CPUE standardization of swordfish (*Xiphias gladius*) caught by Taiwanese longline fishery in the Indian Ocean for 1980-2007

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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 for canning and the other on tropical tuna species (bigeye tuna and yellowfin tuna) for sashimi market. Since 1990's, however, swordfish has become a seasonal target species to some of the fleets.

Most of swordfish catch in the Indian Ocean was made by lognline fisheries especially for Taiwanese longline fishery (seasonal targeting fishery) and Japanese longline fishery (exploited as bycatch), which have the longest period of catch data series. Furthermore, Taiwanese longline fishery made highest proportion of swordfish (about 50-70%) than other fisheries since 1970's although the proportion (about 40-55%) decreased during recent decades.

In this paper, we attempted to the standardize CPUE of swordfish caught by Taiwanese longline fisheries in the Indian Ocean for the data up to 2007.

MATERIAL AND METHODS

Catch and Effort data

In this study, daily set-by-set catch and effort data (logbook) of Taiwanese longline fishery during 1980-2007 were provided by Oversea Fisheries Development Council (OFDC). 5-degree longitude and latitude data were only available before 1994, thereafter about 88% of total data for 1994-2007 contained 1-degree longitude and latitude information. In addition, the data of number of hooks between float

(NHBF) were available since 1995 and the percentage of data with NHBF and the percentage of data with NHBF was about 81% of the total data from 1995 to 2007.

Environmental data

The details of environmental data used in this study were described in the paper of Nishida and Wang (2009).

GLM Model

In this study, 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, quarter, area and targeting. For the data sets with 5x5-degree information, the environmental effects included in the GLM are Indian Oscillation Index and temperature and salinity at 45m depth. The interactions for the main effects are also included into the model.

$$\log(CPUE + c) = \mu + Y + Q + NA + G + T + S + IOI + \text{interactions} + \varepsilon$$

where

where	*CPUE*	is the nominal CPUE of swordfish (catch in number/1000 hooks),
	c	is the constant value (i.e. 10% of the average nominal CPUE),
	μ	is the intercept,
	Y	is the effect of year,
	Q	is the effect of quarter,
	NA	is the effect of fishing area,
	G	is the effect of targeting,
	T	is the effect of temperature,
	S	is the effect of salinity,
	IOI	is the effect of Indian Oscillation Index,
	Interactions	is the interactions between main effects,
	ε	is the error term, $\varepsilon \sim N(0, \sigma^2)$.

For the data sets with 1x1-degree information, the environmental effects included in the GLM are Indian Oscillation Index, sheer currents, amplitude of the shear current, temperature gradient (degree/100km), salinity gradient, temperature and salinity at 45 m depth.

$$\log(CPUE + c) = \mu + Y + Q + NA + G + T45 + S45 + IOI + MP + SC + AM + TG + SG + \text{interactions} + \varepsilon$$

where	*CPUE*	is the nominal CPUE of swordfish (catch in number/1000 hooks),
	c	is the constant value (i.e. 10% of the average nominal CPUE),
	μ	is the intercept,
	Y	is the effect of year,
	Q	is the effect of quarter,
	NA	is the effect of fishing area,
	G	is the effect of targeting,
	T45	is the effect of temperature at 45 m depth,
	S45	is the effect of salinity at 45 m depth,
	IOI	is the effect of Indian Oscillation Index,
	MP	is the effect of moon phase,
	SC	is the effect of shear currents,
	AM	is the effect of amplitude of the shear current,,
	TG	is the effect of temperature gradient,
	SG	is the effect of salinity gradient (density per 100km),
	Interactions	is the interactions between main effects,
	ε	is the error term, $\varepsilon \sim N(0, \sigma^2)$.

However, Hinton and Maunder (2004) indicated that interactions with the year effect would invalidate the year effect as an index of abundance. For the interactions related to year effect, therefore, only the interactions among the effects of year, quarter and area are considered in the GLM.

Fishing areas used in this study were redefined by four new areas based on the IOTC statistics areas for swordfish in the Indian Ocean (Fig. 1):

1. NW: IOTC SWO area 1 and 3;
2. NE: IOTC SWO area 2 and 4;
3. SW: IOTC SWO area 5, 7 and 9;
4. SE: IOTC SWO area 6 and 8.

Due to the absence of NHBF information before 1995, two indices were used to express the effects of targetings:

1. Three categories of swordfish catch composition defined based on the information of NHBF (1: <8%; 2: 8-15%; 3: >15%) (Chang and Wang, 2004; Wang et al., 2005).
2. Four categories of NHBF used by Nishida and Wang (2006) (1: <9; 2: 10-12; 3: 13-14; 4: >14). Semba et al. (2008) added the additional category for NHBF

less than 4. However, there was no NHBF less than 4 for Taiwanese data and thus we used four categories in this study.

Based on the data availability, four data series were used for standardizing the CPUE:

Case 1: Data with 5x5-degree information for 1980-2007 are used to standardize CPUE and swordfish catch composition is used as target effect.

Case 2: Data with 5x5-degree information for 1995-2007 are used to standardize CPUE and NHBF is used as target effect.

