ISC/21/SHARKWG-1/03

Updated CPUE of shortfin mako, *Isurus oxyrinchus*, caught by Japanese research and training vessels in the western and central North Pacific[1]

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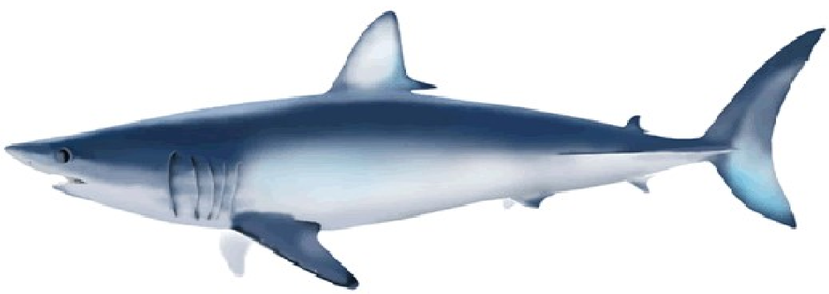

[1] Working document submitted to the ISC Shark Working Group Workshop, 22-26 February 2021, Web-meeting. **Document not to be cited without author's permission.**

Abstract

This working paper presents updated annual standardized catch per unit of effort (CPUE: catch number per 1,000 number of hooks) for shortfin mako caught by longline fishery of Japanese training and research vessels during 1992 and 2019 in the North Pacific. The author used the same estimation methods used in the previous analysis. Since the reporting rates of sharks during 2001 and 2013 are clearly lower than those before 2000, the author removed the data with lower reporting rates using the filtering method based on the prediction of the binomial generalized linear model. Then we standardize the nominal CPUE using two-step model (binomial model for presence/absence and Poisson model for positive catch) in consideration of the characteristics in the data with high zero catch ratio and small over-dispersions. The annual trends in the standardized CPUE slightly increased with large fluctuations until 2007, and then its gradually decreased until 2013. Thereafter, the annual trends in the CPUE sharply increased associated with the lower fishing effort. The CVs of the standardized CPUE were smaller than 0.16 over the years. These results suggested that the recent abundance of shortfin mako in the western and central North Pacific is likely to be on the rise due to the reduction of fishing effort.

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.

National Research Institute of Far Seas Fisheries had started to collect the data of shortfin mako caught by the longline gear of Japanese research and training vessels (JRTVs) since 1992. The data was collected from the research vessels belonging to, or chartered to, national or prefectural fisheries research institutes, and vocational training vessels attached to fisheries high schools throughout Japan. The JRTVs commonly operates the water around Hawaii due to reputedly calm sea conditions and the attractiveness to students of Honolulu port call.

In order to conduct the stock assessment in 2018, the author provided with standardized CPUE of shortfin mako caught by Japanese research and training vessels (JRTVs) in the western and central North Pacific from 1994 to 2016 using generalized linear model (GLM) (Kai, 2017). Since the information estimated from the fishery-independent data is very useful for improving the stock assessment, the standardized CPUE was used as a measure of relative population abundances in the basecase model (ISC, 2018).

Main objectives of this working paper are to update the annual standardized CPUE of shortfin mako caught by longline gear of JRTVs in the North Pacific Ocean, and to discuss the population trends in recent years. The author analyzes the temporal changes in the reporting rate and attempt to remove unreliable data, and then, the author standardizes the nominal CPUE using the GLM for the filtered data from 1992 to 2019.

Materials and Methods

The author estimates the annual standardized CPUE using similar methods used in the stock assessment in 2018 to maintain the consistency of the methodology.

Data sources

This study used longline logbook data collected from JRTVs in the western and central North Pacific from 1992 to 2019 (**Fig. 1**). Set-by-set operational data used in this study includes information on species of sharks, operation time (year, month), catch numbers, amount of effort (number of hooks), number of branch lines between floats (hooks between floats: HBF) as a proxy for gear configuration, location of sets by latitude-longitude resolution of 1° × 1°, trip identity, sea surface temperature (SST), and leader type (nylon or others). A deep-set is identified by the number of HBF, which determines fishing depth (Nakano et al., 1997). A deep-set fishery was defined as one that uses a large number of HBF (6–16 hooks). The number of HBF with the most catches for shortfin mako was between 11 and 15, and a small change in gear configuration was observed (**Fig. A1**).

