ISC/15/BILLWG-1/4

International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean

Update of standardized CPUE of striped marlin in the Northwestern Pacific Ocean, based on coastal small longline fishery from 1994 to 2013.

Seiji OHSHIMO [1] Minoru KANAIWA [2] and Kotaro YOKAWA [1]

1 National Fisheries Research Institute of Far Seas Fisheries, 5-7-1 Orido Shimizu-ku, Shizuoka, Japan, 424-8633

2 Tokyo University of Agriculture, 196 Yasaka Abashiri, Hokkaido, Japan, 099-2493

Working document submitted to the ISC Billfish Working Group Workshop, 13-20 January 2015, Honolulu, Hawaii, USA. Document not to be cited without author's written permission.

Abstract

This paper is update of standardized CPUE and decadal distribution change of stripe marlin (*Kajikia audax*) caught by Japanese coastal longline fisheries (defined as the longliners less than 20 tons) in the Northwestern Pacific Ocean from 1994 to 2013. The operations of Japanese coastal longliners widely covered the northwest Pacific west of 160E until the end of the 1990s when the coverage of its effort started to shrink. High CPUE area seems to be decreased in the period analyzed and this could be due to the shrink of habitat of striped marlin caused by the decrease of its abundance. Annual trends of CPUEs standardized by different methods and models generally were similar each other, and the estimated increasing trend since 2009 should indicate the recovery of the abundance of striped marlin in the area analyzed.

Introduction

This paper is update of standardized CPUE of stripe marlin (*Kajikia audax*) caught by Japanese coastal longline fisheries (defined as the longliners less than 20 tons) in the Northwestern Pacific Ocean from 1994 to 2013. The standardized CPUE (estimated abundance index) is to be used for the stock assessments of the Northwestern and central striped marlin stock (e.g. Piner et al. 2013). In addition, decadal changes of distribution pattern of effort of this fleet and its interaction with striped marlin were described in this paper.

Materials and Methods

Japan Fishery Agency started to collect the log book of Japanese coastal longliners (defined as the longliners less than 20 tons) in 1994. Though the coverage of log book is not precisely known, it is roughly estimated to be between 80 – 95 % in the early period and it increased into more than 95% in most recent years. Set by set data is used in this study for the analysis of CPUE.

Standardization of CPUE of striped marlin is calculated by the generalized linear model (GLM) with negative binominal error and delta log-normal model with Gaussian error.

Model 1: GLM with negative binomial error

Catch ~ factor(year)+factor(qt)+factor(area)+factor(hpb)
factor(area)*factor(hpb)+factor(qt)*factor(area)+offset(log(hooks))

, where catch. qt, area, hpb represent catch number of striped marlin, quarterly (1-4) and area (1-5) and hooks per basket, respectively. Area was stratified into five (Fig. 1), and same stratification by Yokawa (2006). Number of hooks per basket (float) was categorized into 12-13 (hpb:1), 14-15 (hpb:2), 16-17 (hpb: 3) and 18-20 (hpb: 4). Data of sets with the number of hooks between floats being larger than 21 and smaller than 11 were excluded from the analysis.

Model 2: Delta log-normal model with Gaussian error

The binomial part in delta model was as follows;

$r_y \sim Bin(1, p_y)$

log(p/1-p) = factor(year) + factor(area)+factor(qt) or

log(p/1-p) = factor(year) + factor(area)*factor(qt) ,

where r_y is response variable on presence (=1) or absence (=0) of a catch, and p represents probability of the presence of a catch at stratum of year and sst, α is coefficient. The lognormal model part was as follows;

$lcpue \sim N(\mu, \sigma^2)$

μ = factor(year)+ +factor(qt)+factor(area)+factor(hpb)

factor(area)*factor(hpb)+factor(qt)*factor(area),

where lcpue and lat represents log transformed CPUE (number/hooks), and latitude at setting longline, respectively.

Results and Discussion

Bubble plot of the nominal CPUE of striped marlin was shown in figure 1, and Japanese coastal longliners mainly catch striped marlin in the off northeast Japan along with Kuroshio extension, west of Kyushu and Okinawa islands as well as south of Ogasawara islands. (areas 1 and 2). The operations of Japanese coastal longliners widely covered the northwest Pacific west of 160E until the end of the 1990s when the coverage of its effort started to shrink. In the period between 2009 and 2013, the distribution of the effort of Japanese coastal longliners was limited to the center of their fishing ground during the 1990s and its density seem became sparse primality due to the decrease of the number of longline boats as well as the increase of joint venture style of operations. Striped marlin is one of the most widely distributed among the Indo-Pacific billfishes (family: Istiophoridae) The geographic distribution of striped marlin is subtropical-temperate, and abundance changes with the latitudinal expansion–contraction of these waters seasonally (Domeier 2006). Spatial distributions of the CPUE of Striped Marlin indicate that there is a seasonal north–south migration, and that the highest densities of CPUE occur in the central North Pacific Ocean (Lien et al., 2014). The seasonal latitudinal migration pattern can also be observed in the data of

Japanese coastal longliners (Figs 3 and 4). It also indicates such pattern only occurs in the sub-tropical part (areas 1 and 2) but not apparent in the tropical parts (areas 3 – 5). Su et al. (2013) suggested the possibility of the northward shift of striped marlin in the north Pacific due to the increase of sea water temperature which was occurred along with global warming tendency in the recent years, our data of the coastal longline CPUE did not show such pattern in the period analyzed (Fig. 2). High CPUE area seems to be decreased in the period analyzed and this could be due to the shrink of habitat of striped marlin caused by the decrease of its abundance. In quarter 3 in area 1, operational ground of Japanese longliners extended to the east in recent years (Figs. 3 and 4). This dispersion of the operational area of Japanese longliners is due to the drop of catch rate of bigeye tuna which was their primarily target species in this fishing ground.

The amount of effort of Japanese coastal longliners largely decreased in the 2000s throughout areas they operated (Fig. 5), but in the most recent years, it suddenly recovered. High CPUE of striped marlin obtained in the northern part of their operational area (areas 1 and 2) and almost negligible in area 5 (Fig. 5).

Annual trend of the nominal CPUE seems rather different among five areas analyzed. In area 1, it decreased in the 1990s and stable after the 2000s but in area 2 decreased until the 2000s and rapidly increased in the 2010s (Fig. 6). In area 3, the nominal CPUE shows general decreasing trend since the beginning of the 2000s. Annual nominal CPUEs in areas 4 and 5 were fluctuated throughout the years analyzed. Operational style of Japanese coastal longliners is rather opportunistic and they frequently change not only their targets but also their operational styles and gears. Such opportunism could cause the large difference of the nominal CPUE trend among areas. Observed unnatural large difference of the nominal CPUE level before and after 2002 in area 3 is believed not to represent actual trend of exploitable abundance of striped marlin in area 3 but is supposed to reflect, at least partially, the change of fishing strategy of this fleet.

Apparent difference of annual trend can also be seen in the quarter specific nominal CPUE (Fig. 7). Annual CPUE in quarter 1 (Jan.-Mar.) was stable through the 1990s and 2000s except in 2008 and increased in the recent years, and in area 2 decreased in the 1990s and 2000s and increased in the recent years. Annual CPUEs in area 3 and 4 have slightly decreasing trends in the 1990s and stable trends after 2000 with fluctuations. As relatively large amount of catches of striped marlin obtained in the areas 1 and 2 in 3rd and 4th quarters where apparently higher level of CPUE obtained, nominal CPUEs in quarters 3 and 4 supposed to more represent the dynamics of this stock than others.

Annual trends of CPUEs standardized by different methods and models generally were similar each other (Fig. 8) with the one by the GLM with negative binominal error model being most optimistic (Fig. 9). Thus the estimated steady increasing trend since 2009 should indicate the recovery of the abundance of striped marlin in the area analyzed. The results of CPUE standardizations are also indicate that higher CPUE obtained by deeper setting in many cases which is apparently conflict with the biology of striped marlin which is spending mostly within surface mixed layers (Appendices 1 and 2). The reason of those unusual results are not clear but supposed to come from the skewed distribution pattern of data in terms of HPB as the improvement of longline gear usually results in higher HPB number (Yokawa, 2004). When the catch and effort data were biased, the 2 steps type of analysis of CPUE would have possibility to amplify the biases involved in the data. The larger scale of unnatural up and down trend observed in the trend of CPUE in the 1990s standardized by 2 step model than that of one step GLM should suggest this thing (Kanaiwa et al. unpublished). Thus, the trend of standardized CPUE by one step negative binominal model would better represent the actual dynamics of the stock the ones standardized by 2 steps delta log normal model.

