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

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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 from 1980 to 2006 and 1995 to 2006 using generalized liner model (GLM).

MATERIAL AND METHODS

Catch and Effort data

In this study, daily shot-by-shot catch and effort data (logbook) of Taiwanese longline fishery during 1980-2006 were provided by Oversea Fisheries Development Council (OFDC). The information of number of hooks between floats (NHBF) was only available since 1995 and the percentage of data with NHBF was about 62% of the total data.

Environmental data

The details of environmental data used in this study were described in another CPUE standardization paper of Semba *et al*. (2008).

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, targeting, temperature and salinity at 15m depth, and IOI. 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 *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, $\varepsilon \sim N(0, \sigma^2)$.

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. SW: IOTC SWO area 5, 7 and 9;
3. NE: IOTC SWO area 2 and 4;
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 of 1980-2006 are used to standardize CPUE and swordfish catch composition is used as target effect.

Case 2: Data of 1990-2006 are used to standardize CPUE and swordfish catch composition is used as target effect.

Case 3: Data of 1995-2006 are used to standardize CPUE and NHBF is used as target effect.

Case 4: Data of 1995-2006 are used to standardize CPUE and NHBF is used as target effect. Besides, additional environmental data, including sheer currents, amplitude of the shear current, temperature gradient (degree/100km), salinity gradient, temperature and salinity at 75, 95, 105 and 135 m depth corresponding to average gear depth by 4 category respectively, were included in the GLM model. Thus the GLM model for Case 4 was

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

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,
	T	is the effect of temperature at the depth that fishing gear operated,
	S	is the effect of salinity at the depth that fishing gear operated,
	IOI	is the effect of Indian Oscillation Index,
	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, $\varepsilon \sim N(0, \sigma^2)$.

Swordfish is exploited by fishing gear operated in different depths. For Case 4, thus we used temperature and salinity by depth corresponding to the average depths of the targeting categories (see Samba *et al*. (2008) for detail). The effects related to environmental data were treated as continuous variable in this study.

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 were included in the model and the interactions of T*IOI and TD*IOI were excluded from the full model because they were not statistically significant. The ANOVA table for Case 1 showed in Table 1 and the distribution of residuals showed in Fig. 2(A). The selected model of Case 1 was:

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

For Case 2 and Case 3, the all of main effects were included in the model and only interaction of T*IOI was excluded from the full model because it was not statistically significant. The ANOVA table for Case 2 and Case 3 showed in Table 2 and 3 and the distributions of residuals showed in Fig. 2(B) and Fig. 3(C). The selected model of Case 2 and Case 3 were:

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

For Case 4, the all of main effects were included in the model and the interactions of NA*IOI, T*S, T*IOI, S*TG, TD*IOI, SC*SG and AM*SG were excluded from the full model because they were not statistically significant. The ANOVA table for Case 4 showed in Table 4 and the distribution of residuals showed in Fig. 2(D). The selected model of Case 4 was:

$$
\begin{aligned}
\log(CPUE + c) = {} & Y + Q + NA + G + T + S + TD + IOI + SC + AM + TG + SG + Y * NA \\
& + Q * NA + Q * G + Q * T + Q * S + Q * TD + Q * IOI + Q * SC \\
& + Q * AM + Q * TG + Q * SG + NA * G + NA * T + NA * S + NA * TD \\
& + NA * SC + NA * AM + NA * TG + NA * SG + G * T + G * S + G * TD \\
& + G * IOI + G * SC + G * AM + G * TG + G * SG + T * TD \\
& + T * SC + T * AM + T * TG + T * SG + S * TD + S * IOI \\
& + S * SC + S * AM + S * SG + TD * SC + TD * AM + TD * TG \\
& + TD * SG + IOI * SC + IOI * AM + IOI * TG + IOI * SG \\
& + SC * AM + SC * SG + AM * TG
\end{aligned}
$$

Nominal and standardized CPUE for each fishing area is shown in Fig. 3. In the northern Indian Ocean, nominal CPUE revealed similar patterns for area NW and NE. The trends of nominal CPUE during 1980-2002 fluctuated with slight increasing patterns and decreased gradually thereafter. In area SW, nominal CPUE were relatively low before 1990, increased substantially in the early 1990' and decreased obviously after 1992. Nominal CPUE in area SE increased before gradually before 1997 and decreased substantially thereafter. Standardized CPUE of Case 1 and 2 generally followed the patterns of nominal CPUE but were much smoother than Nominal CPUE. Although different data series were used for Case 1 and 2, standardized CPUEs revealed very similar results for four areas. Due to no data of NHBF in 2004, standardized CPUE in 2004 was not available. Standardized CPUEs of Case 3 and 4 had more fluctuations than those of Case 1 and 2 though they still followed the patterns of nominal CPUE for four areas. Based on the results of this study, however, the standardized CPUE slightly increased before mid 1990's and revealed decreasing patterns for four areas in the last decade.