Case 3: Data with 1x1-degree information for 1994-2007 are used to standardize CPUE and swordfish catch composition is used as target effect.

Case 4: Data with 1x1-degree information for 1995-2007 are used to standardize CPUE and NHBF is used as target effect.

Adjustment by area size

The estimation of annual nominal and standardized CPUE is calculated from the weighted average of the area indices (Punt et al., 2000).

$$U_y = \sum_a S_a U_{y,a}$$

Where U_y is CPUE for year y,

$U_{y,a}$ is CPUE for year y and area a,

S_a is the relative size of the area a to the four new areas.

The relative sizes of nine IOTC statistics areas for swordfish in the Indian Ocean (Nishida and Wang et al., 2006) were used to be aggregated into four new areas used in this study.

RESULTS AND DISCUSSION

For Case 1, the all of main effects and interactions were included in the model. The ANOVA table for Case 1 is shown in Table 1. The selected model of Case 1 is:

$$\begin{aligned}
&\log(CPUE + c) = Y + Q + A + G + T + S + IOI \\
&+Y*A + Y*Q + Y*Q*A + Q*A + Q*G + Q*T + Q*S + Q*IOI \\
&+A*G + A*T + A*S + A*IOI + G*T + G*S + G*IOI + T*S \\
&+T*IOI + S*IOI
\end{aligned}$$

For Case 2, the main effect of IOI was excluded from the model because it was not statistically significant. All interactions for remaining main effects were included in the model. The ANOVA table for Case 2 is shown in Table 2. The selected model of Case 2 is:

$$\log(CPUE+c)=Y+Q+A+G+T+S$$
$$+Y*A+Y*Q+Y*Q*A+Q*A+Q*G+Q*T+Q*S+A*G$$
$$+A*T+A*S+G*T+G*S+T*S$$

For Case 3, the main effect of S45, IOI and MP, and the interactions of A*AM, SDIFF*AM, AM*TDIFF and SDIFF*TDIFF were excluded from the model because they were not statistically significant. The ANOVA table for Case 3 is shown in Table 3. The selected model of Case 3 is:

$$\log(CPUE+c)=Y+Q+A+G+SDIFF+SC+AM+T45+TDIFF$$
$$+Y*A+Y*Q+Y*Q*A+Q*A+Q*G+Q*SDIFF+Q*SC$$
$$+Q*AM+Q*T45+Q*TDIFF+A*G+A*SDIFF+A*SC$$
$$+A*T45+A*TDIFF+G*SDIFF+G*SC+G*AM+G*T45$$
$$+G*TDIFF+SDIFF*SC+SDIFF*T45+SC*AM+SC*T45$$
$$+SC*TDIFF+AM*T45+T45*TDIFF$$

For Case 4, the main effect of MP and SEIFF, and the interactions of Q*SC and IOI*AM were excluded from the model because they were not statistically significant. The ANOVA table for Case 4 is shown in Table 4. The selected model of Case 4 is:

$$\log(CPUE+c)=Y+Q+A+G+IOI+SC+AM+T45+S45+TDIFF$$
$$+Y*A+Y*Q+Y*Q*A+Q*A+Q*G+Q*IOI+Q*AM+Q*T45$$
$$+Q*S45+Q*TDIFF+A*G+A*IOI+A*SC+A*AM+A*T45$$
$$+A*S45+A*TDIFF+G*IOI+G*SC+G*AM+G*T45+G*S45$$
$$+G*TDIFF+IOI*SC+IOI*T45+IOI*S45+IOI*TDIFF+SC*AM$$
$$+SC*T45+SC*S45+SC*TDIFF+AM*T45+AM*S45+AM*TDIFF$$
$$+T45*TDIFF+T45*S45+S45*TDIFF$$

The area-specific nominal CPUEs are shown in Fig. 2. For the northern areas (NW and NE), the nominal CPUEs fluctuated without obvious patterns but they revealed a slight increasing trend after 1995. For southern areas, nominal CPUEs substantially increased around the mid 1990s and thereafter they substantially decreased. The area-specific standardized CPUEs are shown in Fig. 3. Similarly, the standardized CPUEs in northern areas fluctuated without obvious patterns even for the period after1995. The patterns of standardized CPUEs in the southern areas are much more stable than those of nominal CPUEs. For area SW, however, the Standardized CPUE gradually decreased since the early 1990s, and the recent CPUE has decreased below the level of 1980s. The standardized CPUE in area SE also reveals a decreasing pattern after 2002.

Fig. 4 shows the area-aggregated CPUE. The area-aggregated nominal CPUE represents different patterns for three time periods. The CPUE was very low before the early 1990s, increased substantially with fluctuations between the early 1990s and the early 2000s, and then decreased gradually. The area-aggregated standardized CPUE was very stable before the early 2000s, thereafter the CPUE decreased gradually.