References

Domeier, M.L. (2006) An analysis of Pacific striped marlin (*Tetrapturus audax*) horizontal movement patterns using pop-up satellite archival tags. Bull. Mar. Sci., 79, 811–825.

Kanaiwa, M, Yokawa, K. and Takeuchi, Y. (2013) The evaluation of CPUE standardization method for zero inflated catch data of longliner by using simulation analysis. 5th Billfish symposium.

Lien, Y.H., SU, N.J., Sun, C.L., Punt, A.E., Yeh, S.Z., DiNardo, G. (2014) Spatial and environmental determinants of the distribution of Striped Marlin (*Kajikia audax*) in the western and central North Pacific Ocean. Environ. Biol. Fish., 97, 267–276.

Piner, K., Lee, H.H., Kimoto, A., Taylor, I.G., Kanaiwa, M., Sun, C.L. (2013) Population dynamics and status of striped marlin (*Kajikia audax*) in the western and central northern Pacific Ocean. Mar. Freshw. Res., 64, 108-118.

Su, N.J., Sun, C.L., Punt, A.E., Yeh, S.Z., DiNardo, G., Chang, Y.J. (2013) An ensemble analysis to predict future habitats of striped marlin (Kajikia audax) in the North Pacific Ocean. ICES J. Mar. Sci., 70(5), 1013–1022.

Yokawa, K. 2005. Standardizations of CPUE of striped marlin caught by Japanese coastal longliners in the northwest Pacific. ISC/05/MARWG/04. 8p.

Yokawa, K. 2006. Updates of standardized CPUE of swordfish caught by Japanese offshore and distant longliners in the North Pacific. ISC/06/MARWG&SWOWG-1/10. 9p.

Yokawa, K. 2004. Preliminary results of a study on the effect of gear configuration in CPUE standardization by GLM methods, Col. Vol. Sci. Pap. ICCAT, 56(1): 178-194.

Table 1 Annual nominal CPUE, standardized CPUE and SE (unit: indiv./1000hook)

Year	Nominal CPUE	Standardized CPUE	SE of standardized CPUE
1994	0.248	0.121	0.057
1995	0.470	0.219	0.057
1996	0.426	0.156	0.061
1997	0.249	0.140	0.058
1998	0.462	0.189	0.058
1999	0.353	0.111	0.057
2000	0.260	0.096	0.056
2001	0.465	0.151	0.056
2002	0.274	0.109	0.059
2003	0.229	0.065	0.071
2004	0.288	0.102	0.056
2005	0.227	0.081	0.059
2006	0.175	0.052	0.069
2007	0.186	0.069	0.060
2008	0.040	0.033	0.511
2009	0.216	0.051	0.123
2010	0.163	0.050	0.093
2011	0.249	0.071	0.067
2012	0.238	0.073	0.073
2013	0.234	0.071	0.057

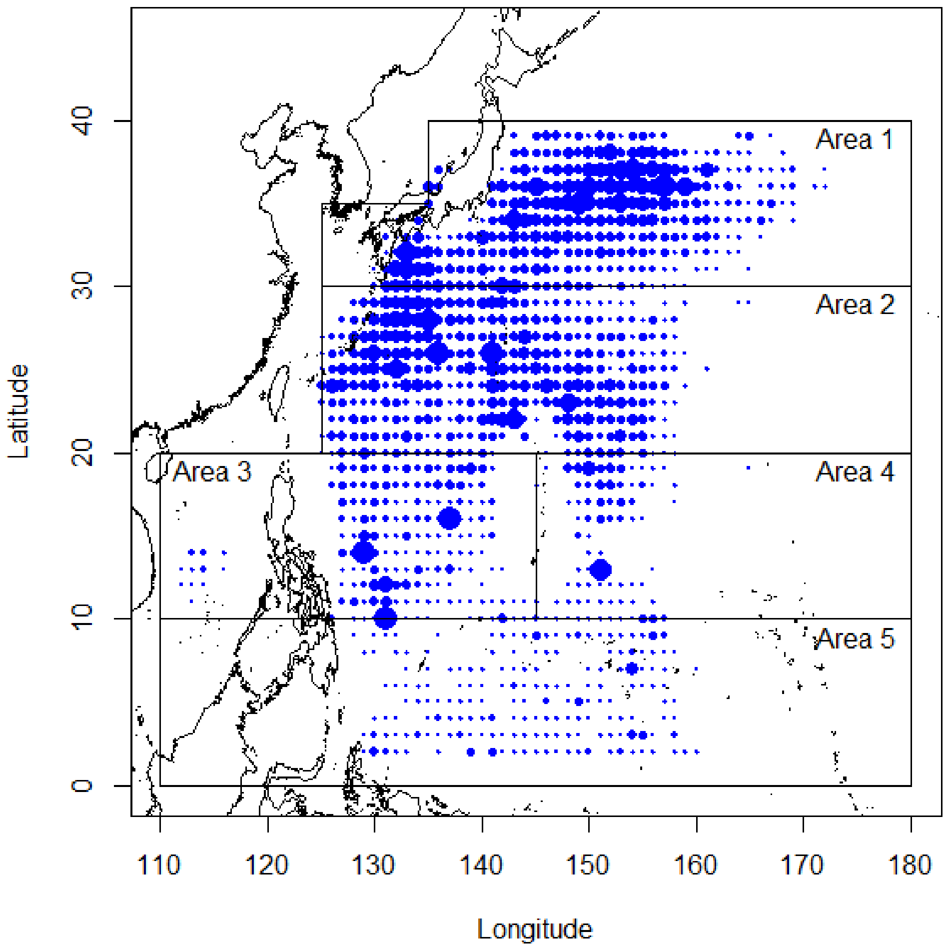


Fig. 1. Bubble plot of the nominal CPUE of striped marlin caught by Japanese coastal longline fishery from 1994 to 2013. CPUEs overlaid on the subarea stratification used in CPUE analysis of this study.

