (sst, S), and mixing layer depth (mld, D) effects:

$$\ln\left(\frac{C_{y,q,a,t,s,d}}{E_{y,q,a,t,s,d}}+x\right)=\mu+Y_y+Q_q+A_a+T_t+S_s+D_d+(Interactions)+\xi_{y,q,a,t,s,d} \qquad (1)$$

where, $C_{y,q,a,t,s,d}$ and $E_{y,q,a,t,s,d}$ are catch (kg) and effort (1000 hooks) for year y, quarter q, area a, target category t, sst (in integer code), and mld (in the order of tenth). μ is the global mean and ξ the error term. The variable x is the overall mean CPUE to avoid the zero catch rate problems.

The factors

Quarter factor was considered in the model because swordfish is a seasonal target species to the fleets and hence the catches (Fig. 3, top) and catch rates of some quarters were higher than the others. Normal definition of four quarters (Qt), i.e., Jan-Mar, Apr-Jun, Jul-Sep, Oct-Dec, were used in the model for several runs (Table 1), but from Fig. 4, the catch pattern is a little bit different from the normal definition. To make it homogeneous within a quarter, we slightly changed the definitions of second and third quarters to be Apr-May and Jun-Sep respectively and renamed as Qt_new.

Based on the homogeneity of historical swordfish catch distributions (Chang, 2003), the same ten areas were defined as in 2003 WPB meeting (Area_2003 in Table 1), except that Area 7 has been extended southward to 45°S and westward to 20°E (Fig. 5). From the bottom panel of Fig. 3, different area has significant trend of swordfish catch. As suggested in 2003 WPB meeting, Areas 3 and 7 have been further split into Areas 31/32 and 71/72 respectively in this study (Fig. 5), according to Longhurst ecosystem criteria. For the study, as did in 2003, Areas 5 and 6 were combined as Area 56, Areas 8 and 9 were combined as Area 89, to reduce the number of area.

The target-shifting practice may affect the swordfish catch rate and hence needs to be accounted for in the model. Due to insufficient information on gear configuration (e.g., HPB), this study used three indices to express the target effect: (1) Target_%_4q: quartile of catch composition of swordfish against the four main species (albacore, bigeye, yellowfin tunas and swordfish). (2) Target_%_hpb: three categories of swordfish catch composition defined based on the information of HPB of 1995-2001, i.e., <8%, 8-15%, >15%. This index has been used in the 2003 WPM meeting. (3) Target_HpB: four categories of HPB defined based the study made in 2003 meeting, i.e., <9, 10-12, 13-14, >14. This index applied only for data with HPB information since 1995.

Sea surface temperature data and mixing layer depth data have been applied in the model this time for some trial runs.

Adjustment by area size

A year-area interaction term was included in the model to capture the effect of catch rates in different area changing at different rates over time. It is commonly assumed that the catch rate for a year and an area is proportional to the fish density in the area during that year (Punt *et al.*, 2000). Hence, the final standardized catch rate could be obtained from the equation:

$$U_y = \sum_a S_a U_{y,a} \qquad (2)$$

where, U_y is the standardized catch rate for year y and $U_{y,a}$ is the standardized catch rate for year *y* and area *a* obtained from the GLM running. S_a is the relative size of the area *a* to the overall studied area.

RESULTS

With combinations of different options of the above-mentioned factors and the consideration of discrepancy in the nature of CPUE in terms of number and weight, we have performed several GLM model runs. Table 1 lists results of some of the specific runs for comparison discussions.

Run 2 & 3

The Run 2 (coded as R-2 in Table 1) is basically the same run as in 2003 meeting, except that the data included 20°S-30°S area in the waters off South Africa and with revised 2001 and preliminary 2002 data. Interactions among the main factors have been examined and those were insignificant, or significant ($P < 0.001$) but led to negligible effects on the change of deviance, were removed from the final model. And thus, only Year*Area and Area*Target were remained in the final model. Areas 1, 2, and 89 were also excluded from the final model.

Since the catch and data records between 40°S-45°S of Area 7 were very few, these data were excluded in Run 2, but were included in Run 3 for comparison. The result in Table 1 shows no obvious difference between them.

Both Run 2 and 3 used swordfish catch composition categories (three) defined from HPB information (Target_%_hpb) in 2003 WPM meeting as the target factor. Only half of the variances could be accounted for by this model (R^2=0.5). No significant trend is observed for the resulted standardized CPUE for these two runs (Fig. 6).

Run 4 & 5 & 6

After Run 4, the target factors all used quartile of swordfish catch composition (Target_%_4q) which has also been applied in 2003 meeting, instead of the pre-defined categories.

Run 4 used the same model and conditions as Run 2 except the target factor. The R^2 (0.71) is much higher than Run 2. Most of the variance can be explained by target effect. The resulted standardized relative CPUE (Fig. 6) is much fluctuated than Run 2 although the pattern is a little bit similar.

Since Run 5, the applied area definition was the new revised one (Area_2004): Area 7 was split into 71 and 72. Area 3 has been split in the beginning but the run can not get reasonable estimation, and thus was combined as one in the final. Since Run 5, the applied definition of quarter was also the new one (slightly changed quarters 2 and 3). Data of 1979 and 1980 were removed for the convenience to interpret the CPUE trend.

The result of Run 5 is similar to that of Run 4 from the deviance analysis in general, but for interpretation of the area effect, Run 5 is more preferable in the study.

