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CPUE standardization for shortfin mako, *Isurus oxyrinchus*, of the Japanese Longline Fishery in the North Pacific Ocean[1]

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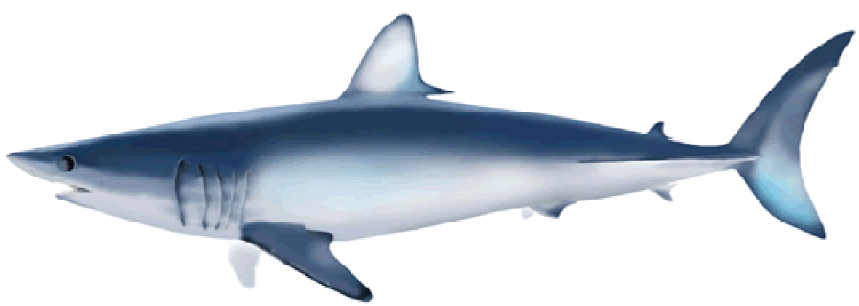

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Abstract

This document paper estimated a historical population trend of shortfin mako in the North Pacific Ocean using a great amount of Japanese longline data from 1994 to 2013. Catch per unit of effort (CPUE) was standardized using negative binomial model, zero-inflated poison model and zero-inflated negative binomial model. The full model of zero-inflated negative binomial model was selected as the best model after comparing AIC and BIC. Annual changes in the CPUE suggested that the historical population trend of shortfin mako had slightly increased since 1990s until 2010, after that it was stable.

Introduction

Shortfin mako, *Isurus oxyrinchus*, is a large pelagic shark species and a highly migratory species with occasional inshore movements and ranges throughout tropical and warm-temperate oceans worldwide between 50^{o}N and 50^{o}S (Compagno 2001). The stock structure of shortfin mako in the Pacific Ocean are divided by the equator with a single stock in the North Pacific and another in the South Pacific. This stock structure is supported by the genetic study (Taguchi et al. 2013) and tagging study (Tim et al. 2011).

Shortfin mako in the North Pacific Ocean is caught by Japanese longliners and drift netters. These commercial fisheries frequently discard or release (and do not report) the shortfin mako to space the storage of the fishing boat for the other valuable target species such as tunas, while some fisheries especially for offshore shallower settings retain shortfin mako, and they mainly unload the shark's body with fin at Kesennuma fishing port in Miyagi Prefecture.

Count data of the sharks on the catch include many zero-valued (excess zero) observations and large values (highly skewed data) when the sharks are aggregated (Bigelow et al. 1999; Ward and Myers 2005). Population trends of by-catch species such a sharks is commonly estimated using the delta lognormal model or zero-inflated model to account for the occurrence of excess zeros (Welsh et al. 1996; Minami 2007; Zuur et al. 2009). The delta lognormal model is a combination of the probability of zero catch assuming a logistic model and the probability of positive catch assuming a log-linear model based on either a truncated Poisson or truncated negative binomial distribution. The zero-inflated model is a zero-inflated probability distribution. Minami et al. 2007 expressed the probabilities as two states; 'perfect state (e.g., no catch)' and 'imperfect state (catch but it is not sure)'. The perfect state is typically modeled with a logistic, while the imperfect state is assumed a complete Poisson (zero-inflated Poisson: ZIP) or complete negative binomial distribution (zero inflated negative binomial: ZINB). ZIP model might be appropriate for infrequently caught species but positive catch occur in small groups. ZINB model might be appropriate for the species that positive catch occur in large aggregation.

This document paper presents the historical catch rates trends of shortfin mako in the North Pacific Ocean using Japanese longline data from 1994 to 2013. Catch per unit effort (CPUE) is standardized based on the zero-inflated negative binomial model because the data of shortfin mako include excess zero and highly skewed data (Fig.1). Negative binomial model (NB) and ZIP are also used to compare the results with that of ZINB. Delta log-normal model is not considered because zero-inflated model may be more appropriate for catch data which is infrequently encountered and the process of the catch are poorly understood (Minami 2007).

Materials and Methods

Data sources

Catch and effort data of Japanese longliners operating in the North Pacific (north of the Equator) from 1994 to 2013 were compiled by the National Research Institute of Far Seas Fisheries (NRIFSF). Logbook records prior to 1994 simply include catches of all species of shark under one column labeled "sharks", which after 2011, the Japanese longliners based at Kesennuma port greatly changed their operational patterns due to the tsunami that was triggered by the Great East Japan Earthquake on March 11 (Ishimura and Bailey 2013), thus only the period from 1994 to 2013 was analyzed with separation of the period into two from 1994 to 2010 and from 2011 to 2013. Set-by-set data used in this study included information on catch number, catch weight, 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 fishery type was defined by tonnage of vessels between 20 and 120 MT, while the distant-water fleet consisted of vessels larger than 120 MT. Sea surface temperature (SST) was obtained from the satellite data (See http://podaac.jpl.nasa.gov/dataset/NCDC-L4LRblend-GLOB-AVHRR OI). The mean SST of the operational date was made to link the set by set logbook data.

Data selection

Shortfin mako was mainly captured by Japanese longliners as a bycatch species (Stevens 1992; Taniuchi 1990) unlike the blue shark which species was seasonally targeted by Japanese offshore fisheries (Ishimura and Bailey 2013; Kai et al. 2014). The fishery dependent data generally had a bias due to the non-reporting and/or under-reporting of bycatch species, especially sharks (Nakano and Clarke 2006). Data selection was commonly used to avoid the bias such as an excesses of unexplained zero-catches. With the Japanese logbook data, Nakano and Clarke (2006) applied the filtering methods based on the reporting ratio (number of sets with sharks recorded / total number of sets) to blue shark and shortfin mako, however, the filtering methods was inappropriate for only shortfin mako because shortfin mako shark was commonly caught with low frequency in a set. Therefore, the filtering method was not applied to the shortfin mako in this study.

Modeling of CPUE standardization

The fishing ground was separated into five areas based on the area stratification of the blue shark in the North Pacific Ocean (Fig. 2). North Pacific Ocean was delineated by 150 ˚W because of the management boundary between Inter-American Tropical Tuna Commission (IATTC) and Western and Central Pacific Fisheries Commission (WCPFC). Then, the remaining area was delineated by the date line due to the Japanese fishery regulations and by the horizontal line at 30 ˚N in consideration of the spatial distribution of the shortfin mako catches (Fig.2) and its seasonal shift on the latitude (Shiozaki et al. 2013, see at Fig. 3).