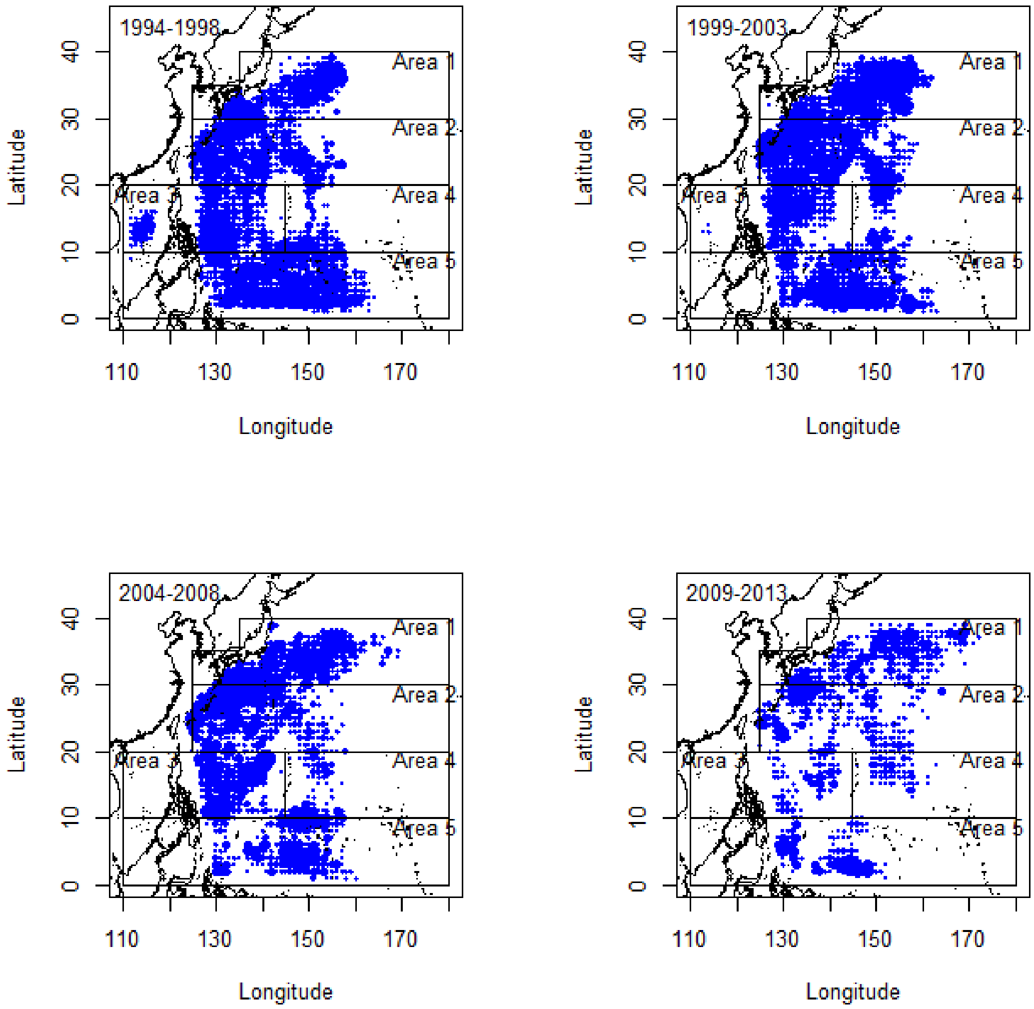


Fig. 2. Bubble plot of the nominal CPUE of striped marlin from 1994 to 1998 (left-top), from 1999-2004 (right-top), 2005-2008 (left-bottom), 2009-2013 (right-bottom).

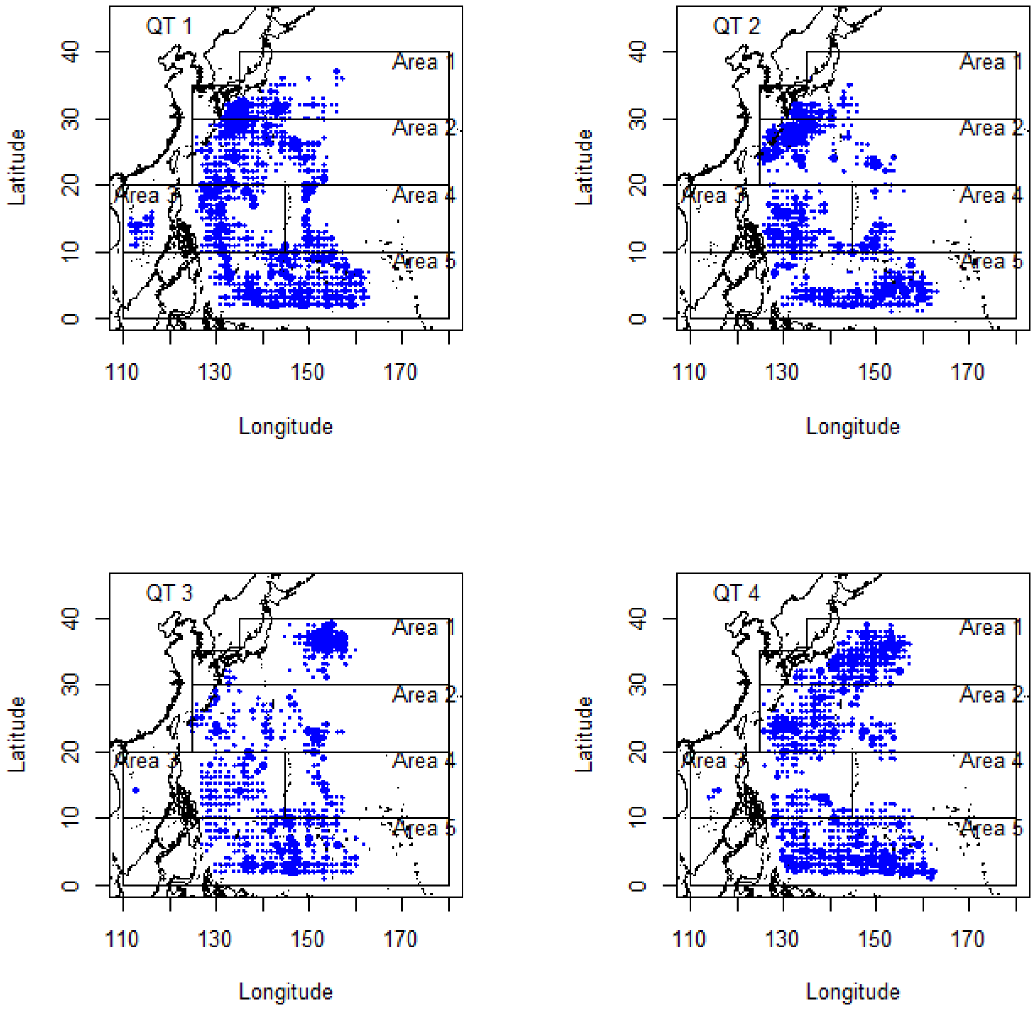


Fig. 3. Quarterly bubble plot of the nominal CPUE of striped marlin from 1994 to 1998.

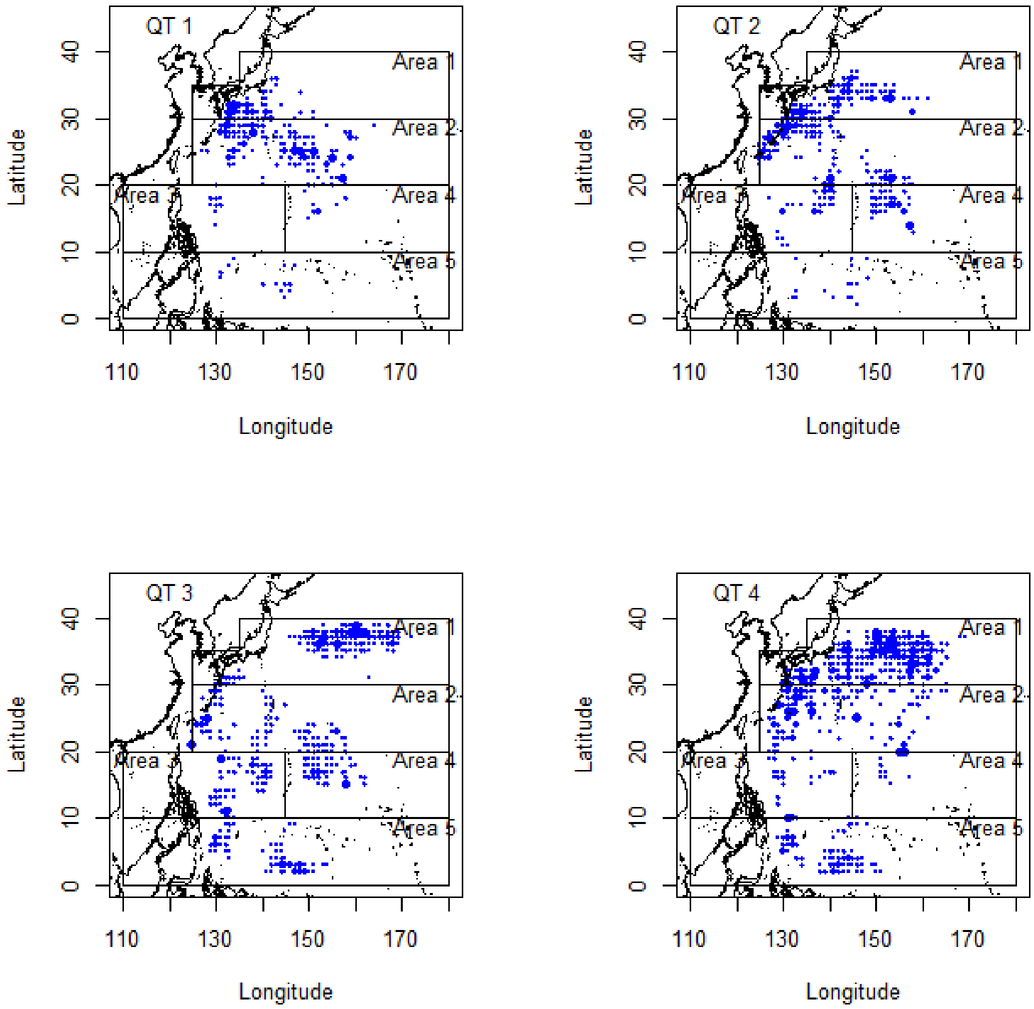


Fig. 4. Quarterly bubble plot of the nominal CPUE of striped marlin from 2008 to 2013.

