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CPUE standardization of swordfish (*Xiphias gladius*) exploited by Japanese tuna longline fisheries in the Indian Ocean using cluster analysis for targeting effect

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Abstract

We conducted to standardize CPUE (STD_CPUE) of swordfish exploited by Japanese tuna longline fishery in the Indian Ocean using 43 years of the set by set catch and effort data (1971-2013). For this time we attempted to use SWO cluster derived from the cluster analyses as targeting correction factor and compared with the traditional one (number of hooks between floats) (NHBF). We also compared STD_CPUE with and without SWO cluster data. As a result, it was suggested that STD_CPUE with SWO cluster data and with SWO clusters produced the best performance. This best STD_CPUE further suggested that STD_CPUE (SWO abundance) continuously decreased from 1971 to 2005 and then increased to 2013, consequently the higher level have been kept in recent 8 years (2006-2013), while there are a lot of noises (ups and downs) throughout the whole period (1971-2013).

Contents

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1. Introduction

We attempted to standardize nominal CPUE (STD_CPUE) of swordfish (*Xiphias gladius*) (SWO) caught by Japanese tuna longline fishery (LL) in the Indian Ocean incorporating cluster analysis to reduce biases caused by targeting effect. We used the set by set catch and effort data to conduct the cluster analyses effectively.

2. Catch and effort data

We used daily set by set catch and effort data (1971-2013) available in the database of the National Research Institute of Far Seas Fisheries, Fisheries Research Agency, Japan. Set by set data are represented by 1°x1° area (Fig. 1).

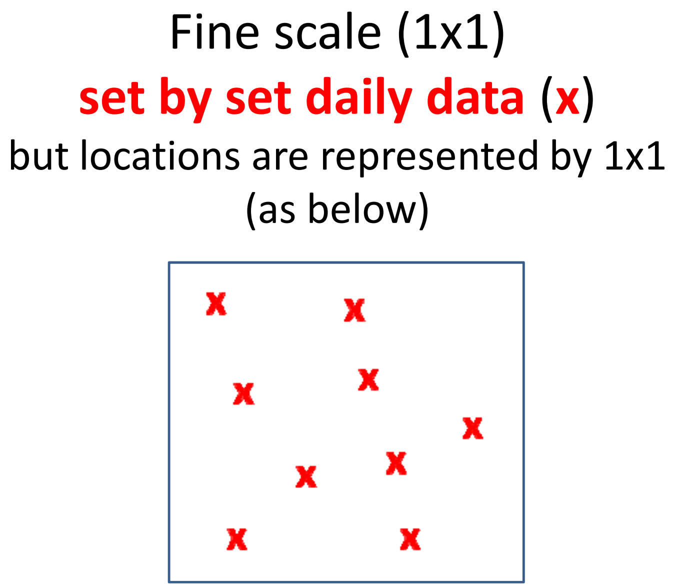


Fig. 1 Definition of the set by set fine scale data which are presented by 1°x1° area in the database of National Research Institute of Far Seas Fisheries (NRIFSF).

3. STD_CPUE

In the past, we used the number of hooks between floats (NHBF) to reduce targeting biases. Recently, "cluster (targeting sets)" evaluated by cluster analysis was reported as effective for targeting effect correction factor in STD_CPUE. In this paper we used both NHBF and Cluster in STD_CPUE and compared their effectiveness.

3.1 Cluster analysis

Cluster analysis was conducted based on species composition of the catches. Eight species groups were used including Albacore (ALB), Bigeye tuna (BET), Yellowfin tuna (YFT), swordfish (SWO), southern Bluefin tuna (SBT), billfish (BIL), sharks (SHK) and other species (OTH) (Fig. 1).

He *et al.* (1997) suggested cluster analysis with two steps to classify the data sets because the large number of data sets make it difficult to conduct direct hierarchical cluster analysis, i.e., 1st step: Non-hierarchical K-means method and 2nd method: Hierarchical Cluster analysis. Both non-hierarchical and hierarchical cluster analyses were conducted using R functions *kmeans* and *hclust* (The R Foundation for Statistical Computing Platform, 2014).

