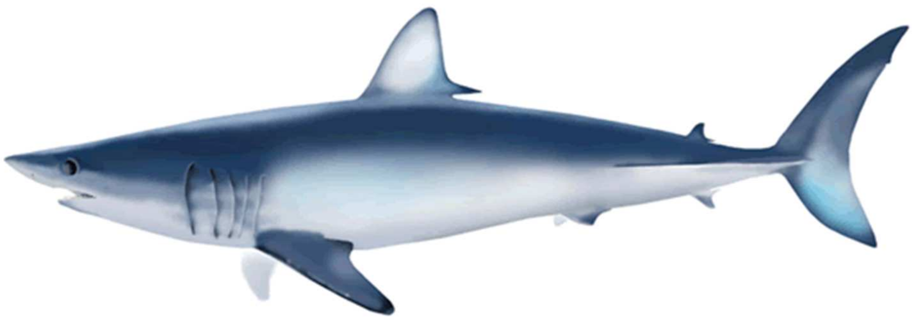
ISC/21/SHARKWG-1/04

Updated CPUE of shortfin mako, *Isurus oxyrinchus*, caught by Japanese shallow-set longliner in the northwestern Pacific from 1994 to 2019[1]

Mikihiko Kai[2]

[2] Fisheries Resources Institute, Japan Fishery Research and Education Agency
5-7-1 Orido, Shimizu-ku, Shizuoka 424-8633, JAPAN
Email: kaim@affrc.go.jp



[1] Working document submitted to the ISC Shark Working Group Workshop, 22-26 February 2021, Web-meeting. **Document not to be cited without author's permission.**

Abstract

This working paper provides with an updated standardized CPUE of shortfin mako caught by Japanese offshore and distant-water shallow-set longline fishery from 1994 to 2019 in the northwestern Pacific. The author basically used the same estimation methods used in the previous analysis. Two filtering methods were used to remove the mis-reporting and inappropriate data. Since the zero-inflated negative binomial model had an issue of model convergence, negative binomial model with the same explanatory variables as used in the previous analysis was used as the best model to standardize the CPUE for the filtered data. The annual standardized CPUE indicated that the historical population trend of shortfin mako had gradually increased until 2011, and then a stable trend was observed except in 2016. The author considered that (1) the increase trends until 2004 was caused by the gradual increase of catch number with a slight increase of fishing effort, (2) the steep increase from 2004 to 2011 was mainly caused by the continuous decrease of the fishing effort with stable annual catches, and (3) the stable trends in recent years were caused by the constant catch and fishing efforts.

Introduction

In 2019, the ISC SHARK-WG determined to change the cycle of benchmark stock assessment for blue shark, *Prionace glauca*, and shortfin mako, *Isurus oxyrinchus*, in the North Pacific Ocean from 3 to 5 years, and approved by ISC Plenary (ISC, 2019). As a condition of the extension of the assessment period, the ISC Plenary requested to do the update assessment between the benchmark assessments. In response to the request, the ISC SHARK-WG conducted future projection after updating the recent annual catch of blue shark (ISC, 2020). However, ISC Plenary expected that an update assessment should be consisted of updated catch, CPUE, and size composition data inputs in the existing assessment model structure, assumptions and parameterization to run the model and projections and generate new advice. The ISC Plenary (ISC, 2020) therefore concluded that these results should be treated as a sensitivity analysis and are not suitable for changing stock status and conservation information from the benchmark assessment in the past. After taking due discussions, the ISC Plenary (ISC, 2020) finally requested that the SHRAK-WG (1) conduct an indicator analysis for shortfin mako and report the results at the ISC 21 Plenary, and (2) provide recommendations on whether a new assessment should occur prior to the scheduled benchmark assessment.

In the previous stock assessment in 2018, the author presented standardized CPUE of shortfin mako caught by Japanese distant-water and offshore shallow-set longline fishery in the northwestern Pacific from 1994 to 2016 (Kai, 2017). The index was initially considered as a high priority for the full stock assessment (ISC, 2018) in considering with the statistical soundness, long timespan, extensive spatial coverage, and relatively high catch rates. However, further explorations showed that the steep increasing trend of this index was inconsistent with all the other indices available, as well as biologically implausible given the current understanding of shortfin mako's population dynamics. Consequently, the SHARK-WG determined not to include this index in the base case model.

The objective of this working document paper is to update standardized CPUE of shortfin mako caught by Japanese offshore and distant-water shallow-set longline fishery until 2019. The standardized CPUE could be useful not only to understand the recent trends in the population of shortfin mako in the northwestern Pacific Ocean, but also to estimate the annual catch.

Materials and Methods

The author used the same materials and methods used in the previous analysis in 2017 (Kai, 2017) except for the updated data from 2017 to 2019.

Data sources

Set-by-set logbook data from Japanese offshore and distant water longline fishery were used to estimate the standardized CPUE over the period 1994-2019. Set-by-set data used in this study included information on catch number, amount of effort (number of hooks), number of branch lines between floats (hooks per basket: HPB) as a proxy for gear configuration, location (longitude and latitude) of set by resolution of 1 × 1 degree square, vessel identity, fishery type (offshore or distant water), and the prefecture in Japan where the longline boats were registered. The offshore-water fleet was defined by tonnage of vessels between 20 and 120 MT, while the distant-water fleet consisted of vessels larger than 120 MT.

Data filtering

Filtering was used for the logbook data to remove the discard and under-reporting data. The vessels were selected by the size (20~150 vessel tonnage) and the registered prefectures ("Tohoku and Hokkaido") because these fisheries frequently target blue shark, while shortfin mako is frequently caught as bycatch but landed. The data was also chosen by the number of hooks per baskets (HPB; 3~5) to select a shallow-set fishery. In addition, two additional filtering methods were used to remove the data of cruise which had apparently discarded or under-reporting the shortfin mako. Filtering (I): the vessels which have similar trends of CPUE to those estimated from the longline research vessel by Ohshimo *et al*. (2016) were selected. In the filtering (I), the delta lognormal model was used to estimate the CPUEs for different combinations of commercial fleets. Same dataset regarding the period (April to June for 2000, 2002-2013), area (25-40° N, 140-150° E), and depth (3-5 HPB) was used to compare the CPUE from the research data (Oshimo *et al*. 2014). Filtering (II): The data of 19 vessels were selected from 28 vessels based on the visual observation of CPUE pattern of each set of shortfin mako in the past. The details of the filtering methods are described in Kai *et al*. (2015). The same datasets regarding the logline vessels were chosen for the filtering (I) and (II) to maintain the consistency with the previous analysis.

