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CPUE standardization of sailfish (*Istiophorus platypterus*) caught by Japanese longline fishery in the Indian Ocean from 1994 to 2014.

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Abstract

CPUE of sailfish (*Istiophorus platypterus*) caught by Japanese longline vessels in the Indian Ocean from 1994 to 2014 was standardized by GLM applying Log-normal error structured model and Negative binomial error structured model. For analysis, considering historical distribution of effort and CPUE, three core sub-areas, Area1: western tropical Indian Ocean, Area2: eastern tropical Indian Ocean, and Area3: West off Madagascar were prepared. The standardized CPUEs derived from both models showed similar trends in all areas. In all areas, CPUEs have been fluctuate around average level and did now show increasing or decreasing trend through the period analyzed. In recent five years, CPUE in Area2 has been lower than average while that in Area3 has been average level. Since that in Area1 has been quite low level, in recent three years in special, this trend is not reliable because of its shortage of data.

Introduction

CPUE standardization for sailfish caught by Japanese longline fishery in the Indian Ocean was conducted in 1998 (Uozumi 1998) for the period from 1967 to 1997. However, as the sailfish catch had been recorded in the logbook as combined catch with shortbill spearfish until 1993, standardized CPUE in that study was that for the combined catch of both species. As sailfish catch has been recorded in the logbook as single species since 1994, sailfish CPUE from 1994 to 2014 was standardized in this document.

Sailfish is known as resident in surface layer, shallower than 10-20m or in the upper uniformly mixed layer above 50m, but undertake vertical excursion into deeper waters (Kerstett r et al., 2011, Mourato et al., 2014, Chiang et al., 2013). This vertical movement to deeper water was supposed to be feeding behavior and the depth range of habitat and diving was supposed to be related with ambient temperature. Considering above behavior of this species, NHF (number of hooks between float), SST (sea surface temperature) and MLD (mixing layer depth) were applied in the model for standardization as the covariates which might affect on the chatchability of longline operation for sailfish.

Materials and methods

1. Catch and effort data used:

Set by set data of Japanese longline operation in the Indian Ocean from 1994 to 2014 was used for this study. In the data used, fishing year and month, the number of hooks between floats (NHF), the number of hooks used per set and sailfish catch in number per set were included.

2. Environmental factors:

As environmental factors, which are available for the analyzed period from 1994 to 2014, SST (Sea Surface Temperature) and MLD (geometric depth below sea surface monthly mean mixing layer) were applied.

Sea surface temperature (SST):
The SST data, whose resolution is 1-degree latitude and 1-degree longitude by month from 1994 to 2014, was downloaded from NEAR-GOOS Regional Real Time Data Base of Japan Meteorological Agency (JMA).

http://goos.kishou.go.jp/rrtdb/database.html

Mixing layer depth (MLD):
Monthly 0.333 degree latitude x 1.0 degree longitude global grid data of geometric depth below sea surface monthly mean mixing layer from January 1994 to December 2014 were downloaded from web site of NCEP Global Ocean Data Assimilation System (GODAS) and were averaged.

ftp://ftp.cdc.noaa.gov/Datasets/godas/

3. Criteria for data screening

As the sailfish is basically by-catch species for Japanese longliners whose target species are mainly bigeye, yellowfin and southern bluefin tunas in the Indian Ocean, considerable effort are exerted in the area where sailfish distributes scarcely. If these effort in such area is included in the CPUE calculation for sailfish, resulted CPUE trend would be affected by the fluctuation of the amount of effort exerted in the area of scarce distribution of this species. In order to avoid this problem, main distribution area of this species are selected to choose data to be used by observing historical distribution of the effort and CPUE.

In the logbook of Japanese longline fishery, fisher men were requested to record the catch of more than 20 species. Since it is ideal that all species caught are recorded in the same intension, reporting rate of by-catch species is often lower than that of target species. Therefore, a filtering method should be prepared to remove logbook with low or no reporting for sailfish.

Three types of criteria was applied for screening the all operational data in the Indian Ocean to compile data used for the sailfish CPUE standardization.

Criteria 1: Core area was selected and all data in other area was removed

Purpose of this criteria is to remove data of outer area of main distribution of sailfish, especially high latitude area, and remove data of area in which the effort didn't cover whole period.

Criteria 2: If sailfish catch was zero in a fishing cruise, all data in the cruise was deleted.

This criteria was used to remove the logbook data in which sailfish was not recorded at all in the cruise in spite of operation was conducted in the core area.

Criteria 3: Data out of the range of NHF from 5 to 25, or that without NHF information was deleted.

By this criteria the data which NHF information was not included or out of the range was removed. NHF is regarded as important indicator for targeting.

4. CPUE standardization by GLM

Two types of error structured model, lognormal model and negative binomial model were applied to standardize sailfish
CPUE.

LogNormal error structured assumption model (GLM procedure of SAS 9.4):
The full model and explanatory variables included in it were as follows.

$$Log\ (CPUE_{ijkl} + const) = \mu + YR_{(i)} + MN_{(j)} + + NHF_{(k)} + SST(l) + MLD(m) + e_{(ijkl....)}$$

Where Log : natural logarithm,
CPUE : catch in number of sailfish per 1000 hooks,
Const : 10% of overall mean of CPUE
μ : overall mean (i.e. intercept),
$YR_{(i)}$: effect of year,
$MN_{(j)}$: effect of fishing season (month),
$AREA_{(k)}$: effect of sub-area,
$NHF_{(l)}$: effect of gear type (the number of hooks between floats),
$SST_{(m)}$: effect of SST (sea surface temperature),
$MLD_{(n)}$: effect of MLD (mixing layer depth),
$e_{(ijkl..)}$: error term.