Nominal and standardized CPUE aggregated by area sizes was shown in Fig. 4. Nominal CPUE was stable before 1991, increased substantially in 1992 and revealed a decreasing pattern thereafter. Standardized CPUE of Case 2 was close to that of Case 1, they were stable before 2002 and decreased gradually since 2003. Although standardized CPUE of Case 3 and 4 fluctuated but they revealed decreasing patterns since 1997.

In this study, two indices (catch composition of swordfish and NHBF) were used to conduct the effects of targeting. Comparing similar data series and environmental data, however, GLM model included NHBF as the effect of targeting had much lower R^2 than the model included catch composition of swordfish as the effect of targeting. More investigations, such the relationship between NHBF categories and swordfish condition of Taiwanese longline fishery in the Indian Ocean, would be necessary for further analyses. For targeting, the materials of fishing gear might be used as an additional effect for targeting. Based on the information from Taiwanese observer program, most of fishermen use nylon (nylon mono or nylon twist) as the material for branch line and some use wires as the materials. At this stage, however, the information related to materials for lines were insufficient for CPUE analyses of Taiwanese longlnie fishery. In addition, swordfish were mainly taken as bycatch although some Taiwanese longline vessels seasonally targeted swordfish in the Indian Ocean. Therefore, a substantial proportion of zero catches of swordfish were contained in the Taiwanese fishery data. The estimation bias could be raised while analyzing the data with large number of zero catches using standard GLM. For further analyses, other analyses models, e.g. delta-lognormal GLM (Lo et. al., 1992; Pennington, 1996), could be applied to standardize the CPUE of swordfish caught by Taiwanese longline fishery in the Indian Ocean.

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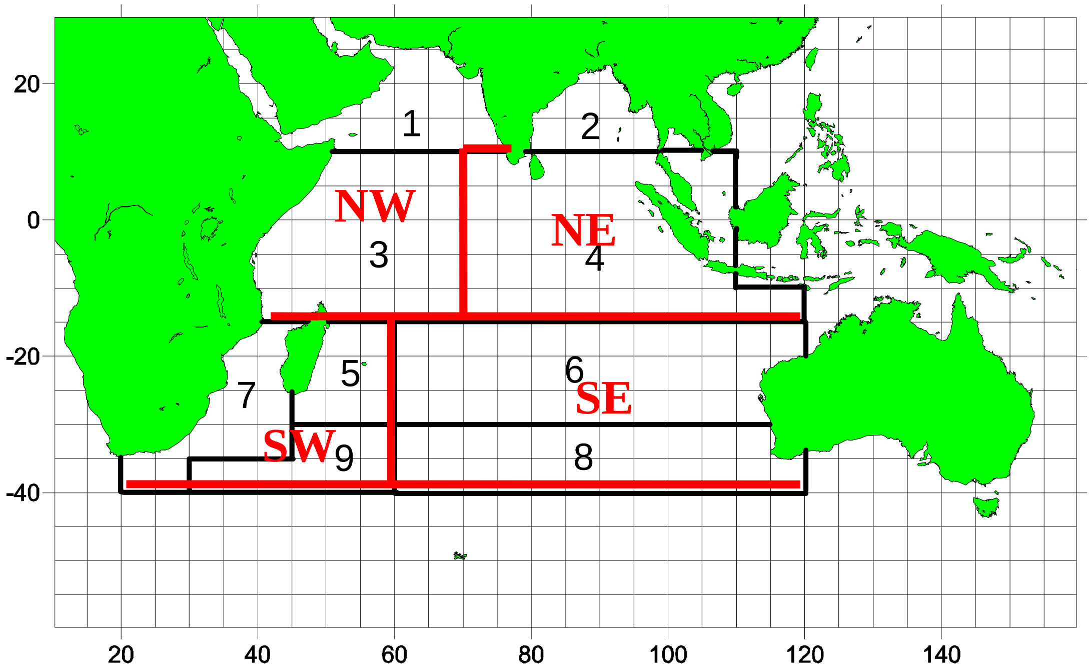
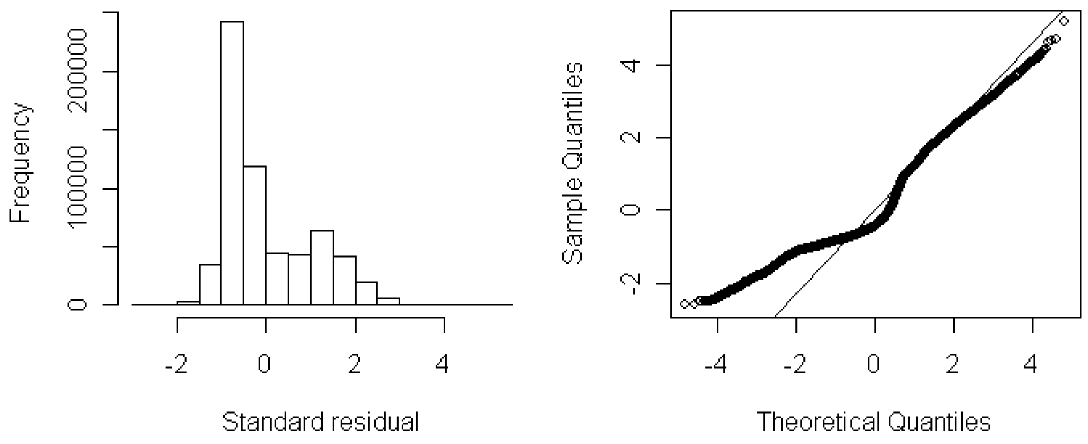