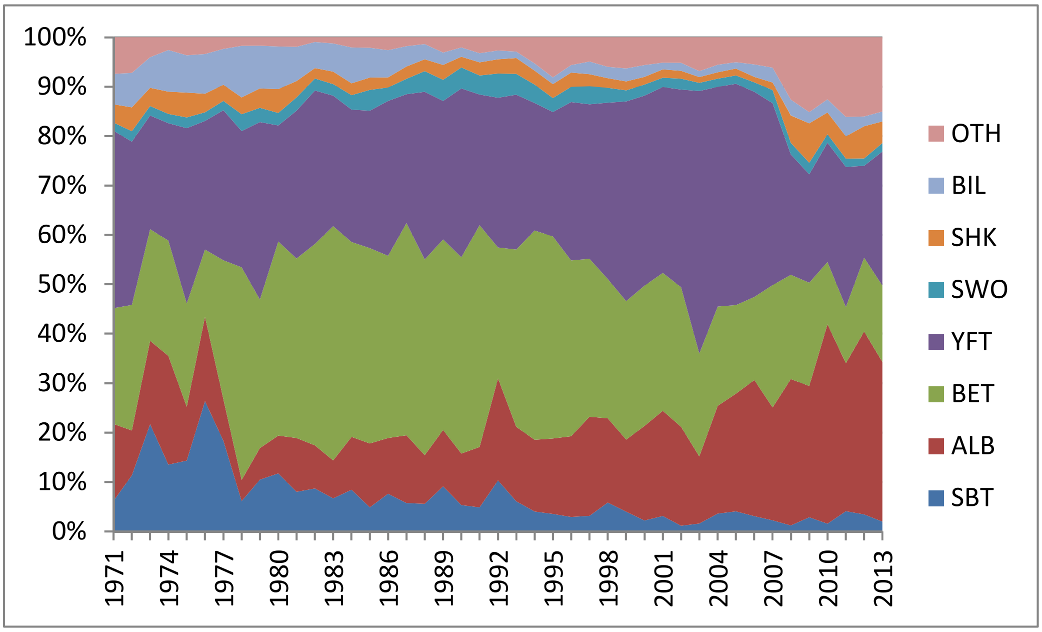


Fig.1 Species compositions of Japanese tuna longline fisheries in the Indian Ocean (1971-2013)

(1) K-means method

As a first step, non-hierarchical cluster analysis (K-means method) was used to group all data sets into 28 clusters for taking the mixture of fishing operations into account into ($C_2^8 = 28$ ways in which 2 species can be chosen from 8 species groups). Table 1 shows average proportions SWO catches for 28 K-means clusters. Cluster 1 consist large average proportions of SWO catches, which are 39.9%.

Table 1 Average proportion catches of swordfish of Japanese longline fishery for 28 non-hierarchical (K-means) clusters.

Cluster	SBT	ALB	BET	YFT	SWO	SHK	OTH	BIL
1	0.008	0.044	0.216	0.135	0.399	0.029	0.020	0.045
2	0.001	0.267	0.070	0.539	0.024	0.015	0.029	0.029
3	0.000	0.015	0.239	0.636	0.029	0.012	0.010	0.030
4	0.001	0.011	0.424	0.136	0.052	0.035	0.021	0.263
5	0.344	0.473	0.069	0.007	0.022	0.016	0.029	0.001
6	0.004	0.493	0.085	0.280	0.024	0.021	0.032	0.033
7	0.004	0.045	0.094	0.109	0.047	0.053	0.026	0.539
8	0.001	0.008	0.884	0.024	0.014	0.004	0.005	0.010
9	0.000	0.012	0.035	0.891	0.013	0.004	0.005	0.014
10	0.002	0.031	0.107	0.466	0.049	0.053	0.031	0.206
11	0.000	0.046	0.069	0.730	0.030	0.018	0.029	0.047
12	0.009	0.302	0.552	0.030	0.023	0.014	0.026	0.006
13	0.003	0.260	0.322	0.256	0.037	0.029	0.030	0.029
14	0.507	0.016	0.002	0.000	0.002	0.024	0.365	0.000
15	0.846	0.007	0.005	0.000	0.003	0.003	0.018	0.000
16	0.001	0.016	0.372	0.460	0.037	0.018	0.015	0.046
17	0.001	0.016	0.531	0.319	0.034	0.012	0.013	0.040
18	0.563	0.157	0.093	0.006	0.030	0.022	0.024	0.001
19	0.000	0.011	0.690	0.183	0.028	0.008	0.009	0.036
20	0.055	0.072	0.116	0.066	0.022	0.498	0.084	0.030
21	0.145	0.026	0.031	0.016	0.004	0.034	0.669	0.005
22	0.040	0.282	0.079	0.038	0.019	0.056	0.238	0.017
23	0.005	0.054	0.730	0.029	0.040	0.016	0.037	0.032
24	0.000	0.061	0.082	0.395	0.025	0.036	0.308	0.062
25	0.003	0.041	0.452	0.038	0.017	0.023	0.361	0.013
26	0.021	0.036	0.524	0.064	0.097	0.110	0.035	0.036
27	0.029	0.758	0.079	0.029	0.015	0.018	0.043	0.005
28	0.015	0.519	0.315	0.030	0.027	0.021	0.030	0.008

(2) Hierarchical Cluster analysis

Secondly, hierarchical cluster analysis with Ward minimum variance method was applied to the squared Euclidean distances calculated from 28 non-hierarchical clusters.

He *et al.* (1997) indicated that the choice for the number of clusters to produce was largely subjective. At least two clusters (tuna sets and swordfish sets) were expected. More than two clusters were produced to allow other possible categories to emerge.

The selection for number of clusters of hierarchical cluster analysis was based on the average proportions of SWO catches obtained from K-means method (Table 1). Various fishing types were also assigned to each data set based on the results of hierarchical cluster analysis. Finally, 10 clusters were chosen. Then clusters 1 and 3 were selected as the SWO cluster because they are neighbors each other in dendrogram (Fig. 3) and they contain much more average proportions of SWO catches than other clusters (Table 2 and Figs. 4-5).

Table 2 Average proportions catches of swordfish and assigned fishing types of Japanese longline fishery for 10 hierarchical clusters

Cluster	SBT	ALB	BET	YFT	SWO	SHK	OTH	BIL	Data sets	%	Fishing type
1	0.008	0.044	0.216	0.135	0.399	0.029	0.020	0.045	6383	1	SWO+BET
2	0.001	0.064	0.218	0.518	0.033	0.022	0.046	0.063	125531	17	YFT+BET
3	0.003	0.023	0.672	0.117	0.034	0.020	0.038	0.043	222774	29	BET
4	0.134	0.663	0.076	0.022	0.018	0.017	0.038	0.003	60175	8	ALB
5	0.013	0.384	0.319	0.102	0.026	0.024	0.056	0.016	107269	14	ALB+BET
6	0.004	0.045	0.094	0.109	0.047	0.053	0.026	0.539	8957	1	BIL
7	0.000	0.029	0.052	0.812	0.021	0.011	0.016	0.030	91469	12	YFT
8	0.726	0.037	0.021	0.002	0.008	0.010	0.087	0.000	105372	14	SBT
9	0.055	0.072	0.116	0.066	0.022	0.498	0.084	0.030	12279	2	SHK
10	0.145	0.026	0.031	0.016	0.004	0.034	0.669	0.005	17204	2	OTH