Data filtering

Incomplete and insufficient data were filtered, as were sets that have little or no information about HBF and locations (latitude and longitude), numbers of hooks that were less than 800, HBF that were less than 6 (i.e. shallow-sets), and operations that were conducted in waters other than the North Pacific. In this study, this filtering step is referred to as "preliminary filtering". In order to remove errors and biases of the set-by-set data caused by under-reporting of actual shark catches, unreliable set-by-set data were further removed based on the information on shark presence in the catch. A minor change was made in the filtering method (Hoyle et al., 2017) and applied to JRTV data from 2001 to 2013 to accommodate a clear decline in annual reporting rates during this period (**Fig. 2a**). The filtering method is referred to as "follow-up filtering". The details in the follow-up filtering were described in Kai (2019).

Standardization of catch rate

The author used a two-part model including binomial model for presence/absence data and a Poisson model for positive catch (Zuur et al., 2009). The author used multiple covariates (year, quarter, month, area, SST, and leader type) in the model to reduce the adverse effects of them on the estimation of annual CPUE. The best combinations of explanatory variables were selected using BIC (Schwarz, 1978). The main interaction terms such as year-quarter and year-area were not included in the models due to a lack of data for some years. The 95 % confidence intervals of standardized CPUE were calculated using the bootstrapping method with 1000 replicates. The goodness-of-fits of the models to the data are diagnosed using the Randomized quantile residuals plot (Dunn and Smyth, 1996).

Results

For the analyses of the follow-up filtering, the full model was selected as the most parsimonious model, and all factors of the deviance table were statistically significant (**Table A1**). The lower and upper 95% confidence intervals of shark reporting reliability for 1992-2000 and 2014–2019 were estimated as 0.885 and 1.212, respectively, and the lower bound was used as a cut-off point (**Fig. A2**). The threshold (i.e. 0.885) appeared to be reasonable because the reduction of catch rates between 2001 and 2013 disappeared (**Fig. 2b**). The preliminary filtering reduced the number of records for this analysis from 36,425 sets to 32,701 sets. The follow-up filtering reduced the number of records for this analysis from 32,701 sets representing 1323 trips to 28,833 sets representing 1159 trips. The differences of yearly changes in number of catch, number of hooks, and nominal CPUE between the data with and without follow-up filtering are shown in **Fig. A3**.

The two-step model selections (**Table A2, A3**) chose the most parsimonious models for binomial and Poisson models. The annual standardized CPUE were estimated using the best models:

Binomial model:

$$\text{logit (P)} = \log(\text{P}/(1-\text{P})) = year + month + area + leader\ type + SST, \quad (1)$$

Poisson model:

$$\log(\text{C}) \sim year + qt + area + leader\ type + offset(\log(hooks)), \quad (2)$$

where P is positive catch ratio, C is positive catch, "*year*" signifies temporal change from 1992 to 2019, "*month*" signifies temporal change from Jan. to Dec., "*area*" signifies spatial change for four areas (**Fig. 1**), "*leader type*" signifies gear change in two types of materials (nylon and others) for branch line, "*SST*" signifies environmental effect and was given using a quadratic equation, "*qt*" signifies temporal change for four seasons (i.e., Jan.-Mar., Apr.-Jun., July-Sept., and Oct.-Dec.), and "*hooks*" signifies number of hooks.

Overall, the different combinations of explanatory variables had small effects on the trends in the standardized CPUEs (**Fig. 3**). The annual positive catch ratio showed a slightly increasing trend from 1992 to 2007, and a slightly decreasing trend was observed with large fluctuations after 2007 (**Fig. 3a**). The annual standardized CPUE of positive catch showed slightly increasing trends from 1992 to 2016, and then the CPUE sharply increased (**Fig. 3b**). The annual combined CPUE showed a slightly increasing trend from 1992 to 2007, and then its gradually decreased until 2013. Thereafter, the combined CPUE showed a significant increasing trend (**Fig. 3c**).

A comparison of the standardized CPUE among current model, previous model (Kai, 2017), and geostatistical model (Kai, 2019) indicated that the annual trends were almost similar while the range of annual fluctuation differed (**Fig. 4**). The CVs of the standardized CPUE were smaller than 0.16 over the 28 years (**Table 1**) and the 95 % confidence intervals were narrow throughout the periods (**Fig. 4**). The annual fishing effort (number of hooks) showed a decreasing trend over the 28 years and the current number of hooks reached to less than 1 million.

Residual plot of binomial model showed a normal distribution, while residual plot of Poisson model showed a slightly skewed normal distribution to the positive (**Fig.**

5). For the residual plots against explanatory variables, the median values were almost zero and there was no large skewness (**Figs. A5, A6**). These results suggested that the two-step model may explain the observation error of the data.