Fig. 1. Area stratification for swordfish in the Indian Ocean.

(A) Case 1



(B) Case 2

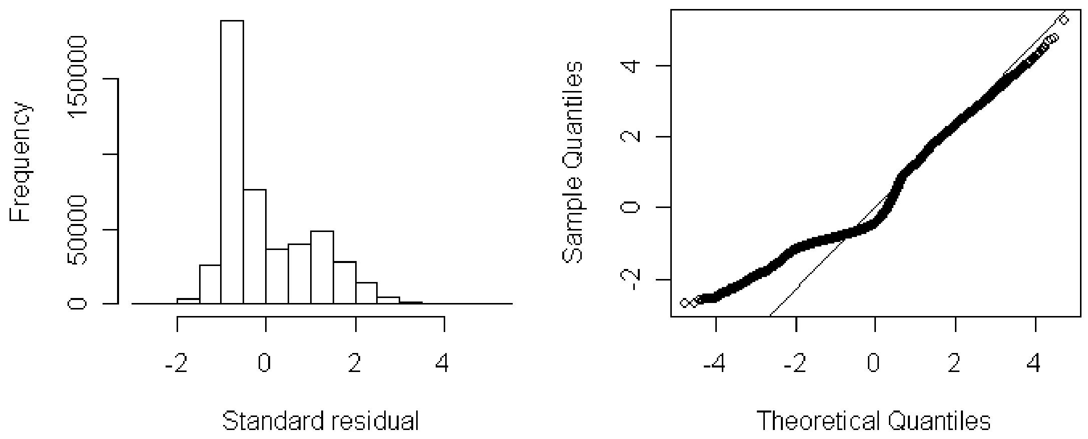
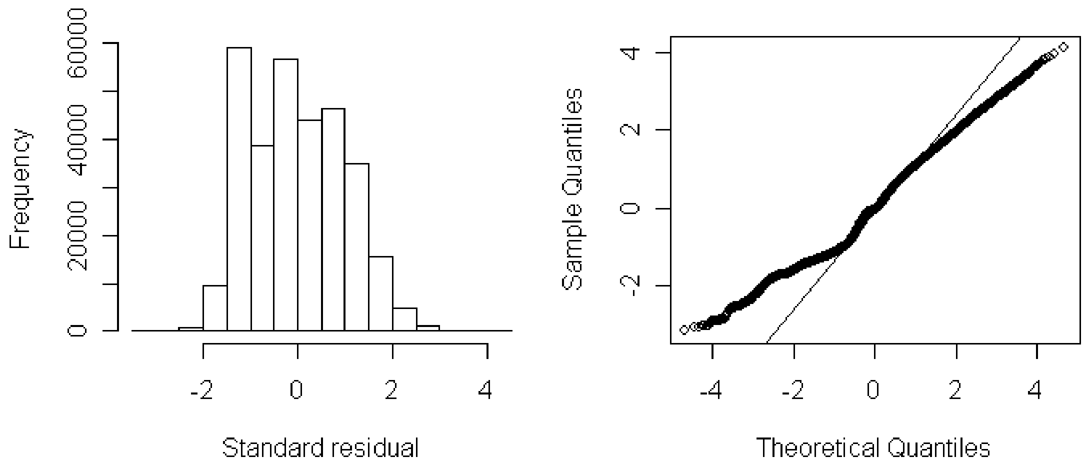


Fig. 2. Distributions and normal probability plot (Q-Q plots) of the standard residuals for the standardization models.