All explanatory variables are applied to the model as class variable and any interaction term was not included in the model.

Negative Binomial error structure assumption model (GENMOD procedure of SAS 9.4):
Negative Binomial error structure assumption was also applied. Basic structure of the model was as follows. Explanatory variables included in the full model was the same as those in full model of log-normal model.

E[Catch] = Effort * exp(Intercept + each explanatory valuables)
where, Catch ~ Negative Binomial(α,β)

In both case of standardization, Basing on the result of ANOVA (type III SS), non-significant effects were removed in step-wise from the initial model based on the F-value ($p<0.05$). In the cases in which the factor is not significant as main factor but is significant as interaction with other factor, the main factor was kept in the model. Furthermore, eight runs with different combinations of explanatory variable which showed significant effect were tried and the model with least AIC (Akaike's Information Criteria) was selected as final model.

Results and discussion

1. Fishery data and area definition

Total catch of sailfish of Japanese longline fishery in the Indian Ocean was around 100mt until 2004 when it increased quickly to 500mt in 2007 and sharply decreased to 84mt in 2010 and has fluctuated between 60 and 90mt thereafter (Fig. 1). More than 30% of sailfish has been caught in West Indian Ocean. Although the peak of catch in 2007 coincide with the highest effort in West Indian Ocean, trend of catch has not necessarily followed effort trend.

Average weight of sailfish recorded in the logbook by Japanese long-liners has slightly fluctuated between 22 and 24kg and quite similar through the period and between West and East Indian Ocean (Fig. 2).

Distribution of effort and catch ratio of sailfish was shown in Fig. 3 from 1994 to 2013 summing up by 5 years. The catch of sailfish has been limited to north of 15°S and the area between African coast and Madagascar. Especially the area off Madagascar has kept high level of effort and CPUE throughout analyzed period. Since quite high CPUE was also observed in Arabian Sea in 2004-2008 and in Andaman Sea in 1994-1998 and 1999-2003, time coverage of effort in those areas were limited.

Considering historical distribution of effort and CPUE describe above, area definition which consists of three core sub-areas, Area1: western tropical Indian Ocean, Area2: eastern tropical Indian Ocean, and Area3: West off Madagascar were prepared for CPUE standardization as shown in Fig. 4.

2. Data filtering and characteristics of remained data

2-1) Result of data filtering

Three steps of filtering method described in the material and method section were applied to the longline operational data from 1994 to 2013 and the change in effort and sailfish catch included in the data was shown in Table 1. Largest change in the number of data was caused by Criteria 1, by which number of 1°x1°x month strata, effort (the number of hooks) and sailfish catch in number were decreased to 20%, 52% and 95% of whole Indian Ocean without criteria. Relatively large decrease in strata and effort rather than catch was supposed to be primarily derived from removal of high latitudinal operations which mainly target on southern Bluefin tuna. Second criteria also largely affected on effort amount which decreased to 57% of remainder of criteria 1 (29% of whole data without applying any criteria). This large impact of Criteria 2 would be interpreted as the relatively low reporting rate of sailfish, minor by-catch species. By applying all three criterion, strata, effort and catch were decreased finally to 16%, 29% and 93% of whole Indian Ocean without criteria, respectively.

2-2) Zero-catch ratio

The number of operation and zero-catch ratio in each area and all area was shown in Fig. 5. In all areas, the number of operation was largely fluctuated and relatively large number of operation was observed during 2006 to 2009. In the case of area 1, operation was almost disappeared since 2010 because of the Piracy of off Somalia (Okamoto 2011). Operation in the area 2 has been fluctuated ranging from 1000 to 6000 since 1997, and that in area 3 has been around 2000 or more since 1997 and relatively small fluctuation except large peak from 2006 to 2008. With respect to zero-catch, it fluctuated between 0.6 and 0.8 with 0.7 as the central level in area 1. That in area 2 which was highest in the three areas shifted around 0.9 without large fluctuation. In area 3, it was lowest, around 0.5 to 0.6 with large fluctuation from 0.3 to 0.8.

2-3) Gear configuration in each area

Number of hooks between float (NHF) is well known as the targeting indicator and quite important factor in the standardization of tuna and tuna-like species caught by longline fishery. As this factor is not only indicator of targeting but also rough indicator of gear depth, it would be important factor to be involved in the standardization model for sailfish, a resident in shallow surface water (Kerstett r et al., 2011, Mourato et al., 2014, Chiang et al., 2013).

In order to observe the historical change in the NHF structure by area, NHF was classified into 6 categories, NHFCL1: 5-7, NHFCL2: 8-10, NHFCL3: 11-13, NHFCL4: 14-16, NHFCL5: 17-19, NHFCL6: 20-25. In Area1, proportion of each NHFCL has been relatively stable, while Area2 and 3, it gradually shifted from small number to large number (Fig. 6). NHFCL6 has been fluctuated between 20% and 40% throughout the period in the Area1 although NHFCL composition in this area after 2010 was uncertain because of very few or no data, while that in Area2 which was 0% in 1994 increased to 80-90% in 2011 and after. In Area3, smaller number of NHFCL was dominant than other two areas, NHFCL1 and 2 accounted about 85% until 1995 after when NHFCL3 increased rapidly up to about 90 or more in 2008 and after. There results of that relatively larger number of NHFCL has been major in Area1 and 2 comparing to Area3 indicate that the fishing mode would be different considerably between tropical areas and the area West off Madagascar.