Discussions

This study presented the annual standardized CPUE of shortfin mako caught by longline gear of JRTV in the western and central North Pacific from 1992 to 2019. The data with lower reporting rates was removed and nominal CPUE was standardized using two-step models. The filtering appeared to be reasonable because the lower reporting rates by vessel-trip between 2001 and 2013 were disappeared (**Fig. 2**). The standardized CPUE suggested that the abundance of shortfin mako had increased remarkably since 2013. The author has no idea for the reason of the rapid increase in the CPUE of positive catch in recent years. The continuous decline of fishing effort since 1994 might had an influence on the rise of abundance index.

The standardized CPUE may be representative of the shortfin mako's abundance in the North Pacific as JRTVs are fishery independent surveys/training and operate in a wide area of North Pacific, especially in the sub-tropical and temperate areas near Hawaii using deep-set longline gear. The deep-set longline fishery in the area has a higher opportunity to catch the shortfin mako larger than 150 cm precaudal length (PCL) than those in any other areas (Sippel et al., 2014). The average body size of shortfin mako caught by JRTVs is larger than those caught by the other fleets. Since the maturity size of male and female of shortfin mako in the North Pacific is 156 and 256 cm PCL (Semba et al. 2011), the abundance indices estimated in this study at least contains the adult male shortfin mako. With regards to the catch of adult female shortfin mako, it is rare to catch in the whole North Pacific as the large size of sharks expose the crew to danger in addition to a small proportion of adult female. These fact supports the representativeness of the abundance indices of shortfin mako in the North Pacific.

Kai (2019) estimated annual standardized CPUE of shortfin mako caught by JRTVs using spatio-temporal generalized linear mixed model (GLMM) incorporating both spatial and temporal effects (Thorson et al., 2015) to improve the precise in the estimation of standardized annual CPUE. However, the new technique is not applied in this study to maintain the consistency of the methodology on the standardization of CPUE with previous one used in the stock assessment in 2018. In the next benchmark stock assessment of shortfin mako, it would be better using the spatio-temporal model to indicate the trend in the abundance. One issue is that the absolute values of standardized

CPUE based on the spati-temporal model are not suitable to estimate the catch because the absolute values are frequently changed by the definition of the area. In future work, it could be essential to investigate the way of estimating the catch from the output of spatio-temporal model.

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Table 1. Summary of output from the CPUE standardization and bootstrapping with 1000 replicates.

Year	Number of catch	Fishing effort	Nominal CPUE	Standardized CPUE	Lower value of 95% CI	Upper value of 95% CI	Standardized CPUE relative to its average	CV
1992	225	3,623	0.06	0.05	0.04	0.06	0.61	0.06
1993	439	4,913	0.09	0.08	0.07	0.09	0.97	0.06
1994	432	4,829	0.09	0.08	0.07	0.09	0.92	0.06
1995	396	4,627	0.08	0.06	0.05	0.07	0.75	0.06
1996	342	4,521	0.07	0.05	0.05	0.06	0.61	0.07
1997	420	4,250	0.10	0.07	0.06	0.08	0.83	0.07
1998	330	2,757	0.12	0.07	0.06	0.08	0.86	0.07
1999	96	857	0.11	0.10	0.08	0.12	1.15	0.11
2000	316	2,730	0.12	0.07	0.06	0.08	0.83	0.07
2001	272	2,893	0.09	0.08	0.07	0.09	0.91	0.07
2002	318	3,028	0.11	0.08	0.07	0.09	0.94	0.07
2003	76	982	0.08	0.09	0.07	0.11	1.04	0.12
2004	260	1,843	0.14	0.09	0.07	0.10	1.01	0.07
2005	269	2,331	0.11	0.08	0.07	0.09	0.93	0.07
2006	267	2,297	0.11	0.08	0.07	0.09	0.95	0.08
2007	162	1,495	0.11	0.10	0.08	0.12	1.17	0.09
2008	163	1,419	0.11	0.08	0.07	0.10	1.00	0.09
2009	47	695	0.07	0.06	0.05	0.08	0.76	0.13
2010	51	746	0.07	0.08	0.05	0.10	0.89	0.15
2011	57	830	0.07	0.06	0.04	0.07	0.68	0.14
2012	71	853	0.08	0.07	0.05	0.08	0.81	0.12
2013	62	1,139	0.05	0.05	0.04	0.06	0.59	0.13
2014	131	1,472	0.09	0.08	0.06	0.09	0.91	0.09
2015	200	1,236	0.16	0.13	0.11	0.15	1.52	0.08
2016	181	1,191	0.15	0.13	0.11	0.16	1.55	0.11
2017	95	1,191	0.08	0.08	0.07	0.09	0.95	0.08
2018	193	1,132	0.18	0.14	0.12	0.17	1.71	0.08
2019	46	336	0.14	0.18	0.14	0.23	2.16	0.12