(C) Case 3



(D) Case 4

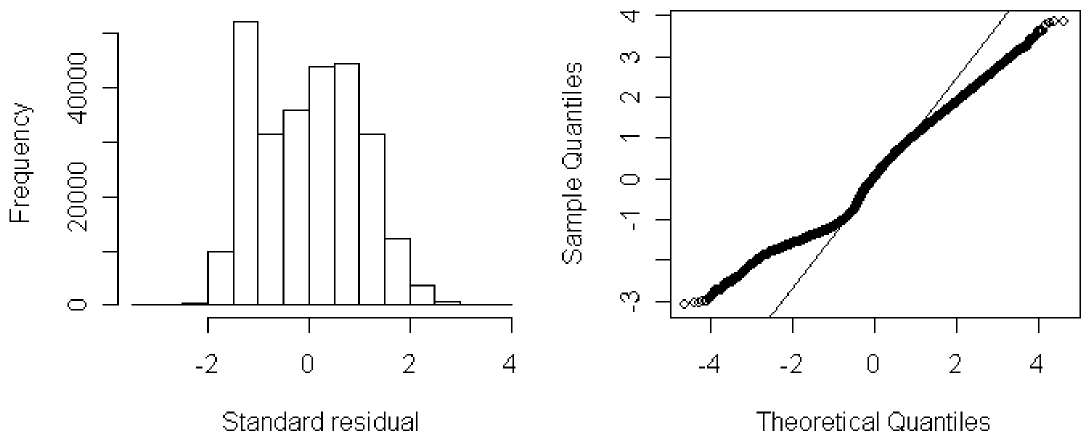
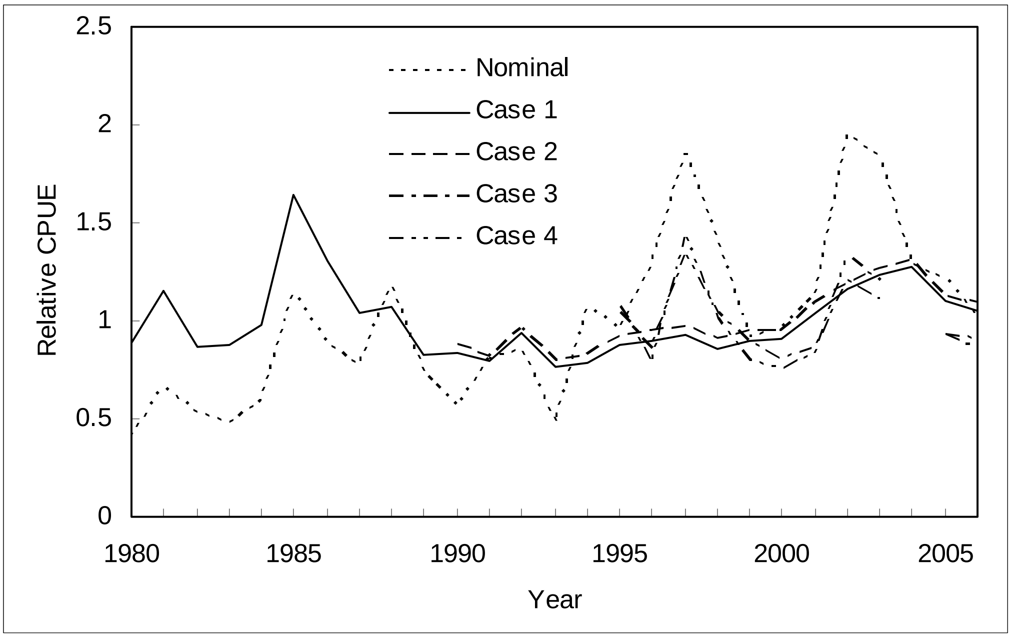


Fig. 2. (Continued).