3. CPUE standardization

3-1) Standardized CPUE

In all areas and in both of Log-Normal and Negative Binomial models, effect of all explanatory variables (year, month, NHF, SST and MLD) included in the full model were significant as shown in ANOVA table in Table 2. However, R-square in Area1 and 2 were quite low, 0.085 and 0.075 respectively while that in Area 3 was still low, 0.257 but higher than those in tropical two areas. As the full model showed least AIC in eight models in all areas and models, full model was selected as the final model in all cases (Table 3).

CPUEs standardized by Log-Normal and Negative Binomial models were shown in relative scale in Fig. 7 by area. Standardized CPUE derived from both models basically showed similar trend. In all areas, CPUEs have been fluctuate around average level and did not show increasing or decreasing trend through the period analyzed. If common trend among three areas are pointed out, CPUE from 2006 to 2008 was relatively higher level in all areas. In recent five years, CPUE in Area2 has been lower than average while that in Area3 has been average level. Since that in Area1 has been quite low level, in recent three years in special, this trend is not reliable because of its quite few data.

Standardized residuals derived from final model of CPUE standardization applying Log-Normal error strata, were expressed as histogram and QQ plot by area (Fig. 8). Bimodal distribution of residual was observed in all areas, and this status was also shown by QQ plots in each area. From these bimodal distribution of residual, it would be indicated that heterogeneity of fisheries are included in each area which could not be standardized enough by applied models. Since the factor which is causing this bimodal residual distribution is unknown at present and remained to be solved in the future, filtering of data for reporting rate might be a candidate of it.

3-2) Effect of each explanatory variable

Effect of each covariate was observed using lsmeans derived from final models of Log-normal and Negative binomial models. Exponential was taken for lsmean and plus 10% of overall mean of CPUE. The CPUE was expressed in relative scale in which average of CPUE in all classes is 1.0.

Basically trends derived from Log-normal and Negative Binomial model were similar.

Month (Fig. 9): In the West Indian Ocean (Area 1 and 3), sailfish CPUE was higher in winter with peak in November and December, while that in East Indian Ocean (Area2) was higher in spring with peak in April and May.

NHF (Fig.10): In the tropical areas (Area 1 and 2), basically CPUE in smaller NHF was higher than that in larger NHF while this trend was not clear in the Area3. Higher CPUE in the smaller NHF would be explained by that the sailfish is resident in the surface water.

SST (Fig. 11): In all areas, relationship between CPUE and SST was observed. That is, higher CPUE was observed at higher SST.

MLD (Fig. 12): Regarding mixing layer depth, since the trend is not clear, higher CPUE was observed in 50-60m in Area2

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Table 1 Change in number of effort and catch by applying three types of filtering criteria.

Filters	Area	Number of 1x1xmonth	Hooks	Sailfish Catch in N
No filter	All IO	85381	1676728995	144301
Filter 1: Area	Area 1	7845	332033516	49941
	Area 2	6196	208646931	10166
	Area 3	3036	323342251	76330
	All Areas	17077	864022698	136437
Filter 1 +	Area 1	6446	188361854	49941
Filter 2: remove	Area 2	4843	139908650	10166
no catch report	Area 3	2618	163623939	76330
	All Areas	13907	491894443	136437
Filter 1+	Area 1	6407	182304324	48995
Filter 2+	Area 2	4809	138171857	10127
Filter 3: NHF 5-25 &	Area 3	2606	159588145	75271
remove no NHF data	All Areas	13822	480064326	134393

Table 2 Results of ANOVA of final models.

AREA 1 Log-Normal 1994-2014 Year base

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	60	11686.832	194.781	91.180	<.0001	R-Square= 0.085997
						CV =
yr	19	5023.827	264.412	123.780	<.0001	-56.86299
mn	11	2361.242	214.658	100.480	<.0001	
nhf	16	2431.585	151.974	71.140	<.0001	
sst	5	1628.925	325.785	152.500	<.0001	
mld	9	241.252	26.806	12.550	<.0001	

AREA 1 N-BIN 1994-2014 Year base

Source	DF	Chi-square	Pr > ChiSq
yr	19	2584.080	<.0001
mn	11	486.460	<.0001
nhf	16	835.440	<.0001
sst	5	909.150	<.0001
mld	9	114.030	<.0001

AREA 2 Log-Normal 1994-2014 Year base

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	61	6505.329	106.645	57.180	<.0001	R-Square= 0.075126
						CV =
yr	20	881.899	44.095	23.640	<.0001	-31.60012
mn	11	602.722	54.793	29.380	<.0001	
nhf	16	642.512	40.157	21.530	<.0001	
sst	5	729.661	145.932	78.250	<.0001	
mld	9	491.809	54.645	29.300	<.0001	

AREA 2 N-BIN 1994-2014 Year base

Source	DF	Chi-square	Pr > ChiSq
yr	20	640.63	<.0001
mn	11	196.13	<.0001
nhf	16	318.08	<.0001
sst	5	284.32	<.0001
mld	9	245.35	<.0001