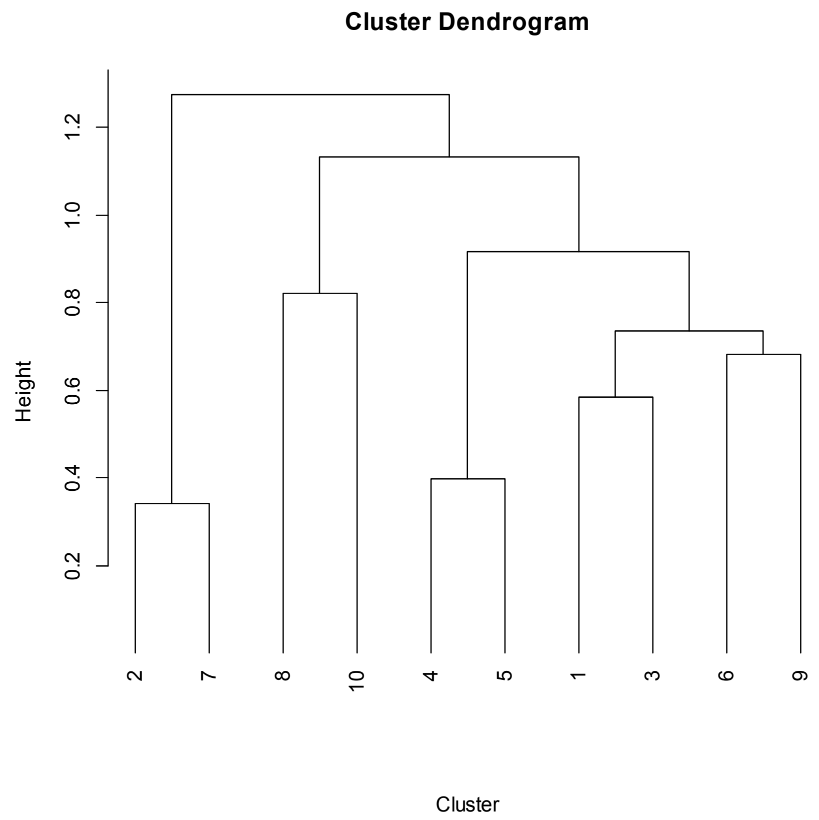


Fig. 3. The dendrogram of hierarchical cluster analysis for classifying the data sets of Japanese longline fishery in the Indian Ocean.

Figs. 4 and 5 show the historical catches by species and species compositions respectively. It is obvious that Clusters 1 and 3 contain relatively large SWO catches since middle 1970s. Large amounts of data sets of Cluster 1 distributed in entire Indian Ocean except south central areas (Fig. 6).