Swordfish and blue sharks were commonly caught by longliners in the shallow water, while tuna species such as bigeye and albacore were caught in the deep water (Nakano et al. 1997). Fishermen adjust the depth of the settings in order to change the target species, and the number of HPB was changed by the depth. Since the number of HPB typically represents the depth of gear setting, and the number of HPB with positive catch of shortfin mako can be distinctively separated into small and large, two gear settings (shallower setting: HPB < 7 and deeper setting: HPB > 6) were used.

In order to conduct CPUE standardization, three generalized linear models (GLMs) were constructed. These were negative binomial model, zero-inflated Poisson model, and zero-inflated negative binomial model (Zuur et al. 2009). The negative binomial model represents an over-dispersed distribution and zero-inflated models represents more zeros than expected negative binomial model (Brodziak and Walsh 2013). If the shortfin makos were presented in the water, the number of the shraks captured would be a random process depending on the season, area, and fishery type etc. due to bycatch. The captured sharks can also be unreported or misidentified, and it is the combination of all processes causes to extra zero observations that produces the zero-inflated component (Brodziak and Walsh 2013).

The GLMs with negative binomial error distribution (NB) with log link is as follows;

$$\text{Log (Catch)} = \text{Intercept} + \alpha_1\text{Year} + \alpha_2\text{Season} + \alpha_3\text{Area} + \alpha_4\text{Fishery} + \alpha_5\text{Gear} + \alpha_6\text{SST} + \text{offset (log (hooks))},\ \text{Catch} \sim \text{NB}$$

where, “Catch” is the response variable and is a positive captured number of shortfin mako, “Effort” is number of hooks (×1000) given as an offset term, α are coefficients of each explanatory variables, “Year” is a year effect from 1994 to 2013, “Season” is a seasonal effect in Q1(Jan-Mar), Q2(Apr-Jun), Q3(Jul-Sep), and Q4(Oct- Dec), “Area” is a horizontal spatial effect (Area 1 – 5, see at Fig. 2), “Fishery type” is a two types of fishery effects (offshore or distant water), “Gear” is an effect of the number of HPB (shallower or deeper setting), and “SST” represents a habitat temperature preference and a linear relation were used as an indicator of habitat preference. The SST variable is a continuous explanatory variable and the others are categorical explanatory variables. The zero-inflated GLMs were constructed using the same explanatory variables as the NB model for the “perfect state” and “imperfect state” (Minami et al. 2007). “Perfect state” is the negative binomial or poison model with log link function and “Imperfect state” is the binomial model with logit link function. Interaction terms were not considered due to the limitation of the computation caused by enormous set by set data (637,807) and complicated models.

A stepwise variable selection with Akaike information criterion (AIC) (Akaike 1973) and Bayesian information criterion (BIC) (Schwarz 1978) was used to provide the best-fit model for standardization of CPUE. The relative importance of each explanatory variables were examined regarding to the reduction of the null Akaike information criterion (AIC) and AIC reduction per degree of freedom (Brodziak and Walsh 2013). These diagnostics were conducted for the zero-inflated negative binomial model. Same explanatory variables were used for other two models. The goodness of fit of three models were compared using AIC. Histograms of Pearson residuals for CPUE values under the three models were drawn to check the goodness of fit at each observation. In addition, histograms of Pearson residuals for CPUE values against each explanatory variables were plotted for the selected best model.

The least squared means (LSMEANS) of each explanatory variables were computed using the same estimation procedure as the SAS package (See http://support.sas.com/

documentation /cdl/en/statug/63347/HTML/default/viewer.htm#statug_glm_a 0000000871. htm). Lower and upper 95 % confidence intervals of the yearly changes in the relative CPUE were estimated using the bootstrap with one hundred nonparametric replicates for the best-fit model (Efron and Tibshirani 1994). These standardized CPUEs were compared with nominal CPUEs of shortfin mako calculated by captured number ×1000/hook number. All computations were performed in R version 2.14.1 for Windows (R Development Core Team 2014). The negative binomial and zero-inflated models were computed with the "MASS" and "pscl" libraries, respectively.

Results

Patterns of the operation and catch

Operational locations of Japanese longliner in the North Pacific and the positive catches showed that shortfin mako sharks were dominantly caught in the North western Pacific Ocean (Fig.2). Area-1 accounted for 74.7 % catch of all areas, area-5 accounted for 12.7 %, and other three areas were less than 10 %. Number of historical catch of shortfin mako was maintained around 13,000 until 2010, after that the trends had slightly decreased (Fig 4 and Table 1). Fishing effort (number of hooks) had continuously decreased since 1994 and decreased 25% in 2013. Nominal CPUE had slightly increased since 1994 to 2010 and then remarkably decreased in 2011. The positive catch ratio (or reporting ratio) of shortfin mako (number of sets with shortfin mako recorded / total number of sets) had slightly increased since 1994 and fluctuated from 14.0 % to 20.7 % in recent 5 years. The further explanations about Japanese log book data in relation to the shortfin mako sharks were described in the appendix D.

Selection of the best model and the diagnostics

The full model (model 1) was selected for the ZINB as the results of the stepwise variable selection with AIC and BIC (Table 2). The effects of each explanatory variables (year, quarter, area, fishery, gear, and sst) were statistically significant ($P(\chi^2) < 0.0001$) and important for the fitted model distributions. The values of percent AIC and changes in AIC per d.f indicated that the impacts of "SST", "Gear" and "Area" effects were higher than those of "Year", "Quarter" and "Fishery" effects (Table 3).

The best fitted model was selected based on the values of AIC which showing the relative goodness of fit of the alternative models to the data. The best fitting model was ZINB with that the lowest values of AIC were AIC = 557,864 for 1994-2010 and AIC = 47,091 for

2011 and 2013, respectively (Table 4). These models were converged (Theta = 0.3763 and 0.703 for 1994-2010 and 2011-2011, respectively).