AREA 3 Log-Normal 1994-2014 Year base

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	65	28677.9307	441.1989	265.45	<.0001	R-Square= 0.256924
						CV =
yr	20	2130.415061	106.520753	64.09	<.0001	-71.61627
mn	11	2579.883204	234.534837	141.11	<.0001	
nhf	15	480.385115	32.025674	19.27	<.0001	
sst	10	9445.424573	944.542457	568.28	<.0001	
mld	9	141.036948	15.670772	9.43	<.0001	

AREA 3 N-BIN 1994-2014 Year base

Source	DF	Type III SS	Mean Square
yr	20	1184.28	<.0001
mn	11	1390.41	<.0001
nhf	15	259.72	<.0001
sst	10	5157.63	<.0001
mld	9	117.19	<.0001

Table 3 AIC calculated for each run for each area.

Area	RUN	AIC Log-Normal	AIC N-BIN
AREA 1	RUN 1: YR + MN	211347.44	134138.29
AREA 1	RUN 2: YR + MN + MLD	211277.57	134042.47
AREA 1	RUN 3: YR + MN + SST	210587.22	133266.58
AREA 1	RUN 4: YR + MN + SST + MLD	210502.22	133170.19
AREA 1	RUN 5: YR + MN + NHF	210267.56	133378.65
AREA 1	RUN 6: YR + MN + NHF + MLD	210197.62	133265.89
AREA 1	RUN 7: YR + MN + NHF + SST	209520.64	132462.77
AREA 1	RUN 8: YR + MN + NHF + SST + MLD	209425.70	132366.74
AREA 2	RUN 1: YR + MN	149840.63	45005.43
AREA 2	RUN 2: YR + MN + MLD	149573.11	44783.37
AREA 2	RUN 3: YR + MN + SST	149508.64	44793.30
AREA 2	RUN 4: YR + MN + SST + MLD	149219.15	44543.79
AREA 2	RUN 5: YR + MN + NHF	149515.71	44743.57
AREA 2	RUN 6: YR + MN + NHF + MLD	149287.55	44532.03
AREA 2	RUN 7: YR + MN + NHF + SST	149152.80	44485.06
AREA 2	RUN 8: YR + MN + NHF + SST + MLD	148907.52	44257.71
AREA 3	RUN 1: YR + MN	173974.79	151118.60
AREA 3	RUN 2: YR + MN + MLD	172861.05	150075.83
AREA 3	RUN 3: YR + MN + SST	167589.31	145059.41
AREA 3	RUN 4: YR + MN + SST + MLD	167517.73	144954.80
AREA 3	RUN 5: YR + MN + NHF	173752.18	144824.27
AREA 3	RUN 6: YR + MN + NHF + MLD	172628.27	150922.27
AREA 3	RUN 7: YR + MN + NHF + SST	167326.06	149862.70
AREA 3	RUN 8: YR + MN + NHF + SST + MLD	167259.16	144725.08

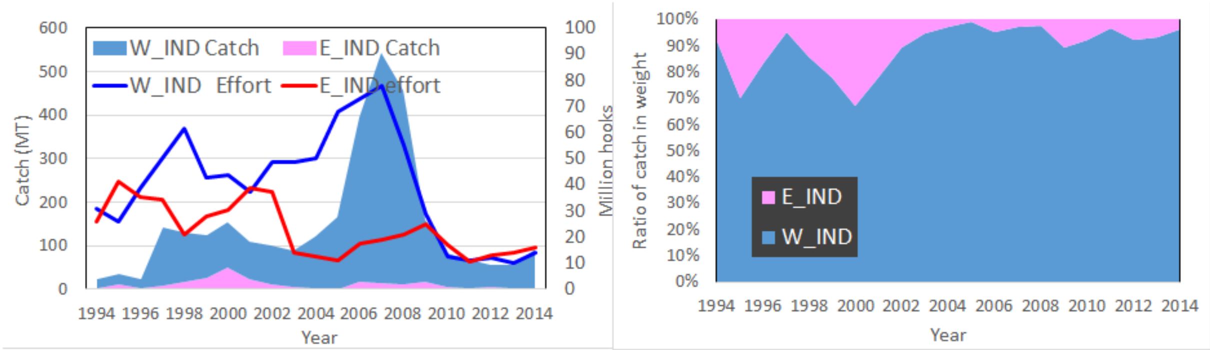

Fig. 1 Catch in weight of Sailfish and effort (hooks) in the West and East Indian Ocean (boundary is 80°E) by Japanese longline fishery (left) and ratio of catch by area (right). Effort was calculated using data of north of 35°S

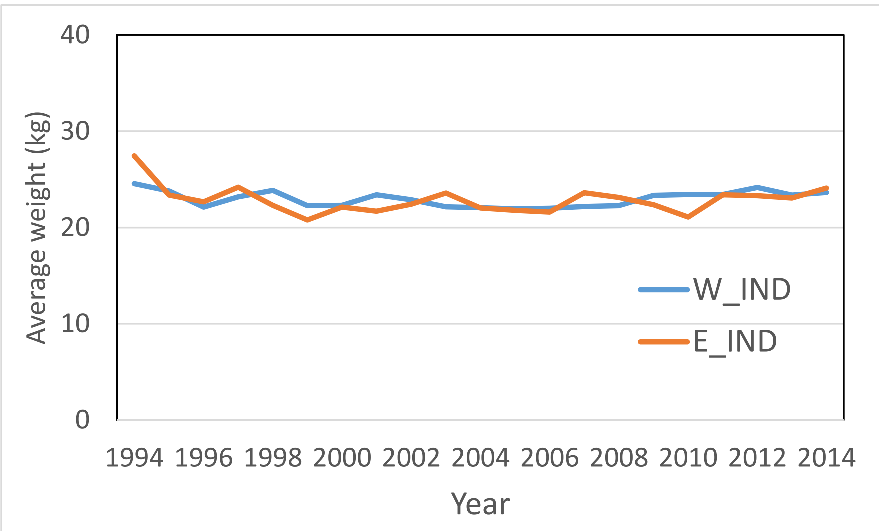

Fig. 2 Average weight of sailfish caught Japanese longline fishery from 1994 to 2014.