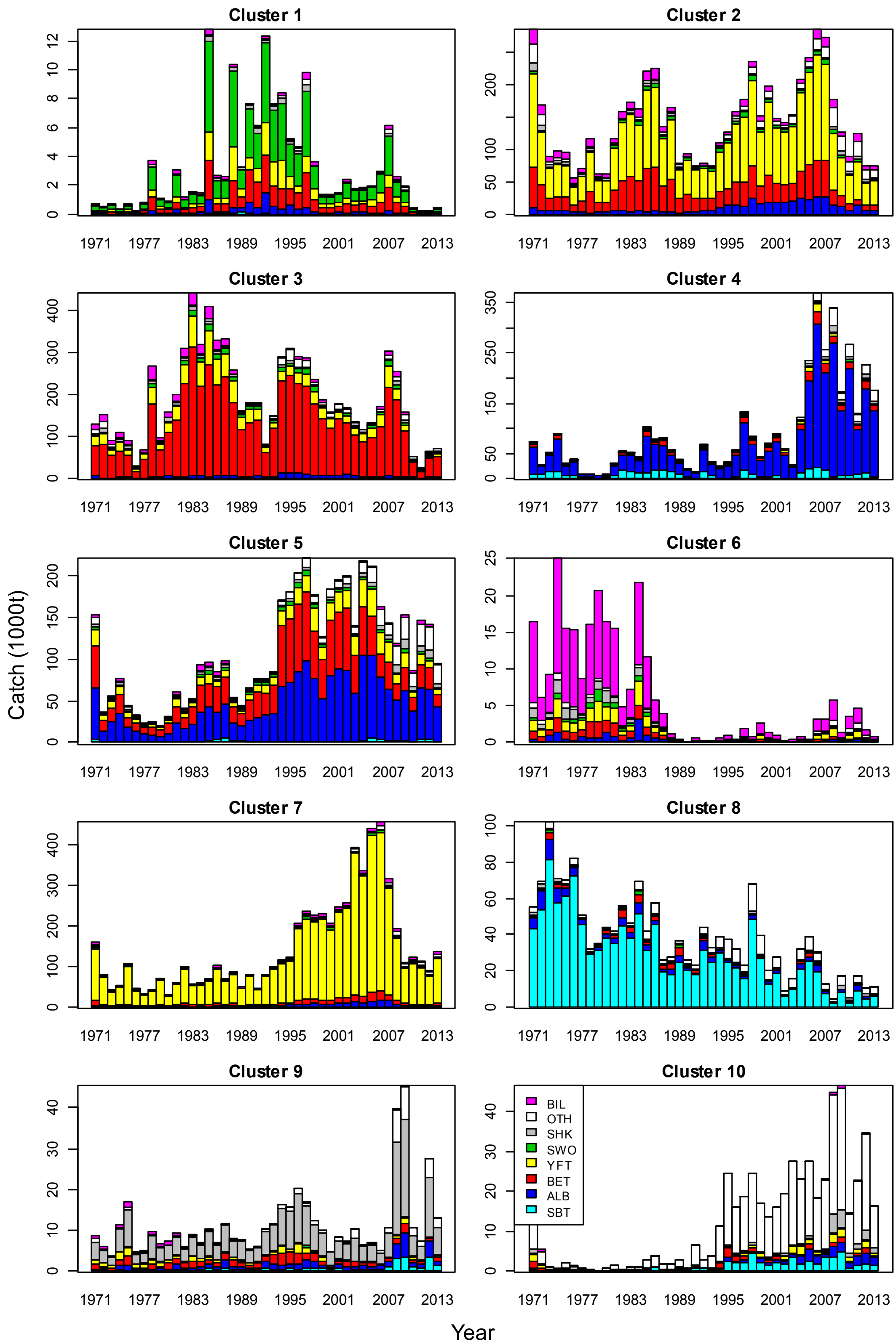


Fig. 4. Annual catches by species of Japanese longline fishery in the Indian Ocean for ten clusters.

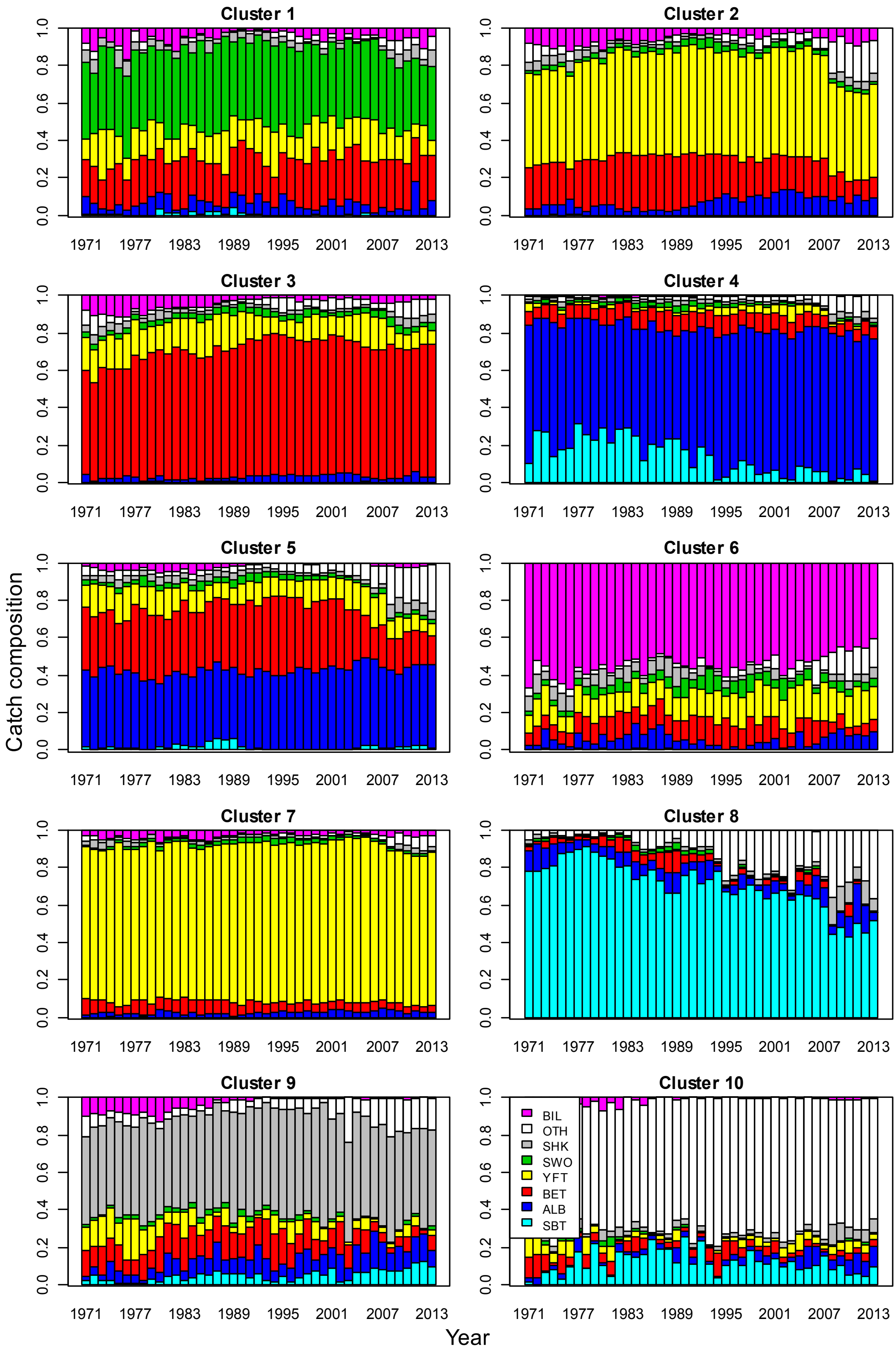


Fig. 5. Annual catch compositions of Japanese longline fishery in the Indian Ocean for ten clusters.