Run 6 is based on Run 5 but used CPUE in terms of catch in number, instead of in weight. This is because of the consideration that the mean size of swordfish catch in different area may change by years after a heavy exploitation. The result indicates an improved R^2 (0.74).

Run 7 & 8

Run 7 and 8 have included additional factors of sst and mld in the GLM model. Run 7 used CPUE in terms of catch in number (as in Run 6), but Run in terms of weight. For these two, result of Run 7 is better than Run 8 in terms of R^2. Standardized CPUE trend seems slightly different between them in the early years (1992-1994) when swordfish became a seasonal target.

Run 10 & 11

Run 10 and 11 were based on Run 7 and 8, respectively, and conduct standardizations individually on Area 3, 4, 71 and 72 where are concerned most by the WPB. The resulted relative CPUE is shown in Fig. 7.

Run 12 & 13

These two runs conducted based on Run 7 and 8, respectively, but applying HPB information as target factor (Target_%_HpB). R^2 of these runs are much smaller than all the runs. Area and quarter factors become more important in explanation of the variance than target factor.

Run 14

Run 14 was conducted based on Run 7. It contains two separate runs: one using data of 1967-1979 using monthly aggregated catch and effort data; the other one using shot by shot data of 1979-2002. Standardized CPUE series of the two runs were combined as one in Fig. 8. The R^2 are 0.92 and 0.75, respectively. This run is to provide an idea about long time series trend of the CPUE.

DISCUSSION

Target factors and interpretation of CPUE trends

In WPTT 2004, the meeting discussed a lot about the Lee and Nishida criteria to deal with the target effect. But the criteria does not consider swordfish and thus not applicable in this study for comparison. This study conducted runs based on three other methods (Table 1). Run 2 and 3 applied the Target_%_hpb; Run 12 and 13 applied Target_HpB and the rest Target_%_4q. Fig. 9 shows example residual plots of the three types of runs. Runs of Target_%_4q and Target_HpB have better fitting results to normal distribution assumption than Target_%_4q. However, Target_HpB model provides least variance explanation and the target factor became not so important.

As to the relative trends of standardized CPUE (Fig. 6), Target_%_hpb model shows relatively flatter trend. Target_HPB on the other hand shows sharp declining trend since 1997 when the swordfish catch was decreasing (Fig. 2). The percentage of HPB reported was lower than 50% before 2001 and increased significantly since 2001 (Fig. 10). This trend may affect the performance of modeling of Target_HPB.

The trend from Target_%_4q models in Fig. 6 show a declining trend since 1981 to a low level during 1989-1991 and then increased in 1992 to a similar level as 1988. Trends of the following years are somewhat different among different runs, but in general have been high during 1992-1997 then declined to 1999 with a slowly increasing trend to 2002.

When viewing the whole series of relative CPUE from 1967-2002 in Run 14 (Fig. 8), the above described trend becomes part of a two-mode CPUE pattern. The series starts with a continuous declining trend since 1967, and then displays two modes in 1978-1989 and 1991-1999 or 2000. For the recent two years of 2001-2002, the CPUE starts to increase again.

The recent increasing trend might be relating to the continuous decrease of catch and relaxing of fishing pressure since 1998. Take the number of vessels access to fishing license in Somalia waters as example. In 1996 when the swordfish catch was good, there were about 80 vessels in the waters for swordfish (and partly bigeye). The number has been decreased to 40 in 1998 and decreased further to 10 in 2000 due to the unprofitable price and low CPUE. Recently the number has been increased again in 2002 for a good fishing condition.

Environmental factors

Environmental factors of sst and mld have been included in some of the runs. Run 5 and 8, and Run 6 and 7, can be two pairs for comparison. From the deviation analysis (Table 1) and relative CPUE (Fig. 6), there is no obvious difference noted between the two runs of each pair. This indicates that there might be no significant relationship between swordfish CPUE and environmental factors.

A preliminary test on the relationship of sst against CPUE of the four main species (albacore, bigeye, yellowfin tunas and swordfish), showed that strong relationships exist for albacore, bigeye and yellowfin tunas ($r>\pm 0.6$), but not for swordfish ($r<0.15$). Similar situation was also noted for mld. This test has supported the results of model runs here.

CPUE in terms of catch in number and weight

Swordfish has been heavily exploited in mid-1990s which might cause changes in size of catch. Therefore, comparison runs have been conducted to see the effect. Run 5 and 6, Run 7 and 8, Run 10 and 11, and Run 12 and 13 are pairs for the discussion. All of the runs show that models with CPUE in number have higher R^2 than with CPUE in weight. As to the CPUE trends, no obvious difference is noted, except for years 1992-1994. In general, CPUE in number shows more clear declining trend after 1993 then CPUE in weight.

The differences in CPUE trends are slightly more obvious for Run 10/11 in Area 7 (Fig. 7) where swordfish was caught mostly, and the declining trends are clearer for model results with CPUE in weight than with CPUE in number, a different impression as above. This might have connections with the decreasing trend of size of catch.

CPUE trends by major area

Fig. 7 shows the standardized relative CPUE by major fishing areas: Areas 3, 4, 71 and 72, from Run 10 and 11. Both Areas 3 and 4 have a mode after 1992, but in general the trends are relatively flatter than Areas 71 and 72. CPUEs of Areas 71 and 72 have reached the highest level in 1992 and 1993, respectively.