(A) New Area NW



(B) New Area SW

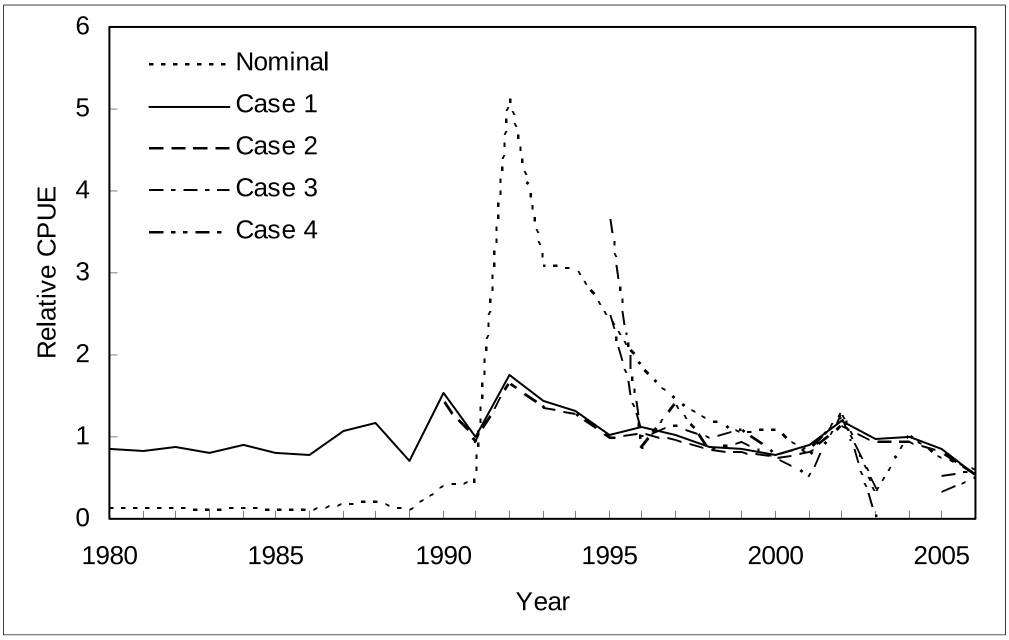
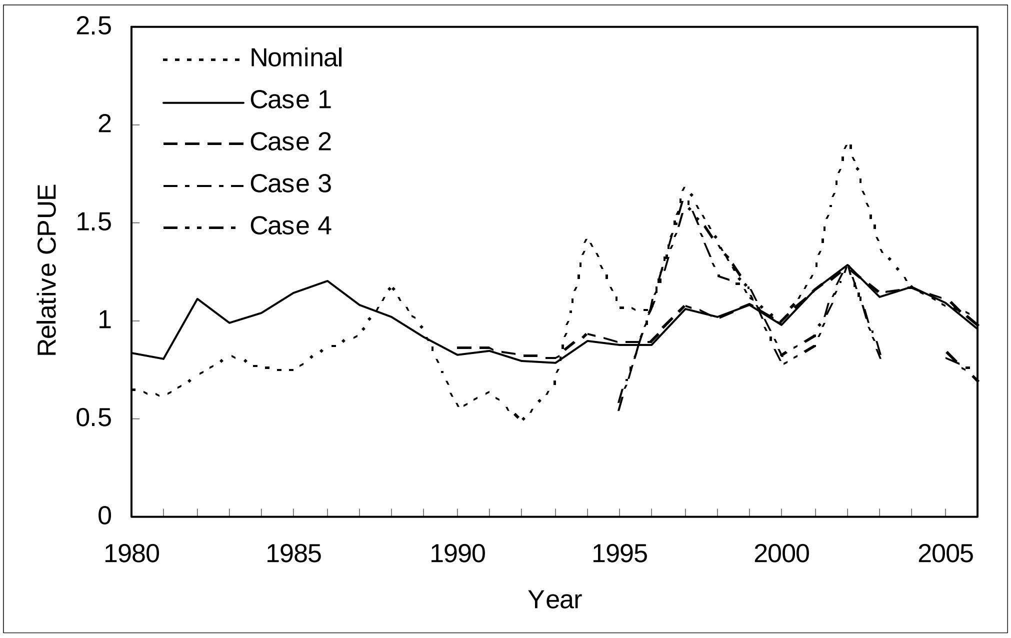


Fig. 3. Nominal and standardized CPUE for four areas (scaled to the average estimates).