CPUE standardization

Standardized CPUE was estimated using the generalized linear model (GLM) with the filtered logbook data from 1994 to 2019. Since the zero-inflated negative binomial model (Zuur et al. 2009) had an issue of model convergence, the negative binomial model (NB) and zero-inflated Poison model (ZIP) were used to update the standardized CPUE. The same model structure (i.e., a combination of explanatory variable) as that used in the previous analysis (Kai, 2016) was used:

$$\text{Log (Catch)} = \text{Intercept} + \alpha_1\text{Year} + \alpha_2\text{Quarter} + \alpha_3\text{Area} + \alpha_4\text{Fishery} + \alpha_5\text{ Quarter} * \text{Area} + \text{offset (log (hook)), Catch} \sim \text{NB}, \quad (1)$$

“Catch” is a captured number of shortfin mako, “Effort” is number of hooks (×1000) given as an offset term, αi is coefficient of each explanatory variable, “Year” is year effect (signify 1994 –2019), “Quarter” is seasonal effect (signify Q1:Jan-Mar, Q2:Apr-Jun, Q3:Jul-Sep, and Q4:Oct- Dec), “Area” is an area effect (signify Area 1–4, see at **Fig. 1**), “Fishery type” is two types of fishery effects (signify offshore and distant water fisheries). These explanatory variables are given as categorical variables. The model structure of ZIP is shown in **Table 1**.

Model selection and diagnostics

To select the best model, the explanatory variable was sequentially removed from the full model in Eq (1). The best model was selected using the AIC (Akaike 1973) and BIC (Schwarz, 1978). For the best model, the goodness of fits was examined using the Pearson residuals and QQ-plot. The residuals were computed using a randomized quantile (Dunn and

Smyth, 1996) to produce continuous normal residuals. To evaluate the uncertainties in the estimates of annual CPUE, the 95% confidence interval (CI) was estimated using a bootstrapping method (i.e., randomly resampling of the set-by-set data from the datasets in the same year) with 1000 iterations for the best model.

Results

Effect of data filtering

Data filtering (I) and (II) reduced the number of datasets from 120,080 to 58,555 after the filtering (I) and to 32,448 after the filtering (II). Annual fishing effort, catch number, nominal CPUE, and ratio of positive catch with and without filtering methods were summarized in **Table 2**. Both filtering (I) and (II) reduced the absolute values of fishing effort and catch number, however, the annual trends of nominal CPUE were similar among them (**Table 2** and **Fig. 2**). Nevertheless, two-stage filtering reduced the effect of steep increase in the nominal CPUE in 1990s and 2000s. In addition, the ratio of positive catch in 1990s and 2000s with filtering much increased compared to those without filtering. These results suggested that the two-stage filtering is useful to reduce the effect of discard or under-reporting.

Selection of the best model and annual trends in CPUE

All models were reasonably converged except for ZINB. The NB model was selected as the most parsimonious model based on AIC and BIC (**Table 1**). The frequency distribution of catch number per operation (**Fig. 3**) indicated that the data has a tendency of overdispersion and the ratio of zero catch was lower in more recent years (**Table 2**). These results supported that the NB is reasonable as the best model.

The annual standardized CPUE suggested that the historical population trend of shortfin mako had gradually increased since 1990s until 2011, and then a stable trend was observed except in 2016 (**Table 3** and **Fig. 4**). The 95% CI of the best model showed that the ranges were narrow during 1994 to 2010, and the ranges after 2010 were wider.

Model diagnostics

Histograms of Pearson residuals and the Q-Q plot for the best model didn't show a serious deviation from normality and the boxplots of Pearson residuals showed no significant biases for all the explanatory variables (**Fig. 5**). These results suggested that the fitting of the best model to the data was good.

Discussions

This document paper estimated a historical population trend of shortfin mako in the northwestern Pacific from 1994 to 2019 using GLM with sufficient spatial-temporal fishery data caught by Japanese shallow-set longline fishery. The estimated annual standardized CPUE suggested that the historical population trend of shortfin mako had slightly increased from 1994 to 2004 (1.94 times and corresponding to $r = 0.059$; where r is the intrinsic growth rate of natural increase per year), steeply increased from 2004 to 2011 (2.30 times and corresponding to $r = 0.119$), and then stabled from 2011 to 2019 (1.00 times and corresponding to $r = 0$) except in 2016. The author considered that (1) the increase trends until 2004 was caused by the gradual increase of catch number with a slight increase of fishing effort, (2) the steep increase from 2004 to 2011 was mainly caused by the continuous decrease of the fishing effort with stable annual catches (**Fig. 2**), and (3) the stable trends in recent years were caused by the constant catch and fishing efforts (**Fig. 2**). Although, shortfin mako shark is known to be vulnerable to high pressure of fisheries because of a low productivity due to slow growth, late maturity, and low fecundity (Semba et al. 2009, 2011), these growth rates of the population are likely to be plausible because the latest study of the population growth rates (r) of shortfin mako estimated from the two-stage sex model showed a similar or higher values (a mean value of r was 0.102 with a range of minimum and maximum values of 0.007-0.318) (Yokoi et al. 2017).