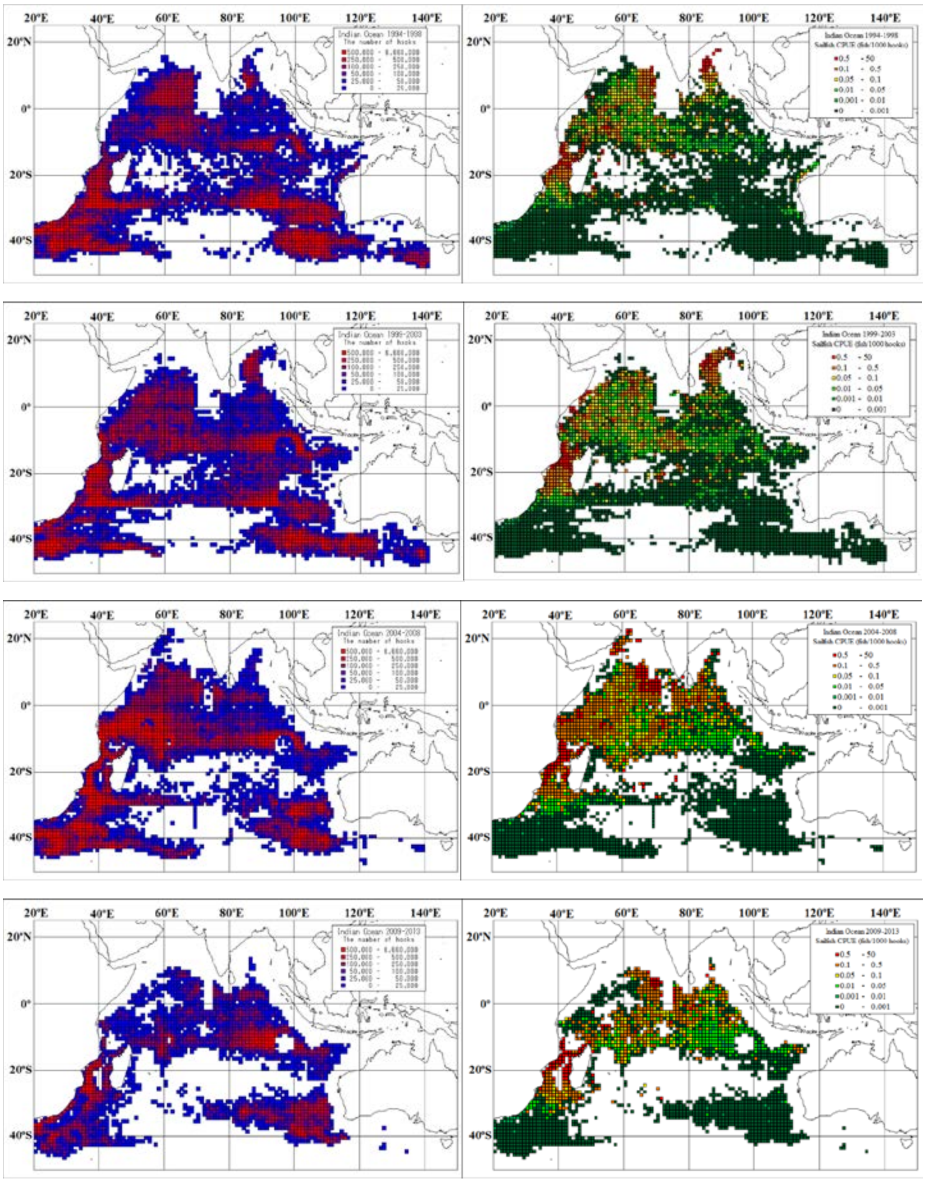

Fig. 3 Geographical distribution of effort (left) and sailfish catch rate (right) of Japanese longline fishery in every five years from 1994 to 2013.

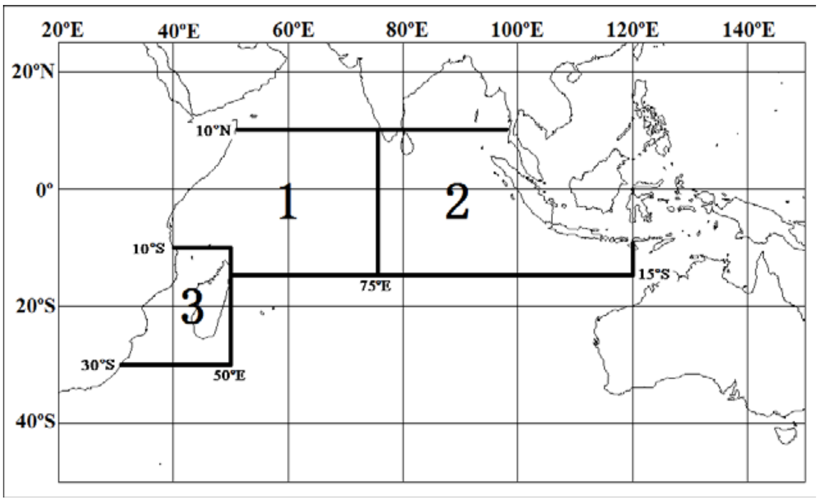

Fig. 4 Area stratification used for sailfish CPUE standardization prepared passed on the effort and CPUE distribution.