After the highest level, both declined continuously and sharply to 2000, and then increased a little bit to 2002.

Considerations on unit stock assumption

This study takes swordfish in the whole Indian Ocean as a unit stock. The nuclear and mitochondrial DNA analyses of Chow and Takeyama (2000) indicated no genetic differentiation between the swordfish samples from the Pacific and Indian Oceans, and assumed that they are one breeding unit. However, a recent study using mitochondrial DNA (Lu, *et al.*, personal comm.) has suggested a three stocks structure for the Indian Ocean swordfish: (1) the northern Madagascar region; (2) the Bay of Bengal; and (3) the rest Ocean region. Since most of the swordfish was made in the western Indian Ocean, especially for Taiwanese fishery, conclusions on stock status presumably will be very different from the current if the one-stock assumption is invalidated.

REFERENCES

Chang, S.K. (2003) Information on the Indian ocean swordfish stock from Taiwanese tuna catch statistics and estimation of its abundance index. *IOTC Proceedings* **6**:325-334.

Chow, S. and H. Takeyama (2000) Nuclear and mitochondrial DNA analyses reveal four genetically separated breeding units of the swordfish. *J. Fish Bio.,* **56**: 1087-1098.

IOTC (2003) Report of the 3rd Session of the IOTC Working Party on Billfish. Perth, Australia, November 10-12, 2003. 32 pp.

Punt, A.E., T.I. Walker, B.L. Taylor and F. Pribac (2000) Standardization of catch and effort data in a spatially-structured shark fishery. *Fish. Res.* **45**: 129-145.

Yokawa, K. and H. Shono (2000) Preliminary stock assessment of swordfish (*Xiphias gladius*) in the Indian Ocean. *IOTC Proceedings,* **3**:154-163.

Table 1. Analysis of deviance table for generalized linear models with different runs fitted to Indian Ocean swordfish data from Taiwanese longline fishery. All the factors listed in the table are significant (P<.0001). Definitions of the runs are listed on the bottom rows of the table. Refer to text for further descriptions. (DF: degree of freedom; SS: sum of square; MS: mean square)

	R-2			**R-3**			**R-4**			**R-5**			**R-6**			**R-7**			**R-8**		
Source	DF	SS	MS	DF	SS	MS	DF	SS	MS	DF	SS	MS	DF	SS	MS	DF	SS	MS	DF	SS	MS
Year	23	232	10	23	235	10	23	443	19	21	630	30	21	647	31	21	623	30	21	612	29
Qt	3	250	83	3	247	82	3	130	43												
Qt_new										3	133	44	3	120	40	3	105	35	3	124	41
Area_2003	4	374	93	4	375	94	4	362	90												
Area_2004										5	268	54	5	266	53	5	142	28	5	86	17
Target_%_4q							3	22110	7370	3	19747	6582	3	20240	6747	3	19927	6642	3	19445	6482
Target_%_hpb	2	9707	4854	2	9715	4858															
Target_HpB																					
sst																19	61	3	19	84	4
mld																15	17	1	15	31	2
Year*Area	92	1011	11	92	1022	11	92	985	11	105	993	9	105	792	8	105	717	7	105	933	9
Area*Target	8	1097	137	8	1098	137	12	745	62	15	706	47	15	559	37	15	555	37	15	696	46
R**2	0.50			0.50			0.71			0.70			0.74			0.74			0.70		
Starting year	1979-			1979-			1979-			1981-			1981-			1981-			1981-		
Ref-Run	as 2003			R-2			R-2			R-4			R-5			R-6			R-7		
Note	*see bottom			inc. south of 40S			target from quartile			new Area & Qt			CPUE in number			CPUE in number			CPUE in weight		
										Area 31+32=3						inc sst, mld			inc sst,mld		

Condition changes of R-2 against 2003 run

1. including 20S-30S, revised 2001 and preliminary 2002
2. excluding south of 40S, without sst or mld, hook<1000, sp_rep_number<4
3. using 2003 Area definition, but exlcuded Area-1,2,89
4. using swo catch comp defined from HpB information as target factor (3 categories)

Table 1. (continuate)

	R-10-3			R-10-4			R-10-71			R-10-72			R-11-3			R-11-4		
Source	DF	SS	MS	DF	SS	MS	DF	SS	MS	DF	SS	MS	DF	SS	MS	DF	SS	MS
Year	21	359	17	21	170	8	21	148	7	21	221	11	21	506	24	21	266	13
Qt																		
Qt_new	3	82	27	3	60	20	3	8	3	3	5	2	3	139	46	3	48	16
Area_2003																		
Area_2004																		
Target_%_4q	3	13169	4390	3	19972	6657	3	1889	630	3	2928	976	3	12292	4097	3	18609	6203
Target_%_hpb																		
Target_HpB																		
sst	6	25	4	4	4	1	12	11	1	14	26	2	6	40	7	4	0	0
mld	9	21	2	7	16	2	11	12	1	11	12	1	9	28	3	7	43	6
Year*Area																		
Area*Target																		
R**2	0.60			0.83			0.75			0.79			0.56			0.77		
Starting year	1981-			1981-			1981-			1981-			1981-			1981-		
Ref-Run	R-7			R-7			R-7			R-7			R-8			R-8		
Note	only Area-3			only Area-4			only Area-71			only Area-72			only Area-3			only Area-4		
	CPUE in number			CPUE in number			CPUE in number			CPUE in number			CPUE in weight			CPUE in weight		