Annual trends of estimates of standardized CPUEs (least squares means) for shortfin mako under three models (NB, ZIP, and ZINB) for the full models were shown in Fig. 5. The trends were different between NB and two zero-inflated models. NB showed a decreasing trend since 1994 to 2004 and a slight increase trend during 2005-2010. The trends of two zero-inflated models were similar. Those relative CPUEs were almost continuously increased since 1994 to 2010 and increased 1.71 (1.39/0.81) times for ZIP and 2.21(1.57/0.71) times for ZINB during the periods (Table 5). As for the trends for 2011-2013, there were no clear increasing and decreasing trends (Fig. 5).

Histograms of Pearson residuals for CPUE values under NB, ZIP, and ZINB for two periods 1994-2010 and 2011-2013 were shown in Fig. 6. Most of the residuals were close to zero and there were no large biases for all models. Box-plots of Pearson residuals for CPUE values under the best fitted ZINB for both periods were shown in Figs. 7 and 8. A small negative biases were observed for the effects of "Area" (area 2), "HPB" (shallow set) and "SST" (less than 25 ˚C) for both periods, however, there were no remarkable biases of residual distribution against for any other explanatory variables (Figs. 7 and 8).

The 95% confidence intervals (CI) of the best fitted model were shown in Fig. 9. The values were narrow (mean CV = 0.044) during 1994 to 2010, and the range after 2010 were wide because of the smaller number of the set by set data than before 2011.

Discussions

This document paper estimated a historical population trend of shortfin mako in the North Pacific using zero-inflated negative binomial model with a great amount of Japanese longline data from 1994 to 2013. The results suggested that the historical population trend of shortfin mako had slightly increased since 1990s until 2010, after that it was stable, while the results were inconsistent with the documentations of previous studies (Tsai et al. 2014; Clarke et al. 2013; Chang and Liu 2009).

Shortfin mako had considered to be vulnerable to the high pressure of fisheries. The World Conservation Union (IUCN) currently lists the shortfin mako as "Near Threatened" due to a lack of evidence that population levels have been sufficiently depleted to warrant listing it as "Vulnerable" (Cailliet et al. 2013). In the North Pacific Ocean, stock status of the shortfin mako is poorly known because a full stock assessment for shortfin mako has not been conducted yet. However, some aspects of the information had documented in the North

Pacific. Population dynamics of shortfin mako in the Northwest Pacific were estimated using demographic model and the number was found to be dropping under current conditions (Tsai et al. 2014). Additionally, it was shown that the annual spawning potential ratio (SPR) was lower than the SPR35% and had a decreasing trend since 2000 (Chang and Liu 2009). These results might be the reflection of the partial stock status in the North Pacific Ocean but the spatial coverage may be insufficient to judge the entire stock status, and large uncertainties are included in terms of the biological parameters in those assessments. Further, standardized catch rate based on the onboard observers in the western and central Pacific Ocean showed a significant declining trends by 7% per year but the performance of the standardized model was poor and the results were less reliable (Clarke et al. 2013). Therefore, a full stock assessment for shortfin mako in the North Pacific Ocean is an urgent issue to manage properly the shortfin mako.

The five areas were considered as the spatial factor. However, it might be at too large resolution to account for the latitudinal and longitudinal gradient. Alternative to this, SST was included in the model because SST had a strong negative correlations with latitude regarding the positive catch of shortfin mako (Fig A2). Additionally, variance inflation factor (VIF), which is an effective way to remove the explanatory variables with excessive correlations among explanatory variables (collinearity) (Zuur et al. 2009), indicated that the location in particular latitude of set by resolution of 5 × 5 degree square was inappropriate due to a high degree of collinearity with SST (Table 6). Further, the clear patterns of the positive catch was not observed for the longitudinal gradient (Fig. 3). Therefore, the effects of latitude and longitude were not included in the model.

Fishery independent data such as a survey data has advantageous over the fishery dependent data because there is no bias of catches due to the discard, release or no-reporting, in particular, for by-catch species like sharks (Nakano and Clarke 2006). Ohshimo et al. (2014) estimated the historical population trends of shortfin mako in the Northwestern Pacific Ocean using fishery independent data (longline research vessel data) from 2000 to 2014. It indicated that the annual population trends were similar increasing trends to those of this study before 2011 but the trends were largely different after 2010. The population trends of shortfin mako after 2010 in this study might include a large uncertainty due to the environmental and operational changes in associated with the Great East Japan Earthquake on March 11. On the other hand, the survey data has some disadvantages. The spatial coverage is limited to the Japanese offshore areas (25-40 ˚N and 140-150 ˚E) and the seasonal coverage is only three months (May-July). Standardized CPUE should be better to be calculated using the catch and effort data that widely covers the main distribution area of the shortfin mako shark (i.e. entire North Pacific Ocean) for its use as an abundance index in the stock assessment. Wider range of size coverage, especially for spawning adult, would attain higher representativeness of the stock. Because Japanese longline data has wider size range (around 50~250 cm in PCL) including spawning adult, the standardized CPUE shown in this study is believed to mostly satisfy these requirements as a good abundance index.

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Tables

Table1 Number of efforts, number of shortfin mako shark in catch, and positive catch ratios

Year	No. of effort (Million hooks)	No. of shortfin mako shark in catch	Ratio of positive catches (%)
1994	136.4	11,157	9.6
1995	130.3	15,804	9.1
1996	111.3	10,852	10.5
1997	104.8	12,226	11.6
1998	106.3	11,543	11.8
1999	115.6	13,852	12.5
2000	107.3	14,598	12.0
2001	112.6	13,249	11.4
2002	101.7	10,982	10.8
2003	96.8	11,914	11.0
2004	86.6	11,836	11.2
2005	76.3	14,155	13.8
2006	72.3	14,816	15.6
2007	63.4	16,393	17.4
2008	58.4	13,758	19.0
2009	46.4	16,245	20.7
2010	46.6	13,853	19.0
2011	47.9	10,069	14.0
2012	44.3	11,712	14.3
2013	34.0	7,871	17.4

Table 2 Model structures and changes in AIC and BIC among models for zero-inflated negative binomial model for two periods 1994-2010 and 2011-2013