In this study, two indices (catch composition of swordfish and NHBF) were used to conduct the effects of targeting. However, the explained variances of the models included the NHBF as the targeting effect (about 16% of total variance; Cases 2 and 4) are much lower than those of the models included the catch composition as the targeting effect (about 60% of total variance; Cases 1 and 3) (Tables 1-4). The information of NHBF is one of the important factor for the change in fishing practice. However, the data of NHBF are available after 1995 when Taiwanese swordfish catches have obviously increased in four areas (Fig. 5). In addition, the changes in NHPB were not significant even for southern areas where the catch composition of swordfish increased substantially after the early 1990s. In contrast, the historical catch composition of swordfish reflected the changes in nominal CPUE (Figs. 6 and 2). This might be the reason that the models included the catch composition as the targeting effect fitted to the observed data well and their standardized CPUEs are relatively smooth than those of the model included the NHBF as the targeting effect (Figs. 3 and 4).

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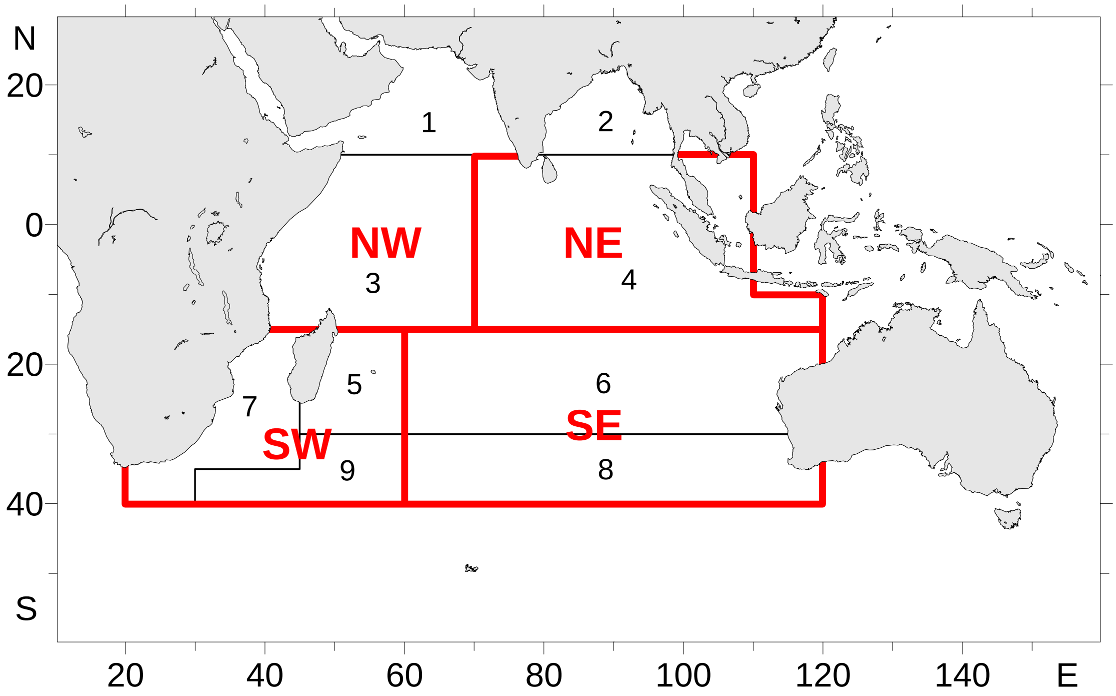

Fig. 1. Area stratification for swordfish in the Indian Ocean.