(C) New Area NE



(D) New Area SE

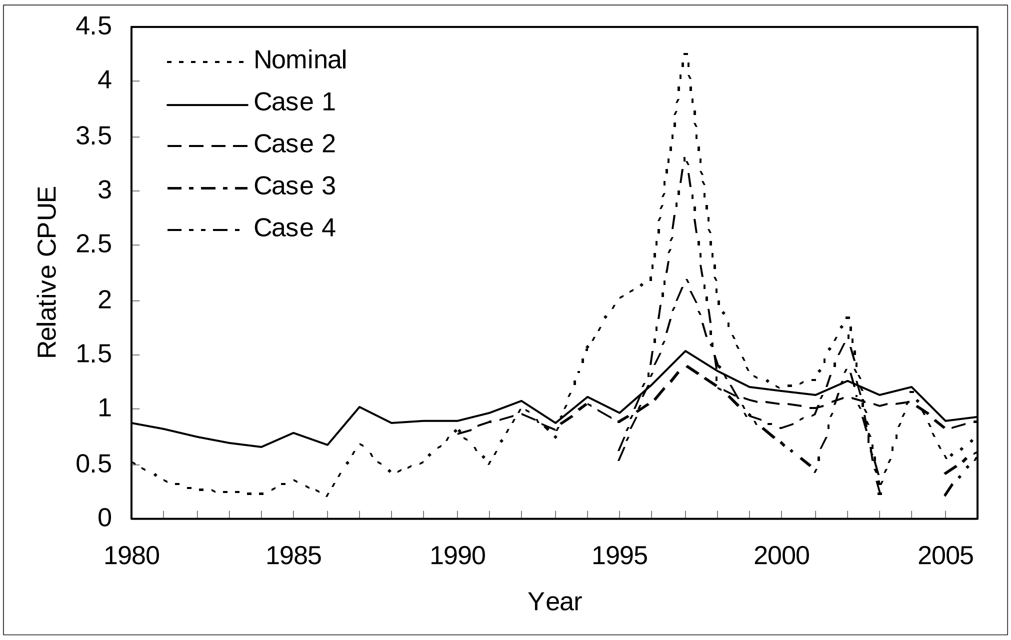


Fig. 3. (continued).

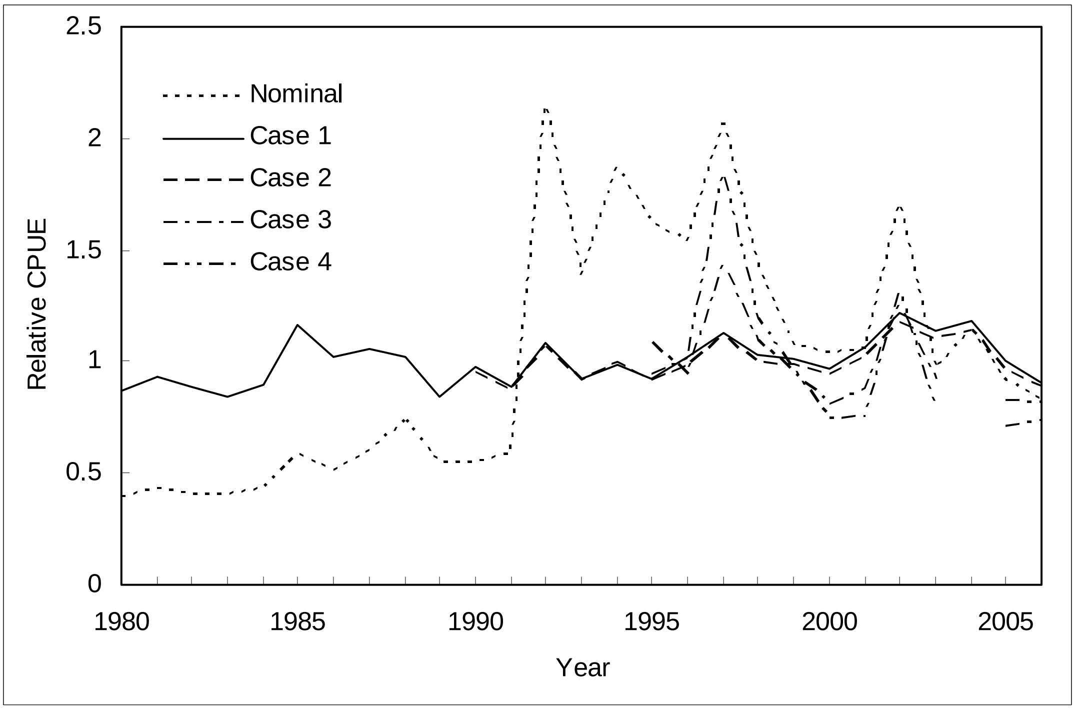


Fig. 4. Nominal and standardized CPUE aggregated by area size (scaled to the average estimates).

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

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	173	773239.263	4469.591	5215.47	<.0001
Error	620940	532137.565	0.857		
Corrected Total	621113	1305376.828			

R-Square	Coeff Var	Root MSE	LNCPUE Mean
0.592349	-63.43004	0.925736	-1.459460

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Y	26	2661.307892	102.357996	119.44	<.0001
Q	3	579.365412	193.121804	225.35	<.0001
NA	3	1058.525379	352.841793	411.72	<.0001
G	2	58.430774	29.215387	34.09	<.0001
T	1	459.432559	459.432559	536.10	<.0001
S	1	418.522190	418.522190	488.36	<.0001
TD	1	67.371707	67.371707	78.61	<.0001
IOI	1	49.498292	49.498292	57.76	<.0001
Y*NA	78	6259.621155	80.251553	93.64	<.0001
Q*NA	9	790.640360	87.848929	102.51	<.0001
Q*G	6	345.429478	57.571580	67.18	<.0001
T*Q	3	423.594401	141.198134	164.76	<.0001
S*Q	3	552.610897	184.203632	214.94	<.0001
TD*Q	3	458.511958	152.837319	178.34	<.0001
IOI*Q	3	128.794560	42.931520	50.10	<.0001
NA*G	6	1090.360983	181.726830	212.05	<.0001
T*NA	3	438.462552	146.154184	170.54	<.0001
S*NA	3	1184.610665	394.870222	460.77	<.0001
TD*NA	3	757.017317	252.339106	294.45	<.0001
IOI*NA	3	12.305009	4.101670	4.79	0.0025
T*G	2	39.833144	19.916572	23.24	<.0001
S*G	2	80.507059	40.253529	46.97	<.0001
TD*G	2	362.304977	181.152488	211.38	<.0001
IOI*G	2	679.062473	339.531237	396.19	<.0001
T*S	1	459.864971	459.864971	536.61	<.0001
T*TD	1	32.606788	32.606788	38.05	<.0001
S*TD	1	54.905848	54.905848	64.07	<.0001
S*IOI	1	43.612762	43.612762	50.89	<.0001