No	Model structure		AIC	Changes in AIC	BIC	Changes in BIC	AIC	Changes in AIC	BIC	Changes in BIC
	Negative binomial model	Binomial model	1994-2010				2011-2013			
1	Year Season Area Fishery Gear SST	Year Season Area Fishery Gear SST	557,864	-	558,485	-	47,091	-	47,326	-
2	Year Season Area Fishery Gear SST	Year Season Area Fishery Gear	567,575	9,711	568,185	9,700	47,222	132	47,449	123
3	Year Season Area Fishery Gear SST	Year Season Area Fishery	577,401	19,537	577,999	19,514	48,470	1,379	48,687	1,362
4	Year Season Area Fishery Gear SST	Year Season Area	578,163	20,299	578,750	20,265	48,468	1,377	48,676	1,351
5	Year Season Area Fishery Gear SST	Year Season	580,767	22,903	581,309	22,824	48,719	1,629	48,893	1,568
6	Year Season Area Fishery Gear SST	Year	581,368	23,504	581,876	23,391	49,057	1,966	49,205	1,879
7	Year Season Area Fishery Gear	Year	589,250	31,385	589,746	31,261	49,449	2,359	49,589	2,263
8	Year Season Area Fishery	Year	591,235	33,371	591,720	33,235	49,535	2,444	49,665	2,340
9	Year Season Area	Year	633,847	75,983	634,321	75,836	58,806	11,716	58,928	11,602
10	Year Season	Year	690,555	132,691	690,984	132,499	67,371	20,280	67,458	20,132
11	Year	Year	691,504	133,639	691,899	133,414	67,422	20,331	67,483	20,157
12	Null	Null	697,581	139,717	697,615	139,130	67,591	20,500	67,617	20,292

Table 3 Impact of each explanatory variable on criterions of AIC for zero-inflated negative binomial model for two periods 1994-2010 and 2011-2013

Main factor	d.f.	Change in AIC	Percent AIC	Change in AIC per d.f.	d.f.	Change in AIC	Percent AIC	Change in AIC per d.f.
	1994-2010				2011-2013			
	Negative binomial model				Negative binomial model			
Null	1	-	-	-	1	-	-	-
Year	16	4,804	0.7	300	2	40	0.1	3
Quarter	3	764	0.1	255	3	17	0.0	6
Area	4	52,707	7.6	13,177	4	7,405	11.0	1,851
Fishery	1	2,967	0.4	2,967	1	589	0.9	589
Gear	1	68,458	9.8	68,458	1	16,651	24.6	16,651
SST	1	66,401	9.5	66,401	1	11,129	16.5	11,129
	Binomial model				Binomial model			
Year	16	3,309	0.5	207	2	80	0.1	5
Quarter	3	3,519	0.5	1,173	3	65	0.1	22
Area	4	61,410	8.8	15,352	4	7,511	11.1	1,878
Fishery	1	2,242	0.3	2,242	1	776	1.1	776
Gear	1	75,797	10.9	75,797	1	16,419	24.3	16,419
SST	1	99,866	14.3	99,866	1	11,521	17.0	11,521

Null AIC = 697,581

Table 4 Comparisons of the AIC among three models (NB: Negative Binomial, ZIP: Zero-Inflated Poisson, and ZINB: Zero-Inflated Negative Binomial) for the full models.

Duration	Model		
	NB	ZIP	ZINB
1994-2010	586,527	699,674	557,864
2011-2013	49,127	59,476	47,091

Table 5 Summaries of the annual catch, effort, nominal CPUE, and estimates of standardized CPUE (least squares means) with the CV under three models (NB: Negative Binomial, ZIP: Zero-Inflated Poisson, and ZINB: Zero-Inflated Negative Binomial) for the full models.

Year	Number of catch	Number of hooks (Millions)	Nominal cpue	Negative binomial (NB)	Zero-inflated poisson (ZIP)	Zero-inflated negative binomial (ZINB)	Normalized nominal cpue	Normalized NB	Normalized ZIP	Normalized ZINB	CV of ZINB
1994	11,157	136.4	0.08	0.29	0.15	0.15	0.50	1.27	0.81	0.71	0.041
1995	15,804	130.3	0.12	0.33	0.18	0.20	0.74	1.42	1.03	0.92	0.046
1996	10,852	111.3	0.10	0.21	0.14	0.16	0.59	0.91	0.81	0.74	0.056
1997	12,226	104.8	0.12	0.31	0.18	0.21	0.71	1.34	1.03	0.97	0.033
1998	11,543	106.3	0.11	0.26	0.17	0.19	0.66	1.14	0.97	0.89	0.031
1999	13,852	115.6	0.12	0.23	0.17	0.19	0.73	1.02	0.96	0.89	0.031
2000	14,598	107.3	0.14	0.20	0.17	0.19	0.83	0.86	0.92	0.90	0.037
2001	13,249	112.6	0.12	0.18	0.15	0.19	0.71	0.78	0.86	0.88	0.037
2002	10,982	101.7	0.11	0.15	0.14	0.17	0.66	0.66	0.77	0.80	0.031
2003	11,914	96.8	0.12	0.16	0.14	0.18	0.75	0.70	0.77	0.83	0.033
2004	11,836	86.6	0.14	0.15	0.13	0.18	0.83	0.67	0.74	0.85	0.031
2005	14,155	76.3	0.19	0.19	0.19	0.22	1.13	0.81	1.04	1.04	0.031
2006	14,816	72.3	0.20	0.21	0.20	0.23	1.24	0.90	1.11	1.08	0.032
2007	16,393	63.4	0.26	0.28	0.21	0.27	1.57	1.24	1.20	1.24	0.035
2008	13,758	58.4	0.24	0.22	0.21	0.25	1.43	0.98	1.15	1.15	0.039
2009	16,245	46.4	0.35	0.26	0.26	0.33	2.13	1.11	1.47	1.54	0.035
2010	13,853	46.6	0.30	0.27	0.25	0.34	1.81	1.19	1.39	1.57	0.036
2011	10,069	47.9	0.21	0.24	0.22	0.25	0.89	1.13	1.13	1.12	0.089
2012	11,712	44.3	0.26	0.19	0.18	0.21	1.12	0.91	0.90	0.94	0.083
2013	7,871	34.0	0.23	0.21	0.19	0.21	0.98	0.97	0.97	0.94	0.088

Table 6 Variance inflation factor (VIF) for two data sets. Shaded values denotes the removable variables due to a high degree of collinearity.