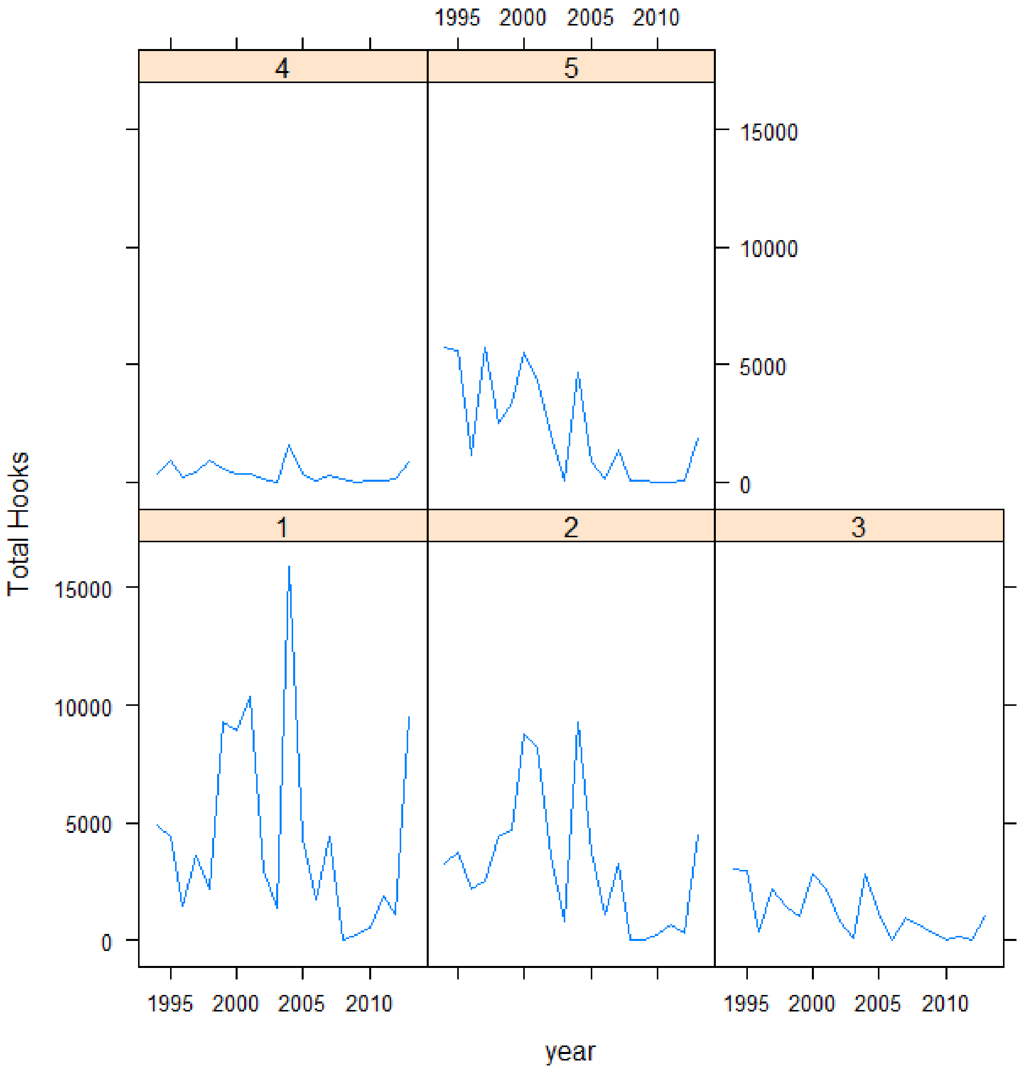


Fig. 5. Amount of effort by area of Japanese coastal longliners in the period between 1994 and 2013.

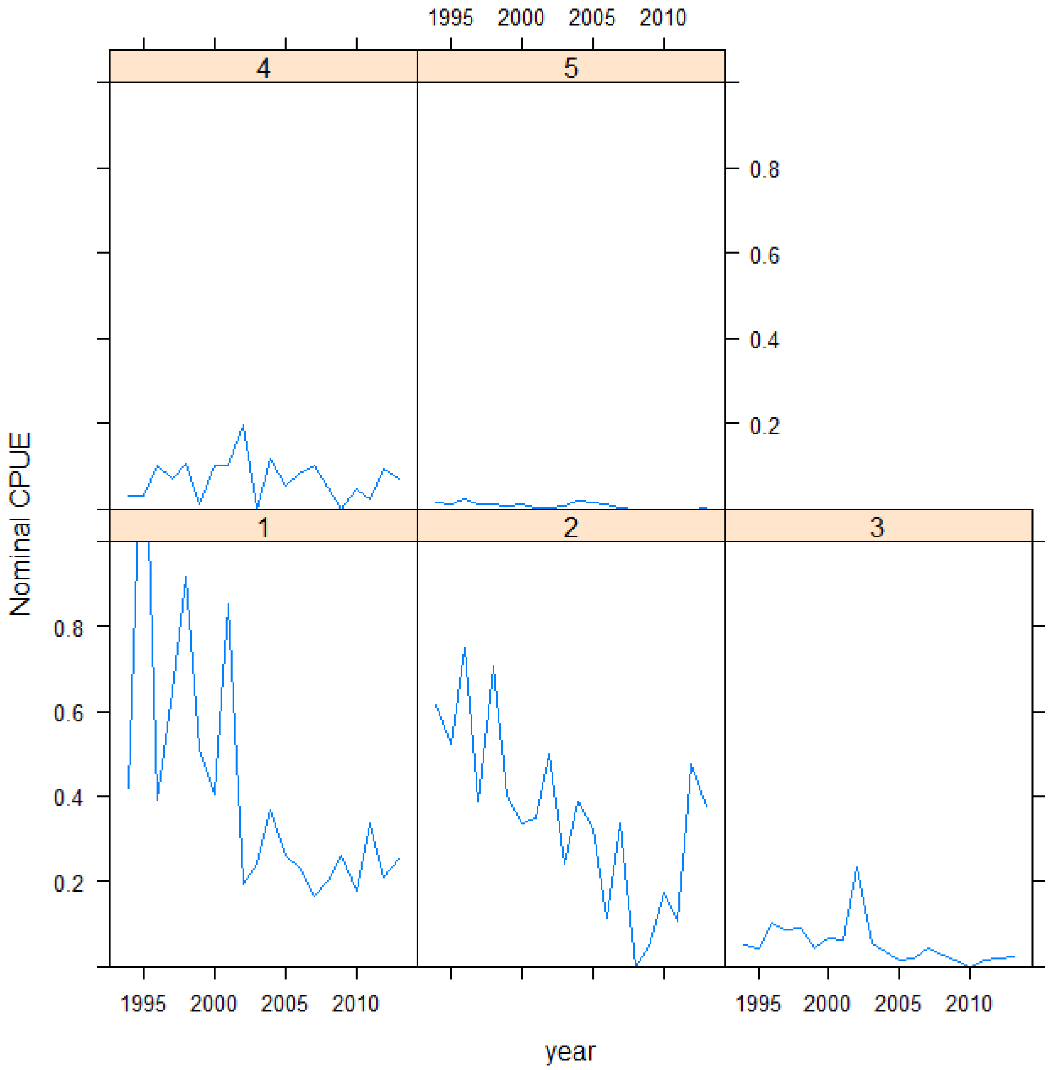


Fig. 6. Area specific nominal CPUEs of striped marlin caught by Japanese coastal longliners in the period between 1994 and 2013.Area 毎の nominal CPUE