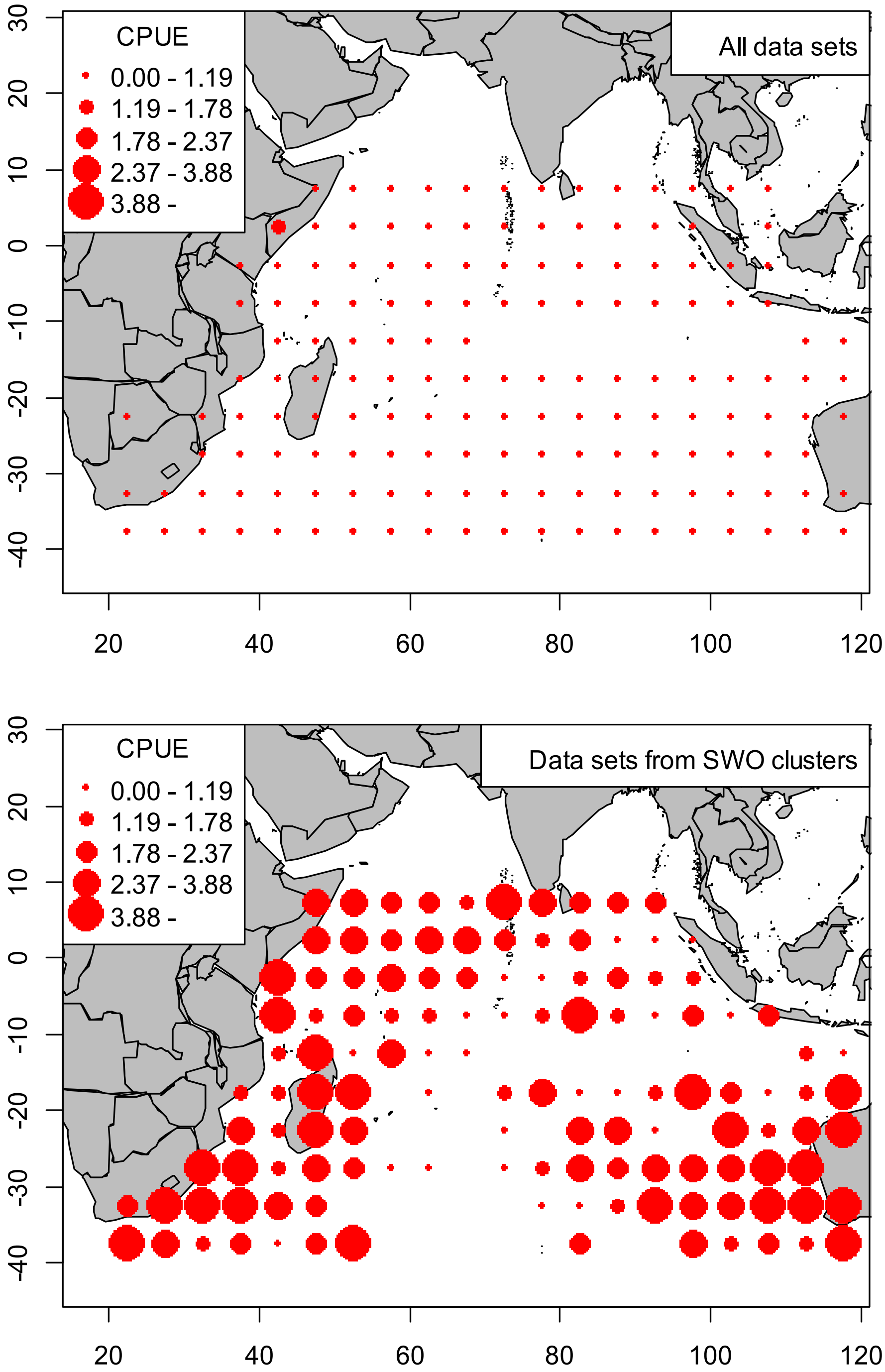


Fig. 6. The distributions for number of data sets of Japanese tuna longline fishery in the Indian Ocean for ten clusters (above: all data and below: data from SWO cluster 1)

3.2 GLM

(1) Covariates

In this study, General Linear Model (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, month, area and targeting effect.

Fishing areas used in this study were defined by four areas based on the IOTC statistical area for swordfish in the Indian Ocean (Fig. 7) (Wang and Nishida, 2011). In addition, local area affect is also included in the GLM. The local effect is represented by 10^{o}x10^{o} block which will reduce biases in local events such as oceanographic anomalies. This effect has been recommended by past WPTT and WPB.