Explanatory variables	VIF	
Periods	1994-2010	2011-2013
year	1.03	1.04
qt	1.16	1.25
area	3.05	2.94
hpb	1.84	1.69
fishery	1.89	1.52
sst	4.70	4.29
lat5	5.90	6.88

Figures

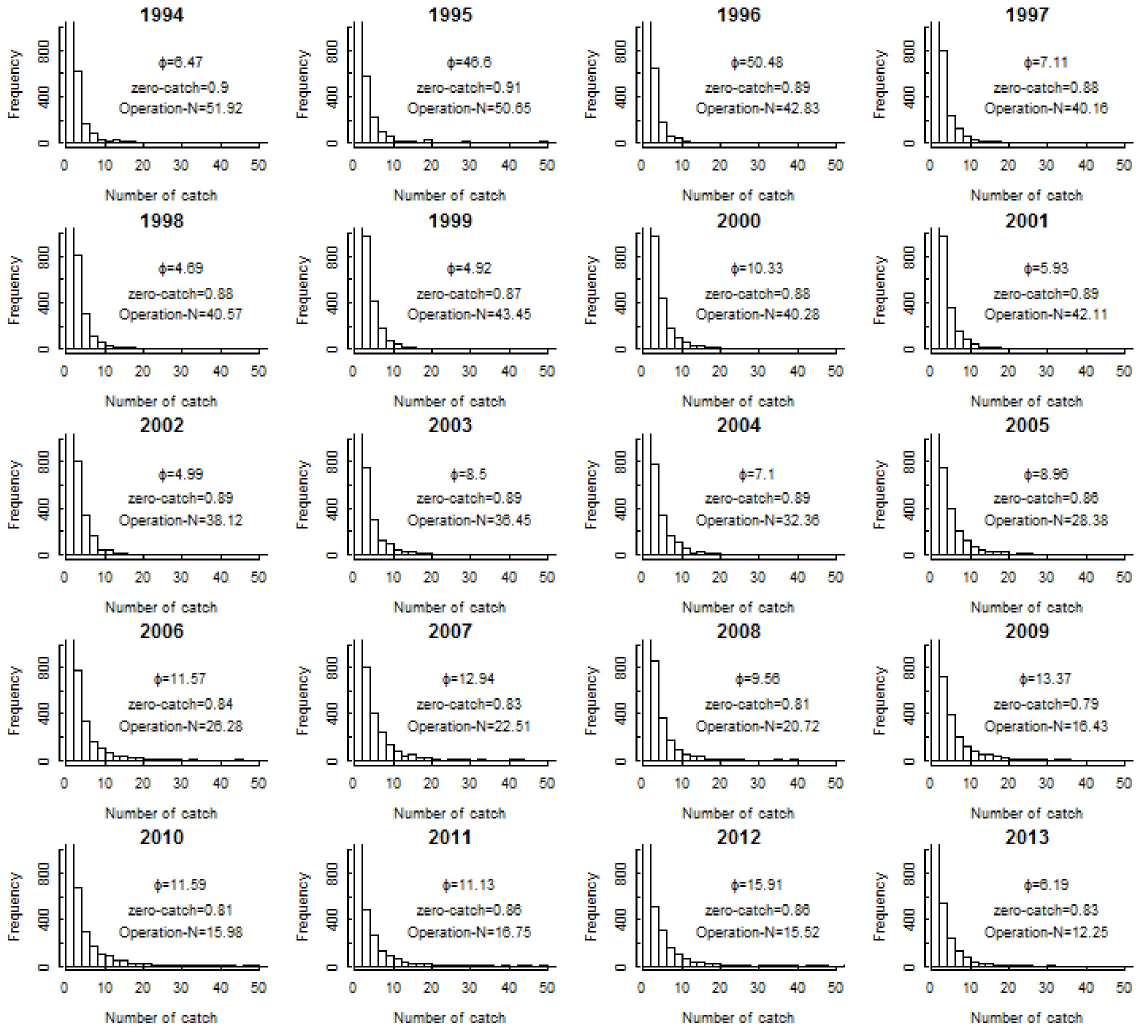


Fig.1 Frequency distribution (Number) of shortfin mako catch per operation from 1994 to 2013. Y axis is truncated by 1000 due to the large number of zero catch. "Φ" denotes the dispersion ratio (mean/variance), "zero-catch" denotes the ratio of zero catch, and "Operation-N" denotes the total number of operation (thousands).

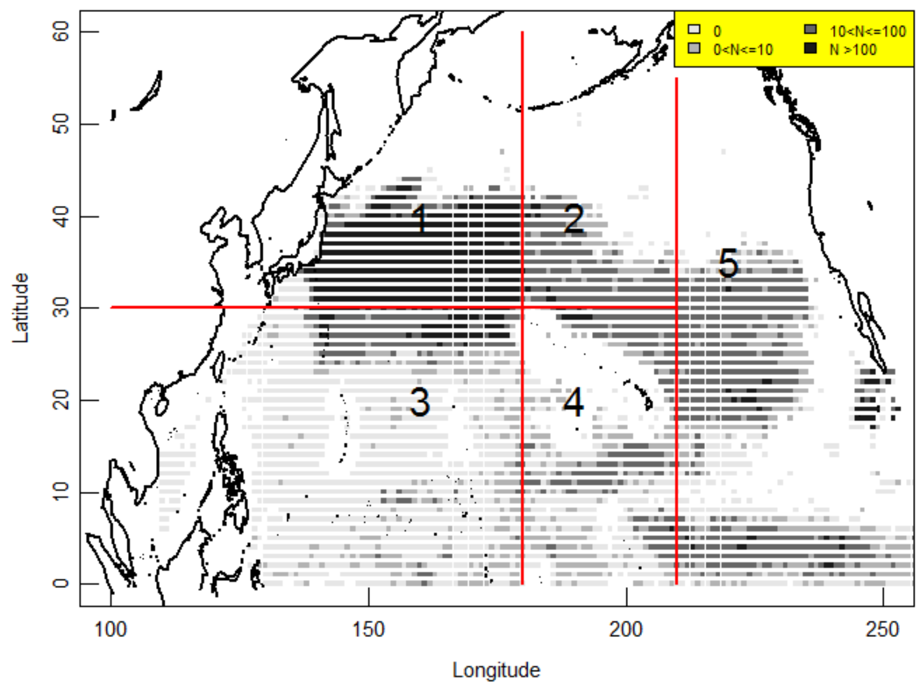


Fig. 2 Catch location of shortfin mako shark in the North pacific and the total number of catch from 1994 to 2013, and area stratification for CPUE standardization.