A comparison of standardized CPUE between this study and previous study (**Fig. 4**) indicated that the updated data slowed down the steep increase of annual standardized CPUE from 2010 to 2016. Kai (2017) clearly showed that the trends in the annual standardized CPUEs estimated by three different models (NB, ZIP, and ZINB) were almost similar after 2010 (see **Fig. 8** in Kai, 2017) and similar trends were observed for the two models (NB and ZIP) in this study. These results suggested that the different error distribution of the statistical model has no large impact on the trends in the standardized CPUE after 2010. The author therefore considered that the steep increasing trend in the standardized CPUE in the previous study was largely influenced by the spike of the nominal CPUE in 2016, however, the updated stable trends in the nominal CPUE from 2017 to 2019 reduced the effect of the spike. Although the spike of nominal CPUE in 2016 was caused by the remarkable increase in the catch number (**Table 2**), the author has no clear reason of the increase in the catch number.

In this study, the target effect was not included in the model because shortfin mako shark is bycatch species unlike the target species such as swordfish and blue shark. In addition, the results of sensitivity to target effect in the previous analysis (Kai, 2017) indicated that the target changes between two target species had a small impact on the annual trends in the CPUE of shortfin mako.

Kai et al. (2017a, b) developed a length aggregated and disaggregated spatio-temporal delta-generalized linear mixed model (GLMM) and apply the method to fishery-dependent catch rates of shortfin mako sharks in the western and central North Pacific. The spatio-temporal model may provide an improvement over conventional time-series and spatially stratified models by yielding more precise and biologically interpretable estimates of abundance (Shelton et al. 2014; Thorson et al. 2015). The results of the analyses suggested that there has been a recent increasing trend in stock abundance since 2008 (Kai et al. 2017a). Although the spatio-temporal model improved the time series of catch rates and the unrealistic increase of the catch rates was disappeared, one issue is the shorter period of the analyses between 2006 and 2014. Then we need to develop the spatio-temporal model to apply it to the whole logbook data from 1994 to 2019 in future work.

The maps of annual nominal CPUE of shortfin mako caught by shallow set longline fishery indicated that the operational locations used in the analysis of base case model were gradually sparse over time (**Fig. 6**). This is largely due to the two-stage filtering. In particular, the selection of the vessels based on the data between 2000 and 2014. Two-stage filtering also had a large impact on the absolute estimates of standardized CPUE, while the slight increasing trends in the standardized CPUE over the years were almost similar among with and without the filtering (**Fig. 2**). The accuracy of the absolute estimates is more important than the relative estimates because the catch number of shortfin mako shark will be estimated through the multiplication by the total fishing effort. However, the current filtering methods have a few issues: (1) the spatial-temporal coverage of the survey data used for the validation of the CPUE trends is limited to small area (25-40 ˚N and 140-150 ˚E) and shorter periods (2000-2014) with one season (May-July), (2) the selection of the vessels based on the visual observation of CPUE pattern of each set of shortfin mako shark is subjective. It may be difficult to solve these issues in future and these filtering might lose the correct data. Further, the impact of the two-stage filtering is small. These facts indicate that two-stage filtering may not be necessary in future analysis. Rather, we should improve the accuracy of the estimate using the spatio-temporal model with the data over 1994-2019 in future work.

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Tables

Table 1. Model structure and changes in AIC and BIC among different model structures. "Δ" denotes a difference between the value of criteria and the minimum value. "NA" denotes unavailability of information criteria due to that the model was not converged.

No	Model structure (combinations of explanatory variables)	Information criterion			
	Negative binomial model	AIC	ΔAIC	BIC	ΔBIC
1	Null	139303	5567	139319	5223
2	Year	136370	2635	136597	2501
3	Year + Quarter	136310	2575	136562	2466
4	Year + Quarter +Area	134673	938	134950	854
5	Year + Quarter +Area + Fishery	134514	778	134799	703
6	Year + Quarter +Area + Fishery + Interaction (Quarter and Area)	133735	0	134096	0
7	*Zero-inflated Poisson model*	168267	34532	168897	34801
	Zero-inflation: Year + Quarter +Area + Fishery				
	Count: Year + Quarter +Area + Fishery + Interaction (Quarter and Area)				
8	*Zero-inflated Negative Binomial model*	NA	NA	NA	NA
	Zero-inflation: Year + Quarter +Area + Fishery				
	Count: Year + Quarter +Area + Fishery + Interaction (Quarter and Area)				

Table 2. Fishing efforts, catch in number of shortfin mako, nominal CPUE, and ratio of positive catch for shallow-set data without 2-stage filtering, with filtering (I), and with filtering (I) and (II).

Year	Without 2-stage filtering				With filtering (I)				With filtering (I) and (II)			
	Fishing effort in number of hooks (mil.)	Catch in number (num.)	Nominal CPUE (per 1000 hooks)	Ratio of positive catch (%)	Fishing effort in number of hooks (mil.)	Catch in number (num.)	Nominal CPUE (per 1000 hooks)	Ratio of positive catch (%)	Fishing effort in number of hooks (mil.)	Catch in number (num.)	Nominal CPUE (per 1000 hooks)	Ratio of positive catch (%)
1994	24.4	3059	0.13	0.19	8.2	1653	0.20	0.26	4.4	1512	0.34	0.48
1995	22.5	3481	0.15	0.23	8.9	2271	0.26	0.32	4.6	1915	0.41	0.52
1996	20.5	4883	0.24	0.30	8.9	3126	0.35	0.40	5.2	2490	0.48	0.51
1997	20.2	6366	0.32	0.33	8.8	3599	0.41	0.41	5.6	2754	0.49	0.47
1998	20.2	6837	0.34	0.39	9.7	3991	0.41	0.43	6.4	3244	0.51	0.51
1999	20.4	8584	0.42	0.44	10.6	5464	0.52	0.53	6.7	4115	0.61	0.60
2000	23.4	11697	0.50	0.47	12.9	8080	0.63	0.57	7.6	5806	0.76	0.66
2001	23.9	10494	0.44	0.46	11.8	6267	0.53	0.54	6.7	3976	0.59	0.58
2002	21.7	8787	0.41	0.45	11.2	5062	0.45	0.50	7.0	3440	0.49	0.53
2003	19.1	9504	0.50	0.45	10.1	6146	0.61	0.52	6.3	4185	0.67	0.56
2004	19.1	9803	0.51	0.47	10.7	5810	0.55	0.49	6.2	4200	0.67	0.59
2005	17.4	12198	0.70	0.55	9.3	6758	0.72	0.54	5.4	5115	0.95	0.65
2006	16.0	11602	0.72	0.59	9.0	7041	0.78	0.59	4.7	5354	1.14	0.75
2007	18.7	14389	0.77	0.60	11.0	9657	0.88	0.58	6.3	7192	1.15	0.74
2008	16.5	11553	0.70	0.64	9.2	7689	0.83	0.64	5.2	5555	1.06	0.78
2009	14.7	13904	0.95	0.65	8.1	10059	1.24	0.67	4.0	5683	1.41	0.73
2010	13.6	11873	0.87	0.65	6.8	7899	1.17	0.71	2.9	3575	1.22	0.76
2011	7.6	8475	1.11	0.76	3.7	4830	1.30	0.82	1.8	2433	1.36	0.82
2012	9.4	10561	1.13	0.70	4.6	5869	1.28	0.79	1.8	2643	1.43	0.83
2013	9.8	7793	0.80	0.68	4.5	4208	0.93	0.75	1.7	1884	1.09	0.81
2014	9.7	11521	1.19	0.76	4.0	4953	1.25	0.77	1.1	1484	1.29	0.77
2015	7.9	11262	1.42	0.74	2.8	4571	1.61	0.75	1.4	1866	1.37	0.69
2016	7.8	14277	1.84	0.89	2.5	5565	2.24	0.89	1.9	3911	2.03	0.88
2017	7.4	10673	1.44	0.86	2.4	3982	1.65	0.87	1.9	2582	1.36	0.88
2018	7.6	11510	1.51	0.88	2.5	4587	1.81	0.90	2.0	2970	1.47	0.90
2019	7.1	10038	1.41	0.89	2.2	3447	1.56	0.90	1.9	2518	1.36	0.88