Table 1. (continuate)

	R-11-71			R-11-72			R-12			R-13			R-14-1967			R-14-1979		
Source	DF	SS	MS	DF	SS	MS	DF	SS	MS	DF	SS	MS	DF	SS	MS	DF	SS	MS
Year	21	163	8	21	290	14	7	258	37	7	255	36	12	30	3	23	620	27
Qt																		
Qt_new	3	12	4	3	4	1	3	248	83	3	295	98	3	5	2	3	106	35
Area_2003																		
Area_2004							5	620	124	5	524	105	5	5	1	5	140	28
Target_%_4q	3	1841	614	3	2672	891							3	4482	1494	3	21445	7148
Target_%_hpb																		
Target_HpB							3	60	20	3	104	35						
sst	12	13	1	14	40	3	18	138	8	18	142	8	15	5	0	18	61	3
mld	11	16	1	11	14	1	15	76	5	15	75	5	12	2	0	12	20	2
Year*Area							35	772	22	35	741	21	60	21	0	115	769	7
Area*Target							15	167	11	15	185	12	15	22	1	15	598	40
R**2	0.73			0.77			0.23			0.23			0.92			0.75		
Starting year	1981-			1981-			1981-			1981-			1967-1978			1979-2002		
Ref-Run	R-8			R-8			R-7			R-8			R-7			R-7		
Note	only Area-71			only Area-72			Target from HpB			Target from HpB			Excld area 1 2 10			Excld area 1 2 89		
	CPUE in weight			CPUE in weight			CPUE in number			CPUE in weight								

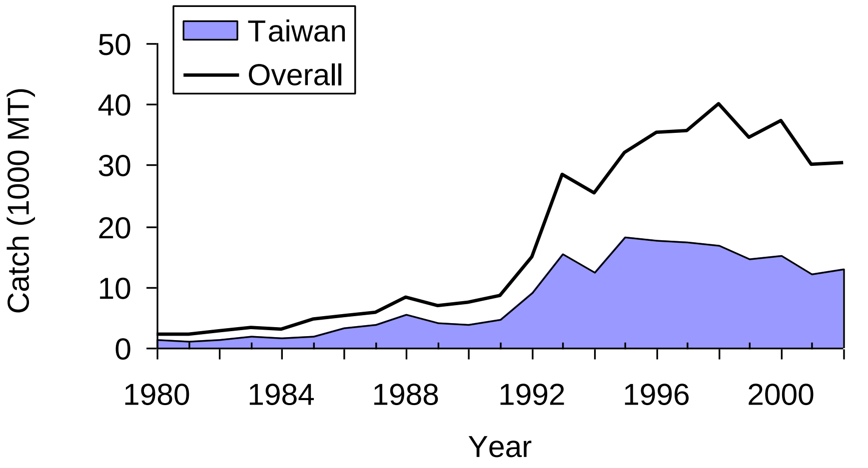

Fig. 1. Catch series of the Indian Ocean swordfish during 1980-2002.

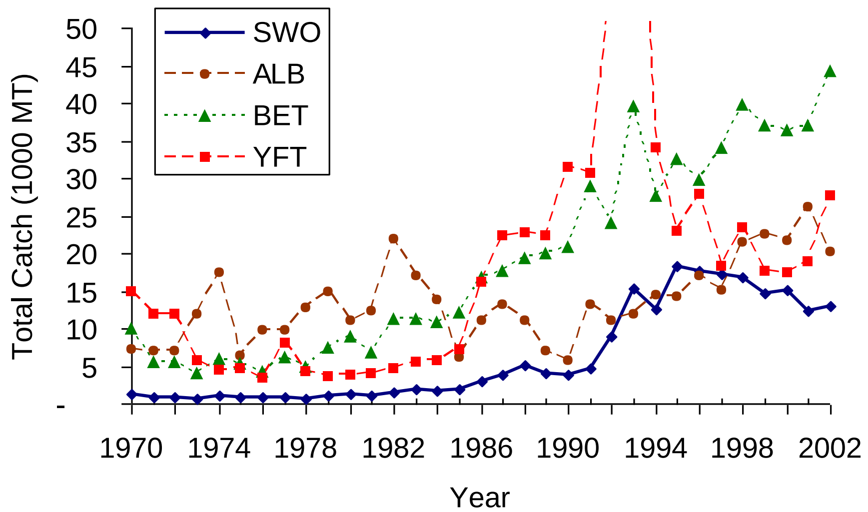

Fig. 2. Annual catches of the major tunas (ALB, BET, YFT) and swordfish (SWO) of the Indian Ocean by Taiwanese longline fishery, 1970-2002. The specific high catches of YFT in 1992 (56,000 MT) and 1993 (88,000 MT) are omitted for clarity of the trends of other species.