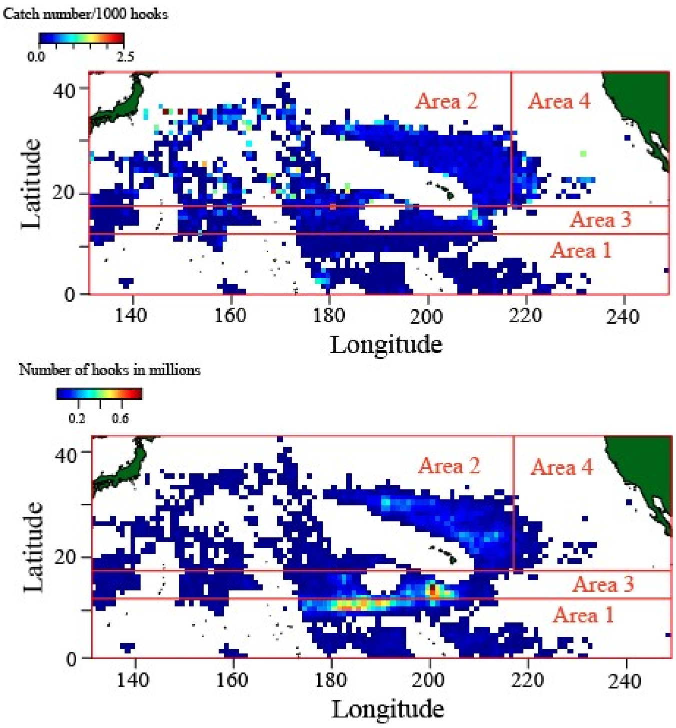

Figure 1. Spatial distributions of nominal CPUE for shortfin mako in the North Pacific (upper) and fishing effort (number of hooks in millions) (lower). Data from 1992 to 2019 were combined. The subareas were assigned using GLM tree.

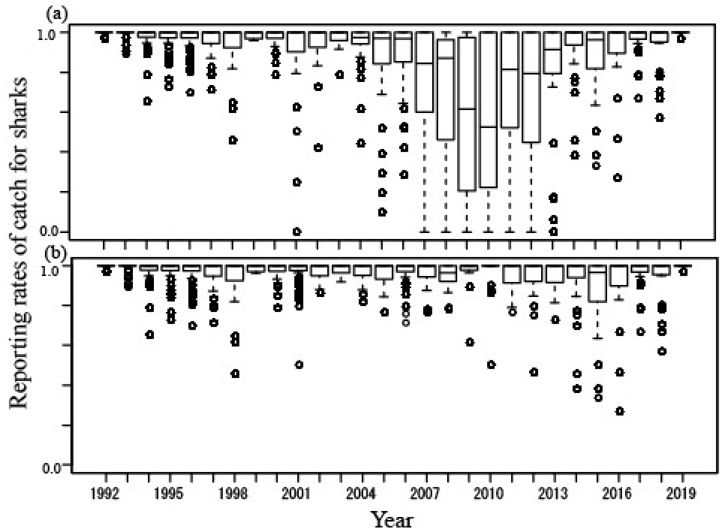

Figure 2. Annual box plots of reporting rates of catch for sharks (a) before filtering and

(b) after filtering.