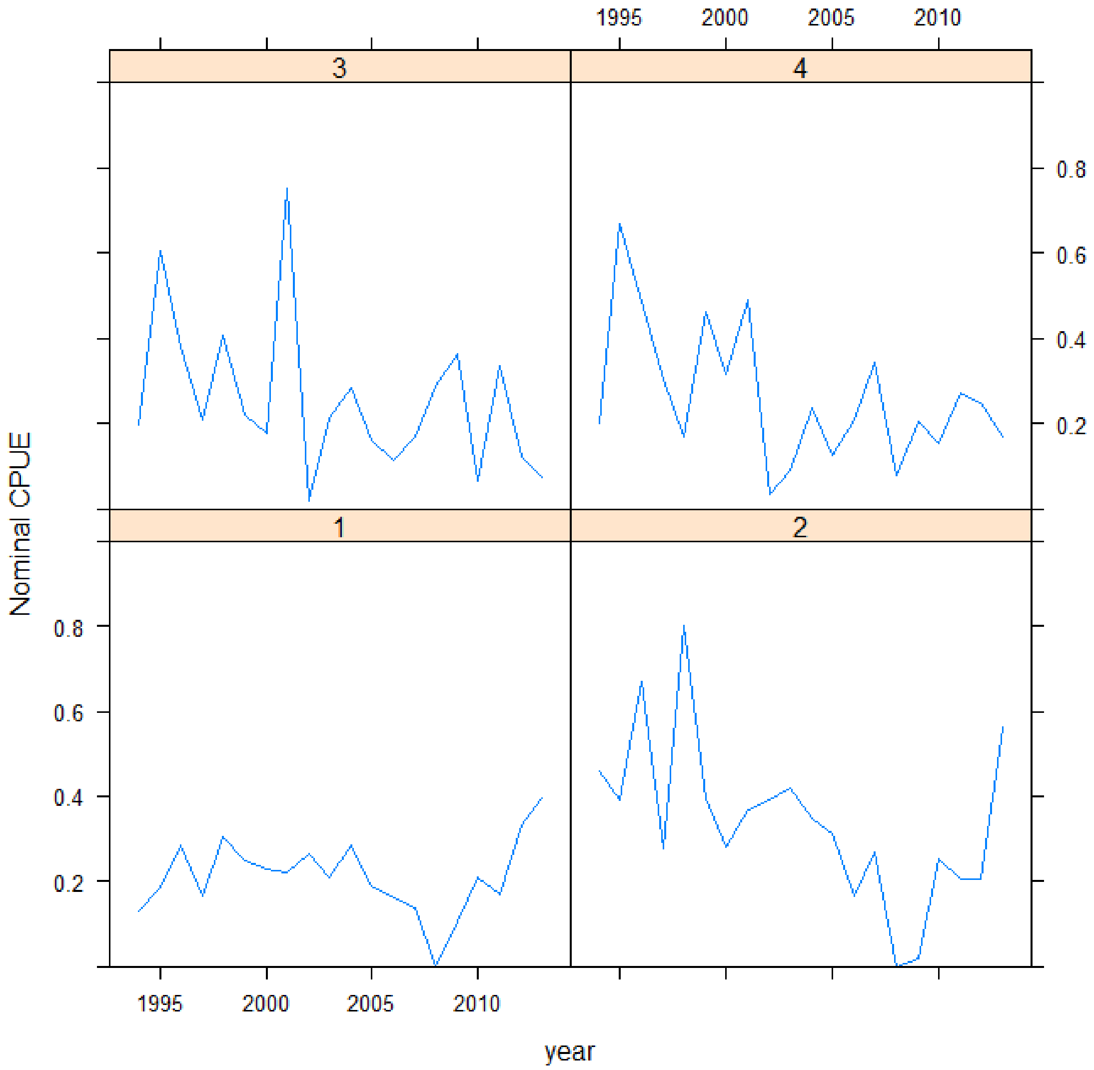


Fig. 7. Quarter specific nominal CPUE of striped marlin caught by Japanese coastal longliners in the period between 1994 and 2013.Qt 毎の nominal CPUE

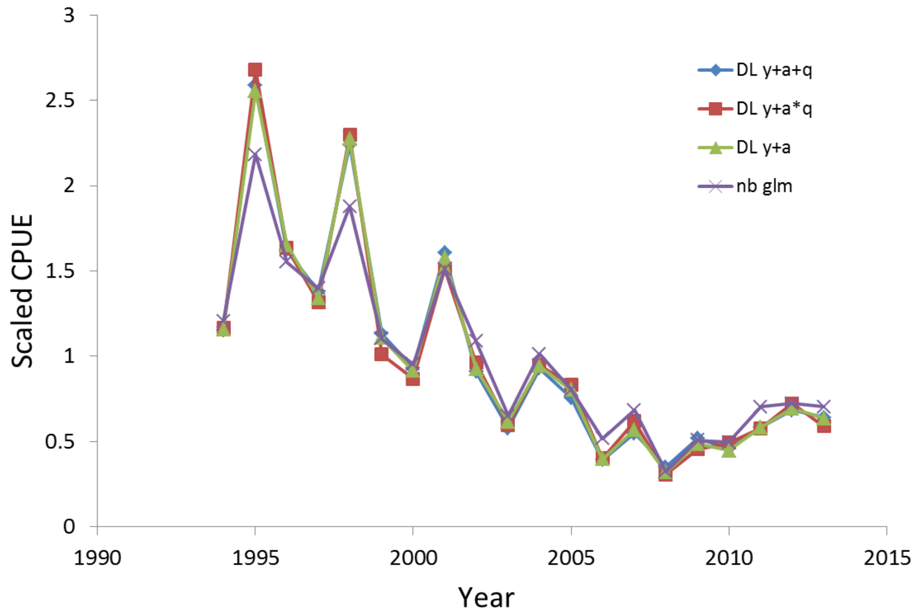


Fig. 8. CPUEs standardized by four different models of striped marlin caught by Japanese coastal longliners in the northwest Pacific in the period between 1994 and 2013.

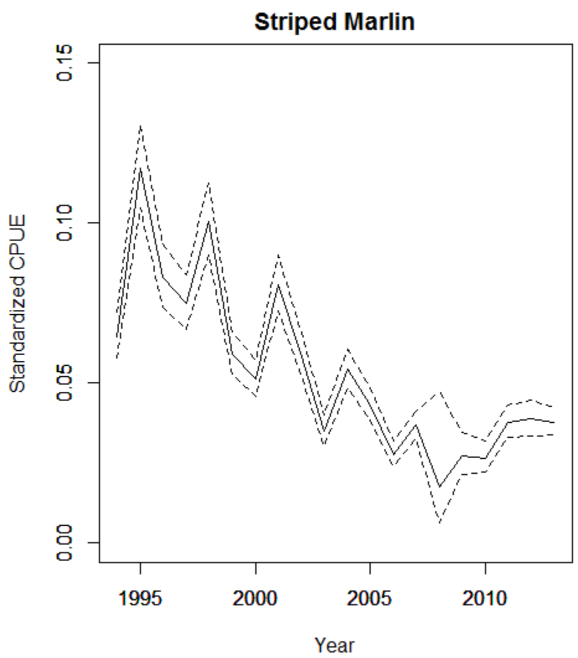
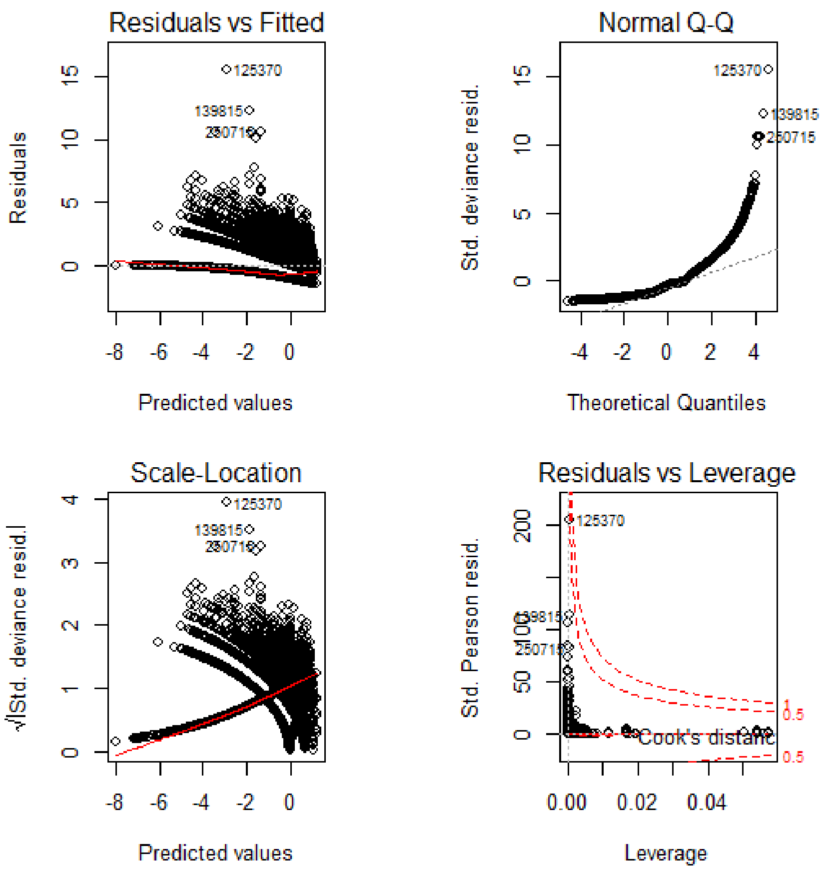
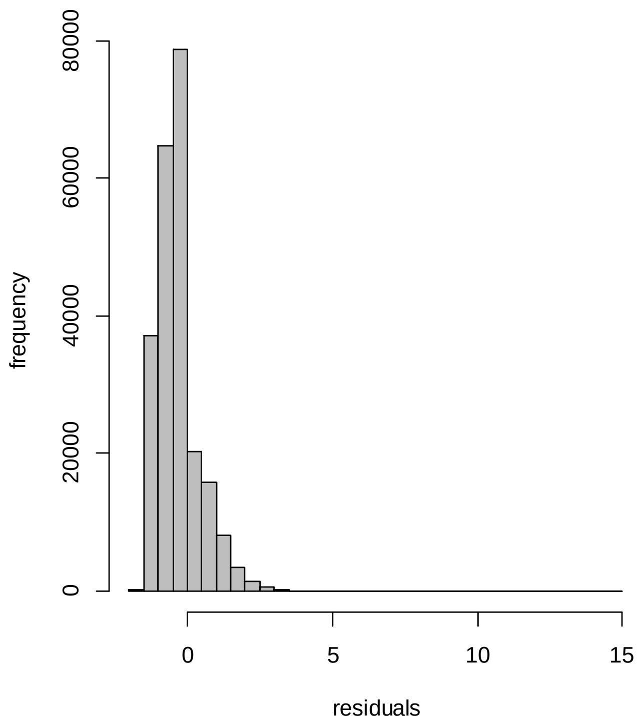