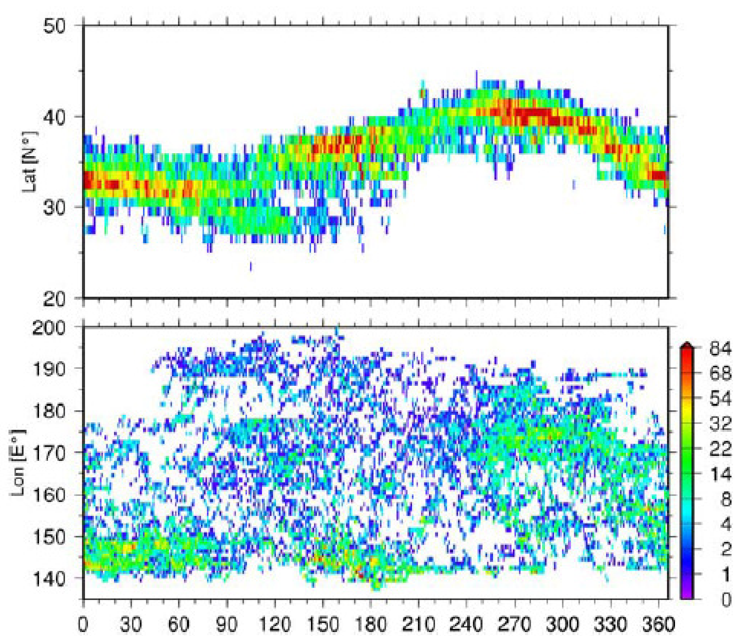


Fig. 3 Spatiotemporal change of catch number (color scale). X-axis is the serial date within a year. Y-axis of upper and lower figure represents latitude and longitude, respectively. Color reflects the number of catch (Referred to fig.2 in Shiozaki et al. 2013).

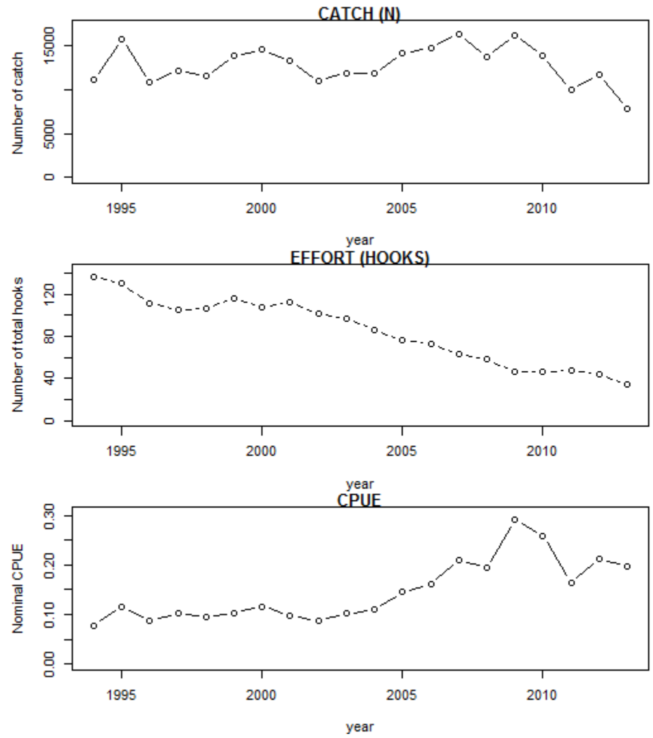


Fig. 4 Annual changes in number of catch for shortfin mako (upper figure), number of total hooks (millions) (middle figure), and nominal CPUE (per 1000 hooks) (lower figure).

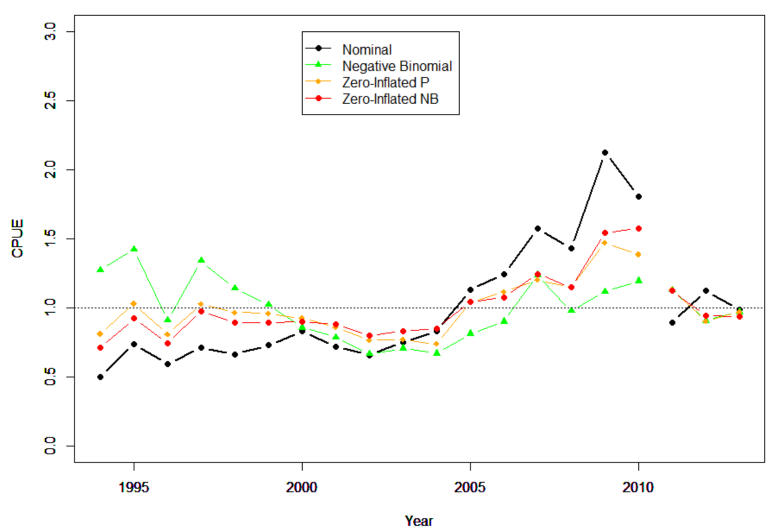


Fig. 5. Annual trends of nominal CPUE and estimates of standardized CPUEs (least squares means) for shortfin mako under three models (NB: Negative Binomial, ZIP: Zero-Inflated Poisson, and ZINB: Zero-Inflated Negative Binomial) for the full models.