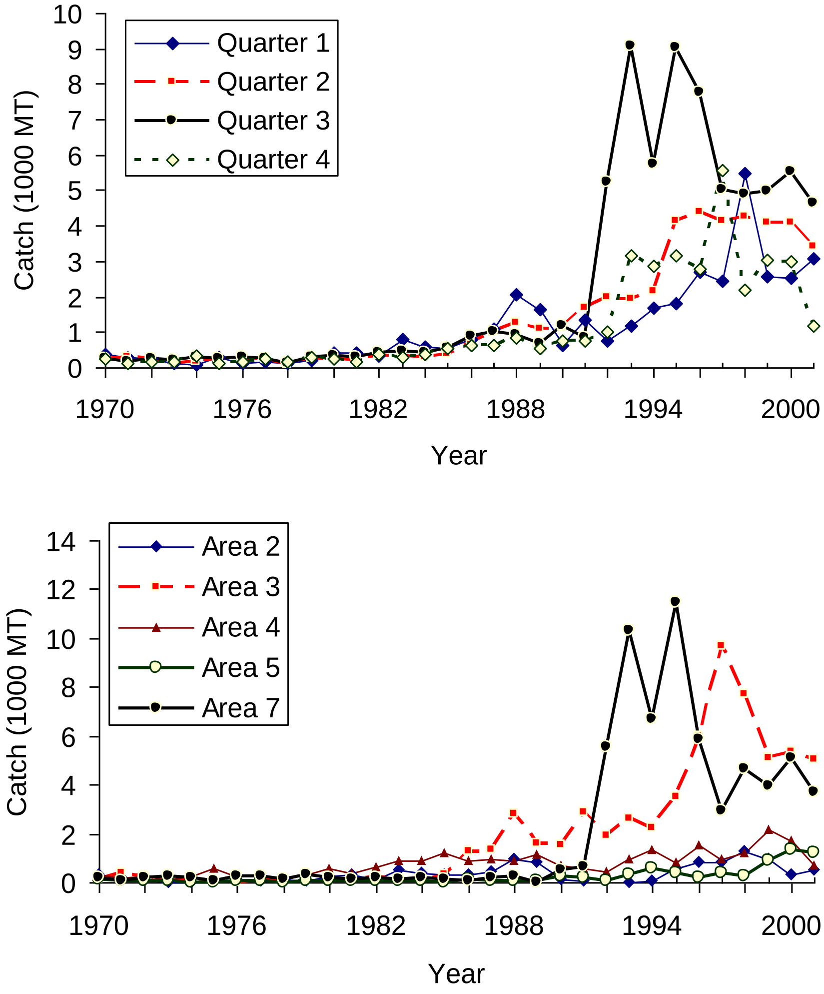

Fig. 3. Catch trends by quarter and area of the Indian Ocean swordfish by Taiwanese longline fishery, 1970-2001. Refer to Fig. 5 for area definition. Only five areas with significant catches are shown in the bottom panel for clarity.

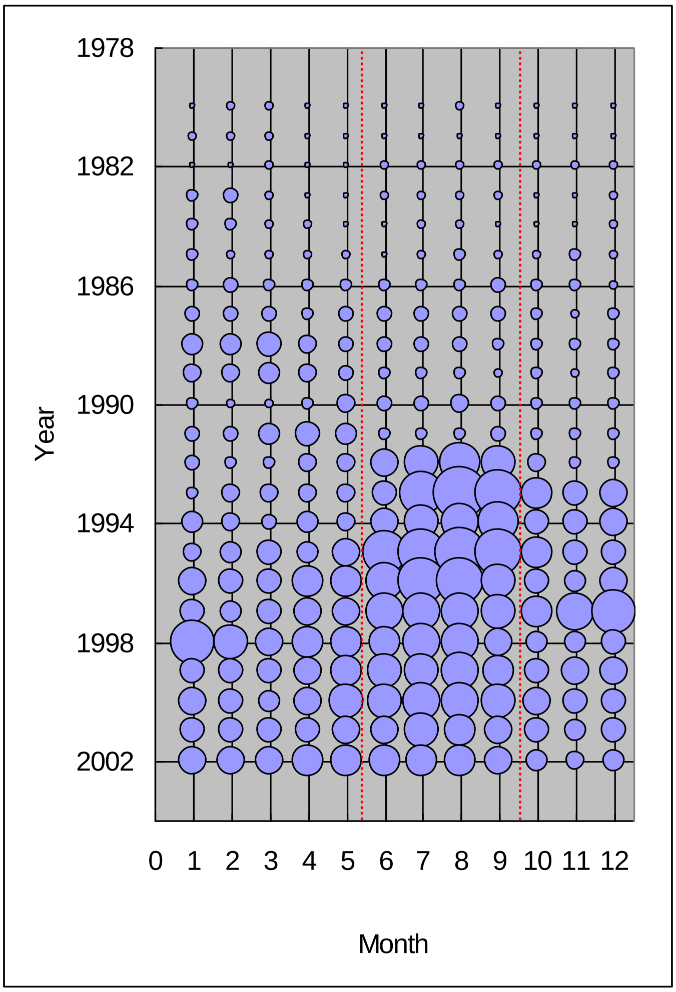

Fig. 4. Monthly catch pattern of the Indian Ocean swordfish by Taiwanese longline fishery during 1979-2002.