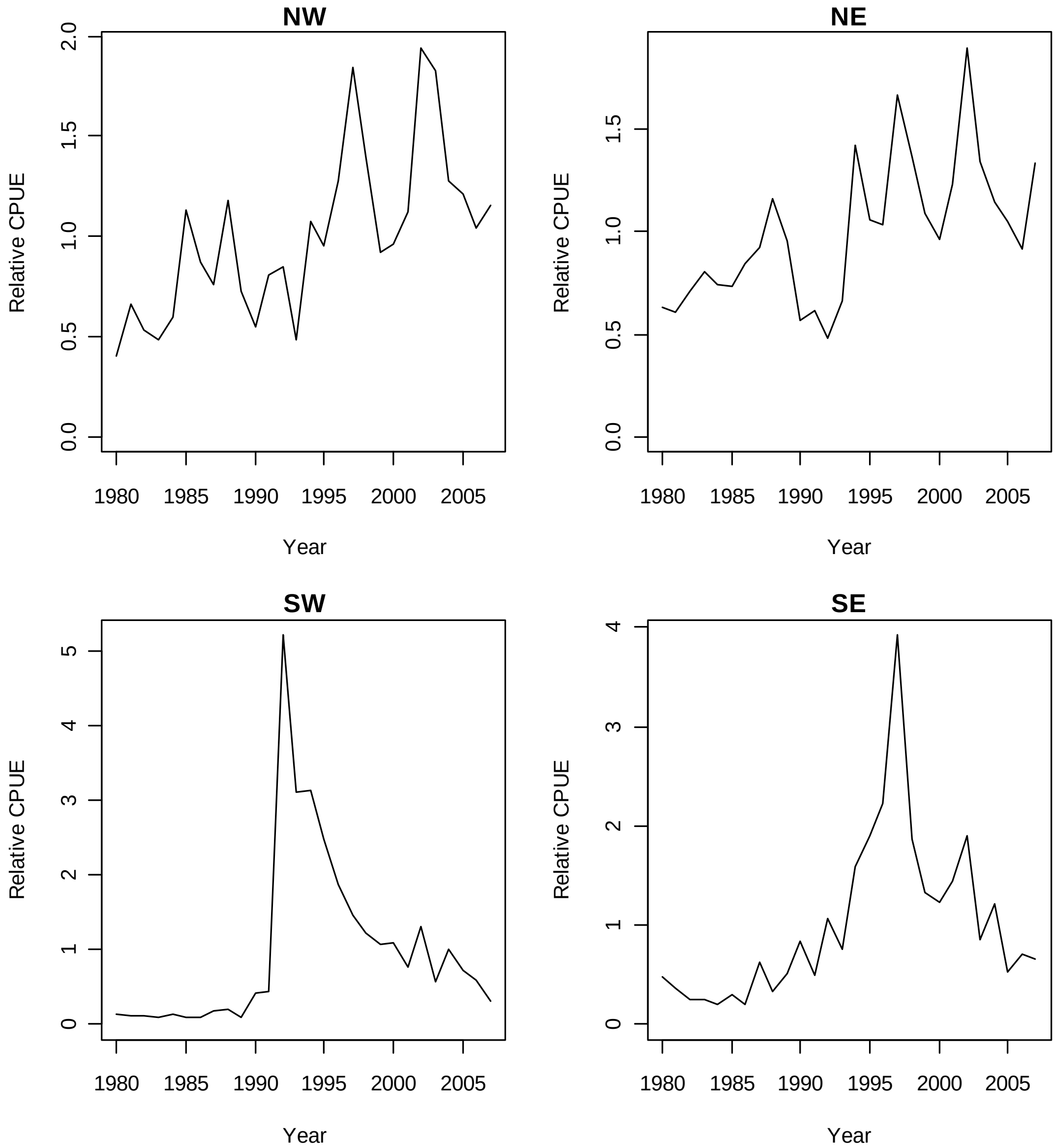

Fig. 2. Nominal CPUE for four areas (scaled to the average estimates).

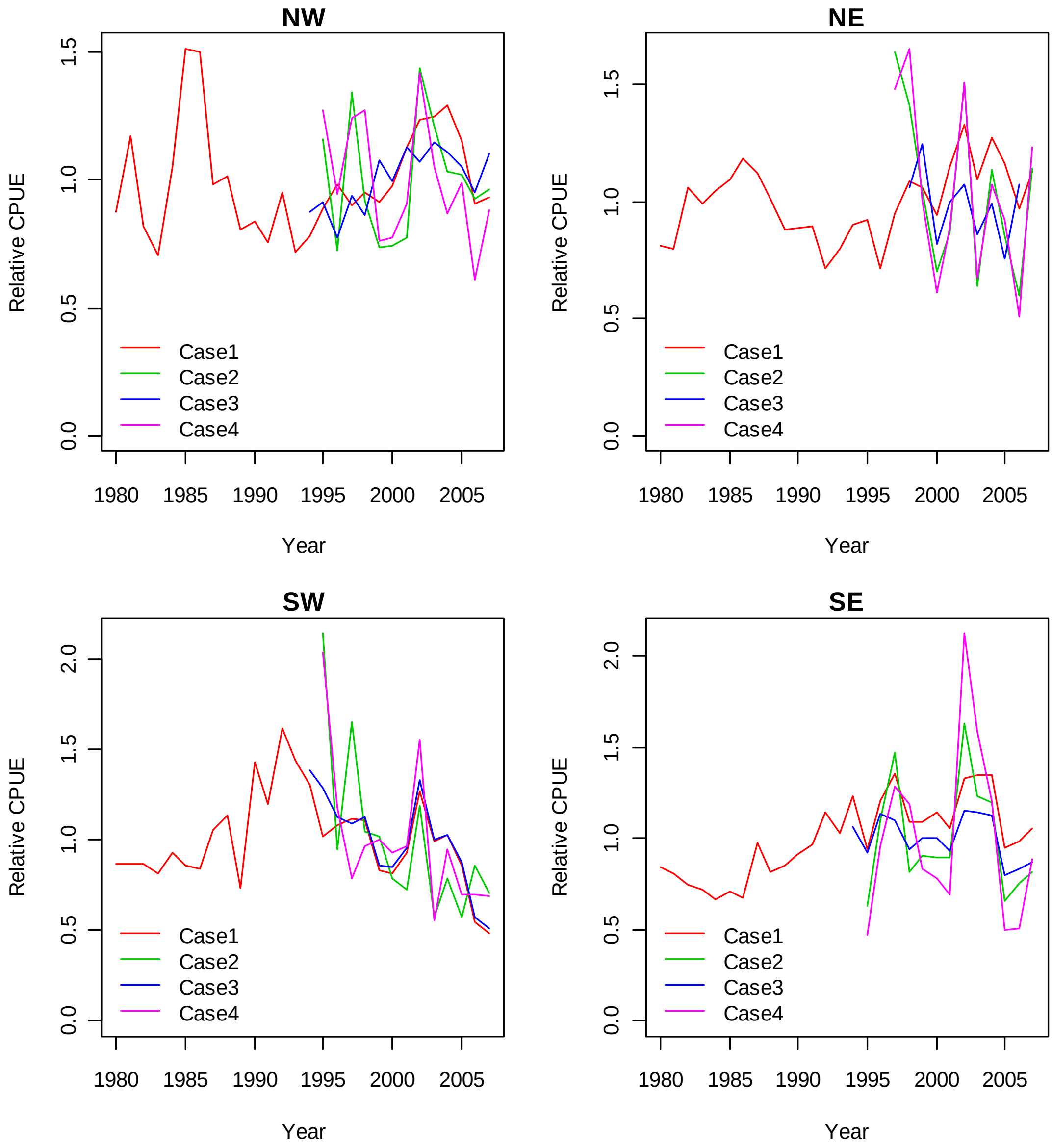

Fig. 3. Standardized CPUE for four areas (scaled to the average estimates).