Table 3. Summaries of the annual nominal CPUE, standardized CPUE with 95 % confidence intervals, and its coefficient of variations (CV) for the best model.

Year	Nominal CPUE	Standardized CPUE	Normalized nominal CPUE	Normalized standardized CPUE	Lower of 95% CI	Upper of 95% CI	CV (%)
1994	0.34	0.28	0.34	0.35	0.33	0.42	0.06
1995	0.41	0.34	0.42	0.43	0.40	0.47	0.04
1996	0.48	0.39	0.48	0.49	0.48	0.57	0.04
1997	0.49	0.38	0.50	0.49	0.46	0.55	0.05
1998	0.51	0.40	0.52	0.51	0.49	0.57	0.04
1999	0.61	0.46	0.62	0.58	0.56	0.63	0.03
2000	0.76	0.50	0.77	0.64	0.65	0.73	0.03
2001	0.59	0.42	0.60	0.53	0.51	0.60	0.04
2002	0.49	0.37	0.50	0.48	0.45	0.52	0.04
2003	0.67	0.52	0.67	0.67	0.62	0.75	0.05
2004	0.67	0.53	0.68	0.68	0.66	0.76	0.04
2005	0.95	0.73	0.96	0.94	0.89	1.04	0.04
2006	1.14	0.82	1.15	1.06	1.03	1.21	0.04
2007	1.15	0.83	1.16	1.06	1.04	1.19	0.04
2008	1.06	0.73	1.08	0.94	0.92	1.08	0.04
2009	1.41	0.95	1.42	1.22	1.16	1.35	0.04
2010	1.22	0.86	1.23	1.10	1.05	1.25	0.04
2011	1.36	1.23	1.37	1.57	1.35	1.68	0.06
2012	1.43	1.11	1.45	1.42	1.32	1.66	0.06
2013	1.09	1.05	1.10	1.35	1.15	1.41	0.05
2014	1.29	1.13	1.31	1.45	1.19	1.65	0.09
2015	1.37	1.09	1.39	1.40	1.21	1.57	0.07
2016	2.03	1.69	2.05	2.16	1.79	2.18	0.05
2017	1.36	1.09	1.37	1.40	1.24	1.49	0.05
2018	1.47	1.20	1.49	1.54	1.34	1.58	0.04
2019	1.36	1.22	1.37	1.56	1.32	1.56	0.05