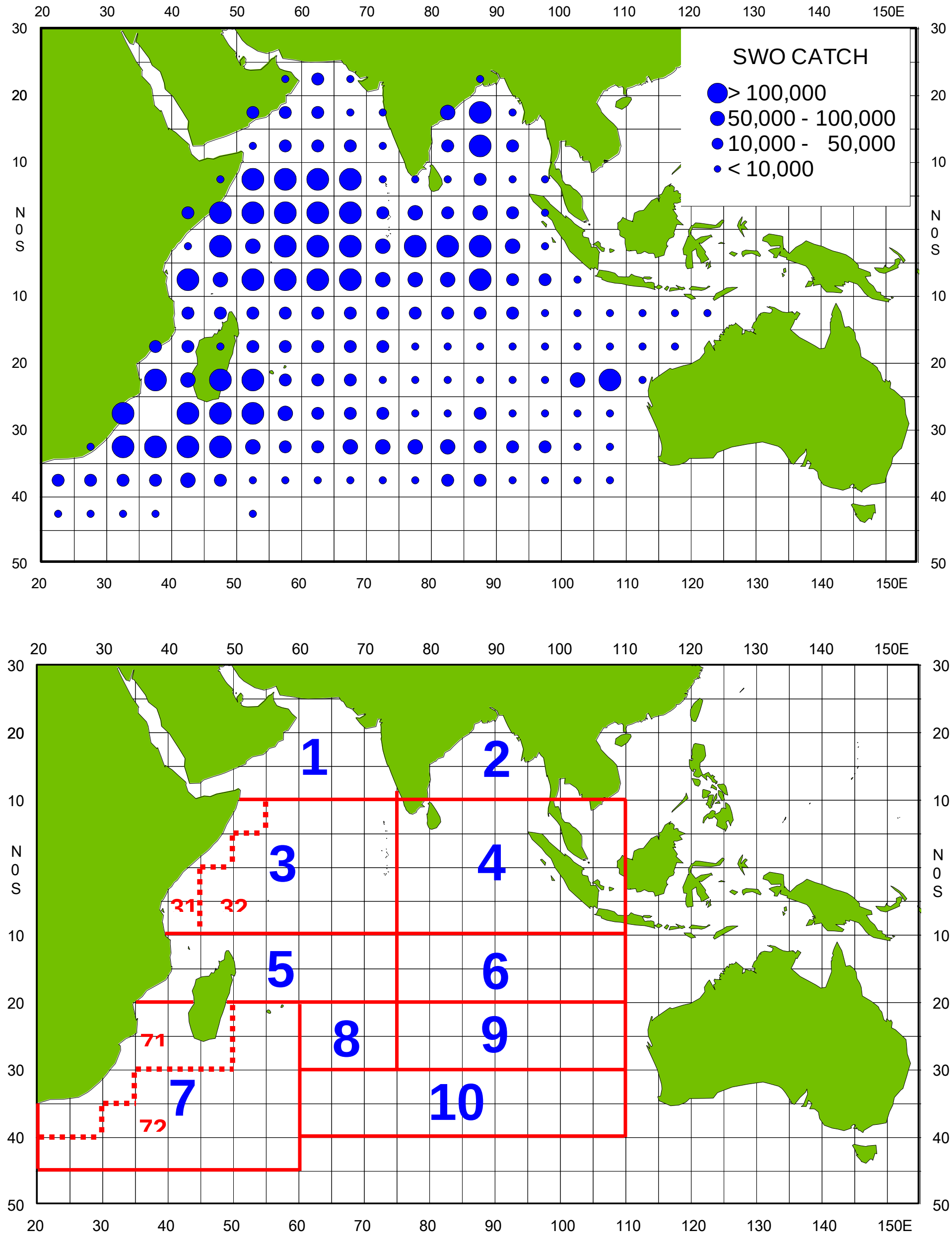

Fig. 5. Average catch distribution of the Indian Ocean swordfish by Taiwanese longline fishery in 1990s (top) and the area stratification (bottom) used in the analysis.