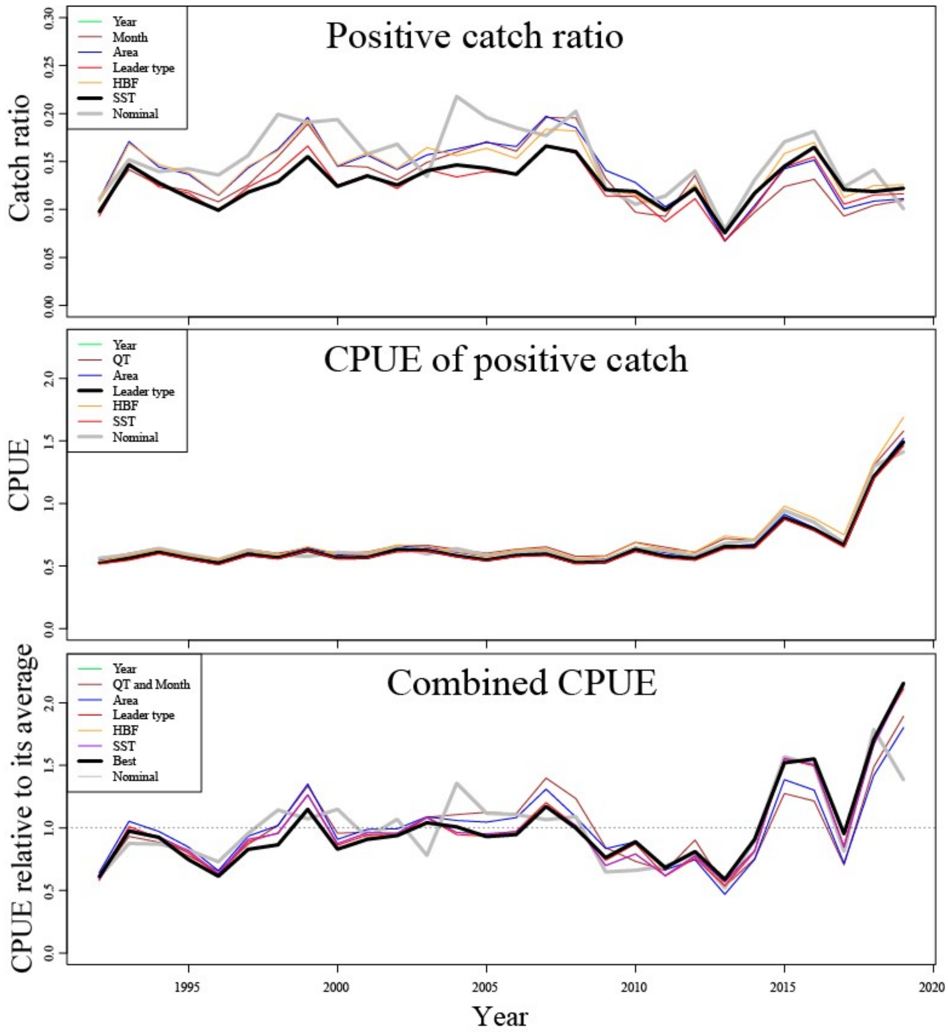

Figure 3. Annual standardized CPUEs of three types of outputs (Upper panel: Positive catch ratio, Middle panel: CPUE of positive catch, Lower Panel: Combined CPUE relative to its average) with different combinations of explanatory variables for two-step model. Thick black line denotes standardized CPUE of the best model. Grey line denotes nominal CPUE. Each explanatory variable from top to the bottom in the legend added to the null model one after another.