Figures

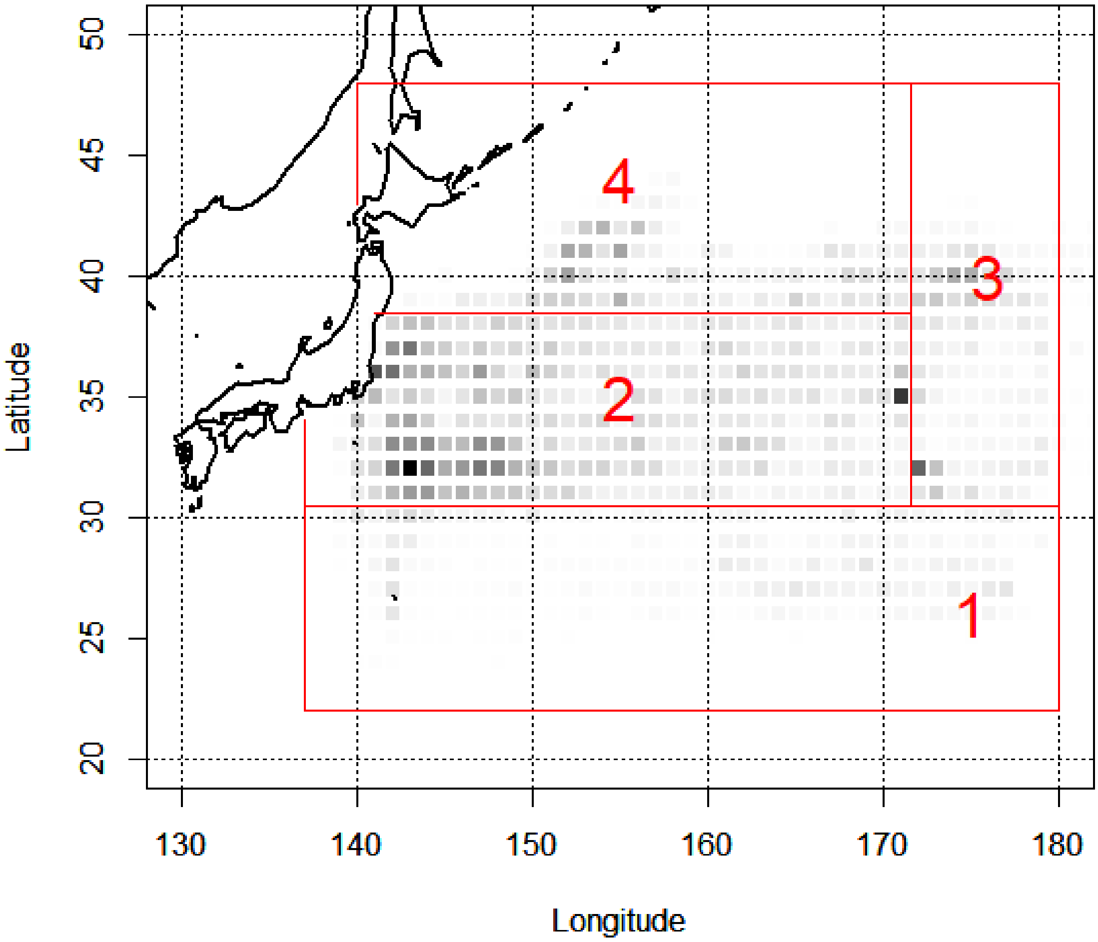

Fig. 1 Catch location of shortfin mako shark in the northwestern Pacific from 1994 to 2019 after 2-stage filtering and subareas determined by GLM-tree. Darker square denotes the higher catch at the location.

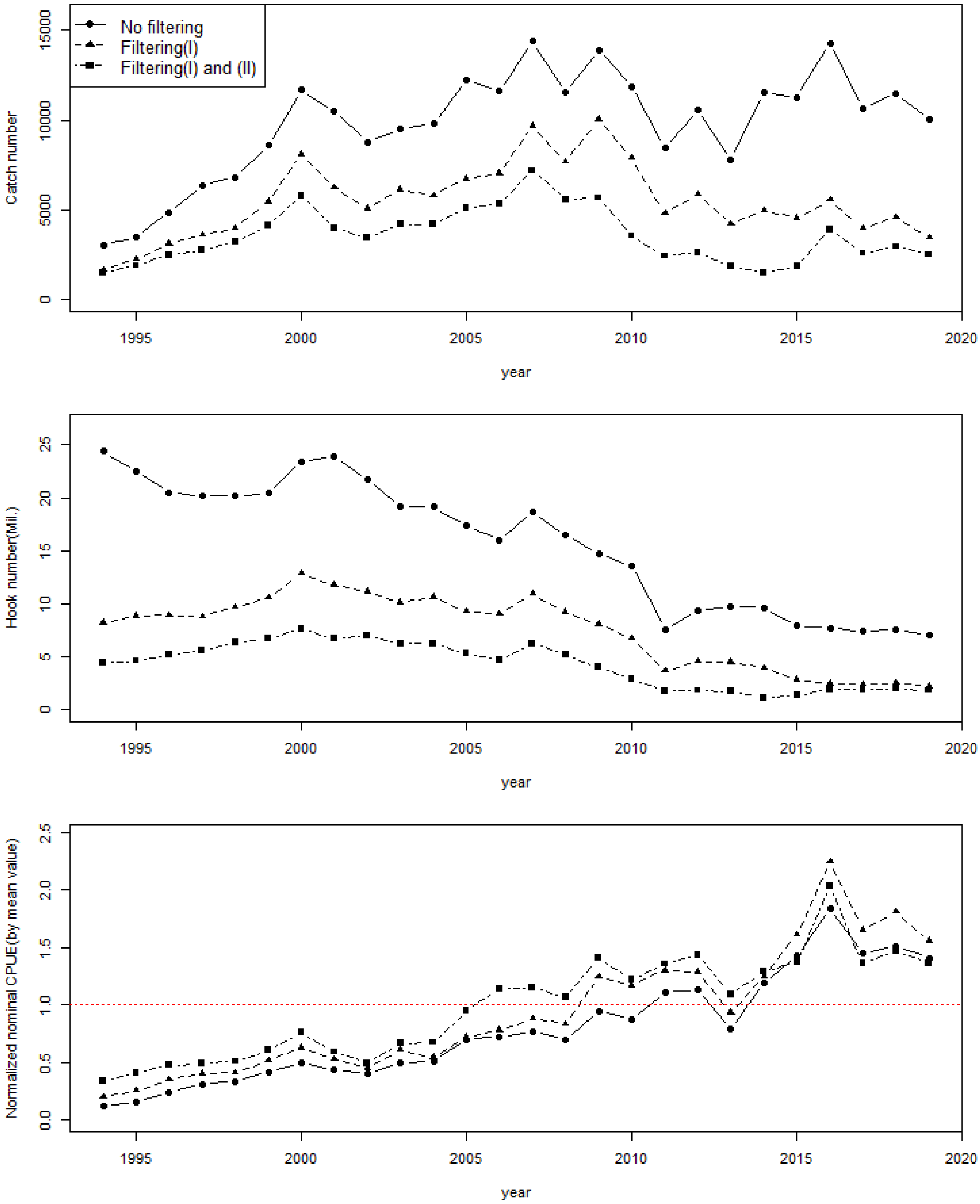

Fig. 2 Annual catch number of shortfin mako (upper figure), number of total hooks (mil.) (middle figure), and normalized nominal CPUE (lower figure) for shallow-set data without 2-stage filtering, filtering (I) only, and 2-stage filtering (I) and (II).