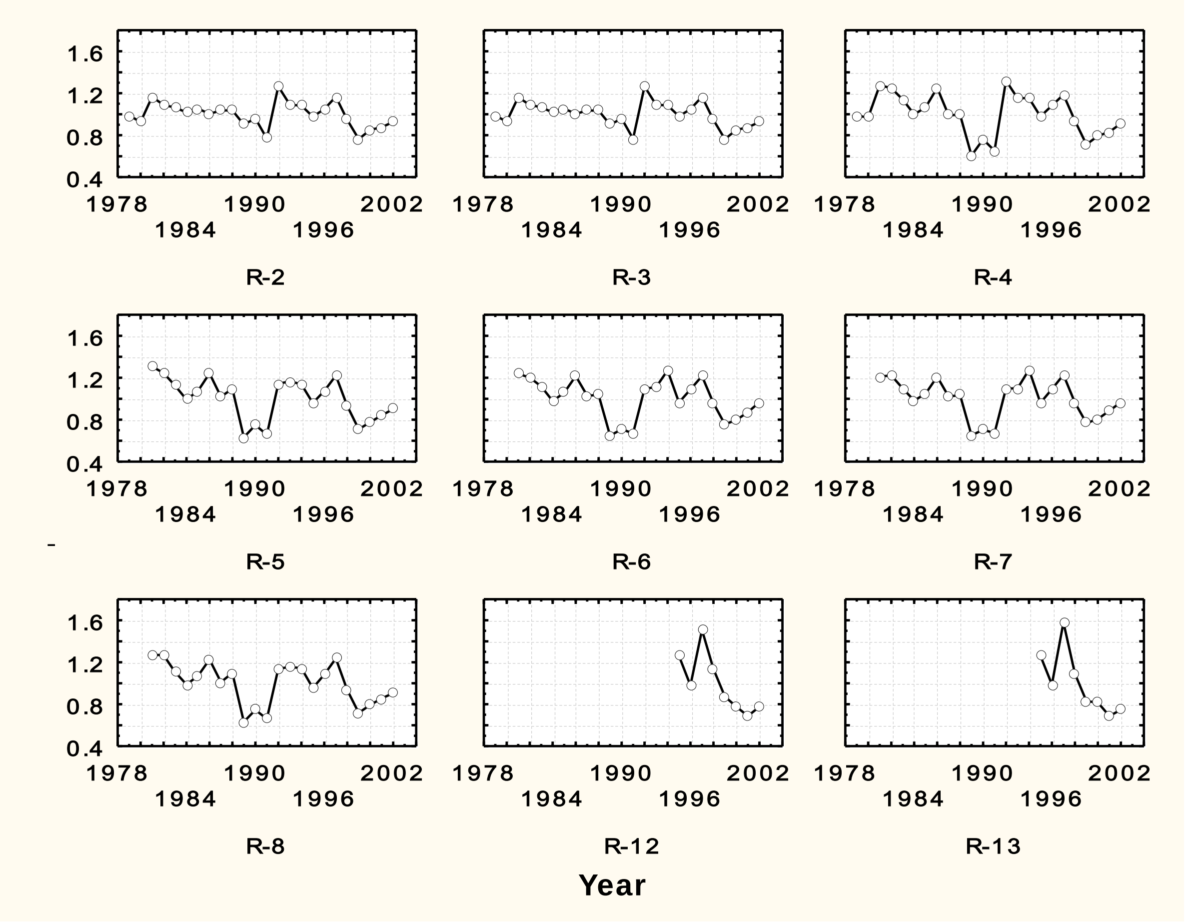

Fig. 6. Results of relative CPUE (standardized) of Indian Ocean swordfish from different runs. Refer to text and Table 1 for definitions of the runs.

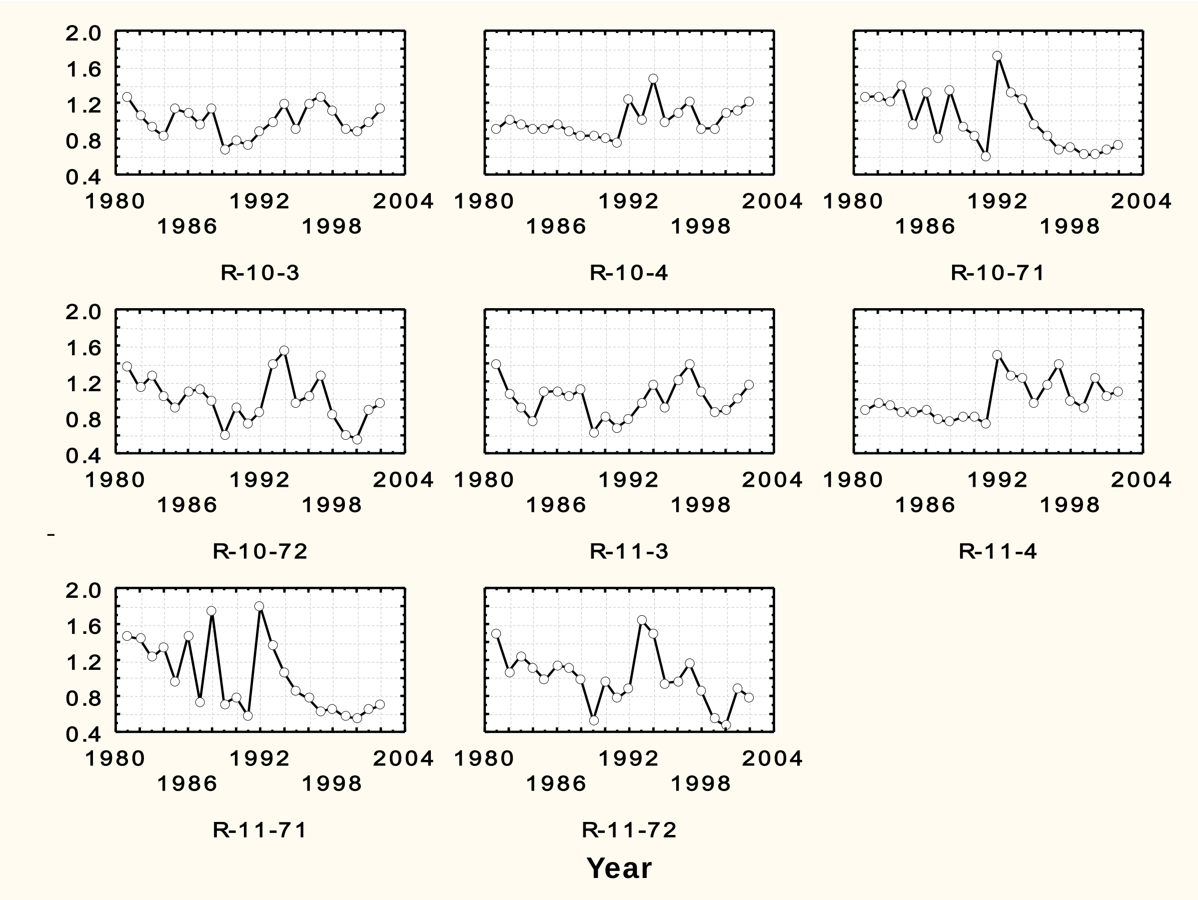

Fig. 7. Results of relative CPUE (standardized) of Indian Ocean swordfish from Run 10 and 11 for Areas 3, 4, 71 and 72. Refer to text and Table 1 for definitions of the runs.