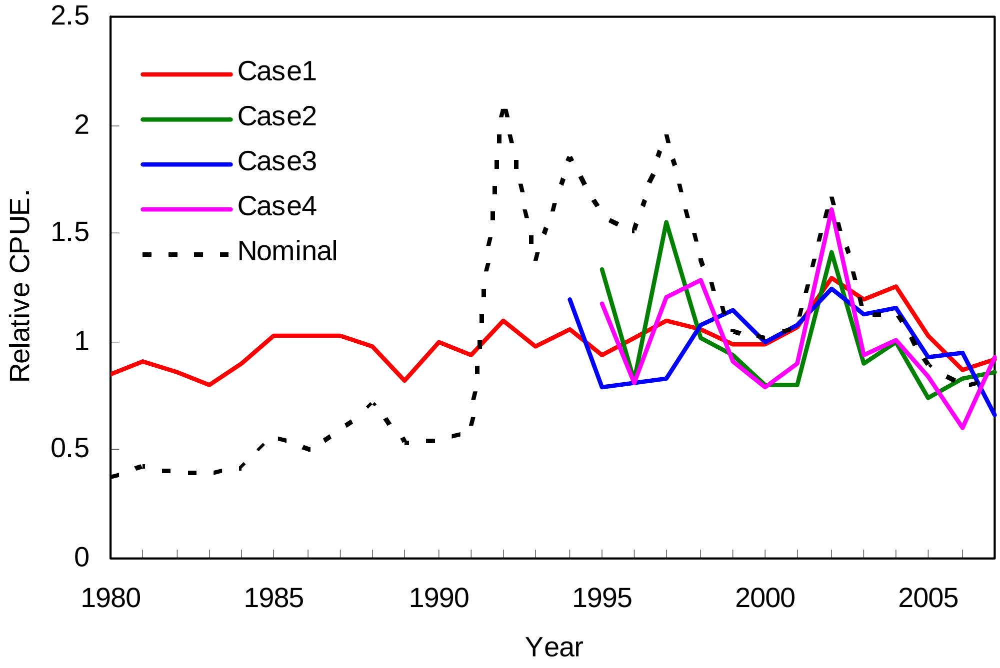

Fig. 4. Nominal and standardized CPUE aggregated by area size (scaled to the average estimates).