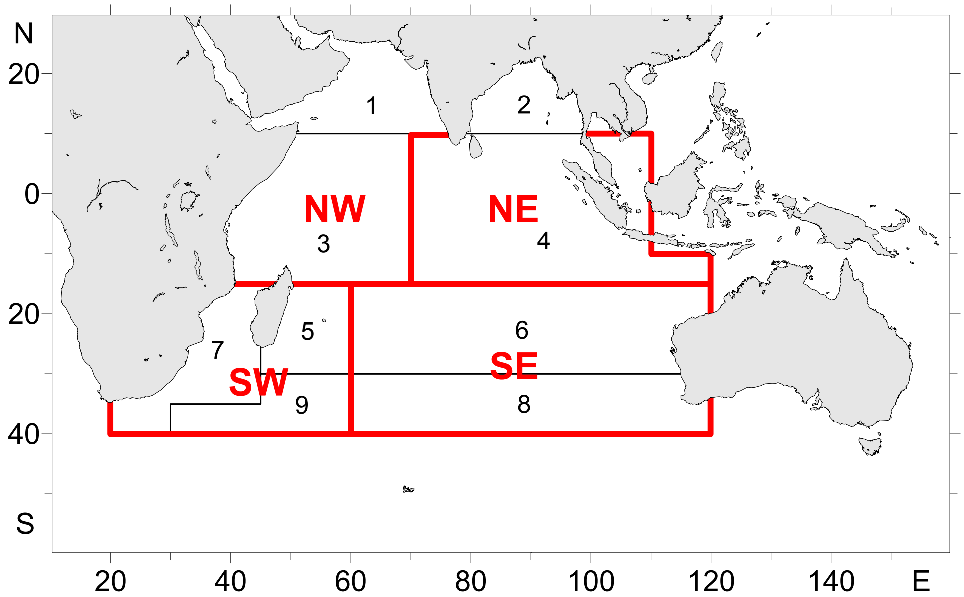


Fig. 7 Area stratification for swordfish in the Indian Ocean

Hinton and Maunder (2004) indicated that interactions with the year effect would invalidate the year effect as an index of abundance. For the interaction associated with year effect, therefore, the interaction between year and area effect was only considered in the GLM. All of effects were treated as category variables.

Regarding targeting effect, we tested three types, i.e., (a) no, (b) SWO cluster related to fishing type and (c) number of hooks between floats (NHBF).

(2) GLM formulation

Then GLM is formulated as below:

ln (CPUE+c) = (mean) + YR + MO + A + A10 + TAR + (interaction) + (error)

where	*mean*	*is mean STD_CPUE*
	CPUE	*is the CPUE of swordfish (catch in number/1000 hooks);*
	c	*is the constant value (i.e. 10% of the average nominal CPUE);*
	YR	*is the effect of year;*
	MO	*is the effect of month;*
	A	*is the effect of area;*
	A10	*is the effect of 10^{o}x10^o area*
	TAR	*is the effect of targeting (NHBF or cluster related to fishing types:1 and 3);*

NHBF: class of number of hooks between floats

Class 1(shallow)	*: 4-7*
Class 2(regular)	*: 8-10*
Class 3(deep)	*:11-13*
Class 4(deep)	*: 14-16*
Class 5(ultra deep)	*: 17-19*
Class 6(ultra deep)	*: 20-*

interactions	*is the interaction between effects.*
error	*is the error term, ε~N(0, σ^2).*

In order to investigate the effectiveness of the effect of cluster related to fishing type when fitting GLM to different data sets, six scenarios with different combination of effects were attempted (Box 1). The model selection is based on the values of the coefficient of determination (r^2) and Akaike information criterion (AIC). The standardized CPUE are calculated based on the estimates of least square means of the interaction between the effects of year and area.

(3) 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 areas used in this study (see below)

Area	NW	NE	SW	SE
Relative area size	0.2478	0.2577	0.1638	0.3307

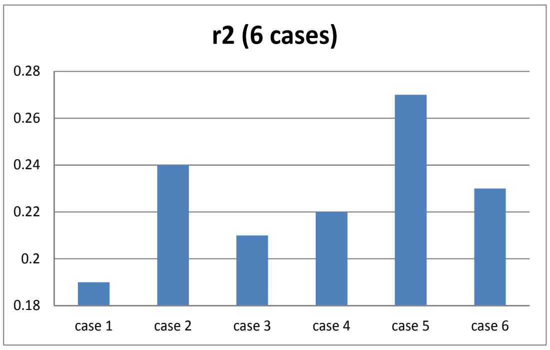
(4) Results

Results of performances of six GLM runs are shown in Box 1. Box 1 suggested that GLM with SWO cluster as targeting effect (scenarios 2 and 5) performed better than GLM with NHBF (scenarios 3 and 6). It also suggested that GLM with SWO cluster 1 and 3 performed better than GLM with all data. Based on r2 and AIC, the scenario 5 with SWO cluster 1+3 data using cluster 1+3 is resulted as the best.

Results of estimated STD_CPUE for 4 areas and the whole Indian Ocean are shown in Table 3 with SE.

Box 1 Six scenarios regarding targeting effect and their performances

Scenario	Data	Targeting Correction factor	No. observations	No. parameters	r^2	AIC
1	ALL	No	725,173	323	0.19	2,493,054
2		Cluster 1+3		453	0.24	2,451,790
3		NHBF	716,557	425	0.21	2,452,515
4	SWO Cluster 1+3	No	219,184	322	0.22	730,631
5		Cluster 1+3		356	0.27	715,198
6		NHBF	216,175	424	0.23	718,743