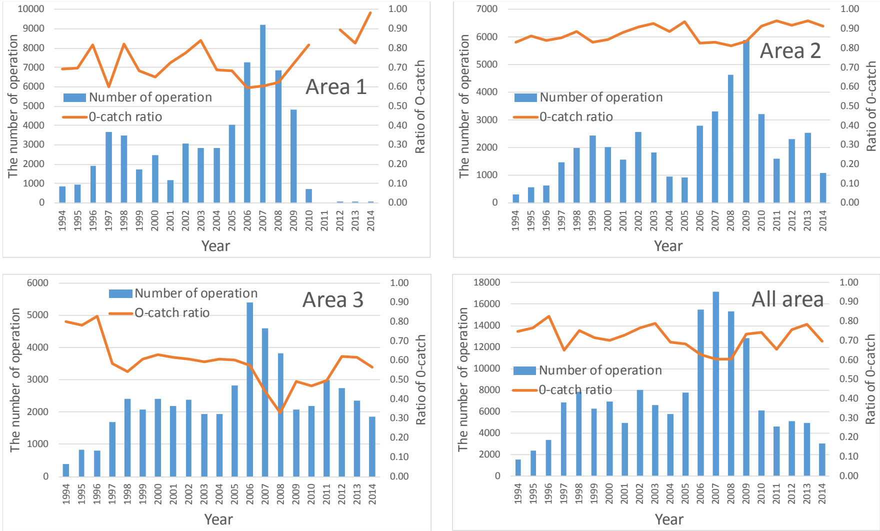

Fig. 5 Annual change of zero-catch ratio in filtered data of each area overlaid with the number of operation.

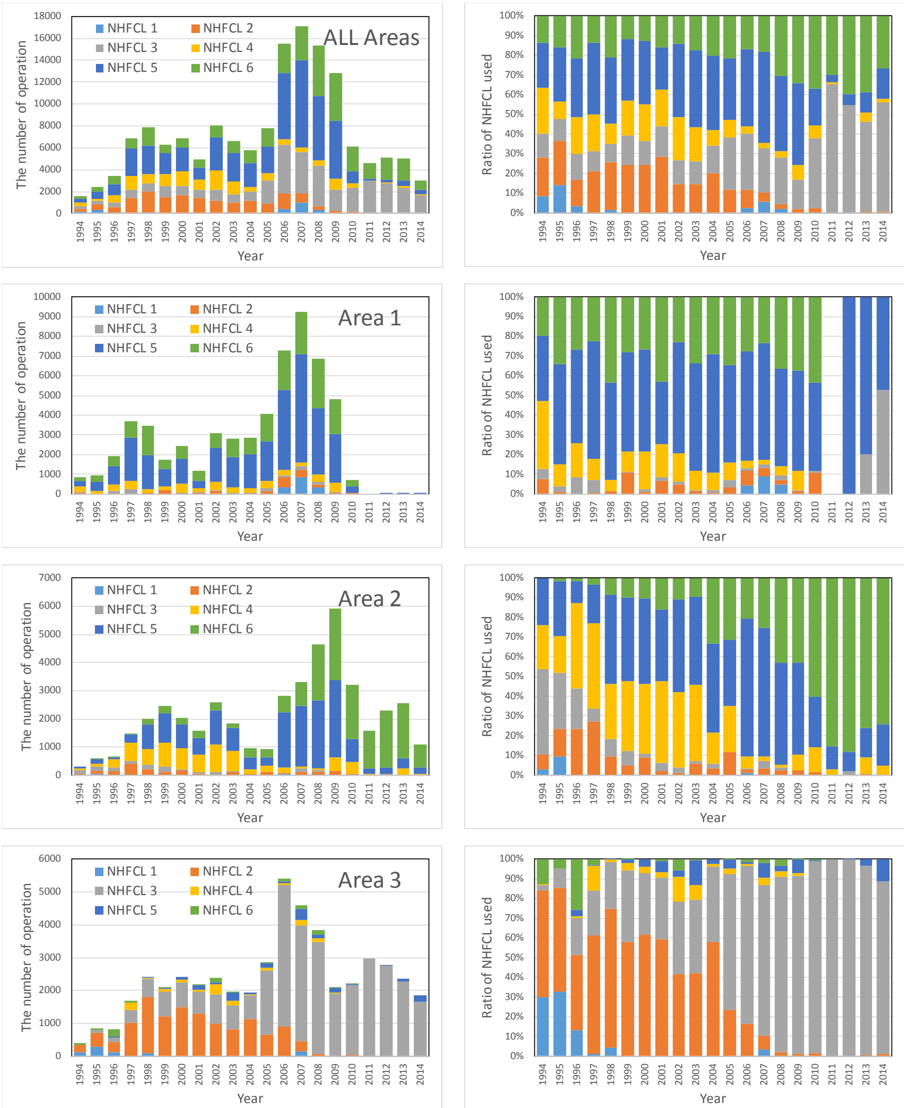

Fig. 6 Annual change of the number of hooks between floats (NHF) used in each area from 1994 to 2014. NHF was classified to 6 classes, NHFCL1: 5-7, NHFCL2: 8-10, NHFCL3: 11-13, NHFCL4: 14-16, NHFCL5: 17-19, NHFCL6: 20-25.