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

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	134	589916.4006	4402.3612	5616.42	<.0001
Error	468785	367451.0867	0.7838		
Corrected Total	468919	957367.4873			

R-Square	Coeff Var	Root MSE	LNCPUE Mean
0.616186	-71.39058	0.885346	-1.240144

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Y	16	1444.742212	90.296388	115.20	<.0001
Q	3	935.613191	311.871064	397.88	<.0001
NA	3	760.464200	253.488067	323.39	<.0001
G	2	49.113774	24.556887	31.33	<.0001
T	1	705.265750	705.265750	899.76	<.0001
S	1	668.018990	668.018990	852.24	<.0001
TD	1	197.343453	197.343453	251.77	<.0001
IOI	1	24.014725	24.014725	30.64	<.0001
Y*NA	48	3828.571311	79.761902	101.76	<.0001
Q*NA	9	658.394932	73.154992	93.33	<.0001
Q*G	6	215.965487	35.994248	45.92	<.0001
T*Q	3	374.108535	124.702845	159.09	<.0001
S*Q	3	885.602878	295.200959	376.61	<.0001
TD*Q	3	312.917700	104.305900	133.07	<.0001
IOI*Q	3	64.144817	21.381606	27.28	<.0001
NA*G	6	943.849262	157.308210	200.69	<.0001
T*NA	3	449.329042	149.776347	191.08	<.0001
S*NA	3	854.995136	284.998379	363.59	<.0001
TD*NA	3	409.871017	136.623672	174.30	<.0001
IOI*NA	3	30.950693	10.316898	13.16	<.0001
T*G	2	10.461092	5.230546	6.67	0.0013
S*G	2	48.284287	24.142144	30.80	<.0001
TD*G	2	305.521081	152.760540	194.89	<.0001
IOI*G	2	549.641138	274.820569	350.61	<.0001
T*S	1	708.805648	708.805648	904.28	<.0001
T*TD	1	40.362787	40.362787	51.49	<.0001
S*TD	1	177.760179	177.760179	226.78	<.0001
S*IOI	1	21.312142	21.312142	27.19	<.0001
TD*IOI	1	30.891700	30.891700	39.41	<.0001

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

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	121	142664.5970	1179.0463	717.33	<.0001
Error	312471	513599.2207	1.6437		
Corrected Total	312592	656263.8177			

R-Square	Coeff Var	Root MSE	LNCPUE Mean
0.217389	-96.75164	1.282057	-1.325101

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Y	10	5240.323054	524.032305	318.82	<.0001
Q	3	1867.953679	622.651226	378.82	<.0001
A	3	5267.446830	1755.815610	1068.23	<.0001
G	3	1871.834981	623.944994	379.60	<.0001
T	1	3374.954671	3374.954671	2053.30	<.0001
S	1	3332.176365	3332.176365	2027.28	<.0001
TD	1	975.806224	975.806224	593.68	<.0001
IOI	1	8.559526	8.559526	5.21	0.0225
Y*A	30	4874.479041	162.482635	98.85	<.0001
Q*A	9	5219.660665	579.962296	352.85	<.0001
Q*G	9	1625.199162	180.577685	109.86	<.0001
T*Q	3	1268.132389	422.710796	257.17	<.0001
S*Q	3	1976.800943	658.933648	400.89	<.0001
TD*Q	3	1069.943271	356.647757	216.98	<.0001
IOI*Q	3	101.867535	33.955845	20.66	<.0001
A*G	9	951.316241	105.701805	64.31	<.0001
T*A	3	1159.159889	386.386630	235.08	<.0001
S*A	3	5530.551358	1843.517119	1121.59	<.0001
TD*A	3	3736.588108	1245.529369	757.77	<.0001
IOI*A	3	161.030945	53.676982	32.66	<.0001
T*G	3	155.590899	51.863633	31.55	<.0001
S*G	3	1928.680720	642.893573	391.13	<.0001
TD*G	3	361.762716	120.587572	73.36	<.0001
IOI*G	3	272.399059	90.799686	55.24	<.0001
T*S	1	3400.424312	3400.424312	2068.80	<.0001
T*IOI	1	56.725531	56.725531	34.51	<.0001
S*TD	1	1048.326114	1048.326114	637.80	<.0001
S*IOI	1	18.234718	18.234718	11.09	0.0009
TD*IOI	1	22.516761	22.516761	13.70	0.0002