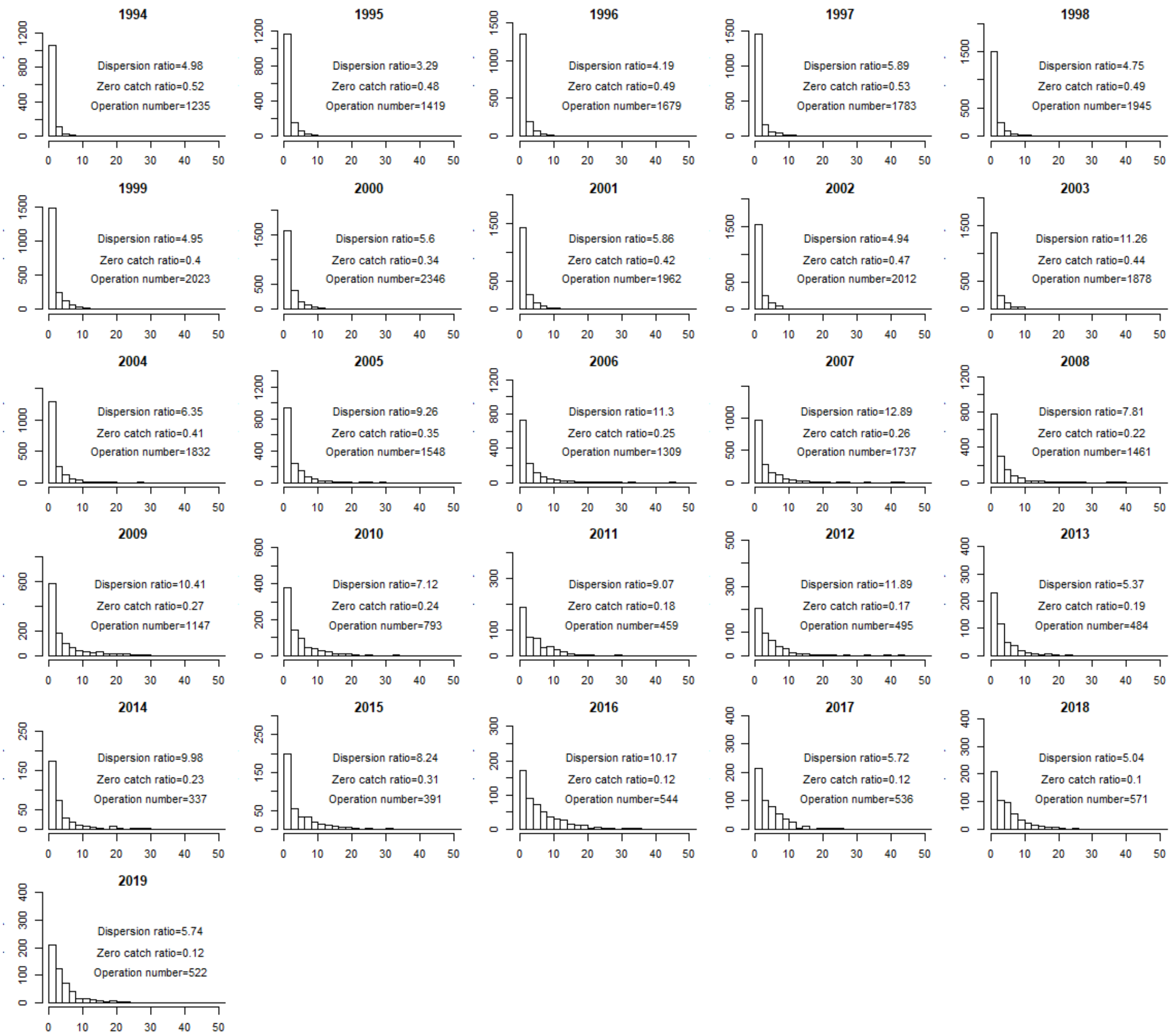

Fig.3 Frequency distribution of catch number of shortfin mako per operation from 1994 to 2019 after 2-stages filtering. "Dispersion ratio" denotes the mean over variance.

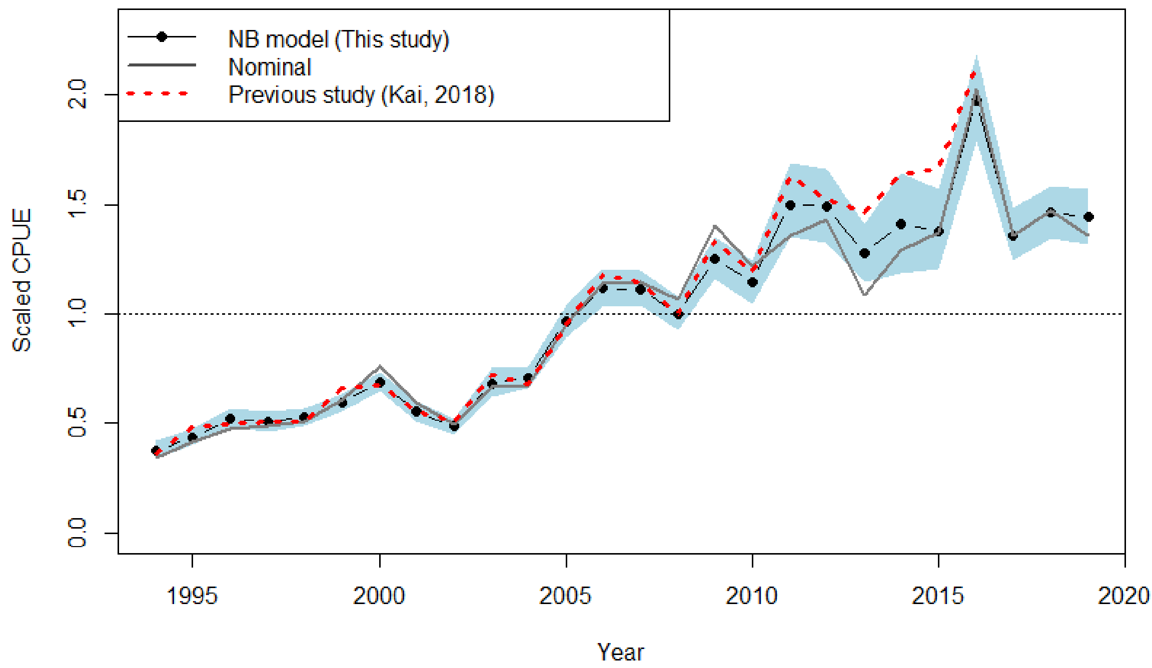

Fig. 4. Annual normalized standardized CPUE (black line with filled black circle) of shortfin mako estimated from negative binomial model (best model) and its 95 % confidence intervals (shade). Grey and red-broken line denotes annual normalized nominal CPUE and annual normalized standardized CPUE in the previous study (Kai, 2017).