Fig. 9 Standardized CPUE (solid line) of negative binomial GLM with 95% confidence intervals (broken lines)

Appendix-1 GLM with negative binomial errors



Appendix Fig. 1 Diagnostic of the GLM analysis for CPUE standardization of striped marlin during 1994 to 2013 (GLM+negative binomial errors)



Appendix Fig.2 Histogram of residuals of negative binomial GLM

Appendix Table 1 Summary of results negative binomial GLM

Call:

glm.nb(formula = mak_n ~ as.factor(yer) + as.factor(f_hpb) +
    as.factor(qt) + as.factor(area) + as.factor(area) * as.factor(f_hpb) +
    as.factor(area) * as.factor(qt) + offset(log(thk)), data = data3,
    init.theta = 0.5903807947, link = log)

Deviance Residuals:

Min	1Q	Median	3Q	Max
-1.4953	-0.8851	-0.3470	-0.1248	15.5113

Coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-8.38229	0.03541	-236.693	< 2e-16	***
as.factor(yer)1995	0.59389	0.02433	24.411	< 2e-16	***

as.factor(yer)1996	0.25260	0.03220	7.844	4.37e-15	***
as.factor(yer)1997	0.14720	0.02744	5.364	8.12e-08	***
as.factor(yer)1998	0.44284	0.02644	16.749	< 2e-16	***
as.factor(yer)1999	-0.08888	0.02368	-3.753	0.000175	***
as.factor(yer)2000	-0.23488	0.02289	-10.261	< 2e-16	***
as.factor(yer)2001	0.22365	0.02213	10.107	< 2e-16	***
as.factor(yer)2002	-0.10186	0.02895	-3.519	0.000434	***
as.factor(yer)2003	-0.61707	0.04831	-12.774	< 2e-16	***
as.factor(yer)2004	-0.17505	0.02164	-8.089	6.02e-16	***
as.factor(yer)2005	-0.40391	0.02842	-14.212	< 2e-16	***
as.factor(yer)2006	-0.84684	0.04599	-18.414	< 2e-16	***
as.factor(yer)2007	-0.56489	0.02986	-18.919	< 2e-16	***
as.factor(yer)2008	-1.31225	0.50803	-2.583	0.009794	**
as.factor(yer)2009	-0.86404	0.11151	-7.749	9.30e-15	***
as.factor(yer)2010	-0.89006	0.07762	-11.466	< 2e-16	***
as.factor(yer)2011	-0.53748	0.04286	-12.541	< 2e-16	***
as.factor(yer)2012	-0.51209	0.05140	-9.963	< 2e-16	***
as.factor(yer)2013	-0.53765	0.02476	-21.712	< 2e-16	***
as.factor(f_hpb)2	0.02899	0.03147	0.921	0.357079	
as.factor(f_hpb)3	0.11862	0.02964	4.002	6.28e-05	***
as.factor(f_hpb)4	0.13200	0.03013	4.381	1.18e-05	***
as.factor(qt)2	0.67816	0.02139	31.702	< 2e-16	***
as.factor(qt)3	0.84417	0.01975	42.742	< 2e-16	***
as.factor(qt)4	0.84439	0.01850	45.652	< 2e-16	***
as.factor(area)2	0.66369	0.04389	15.122	< 2e-16	***
as.factor(area)3	-0.61518	0.13197	-4.661	3.14e-06	***
as.factor(area)4	-0.48014	0.26197	-1.833	0.066835	.
as.factor(area)5	-5.02930	1.00333	-5.013	5.37e-07	***
as.factor(f_hpb)2:as.factor(area)2	-0.09352	0.04464	-2.095	0.036160	*
as.factor(f_hpb)3:as.factor(area)2	-0.14061	0.04256	-3.303	0.000955	***
as.factor(f_hpb)4:as.factor(area)2	-0.11178	0.04397	-2.542	0.011009	*
as.factor(f_hpb)2:as.factor(area)3	0.11190	0.14492	0.772	0.440057	
as.factor(f_hpb)3:as.factor(area)3	-0.24763	0.13712	-1.806	0.070931	.
as.factor(f_hpb)4:as.factor(area)3	-0.69822	0.13390	-5.215	1.84e-07	***
as.factor(f_hpb)2:as.factor(area)4	1.08397	0.28475	3.807	0.000141	***

as.factor(f_hpb)3:as.factor(area)4	0.75553	0.26280	2.875	0.004041	**
as.factor(f_hpb)4:as.factor(area)4	-0.12741	0.26270	-0.485	0.627679	
as.factor(f_hpb)2:as.factor(area)5	2.15593	1.02360	2.106	0.035185	*
as.factor(f_hpb)3:as.factor(area)5	2.15075	1.00606	2.138	0.032533	*
as.factor(f_hpb)4:as.factor(area)5	2.26522	1.00310	2.258	0.023932	*
as.factor(qt)2:as.factor(area)2	-0.17187	0.02667	-6.443	1.17e-10	***
as.factor(qt)3:as.factor(area)2	-2.21336	0.04230	-52.331	< 2e-16	***
as.factor(qt)4:as.factor(area)2	-2.01059	0.03091	-65.053	< 2e-16	***
as.factor(qt)2:as.factor(area)3	-1.13288	0.05464	-20.732	< 2e-16	***
as.factor(qt)3:as.factor(area)3	-2.46890	0.08864	-27.855	< 2e-16	***
as.factor(qt)4:as.factor(area)3	-2.11274	0.09621	-21.960	< 2e-16	***
as.factor(qt)2:as.factor(area)4	-1.91576	0.07961	-24.063	< 2e-16	***
as.factor(qt)3:as.factor(area)4	-3.54688	0.12825	-27.655	< 2e-16	***
as.factor(qt)4:as.factor(area)4	-3.19633	0.16638	-19.210	< 2e-16	***
as.factor(qt)2:as.factor(area)5	-1.26707	0.08922	-14.201	< 2e-16	***
as.factor(qt)3:as.factor(area)5	-1.83228	0.10273	-17.836	< 2e-16	***
as.factor(qt)4:as.factor(area)5	-1.92258	0.09457	-20.330	< 2e-16	***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for Negative Binomial(0.5904) family taken to be 1)