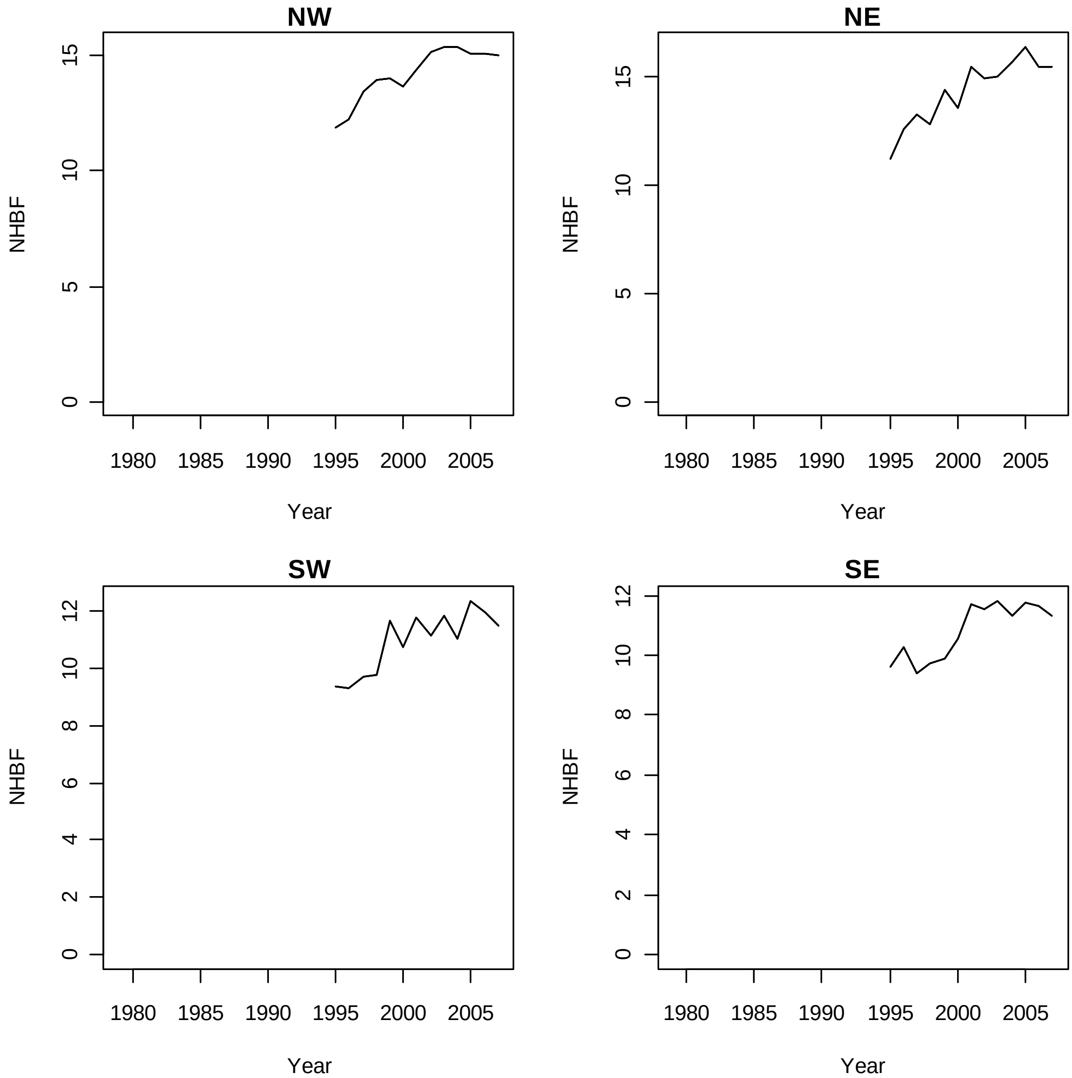

Fig. 5. Annual average number of hooks between float for four areas.

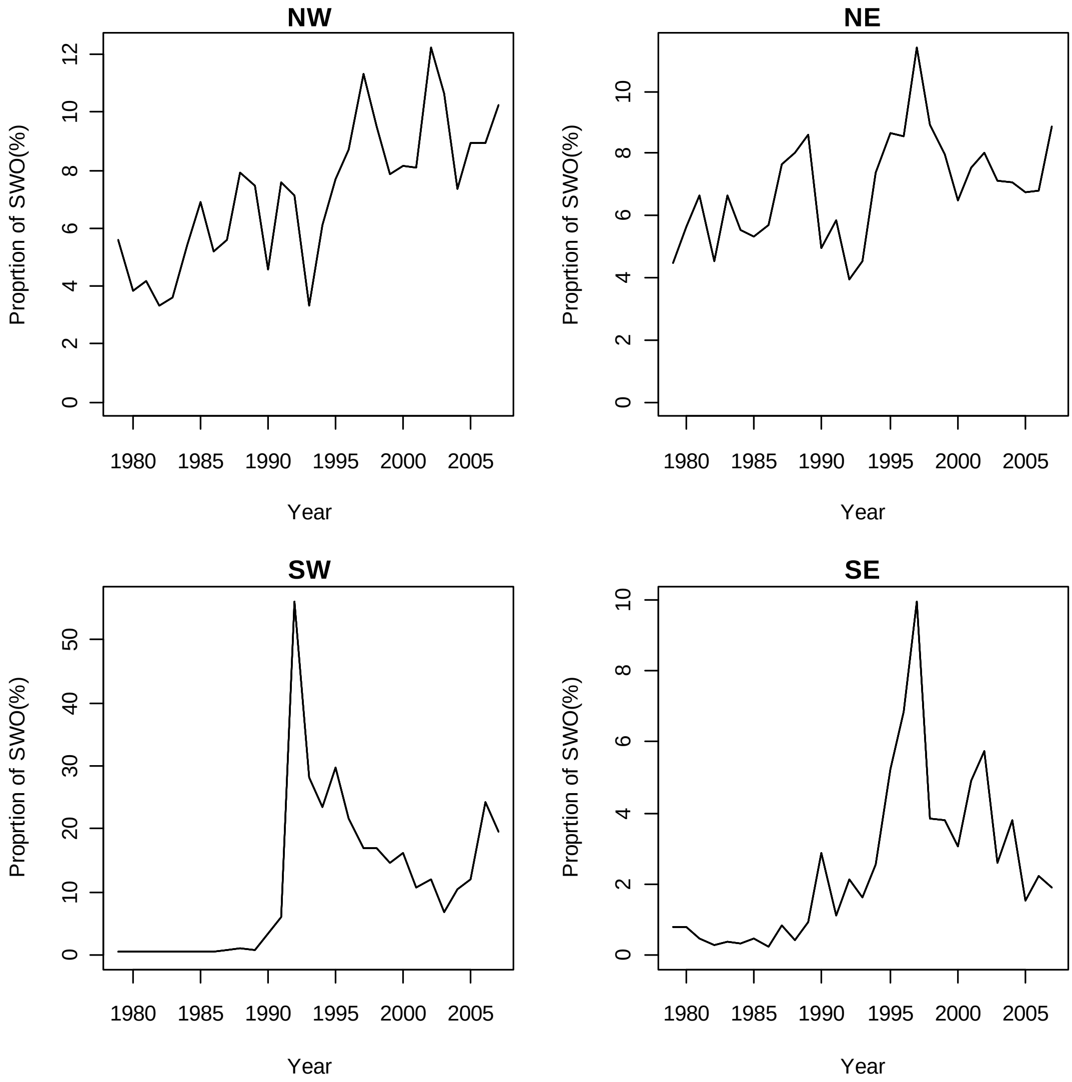

Fig. 6. Annual average catch compositions of swordfish for four areas.