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

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	175	107879.9671	616.4570	351.89	<.0001
Error	266551	466953.3914	1.7518		
Corrected Total	266726	574833.3585			

R-Square	Coeff Var	Root MSE	LNCPUE Mean
0.187672	-112.7623	1.323569	-1.173769

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Y	10	4130.704269	413.070427	235.79	<.0001
Q	3	299.092730	99.697577	56.91	<.0001
NA	3	1195.345570	398.448523	227.45	<.0001
G	3	573.923170	191.307723	109.20	<.0001
T	1	691.037936	691.037936	394.47	<.0001
S	1	32.553851	32.553851	18.58	<.0001
TD	1	9.231883	9.231883	5.27	0.0217
IOI	1	27.530472	27.530472	15.72	<.0001
SC	1	116.861286	116.861286	66.71	<.0001
AM	1	80.800765	80.800765	46.12	<.0001
TG	1	6.495508	6.495508	3.71	0.0542
SG	1	188.039888	188.039888	107.34	<.0001
Y*NA	30	4018.953478	133.965116	76.47	<.0001
Q*NA	9	1812.525180	201.391687	114.96	<.0001
Q*G	9	1319.740805	146.637867	83.71	<.0001
T*Q	3	226.884484	75.628161	43.17	<.0001
S*Q	3	237.552955	79.184318	45.20	<.0001
TD*Q	3	249.370528	83.123509	47.45	<.0001
IOI*Q	3	330.917144	110.305715	62.97	<.0001
SC*Q	3	204.380834	68.126945	38.89	<.0001
AM*Q	3	81.606801	27.202267	15.53	<.0001
TG*Q	3	132.442381	44.147460	25.20	<.0001
SG*Q	3	22.816747	7.605582	4.34	0.0046
NA*G	9	1486.758806	165.195423	94.30	<.0001
T*NA	3	668.418246	222.806082	127.18	<.0001
S*NA	3	1076.043879	358.681293	204.75	<.0001
TD*NA	3	157.299282	52.433094	29.93	<.0001

Table 4. (Continued).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SC*NA	3	1717.762777	572.587592	326.85	<.0001
AM*NA	3	1130.622814	376.874271	215.13	<.0001
TG*NA	3	167.218985	55.739662	31.82	<.0001
SG*NA	3	282.595688	94.198563	53.77	<.0001
T*G	3	102.107094	34.035698	19.43	<.0001
S*G	3	709.866410	236.622137	135.07	<.0001
TD*G	3	38.388419	12.796140	7.30	<.0001
IOI*G	3	285.659852	95.219951	54.35	<.0001
SC*G	3	1105.204509	368.401503	210.29	<.0001
AM*G	3	511.102024	170.367341	97.25	<.0001
TG*G	3	70.422670	23.474223	13.40	<.0001
SG*G	3	283.120316	94.373439	53.87	<.0001
T*TD	1	226.401533	226.401533	129.24	<.0001
T*SC	1	385.660670	385.660670	220.15	<.0001
T*AM	1	172.516972	172.516972	98.48	<.0001
T*TG	1	0.182135	0.182135	0.10	0.7471
T*SG	1	20.470129	20.470129	11.68	0.0006
S*TD	1	4.578908	4.578908	2.61	0.1059
S*IOI	1	28.984079	28.984079	16.54	<.0001
S*SC	1	84.522568	84.522568	48.25	<.0001
S*AM	1	87.860220	87.860220	50.15	<.0001
S*SG	1	174.622424	174.622424	99.68	<.0001
TD*SC	1	180.431903	180.431903	103.00	<.0001
TD*AM	1	81.790588	81.790588	46.69	<.0001
TD*TG	1	0.091883	0.091883	0.05	0.8189
TD*SG	1	23.413776	23.413776	13.37	0.0003
IOI*SC	1	21.304700	21.304700	12.16	0.0005
IOI*AM	1	15.616094	15.616094	8.91	0.0028
IOI*TG	1	40.088886	40.088886	22.88	<.0001
IOI*SG	1	151.415777	151.415777	86.43	<.0001
SC*AM	1	65.938722	65.938722	37.64	<.0001
SC*SG	1	16.629036	16.629036	9.49	0.0021
AM*TG	1	148.284136	148.284136	84.65	<.0001
TG*SG	1	69.609144	69.609144	39.73	<.0001