Null deviance: 213784 on 230930 degrees of freedom

Residual deviance: 142649 on 230877 degrees of freedom

AIC: 388709

Number of Fisher Scoring iterations: 1

Theta: 0.59038

Std. Err.: 0.00508

2 x log-likelihood: -388598.72600

Appendix table 2 Analysis deviance table of negative binomial GLM

Model: Negative Binomial(0.6274), link: log

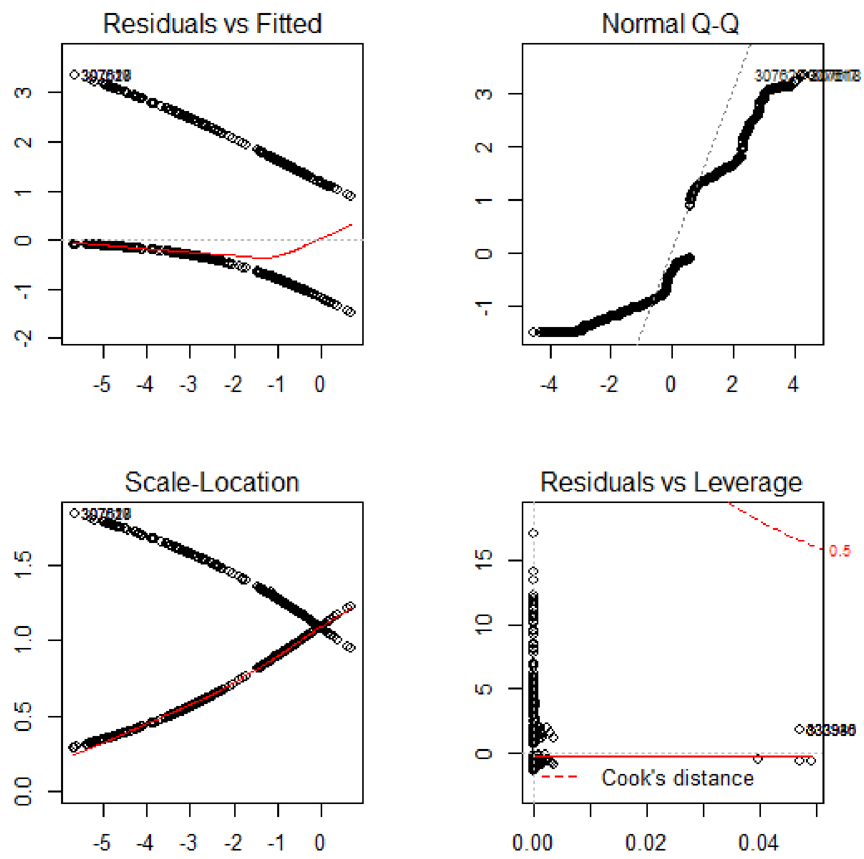
Response: mak_n

Terms added sequentially (first to last)

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)	
NULL			230930	219033		
as.factor(yer)	19	6007	230911	213026	< 2.2e-16	***
as.factor(f_hpb)	3	4702	230908	208324	< 2.2e-16	***
as.factor(qt)	3	2037	230905	206287	< 2.2e-16	***
as.factor(area)	4	50174	230901	156114	< 2.2e-16	***
as.factor(yer):as.factor(area)	71	5779	230830	150334	< 2.2e-16	***
as.factor(f_hpb):as.factor(area)	12	378	230818	149956	< 2.2e-16	***
as.factor(qt):as.factor(area)	12	7191	230806	142765	< 2.2e-16	***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

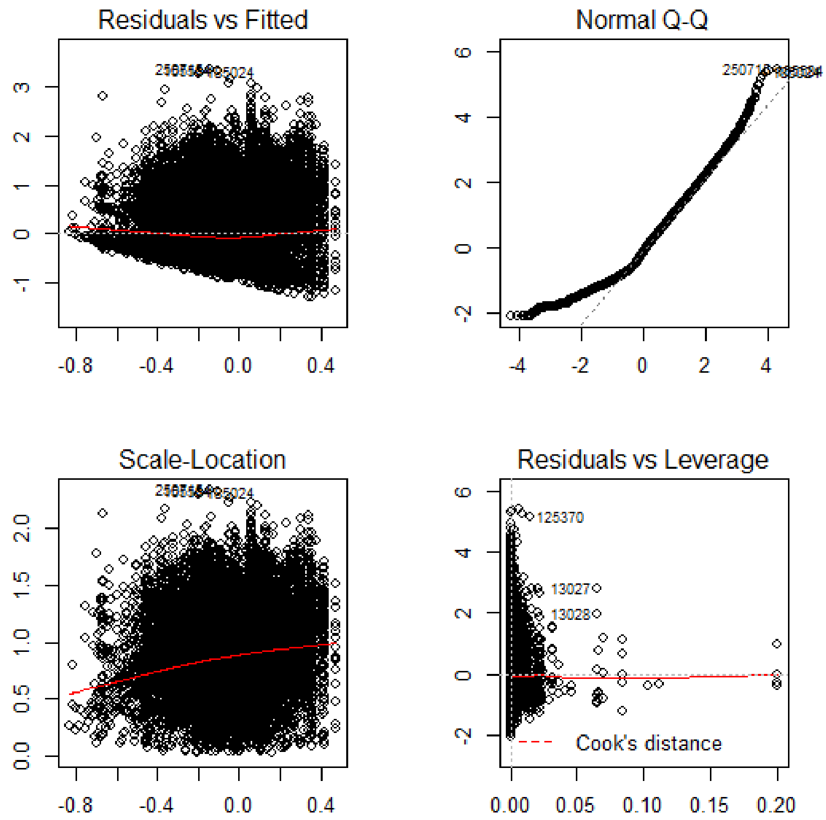
Appendix-2 Delta log-normal model



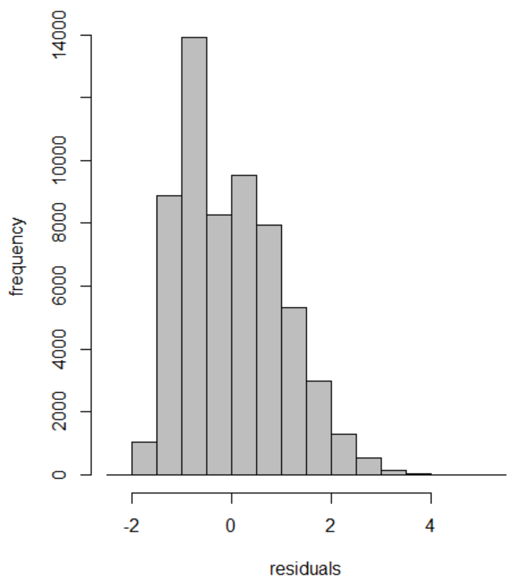
Appendix Fig. 3 Diagnostic of the GLM analysis for binomial part of striped marlin during 1994 to 2013

```
glm(formula = bin ~ as.factor(yer) + as.factor(qt) + as.factor(area),
    family = binomial, data = data4)

Deviance Residuals:
    Min        1Q    Median        3Q       Max
-1.4966   -0.9258   -0.3483    1.1244    3.3702

Coefficients:
                      Estimate Std. Error z value Pr(>|z|)
(Intercept)          -0.38823    0.02641 -14.702  < 2e-16 ***
as.factor(yer)1995    0.51420    0.03167  16.236  < 2e-16 ***
as.factor(yer)1996    0.19550    0.04086   4.785 1.71e-06 ***
```

```
as.factor(yer)1997 -0.02877    0.03491   -0.824   0.40983
as.factor(yer)1998  0.42445    0.03453   12.293   < 2e-16 ***
as.factor(yer)1999 -0.06656    0.02955   -2.253   0.02427 *
as.factor(yer)2000 -0.18981    0.02830   -6.706 2.00e-11 ***
as.factor(yer)2001  0.20119    0.02787    7.219 5.24e-13 ***
as.factor(yer)2002 -0.27695    0.03765   -7.356 1.90e-13 ***
as.factor(yer)2003 -0.60127    0.05663 -10.617   < 2e-16 ***
as.factor(yer)2004 -0.20907    0.02763   -7.567 3.81e-14 ***
as.factor(yer)2005 -0.33884    0.03611   -9.385   < 2e-16 ***
as.factor(yer)2006 -0.99344    0.05394 -18.416   < 2e-16 ***
as.factor(yer)2007 -0.63130    0.03671 -17.199   < 2e-16 ***
as.factor(yer)2008 -0.72869    0.50810   -1.434   0.15153
as.factor(yer)2009 -0.51762    0.12467   -4.152 3.30e-05 ***
as.factor(yer)2010 -0.58768    0.08678   -6.772 1.27e-11 ***
as.factor(yer)2011 -0.59360    0.05469 -10.853   < 2e-16 ***
as.factor(yer)2012 -0.34825    0.06490   -5.366 8.06e-08 ***
as.factor(yer)2013 -0.48036    0.03074 -15.628   < 2e-16 ***
as.factor(qt)2      0.59895    0.01572   38.112   < 2e-16 ***
as.factor(qt)3     -0.02826    0.01882   -1.502   0.13313
as.factor(qt)4      0.05460    0.01685    3.240   0.00119 **
as.factor(area)2   -0.38849    0.01277 -30.421   < 2e-16 ***
as.factor(area)3   -2.50224    0.03225 -77.579   < 2e-16 ***
as.factor(area)4   -2.43449    0.05247 -46.400   < 2e-16 ***
as.factor(area)5   -4.29418    0.05213 -82.379   < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 223368  on 189449  degrees of freedom
Residual deviance: 187611  on 189423  degrees of freedom
AIC: 187665
```