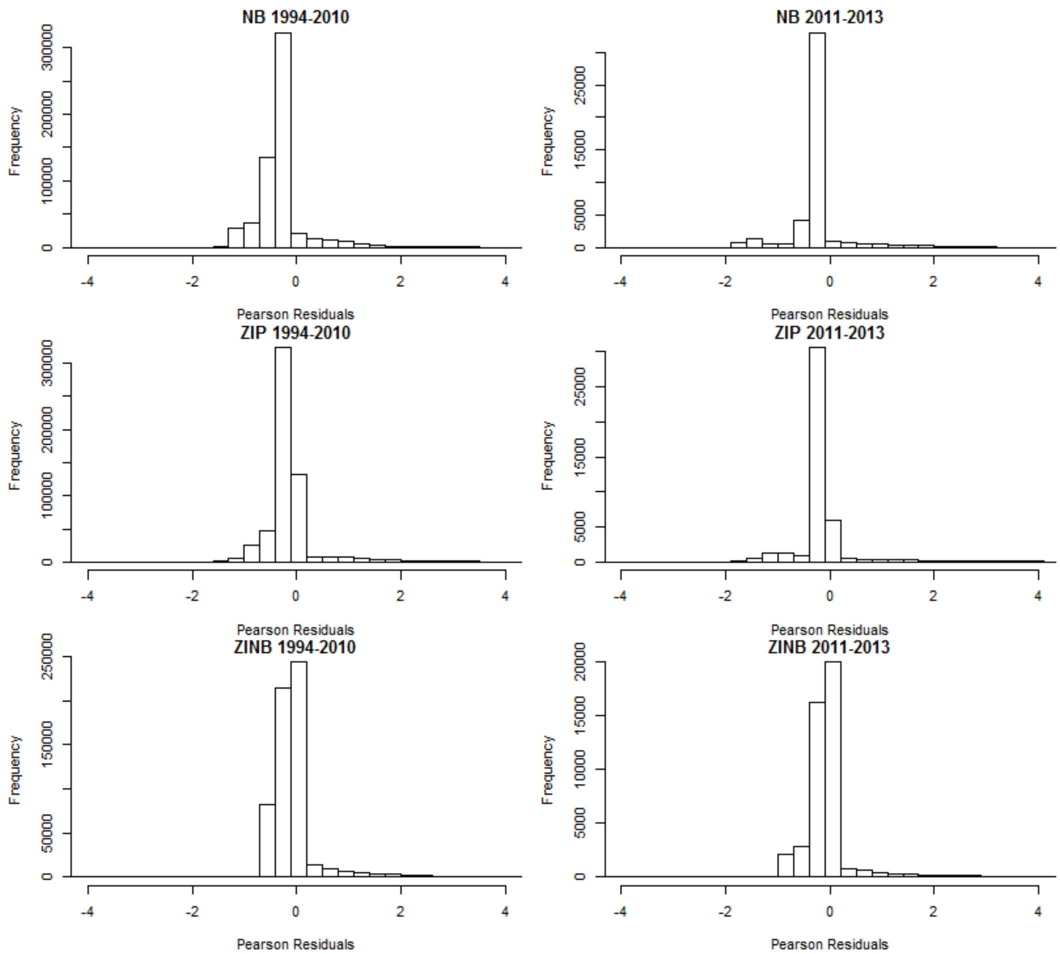


Fig. 6 Histograms of Pearson residuals for CPUE values under the Negative Binomial (NB), Zero-Inflated Poisson (ZIP), and Zero-Inflated Negative Binomial (ZINB) for two periods 1994-2010 and 2011-2013.

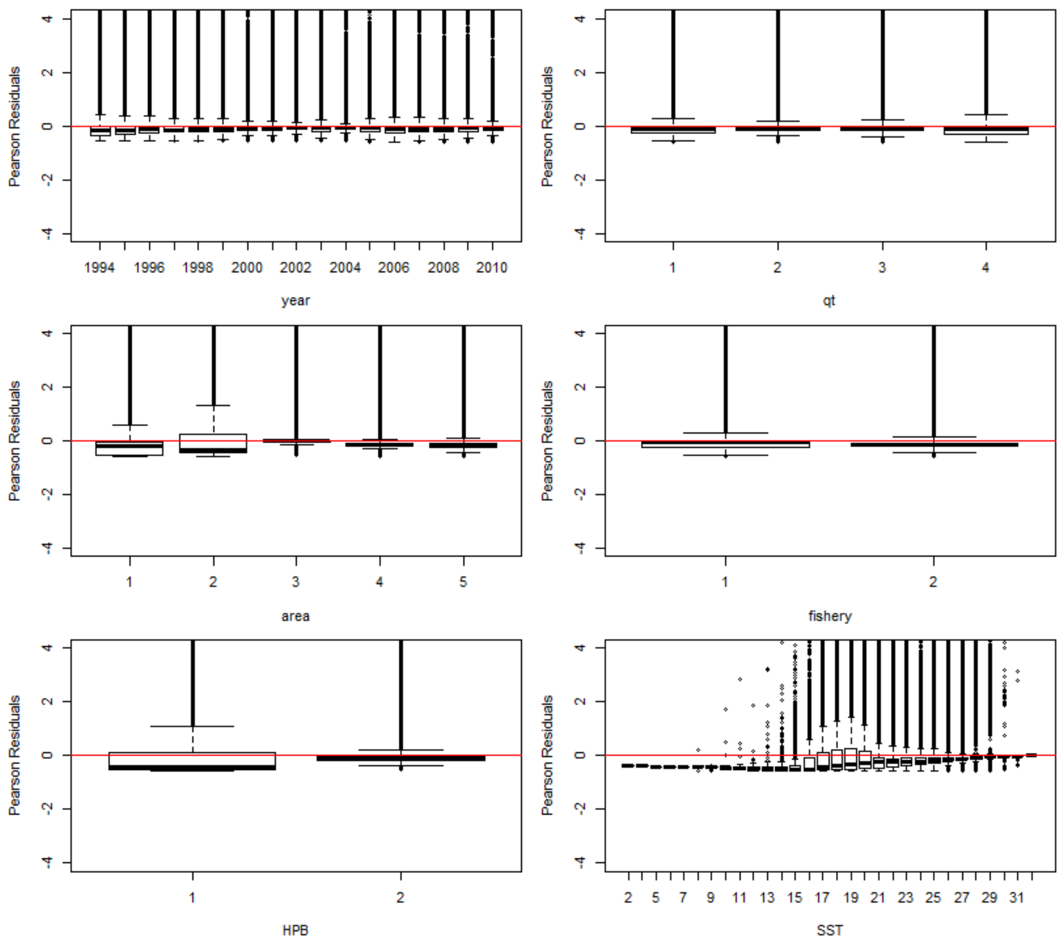


Fig. 7 Box plots of Pearson residuals for CPUE values for 1994-2010 against each explanatory variables under Zero-Inflated Negative Binomial (ZINB). Numerical values 1 and 2 of “fishery” denotes “offshore” and “distant water”, respectively. Numerical values 1 and 2 of “HPB” denotes “shallow set” and “deep set”, respectively.