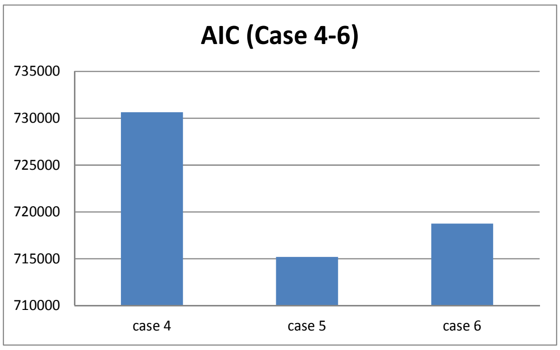


Table 3 Estimated STD_CPUE for 4 areas and whole Indian Ocean

NE		
	case 5	SE
1971	0.24976	0.0294
1972	0.31029	0.0373
1973	0.18687	0.0282
1974	0.23128	0.0264
1975	0.1641	0.0207
1976	0.25339	0.0347
1977	0.25435	0.0377
1978	0.39913	0.0422
1979	0.23956	0.0281
1980	0.30889	0.0333
1981	0.3146	0.0332
1982	0.30221	0.0315
1983	0.28116	0.0288
1984	0.24993	0.0261
1985	0.32205	0.0327
1986	0.29116	0.0301
1987	0.39068	0.0394
1988	0.34224	0.0348
1989	0.2652	0.0306
1990	0.22385	0.0256
1991	0.23847	0.0270
1992	0.21444	0.0286
1993	0.29079	0.0352
1994	0.36656	0.0456
1995	0.24731	0.0291
1996	0.31879	0.0357
1997	0.26047	0.0288
1998	0.29815	0.0316
1999	0.21563	0.0241
2000	0.20672	0.0245
2001	0.13849	0.0173
2002	0.15312	0.0186
2003	0.16421	0.0203
2004	0.11848	0.0160
2005	0.13518	0.0184
2006	0.16706	0.0194
2007	0.23266	0.0246
2008	0.24298	0.0253
2009	0.20872	0.0225
2010	0.19751	0.0226
2011	0.19793	0.0263
2012	0.1854	0.0224
2013	0.28724	0.0309

NW		
	case 5	SE
1971	0.36945	0.0451
1972	0.61492	0.0645
1973	0.54952	0.0605
1974	0.49129	0.0532
1975	0.64864	0.0675
1976	0.5635	0.0773
1977	0.57028	0.0742
1978	1.06787	0.1033
1979	0.58428	0.0649
1980	0.4836	0.0534
1981	0.47329	0.0485
1982	0.5972	0.0585
1983	0.48969	0.0485
1984	0.54815	0.0542
1985	0.85274	0.0808
1986	0.77576	0.0744
1987	0.74663	0.0718
1988	0.84319	0.0812
1989	0.62132	0.0615
1990	0.57474	0.0580
1991	0.43039	0.0456
1992	0.6595	0.0707
1993	0.84834	0.0866
1994	0.7634	0.0773
1995	0.78671	0.0795
1996	0.68249	0.0679
1997	0.78738	0.0761
1998	0.74551	0.0723
1999	0.67746	0.0688
2000	0.63615	0.0649
2001	0.54216	0.0612
2002	0.48807	0.0499
2003	0.53546	0.0543
2004	0.50066	0.0511
2005	0.38899	0.0398
2006	0.4411	0.0444
2007	0.63478	0.0610
2008	0.56522	0.0553
2009	0.64078	0.0632
2010	1.05359	0.1292
2011		
2012	0.85312	0.1015
2013	0.74561	0.0877

SE		
	STD_CPUE	SE
1971	0.70433	0.0611
1972	0.72794	0.1070
1973	0.69652	0.0786
1974	0.5026	0.0568
1975	0.40836	0.0437
1976	0.74531	0.1210
1977	1.02804	0.1085
1978	1.04064	0.0907
1979	0.73615	0.0742
1980	0.42142	0.0402
1981	0.63734	0.0630
1982	0.48025	0.0588
1983	0.58083	0.0572
1984	0.55875	0.0531
1985	0.64332	0.0656
1986	0.58769	0.0597
1987	0.52859	0.0464
1988	0.81841	0.0909
1989	0.77444	0.0867
1990	0.31812	0.0292
1991	0.36848	0.0303
1992	0.37887	0.0332
1993	0.44864	0.0360
1994	0.36454	0.0293
1995	0.31664	0.0254
1996	0.36613	0.0292
1997	0.56275	0.0436
1998	0.54137	0.0439
1999	0.53064	0.0430
2000	0.38771	0.0321
2001	0.3642	0.0294
2002	0.438	0.0353
2003	0.40421	0.0362
2004	0.58106	0.0523
2005	0.35297	0.0373
2006	0.44831	0.0526
2007	0.58775	0.0804
2008	0.5657	0.0696
2009	0.58003	0.0709
2010	0.74746	0.1153
2011	0.74878	0.1135
2012	0.66184	0.1139
2013	0.70304	0.0882

SW		
	STD_CPUE	SE
1971	1.60299	0.2578
1972	3.18803	0.7110
1973	1.24136	0.3198
1974	0.852	0.1466
1975	0.8681	0.2411
1976	1.33763	0.3588
1977	1.01531	0.3814
1978	1.01751	0.1594
1979	1.26417	0.2068
1980	1.26918	0.1779
1981	0.68024	0.0938
1982	0.4991	0.0731
1983	0.77505	0.1173
1984	2.04457	0.2802
1985	1.89297	0.2389
1986	0.98522	0.1315
1987	0.87688	0.1200
1988	1.31234	0.1676
1989	1.53456	0.1909
1990	1.5358	0.1871
1991	0.89931	0.1107
1992	0.78672	0.0968
1993	0.66082	0.0846
1994	0.65992	0.0819
1995	0.40849	0.0533
1996	0.42173	0.0547
1997	0.4279	0.0555
1998	0.35243	0.0469
1999	0.29675	0.0408
2000	0.32933	0.0456
2001	0.28834	0.0406
2002	0.27849	0.0397
2003	0.30083	0.0419
2004	0.27838	0.0398
2005	0.31439	0.0446
2006	0.41436	0.0691
2007	0.59456	0.1069
2008	1.13156	0.2284
2009	0.56332	0.1126
2010	0.55892	0.0893
2011	0.30346	0.0526
2012	0.3641	0.0570
2013	0.29652	0.0544