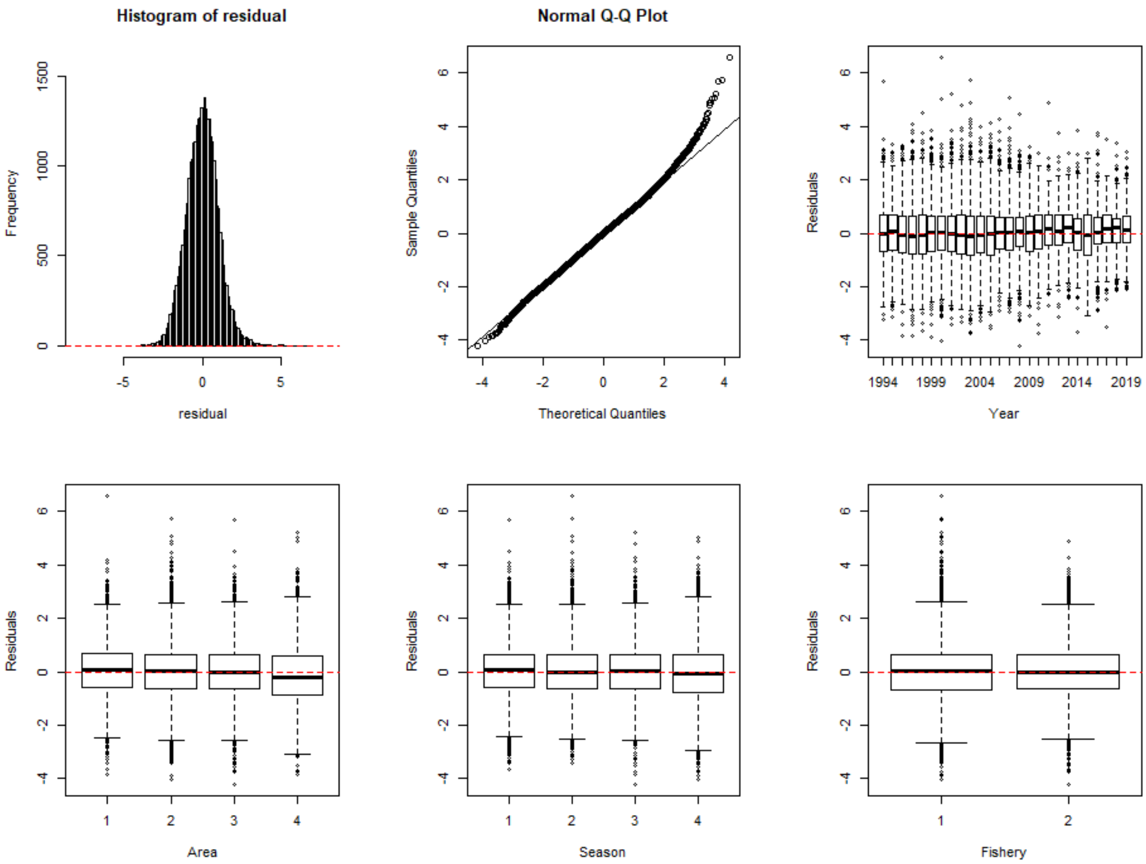

Fig. 5 Model diagnostics regarding the goodness of fits. Frequency distribution of Pearson residuals from the best model (NB), Q-Q plot, and Pearson residuals against each explanatory variable. Numerical values 1 and 2 of "fishery type" denotes "offshore fishery" and "distant water fishery", respectively.