Table 1. ANOVA table of the selected model for Case 1.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	491	875744.348	1783.593	2090.93	<.0001
Error	698093	595484.112	0.853		
Corrected Total	698584	1471228.460			

R-Square	Coeff Var	Root MSE	LNCPUE Mean
0.595247	-62.32107	0.923588	-1.481984

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Y	27	3049.706346	112.952087	132.42	<.0001
Q	3	687.049089	229.016363	268.48	<.0001
A	3	2281.613744	760.537915	891.59	<.0001
G	2	31.988752	15.994376	18.75	<.0001
T	1	1271.726854	1271.726854	1490.86	<.0001
S	1	1444.466327	1444.466327	1693.36	<.0001
IOI	1	46.892515	46.892515	54.97	<.0001
Y*A	81	5310.515389	65.561918	76.86	<.0001
Y*Q	81	1071.189139	13.224557	15.50	<.0001
Y*Q*A	243	3798.985674	15.633686	18.33	<.0001
Q*A	9	351.952337	39.105815	45.84	<.0001
Q*G	6	404.546941	67.424490	79.04	<.0001
T*Q	3	730.554373	243.518124	285.48	<.0001
S*Q	3	89.482676	29.827559	34.97	<.0001
IOI*Q	3	25.573128	8.524376	9.99	<.0001
A*G	6	2189.158007	364.859668	427.73	<.0001
T*A	3	2519.535076	839.845025	984.56	<.0001
S*A	3	125.604693	41.868231	49.08	<.0001
IOI*A	3	93.645317	31.215106	36.59	<.0001
T*G	2	45.341451	22.670726	26.58	<.0001
S*G	2	52.161131	26.080566	30.57	<.0001
IOI*G	2	226.253988	113.126994	132.62	<.0001
T*S	1	1461.173696	1461.173696	1712.95	<.0001
T*IOI	1	39.479019	39.479019	46.28	<.0001
S*IOI	1	12.649672	12.649672	14.83	0.0001

Table 2. ANOVA table of the selected model for Case 2.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	248	120597.2778	486.2793	288.73	<.0001
Error	387350	652375.0623	1.6842		
Corrected Total	387598	772972.3401			

R-Square	Coeff Var	Root MSE	LNCPUE Mean
0.156018	-109.7387	1.297768	-1.182597

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Y	12	2963.819479	246.984957	146.65	<.0001
Q	3	3374.211788	1124.737263	667.82	<.0001
A	3	7041.087587	2347.029196	1393.56	<.0001
G	3	3855.040398	1285.013466	762.98	<.0001
T	1	2876.082164	2876.082164	1707.68	<.0001
S	1	3212.498592	3212.498592	1907.43	<.0001
Y*A	36	3180.601079	88.350030	52.46	<.0001
Y*Q	36	1792.704266	49.797341	29.57	<.0001
Y*Q*A	107	3926.728549	36.698398	21.79	<.0001
Q*A	9	3350.419271	372.268808	221.04	<.0001
Q*G	9	1040.650790	115.627866	68.65	<.0001
T*Q	3	3735.916958	1245.305653	739.40	<.0001
S*Q	3	1165.211496	388.403832	230.62	<.0001
A*G	9	865.420732	96.157859	57.09	<.0001
T*A	3	7075.072148	2358.357383	1400.28	<.0001
S*A	3	1483.870331	494.623444	293.68	<.0001
T*G	3	4162.326867	1387.442289	823.80	<.0001
S*G	3	622.375785	207.458595	123.18	<.0001
T*S	1	3302.523710	3302.523710	1960.89	<.0001

Table 3. ANOVA table of the selected model for Case 3.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	282	302755.6281	1073.6015	1309.53	<.0001
Error	240392	197082.9723	0.8198		
Corrected Total	240674	499838.6004			