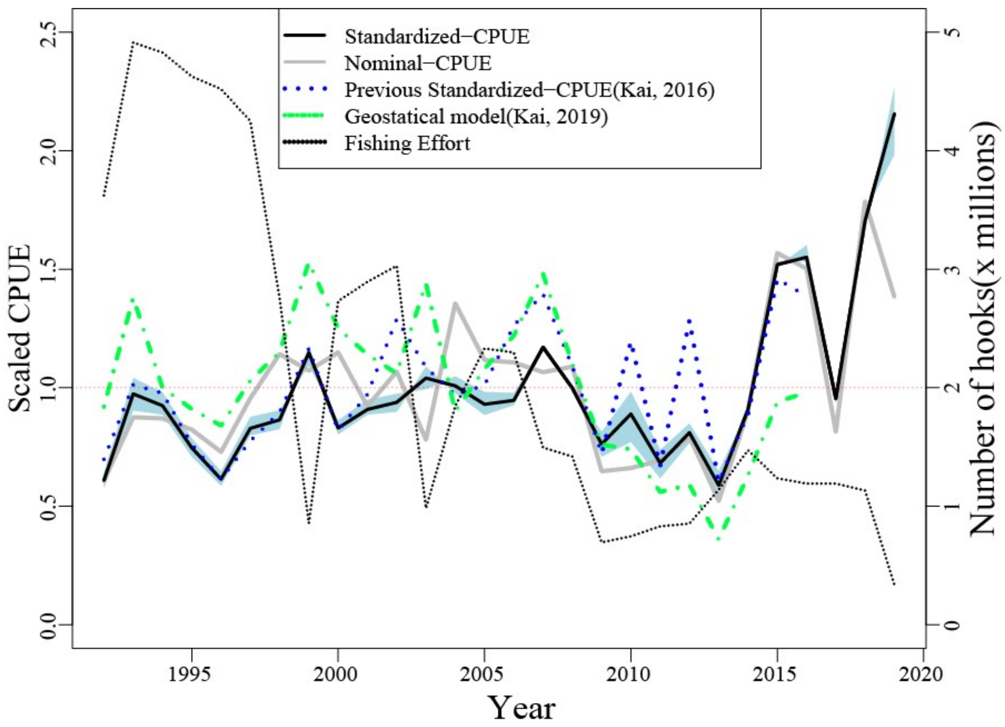

Figure 4. Annual standardized CPUE relative to its average for shortfin mako (Black solid line) with 95 % confidence intervals (shadow) and annual fishing effort (black dotted line). Gray solid line denotes nominal CPUE relative to its average. Blue dotted line denotes standardized CPUE estimated in the previous analysis (Kai, 2016) and green broken line denotes standardized CPUE estimated by spatio-temporal model (Kai, 2019). Red horizontal line denotes mean of relative values (1.0).

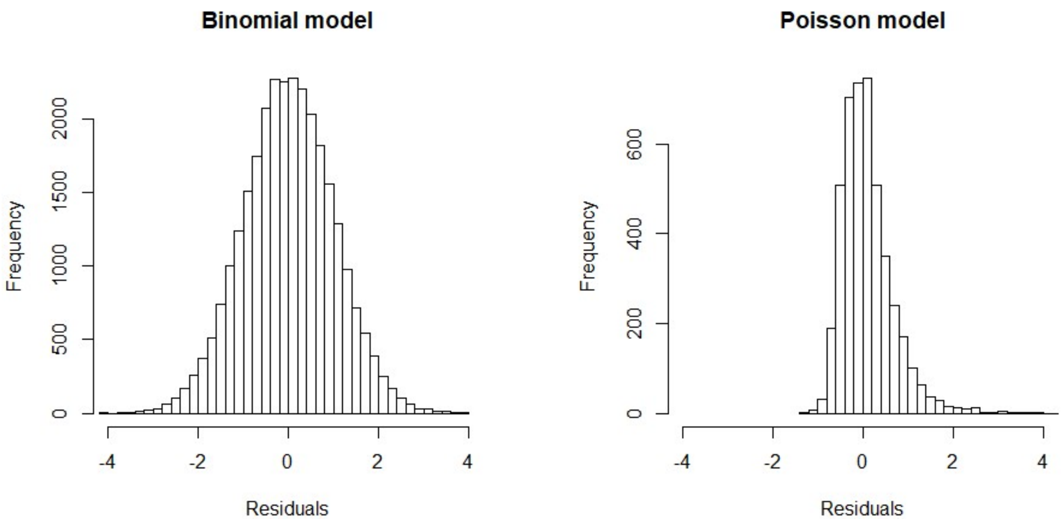

Figure 5. Frequency distributions of the randomized quantile residuals for Binomial model and Poisson model.

Table A1. Type-II analysis of deviance table for model components produced by the binomial generalized linear model. LR Chisq denotes Likelihood Ratio Chi-Square statistics, DF is degree of freedom, and Pr is significant probability for each factor.

Factor	LR Chisq	Df	Pr(>Chisq)
Month	107.78	11	< 0.001
Latitude by 5^o	289.78	9	< 0.001
Longitude by 5^o	322.86	22	< 0.001
Hooks between float	80.55	10	< 0.001

Table A2. Summary of output for selecting a combination of explanatory variables. Shade denotes the best model selected from BIC.

Model	Error distribution	Explantory variables	Number of parameters	Deviance	BIC	ΔBIC
M-1	Binomial	Year, Qt, Area, Leader type, HBF	45	21,652	22,114	54
M-2		Year, Month, Lat5,Lon5,Leader type, HBF	82	21,367	22,209	149
M-3		Year, Month, Area, Leader type, HBF	53	21,516	22,060	0
M-4		Year, Qt, Lat5,Lon5,Leader type, HBF	74	21,498	22,258	198
M-5	Poisson	Year, Qt, Area, Leader type, HBF	45	1,267	11,366	0
M-6		Year, Month, Lat5,Lon5,Leader type, HBF	79	1,190	11,576	209
M-7		Year, Month, Area, Leader type, HBF	53	1,245	11,412	45
M-8		Year, Qt, Lat5,Lon5,Leader type, HBF	71	1,202	11,521	154

Table A3. Summary of output for selecting a combination of explanatory variables. Shade denotes the best model selected from BIC.