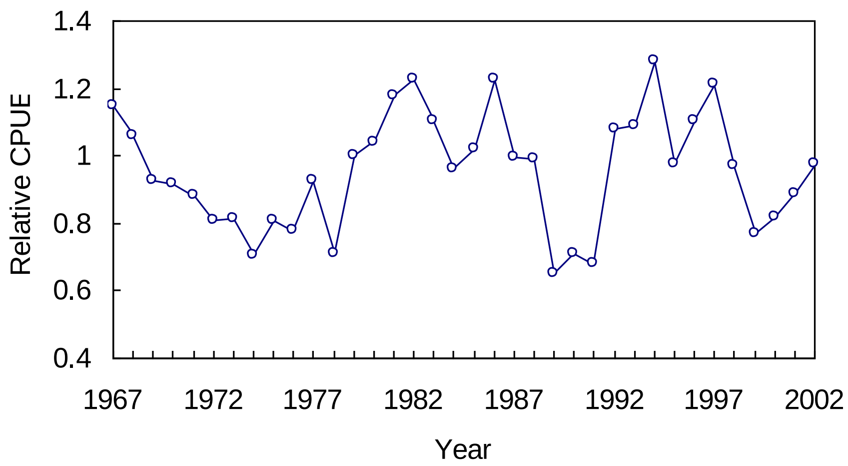

Fig. 8. Relative CPUE from GLM fitting to Taiwanese swordfish data of the Indian Ocean. Data of 1967-1978 were calculated based on monthly aggregated data and that of 1979-2002 on shot by shot logbook data.

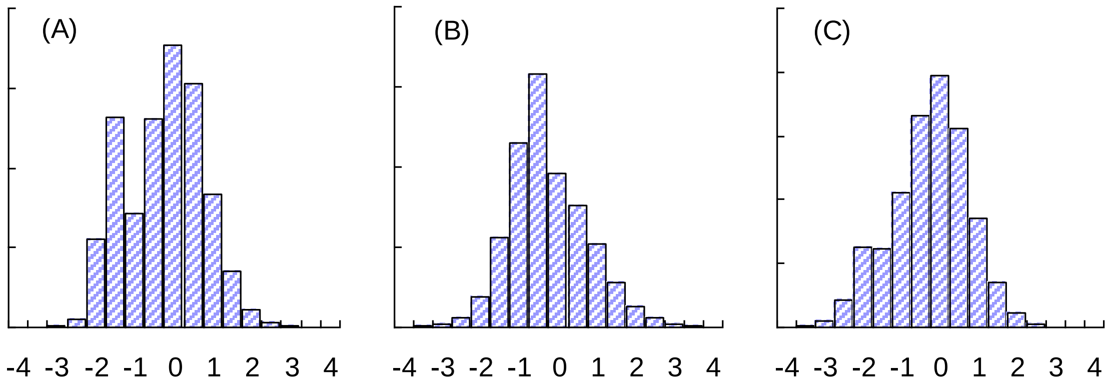

Fig. 9. Three principle histograms of residuals for analysis based on log-normal error-model for three different assumptions on target factors: (A) Target_%_hpb, (B) Target_%_4q, and (C) Target_HpB. Refer to Material and Methods section of the definition.

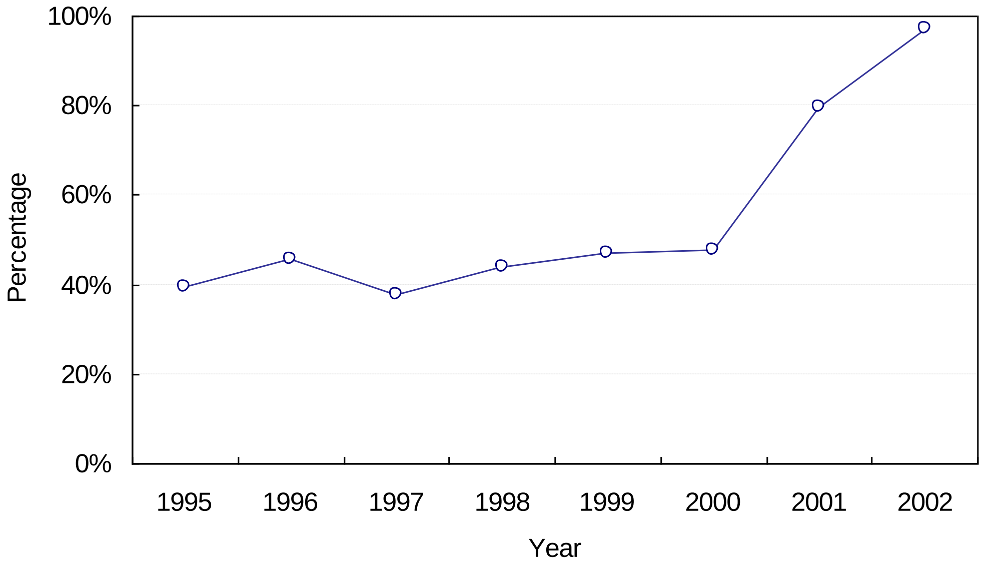

Fig. 10. Percentage of data records with hooks per basket information reported to the overall data records in the logbooks of Taiwan Indian Ocean longline fishery.