R-Square	Coeff Var	Root MSE	LNCPUE Mean
0.605707	-64.03251	0.905450	-1.414048

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Y	13	361.278664	27.790666	33.90	<.0001
Q	3	206.081434	68.693811	83.79	<.0001
A	3	214.206518	71.402173	87.09	<.0001
G	2	99.488270	49.744135	60.68	<.0001
SDIFF	1	34.738865	34.738865	42.37	<.0001
SC	1	329.084876	329.084876	401.40	<.0001
AM	1	31.473401	31.473401	38.39	<.0001
T45	1	302.125044	302.125044	368.52	<.0001
TDIFF	1	6.719371	6.719371	8.20	0.0042
Y*A	39	1409.630468	36.144371	44.09	<.0001
Y*Q	39	470.612004	12.066974	14.72	<.0001
Y*Q*A	113	1485.602143	13.146922	16.04	<.0001
Q*A	9	106.436837	11.826315	14.43	<.0001
Q*G	6	397.997298	66.332883	80.91	<.0001
SDIFF*Q	3	35.880657	11.960219	14.59	<.0001
SC*Q	3	11.005706	3.668569	4.47	0.0038
AM*Q	3	81.226956	27.075652	33.03	<.0001
T45*Q	3	189.368331	63.122777	76.99	<.0001
TDIFF*Q	3	51.953733	17.317911	21.12	<.0001
A*G	6	964.871242	160.811874	196.15	<.0001
SDIFF*A	3	36.074645	12.024882	14.67	<.0001
SC*A	3	192.361438	64.120479	78.21	<.0001
T45*A	3	202.053478	67.351159	82.15	<.0001
TDIFF*A	3	79.709585	26.569862	32.41	<.0001
SDIFF*G	2	9.822468	4.911234	5.99	0.0025
SC*G	2	50.550438	25.275219	30.83	<.0001
AM*G	2	5.342108	2.671054	3.26	0.0385
T45*G	2	19.235191	9.617596	11.73	<.0001
TDIFF*G	2	173.635126	86.817563	105.90	<.0001
SDIFF*SC	1	6.017235	6.017235	7.34	0.0067
SDIFF*T45	1	32.230738	32.230738	39.31	<.0001
SC*AM	1	14.451769	14.451769	17.63	<.0001
SC*T45	1	324.204704	324.204704	395.45	<.0001
SC*TDIFF	1	56.556074	56.556074	68.98	<.0001
AM*T45	1	34.485262	34.485262	42.06	<.0001
T45*TDIFF	1	5.479481	5.479481	6.68	0.0097

Table 4. ANOVA table of the selected model for Case 4.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	298	119408.9323	400.7011	241.05	<.0001
Error	364029	605131.3858	1.6623		
Corrected Total	364327	724540.3181			

R-Square	Coeff Var	Root MSE	LNCPUE Mean
0.164806	-109.8338	1.289309	-1.173872

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Y	12	2659.806860	221.650572	133.34	<.0001
Q	3	1424.976599	474.992200	285.74	<.0001
A	3	2756.977890	918.992630	552.84	<.0001
G	3	1964.505316	654.835105	393.93	<.0001
IOI	1	33.460373	33.460373	20.13	<.0001
SC	1	1165.125962	1165.125962	700.91	<.0001
AM	1	162.205334	162.205334	97.58	<.0001
T45	1	62.108659	62.108659	37.36	<.0001
S45	1	81.596744	81.596744	49.09	<.0001
TDIFF	1	182.842941	182.842941	109.99	<.0001
Y*A	36	1881.272205	52.257561	31.44	<.0001
Y*Q	36	1749.959682	48.609991	29.24	<.0001
Y*Q*A	107	4458.149450	41.664948	25.06	<.0001
Q*A	9	2951.425046	327.936116	197.28	<.0001
Q*G	9	751.690673	83.521186	50.24	<.0001
IOI*Q	3	143.675581	47.891860	28.81	<.0001
AM*Q	3	99.644252	33.214751	19.98	<.0001
T45*Q	3	1577.331590	525.777197	316.29	<.0001
S45*Q	3	1224.210479	408.070160	245.48	<.0001
TDIFF*Q	3	43.148057	14.382686	8.65	<.0001
A*G	9	1010.563127	112.284792	67.55	<.0001
IOI*A	3	104.974135	34.991378	21.05	<.0001
SC*A	3	716.848606	238.949535	143.74	<.0001
AM*A	3	263.483249	87.827750	52.83	<.0001
T45*A	3	2759.514824	919.838275	553.35	<.0001
S45*A	3	539.171072	179.723691	108.12	<.0001
TDIFF*A	3	595.123603	198.374534	119.34	<.0001
IOI*G	3	202.211521	67.403840	40.55	<.0001
SC*G	3	400.057999	133.352666	80.22	<.0001
AM*G	3	420.909414	140.303138	84.40	<.0001
T45*G	3	1930.204658	643.401553	387.05	<.0001
S45*G	3	218.033668	72.677889	43.72	<.0001
TDIFF*G	3	201.807839	67.269280	40.47	<.0001
IOI*SC	1	20.586665	20.586665	12.38	0.0004
IOI*T45	1	26.841842	26.841842	16.15	<.0001
IOI*S45	1	42.485807	42.485807	25.56	<.0001
IOI*TDIFF	1	8.533898	8.533898	5.13	0.0235
SC*AM	1	276.255555	276.255555	166.19	<.0001
SC*T45	1	1346.649756	1346.649756	810.10	<.0001
SC*S45	1	259.644494	259.644494	156.19	<.0001
SC*TDIFF	1	238.937500	238.937500	143.74	<.0001
AM*T45	1	169.832942	169.832942	102.17	<.0001
AM*S45	1	16.715047	16.715047	10.06	0.0015
AM*TDIFF	1	15.006871	15.006871	9.03	0.0027
T45*TDIFF	1	178.756790	178.756790	107.53	<.0001
T45*S45	1	71.847000	71.847000	43.22	<.0001
S45*TDIFF	1	130.320220	130.320220	78.40	<.0001