Model	Error distribution	Explantory variables	Number of parameters	Deviance	BIC	ΔBIC
M-1	Binomial	Year	28	24,706	24,994	3079.7
M-2		Year, Month	39	22,731	23,131	1217.1
M-3		Year, Month, Area	42	21,721	22,152	237.7
M-4		Year, Month, Area, Leader type	43	21,573	22,014	99.9
M-5		Year, Month, Area, Leader type, HBF	53	21,516	22,060	145.9
M-6		Year, Month, Area, Leader type, SST	45	21,452	21,914	0.0
M-7	Poisson	Year	28	1,358	11,314	6.1
M-8		Year, Qt	31	1,339	11,321	12.4
M-9		Year, Qt, Area	34	1,302	11,309	0.4
M-10		Year, Qt, Area, Leader type	35	1,293	11,308	0.0
M-11		Year, Qt, Area, Leader type, HBF	45	1,267	11,366	58.0
M-12		Year, Qt, Area, Leader type, SST	37	1,282	11,314	5.6

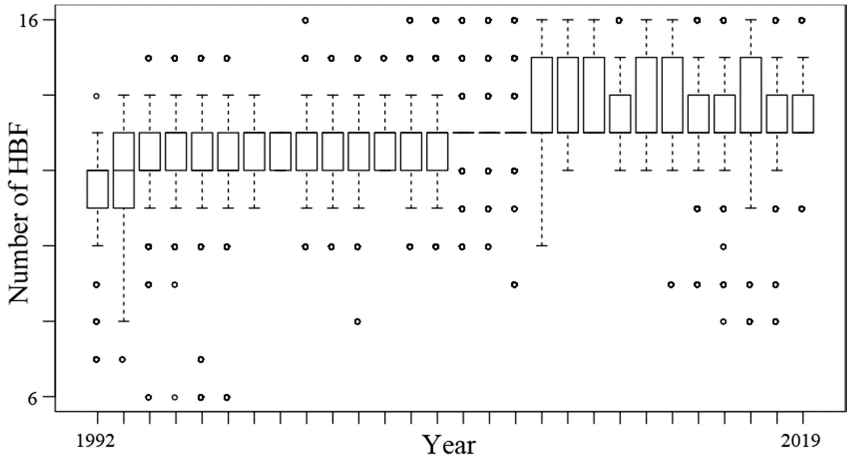

Figure A1. Box plot of number of hooks between floats (HBF) by year.

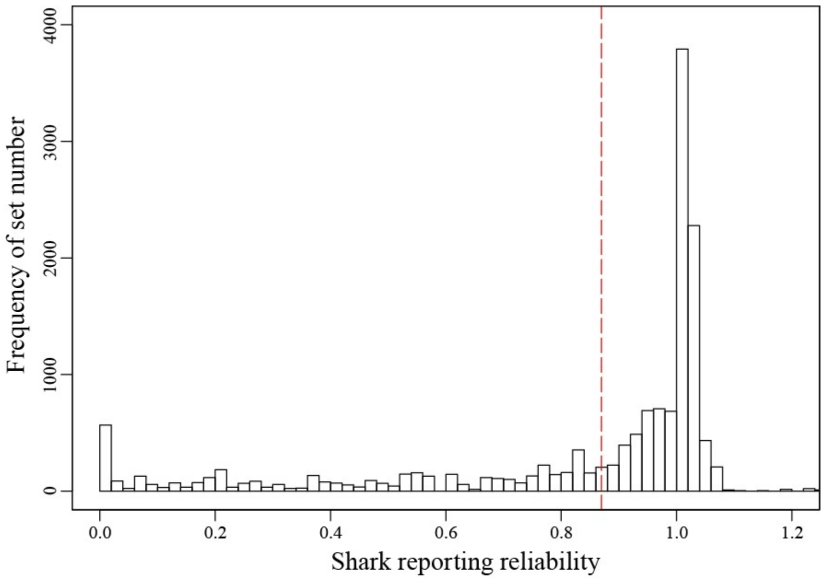

Figure A2. Frequency of set number by *shark reporting reliability* computed from the combined data of 2001 through 2013. Broken red vertical line denotes a threshold for data cut-off.