ALL area	(area size weighted)	
	STD_CPUE	SE
1971	0.65263	0.0261
1972	0.99838	0.05561
1973	0.62163	0.04096
1974	0.48971	0.02336
1975	0.4851	0.03369
1976	0.67362	0.05182
1977	0.71629	0.06385
1978	0.88493	0.03318
1979	0.66048	0.02846
1980	0.54846	0.02101
1981	0.52213	0.01873
1982	0.46937	0.01905
1983	0.51492	0.01973
1984	0.72294	0.02314
1985	0.82244	0.02627
1986	0.62783	0.02159
1987	0.60769	0.0205
1988	0.78775	0.02723
1989	0.73334	0.02528
1990	0.5604	0.01637
1991	0.4392	0.01369
1992	0.47728	0.01673
1993	0.54731	0.01772
1994	0.51624	0.01738
1995	0.43567	0.01292
1996	0.44505	0.0133
1997	0.52366	0.01401
1998	0.50277	0.01359
1999	0.45212	0.01243
2000	0.39734	0.01208
2001	0.34172	0.01053
2002	0.35419	0.01019
2003	0.36164	0.01118
2004	0.39614	0.01157
2005	0.30197	0.01092
2006	0.37121	0.01736
2007	0.51301	0.02504
2008	0.57833	0.03083
2009	0.50096	0.02503
2010	0.65922	0.03036
2011	0.34635	0.02801
2012	0.54432	0.02565
2013	0.54439	0.02387

Fig. 8 shows the trend of STD_CPUE of scenario 5 (best one) is suggested that STD_CPUE (SWO abundance) continuously decreased from 1971 to 2005 and then increased to 2013, consequently the higher level have been kept in recent 8 years (2006-2013), while there are a lot of noises (ups and downs) throughout the whole period (1971-2013).

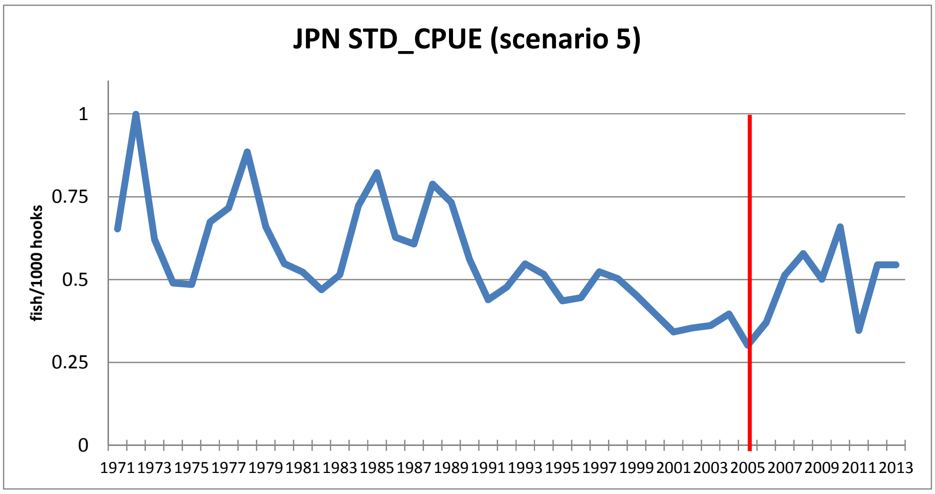


Fig. 8 Trend of the estimated Japanese tuna LL SWO STD_CPUE (1971-201)

We plotted trends of STD_CPUE for scenario 5 and 6 and compare targeting effect between cluster (5) and NHBF (6). STD_CPUE with NHBF show more jumps, while STD_CPUE by cluster effectively smooth out these bumps. This suggests that STD_CPUE with NHBF unlikely standardize nominal CPUE completely. Hence we suggest using STD_CPUE based on SWO cluster for stock assessments.

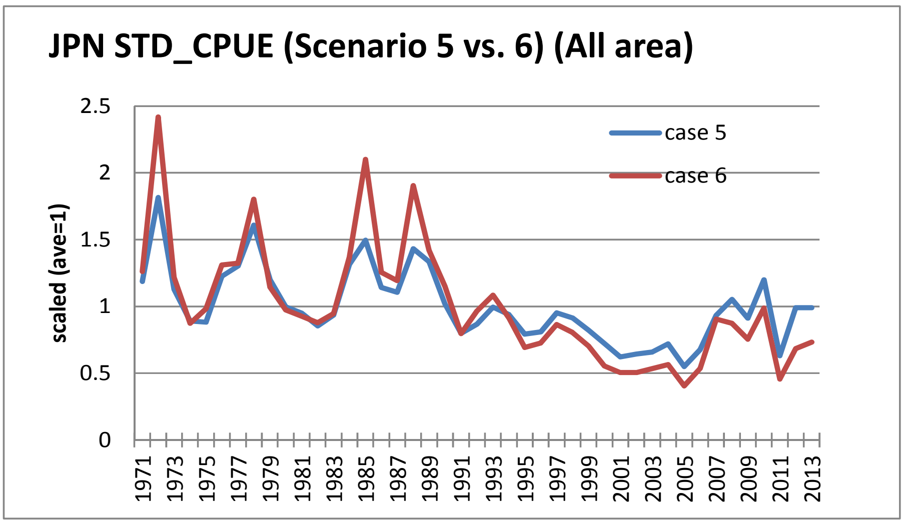


Fig. 8 Comparison of STD_CPUE based on targeting effect between SWO cluster (scenario 5) and NHBF (scenario 6).

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