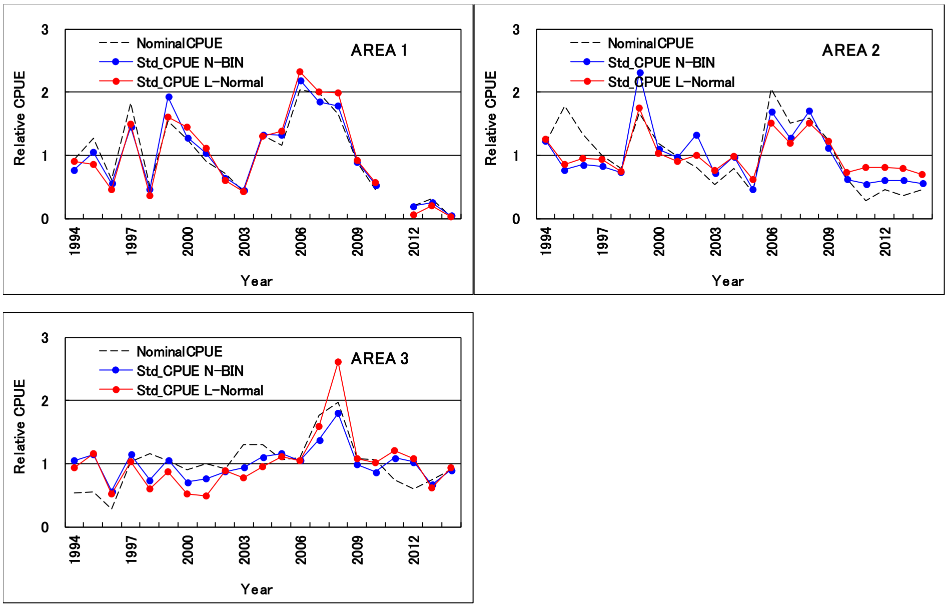

Fig. 7 Annual trends of CPUE standardized by Negative binomial and Log-Normal model from 1994 to 2014 in each area overlaid with nominal CPUE.

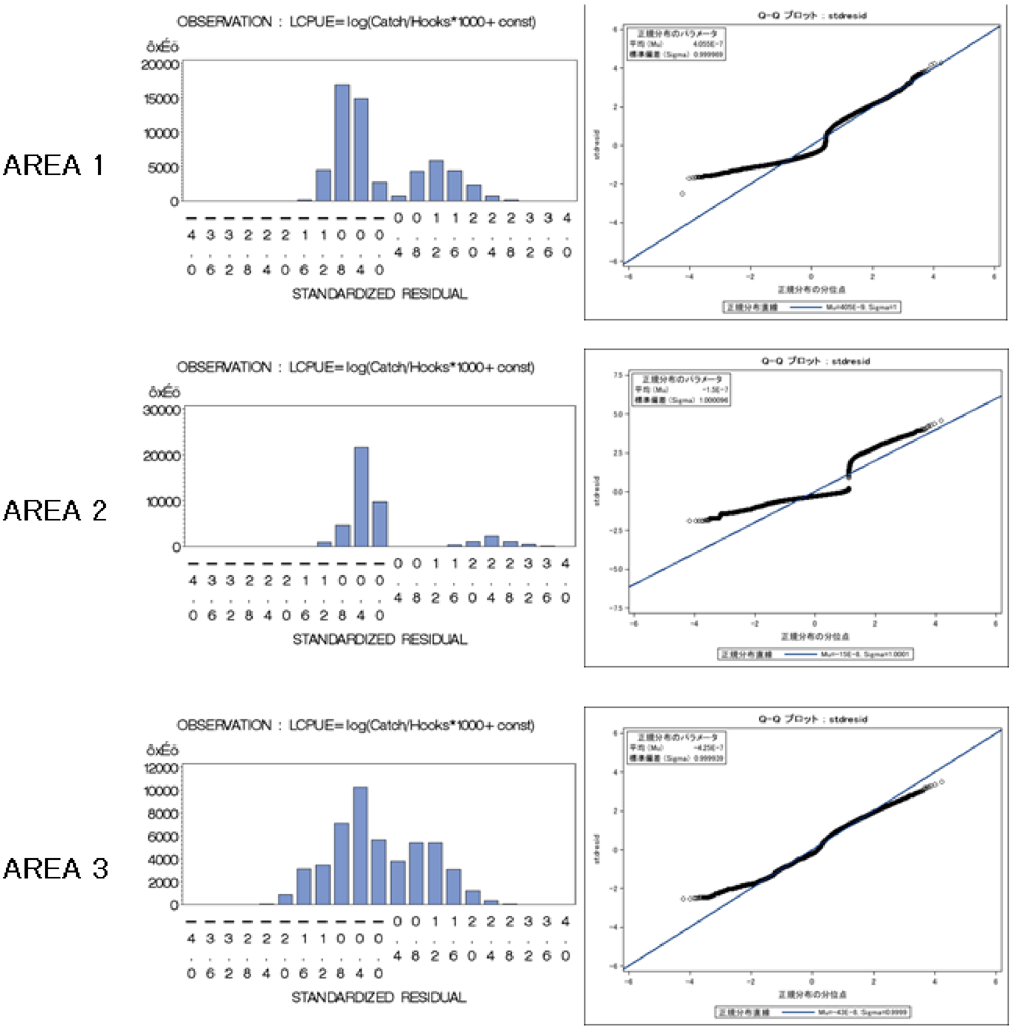

Fig. 8 Standardized residuals in CPUE of final model by each area standardized Log-Normal error structure model.