Appendix Fig. 4 Diagnostic of the GLM analysis for standardization of CPUE of positive catch of striped marlin during 1994 to 2013



Appendix Fig. 5 Histogram of residuals of delta log-normal GLM

Appendix table 4 Summary of results of delta log-normal GLM

```
Call:
glm(formula = lcpue ~ as.factor(yer) + as.factor(f_hpb) + as.factor(qt) +
    as.factor(area) + as.factor(area) * as.factor(f_hpb) + as.factor(area) *
    as.factor(qt), family = gaussian, data = data3[data3$mak_n >
    0, ])

Deviance Residuals:
    Min       1Q    Median       3Q      Max
-1.2967  -0.5091  -0.0744   0.4202   3.3643

Coefficients:
                                     Estimate Std. Error t value Pr(>|t|)
(Intercept)                         -0.228344   0.020795 -10.981  < 2e-16 ***
as.factor(yer)1995                   0.362062   0.013827  26.185  < 2e-16 ***
as.factor(yer)1996                   0.167797   0.018414   9.113  < 2e-16 ***
as.factor(yer)1997                   0.205740   0.016043  12.824  < 2e-16 ***
as.factor(yer)1998                   0.293820   0.015033  19.545  < 2e-16 ***
as.factor(yer)1999                   0.041423   0.013457   3.078  0.00208 **
as.factor(yer)2000                  -0.041083   0.013031  -3.153  0.00162 **
```

as.factor(yer)2001	0.153100	0.012540	12.208	< 2e-16	***
as.factor(yer)2002	0.015967	0.016808	0.950	0.34215	
as.factor(yer)2003	-0.136345	0.027504	-4.957	7.17e-07	***
as.factor(yer)2004	-0.026038	0.012420	-2.096	0.03604	*
as.factor(yer)2005	-0.110857	0.016308	-6.798	1.07e-11	***
as.factor(yer)2006	-0.154204	0.027584	-5.590	2.27e-08	***
as.factor(yer)2007	-0.160172	0.017090	-9.372	< 2e-16	***
as.factor(yer)2008	-0.514559	0.276195	-1.863	0.06246	.
as.factor(yer)2009	-0.326191	0.064564	-5.052	4.38e-07	***
as.factor(yer)2010	-0.373115	0.045097	-8.274	< 2e-16	***
as.factor(yer)2011	-0.136462	0.025596	-5.331	9.78e-08	***
as.factor(yer)2012	-0.204619	0.030278	-6.758	1.41e-11	***
as.factor(yer)2013	-0.146136	0.014352	-10.182	< 2e-16	***
as.factor(f_hpb)2	0.008265	0.018088	0.457	0.64772	
as.factor(f_hpb)3	-0.072993	0.016998	-4.294	1.76e-05	***
as.factor(f_hpb)4	-0.116147	0.017296	-6.715	1.89e-11	***
as.factor(qt)2	0.177710	0.012484	14.234	< 2e-16	***
as.factor(qt)3	0.279546	0.011532	24.241	< 2e-16	***
as.factor(qt)4	0.239150	0.010835	22.071	< 2e-16	***
as.factor(area)2	0.177211	0.024919	7.112	1.16e-12	***
as.factor(area)3	0.035538	0.079716	0.446	0.65574	
as.factor(area)4	-0.017208	0.179727	-0.096	0.92372	
as.factor(area)5	-0.333405	0.617304	-0.540	0.58913	
as.factor(f_hpb)2:as.factor(area)2	-0.065158	0.025257	-2.580	0.00989	**
as.factor(f_hpb)3:as.factor(area)2	-0.048403	0.024059	-2.012	0.04424	*
as.factor(f_hpb)4:as.factor(area)2	-0.020408	0.024865	-0.821	0.41178	
as.factor(f_hpb)2:as.factor(area)3	0.023165	0.091460	0.253	0.80006	
as.factor(f_hpb)3:as.factor(area)3	-0.098632	0.085426	-1.155	0.24826	
as.factor(f_hpb)4:as.factor(area)3	-0.089792	0.082544	-1.088	0.27668	
as.factor(f_hpb)2:as.factor(area)4	0.328865	0.200663	1.639	0.10124	
as.factor(f_hpb)3:as.factor(area)4	0.162501	0.183327	0.886	0.37540	
as.factor(f_hpb)4:as.factor(area)4	0.011112	0.184185	0.060	0.95189	
as.factor(f_hpb)2:as.factor(area)5	0.216472	0.637462	0.340	0.73417	
as.factor(f_hpb)3:as.factor(area)5	-0.044612	0.620729	-0.072	0.94271	
as.factor(f_hpb)4:as.factor(area)5	0.036906	0.618412	0.060	0.95241	

as.factor(qt)2:as.factor(area)2	-0.010936	0.015323	-0.714	0.47541	
as.factor(qt)3:as.factor(area)2	-0.192006	0.032200	-5.963	2.49e-09	***
as.factor(qt)4:as.factor(area)2	-0.367928	0.019227	-19.136	< 2e-16	***
as.factor(qt)2:as.factor(area)3	-0.198739	0.038373	-5.179	2.24e-07	***
as.factor(qt)3:as.factor(area)3	-0.161446	0.076147	-2.120	0.03399	*
as.factor(qt)4:as.factor(area)3	-0.291331	0.063493	-4.588	4.48e-06	***
as.factor(qt)2:as.factor(area)4	-0.323542	0.059820	-5.409	6.38e-08	***
as.factor(qt)3:as.factor(area)4	-0.598464	0.094407	-6.339	2.33e-10	***
as.factor(qt)4:as.factor(area)4	-0.536323	0.114308	-4.692	2.71e-06	***
as.factor(qt)2:as.factor(area)5	-0.101850	0.066019	-1.543	0.12290	
as.factor(qt)3:as.factor(area)5	-0.148489	0.078509	-1.891	0.05858	.
as.factor(qt)4:as.factor(area)5	-0.269931	0.066682	-4.048	5.17e-05	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 0.3807013)

Null deviance: 25193 on 59941 degrees of freedom
Residual deviance: 22799 on 59888 degrees of freedom
AIC: 112276

Number of Fisher Scoring iterations: 2

Appendix table 5 Analysis deviance table of delta log-normal GLM
Model: gaussian, link: identity

Response: lcpue

Terms added sequentially (first to last)

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)	
NULL			59941	25193		
as.factor(yer)	19	1486.18	59922	23707	< 2.2e-16	***
as.factor(f_hpb)	3	165.46	59919	23541	< 2.2e-16	***

as.factor(qt)	3	301.91	59916	23239	< 2.2e-16 ***
as.factor(area)	4	218.96	59912	23020	< 2.2e-16 ***
as.factor(f_hpb):as.factor(area)	12	13.69	59900	23007	0.0003297 ***
as.factor(qt):as.factor(area)	12	207.09	59888	22799	< 2.2e-16 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' '