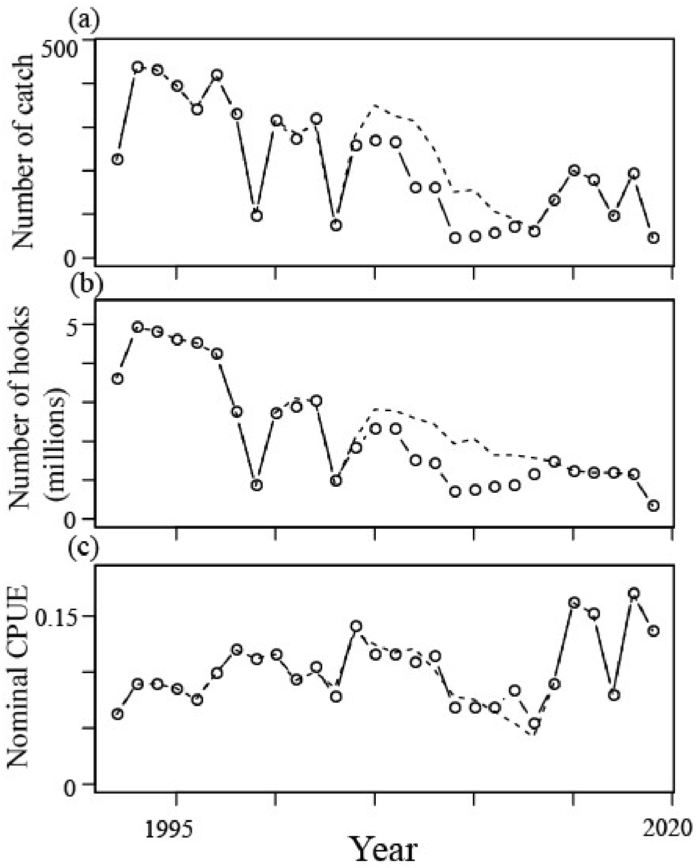

Figure A3. Annual catch in numbers, number of hooks (millions), and nominal CPUE (per 1000 hooks) for (a–c) shortfin mako before filtering (broken line) and after filtering (solid line with open circle).

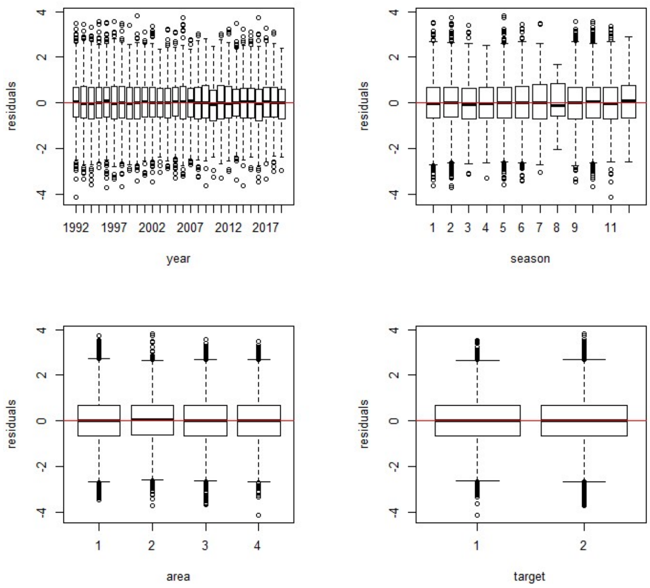

Fig. A5 Residual plots of the binomial model for each explanatory variable.

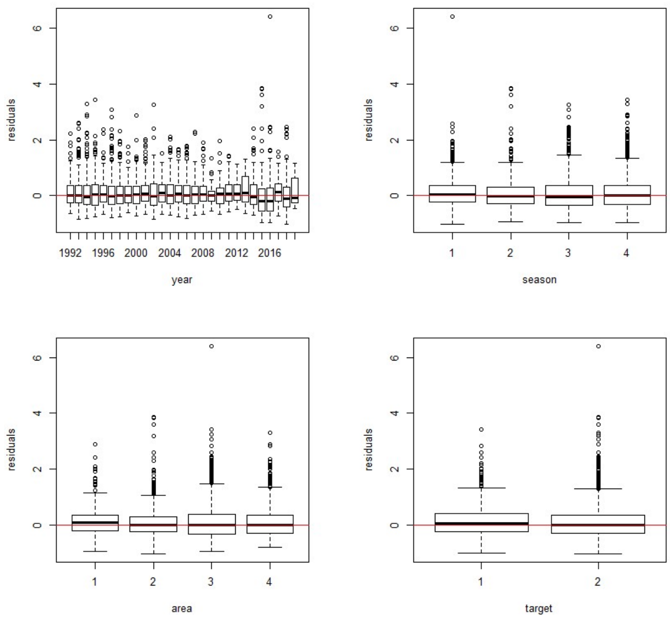

Fig. A6 Residual plots of the Poisson model for each explanatory variable.