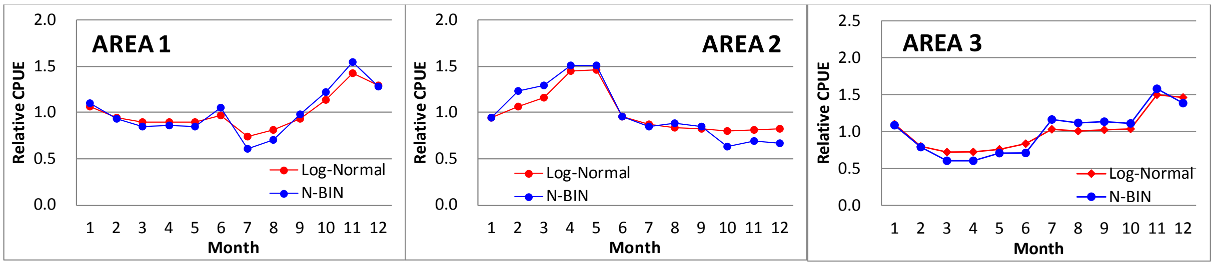

Fig. 9 Effect of month by area.

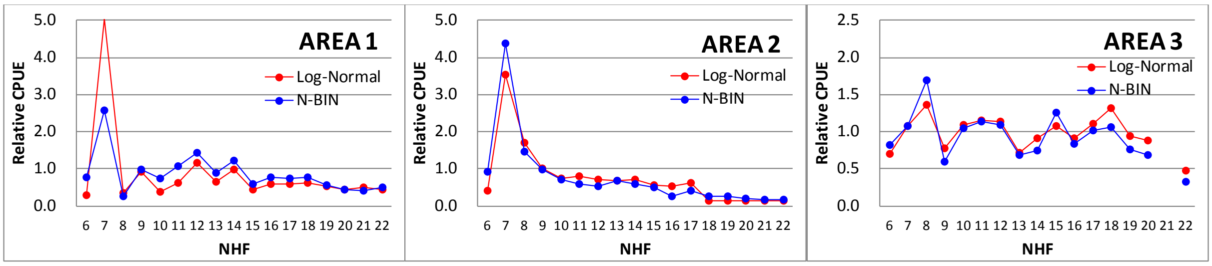

Fig. 10 Effect of NHF by area.

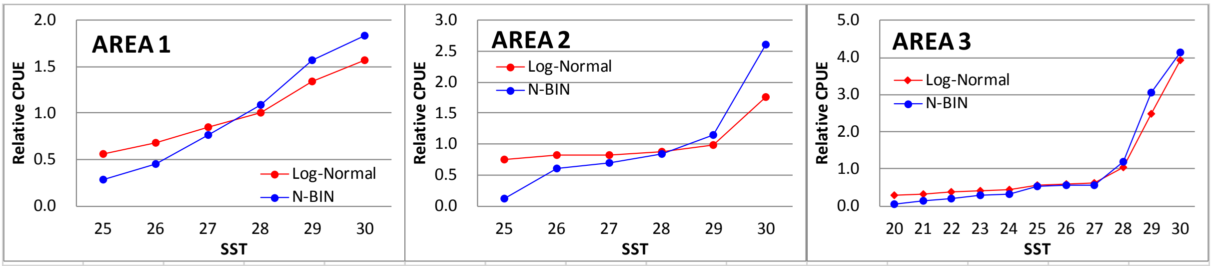

Fig. 11 Effect of sea surface temperature by area.

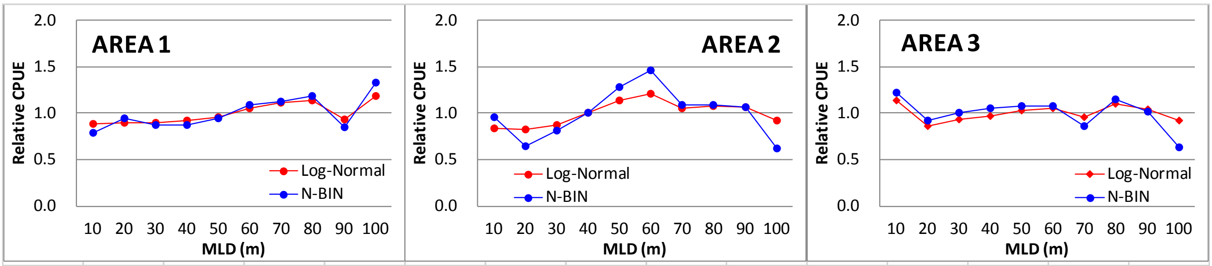

Fig. 12 Effect of mixing layer depth by area.