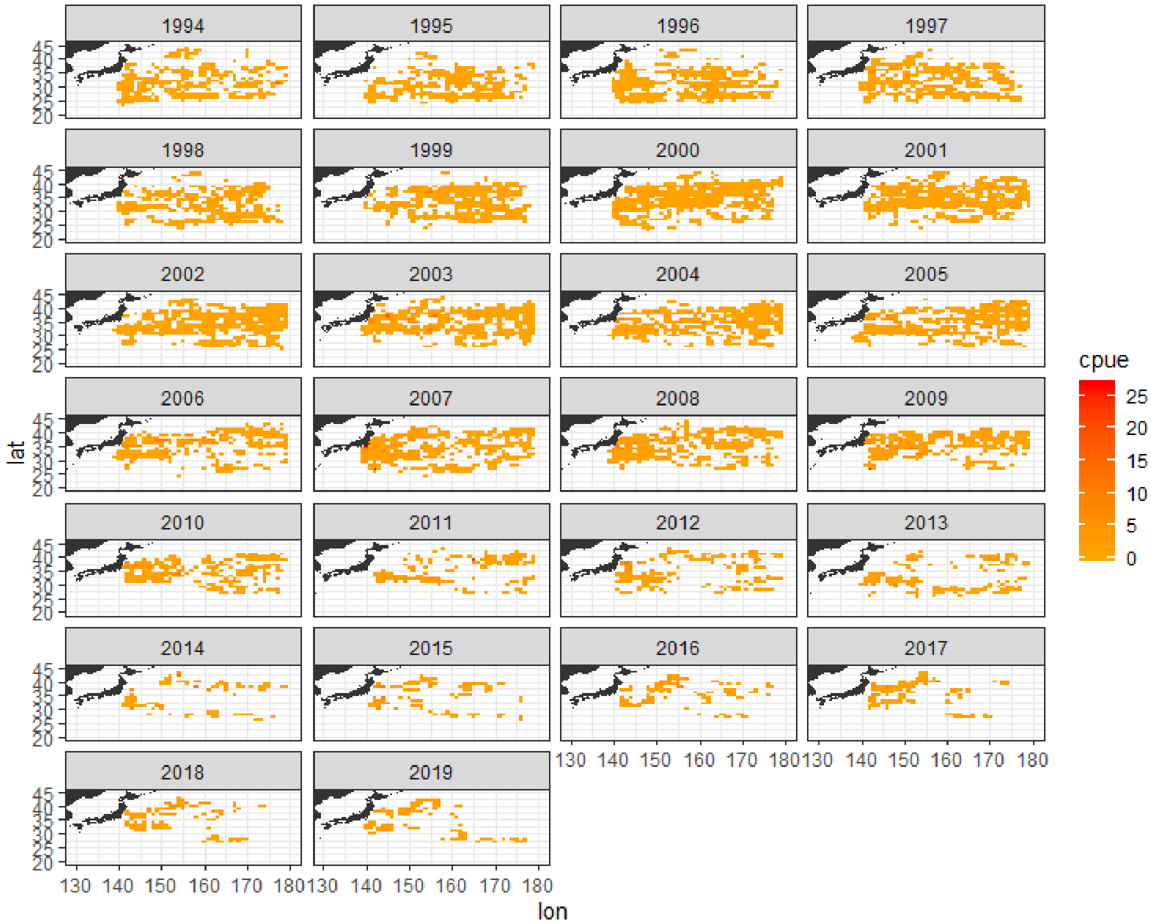

Fig. 6 Maps of average nominal CPUE (per 1000 hooks) for shortfin mako shark in the northwestern Pacific from 1994 to 2019.

Appendix

Summary of output for negative binomial (the best) model from R

```
Call:
glm.nb(formula = mako ~ as.factor(year) + as.factor(qt) + as.factor(area4) +
    as.factor(fishery) + as.factor(area4):as.factor(qt) + offset(log(hook)),
    data = temp, init.theta = 0.7223402641, link = log)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.0959  -1.2664  -0.4319   0.2504   6.3667

Coefficients:
                           Estimate Std. Error  z value Pr(>|z|)
(Intercept)                -7.97760    0.05301 -150.500  < 2e-16 ***
as.factor(year)1995         0.20090    0.05889    3.412 0.000646 ***
as.factor(year)1996         0.33384    0.05619    5.942 2.82e-09 ***
as.factor(year)1997         0.32599    0.05553    5.870 4.35e-09 ***
as.factor(year)1998         0.35903    0.05426    6.616 3.68e-11 ***
as.factor(year)1999         0.50091    0.05337    9.386  < 2e-16 ***
as.factor(year)2000         0.58663    0.05189   11.305  < 2e-16 ***
as.factor(year)2001         0.41219    0.05376    7.667 1.76e-14 ***
as.factor(year)2002         0.29994    0.05390    5.565 2.62e-08 ***
as.factor(year)2003         0.63783    0.05438   11.729  < 2e-16 ***
as.factor(year)2004         0.65791    0.05463   12.042  < 2e-16 ***
as.factor(year)2005         0.97795    0.05539   17.656  < 2e-16 ***
as.factor(year)2006         1.09540    0.05668   19.326  < 2e-16 ***
as.factor(year)2007         1.09608    0.05391   20.332  < 2e-16 ***
as.factor(year)2008         0.97377    0.05586   17.432  < 2e-16 ***
as.factor(year)2009         1.23797    0.05846   21.175  < 2e-16 ***
as.factor(year)2010         1.13775    0.06397   17.786  < 2e-16 ***
as.factor(year)2011         1.49205    0.07443   20.046  < 2e-16 ***
as.factor(year)2012         1.39413    0.07295   19.112  < 2e-16 ***
as.factor(year)2013         1.34128    0.07435   18.039  < 2e-16 ***
as.factor(year)2014         1.41099    0.08324   16.951  < 2e-16 ***
as.factor(year)2015         1.37403    0.07926   17.337  < 2e-16 ***
as.factor(year)2016         1.81048    0.07022   25.785  < 2e-16 ***
as.factor(year)2017         1.37348    0.07138   19.241  < 2e-16 ***
as.factor(year)2018         1.47014    0.06992   21.027  < 2e-16 ***
as.factor(year)2019         1.48352    0.07188   20.640  < 2e-16 ***
as.factor(qt)2             -0.71602    0.03956  -18.098  < 2e-16 ***
```

```
as.factor(qt)3                  -0.55123    0.09566   -5.762 8.30e-09 ***
as.factor(qt)4                  -0.02790    0.15676   -0.178 0.858750
as.factor(area4)2                0.23305    0.03645    6.394 1.61e-10 ***
as.factor(area4)3                0.27259    0.05423    5.026 5.00e-07 ***
as.factor(area4)4               -2.03775    0.71322   -2.857 0.004275 **
as.factor(fishery)2             -0.23504    0.01861  -12.632  < 2e-16 ***
as.factor(qt)2:as.factor(area4)2  1.12772    0.04815   23.419  < 2e-16 ***
as.factor(qt)3:as.factor(area4)2  0.70508    0.10215    6.903 5.11e-12 ***
as.factor(qt)4:as.factor(area4)2  0.17343    0.15893    1.091 0.275190
as.factor(qt)2:as.factor(area4)3 -0.03013    0.07395   -0.407 0.683681
as.factor(qt)3:as.factor(area4)3 -0.06630    0.11037   -0.601 0.548037
as.factor(qt)4:as.factor(area4)3 -0.30803    0.16534   -1.863 0.062457 .
as.factor(qt)2:as.factor(area4)4  3.25486    0.75164    4.330 1.49e-05 ***
as.factor(qt)3:as.factor(area4)4  2.82146    0.71951    3.921 8.80e-05 ***
as.factor(qt)4:as.factor(area4)4  2.02252    0.73029    2.769 0.005614 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for Negative Binomial(0.7223) family taken to be 1)

    Null deviance: 40399  on 32447  degrees of freedom
Residual deviance: 34052  on 32406  degrees of freedom
AIC: 133735

Number of Fisher Scoring iterations: 1

              Theta:  0.72234
          Std. Err.:  0.00852

 2 x log-likelihood:  -133649.32900
```