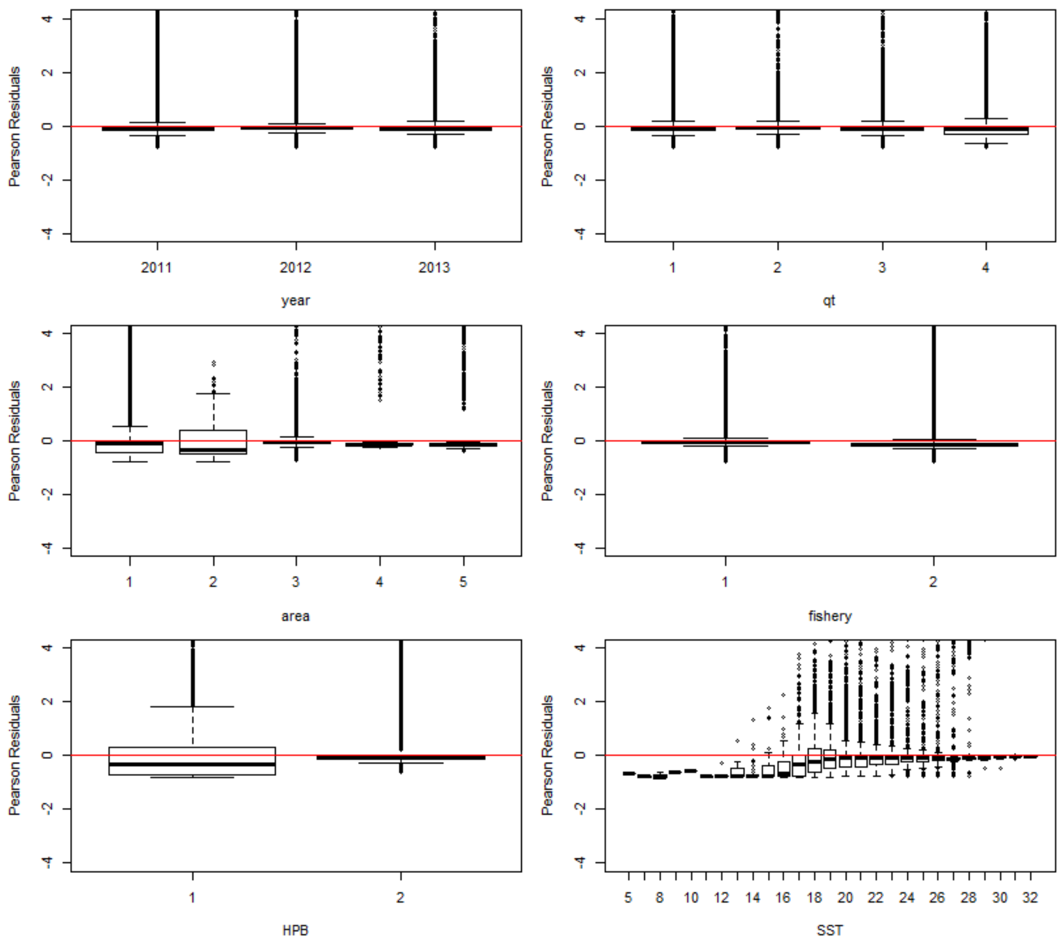


Fig. 8 Box plots of Pearson residuals for CPUE values for 2011-2013 against each explanatory variables under Zero-Inflated Negative Binomial (ZINB). Numerical values 1 and 2 of “fishery” denotes “offshore” and “distant water”, respectively. Numerical values 1 and 2 of “HPB” denotes “shallow set” and “deep set”, respectively.

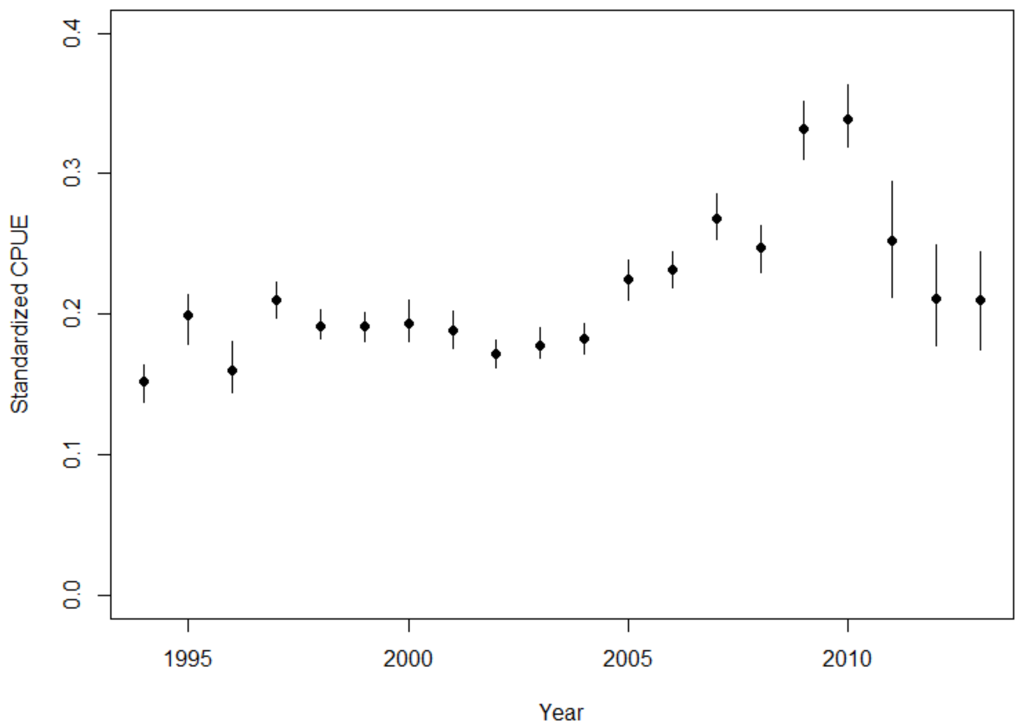


Fig. 9 Standardized CPUE by the best fitted ZINB (filled black circle) and the 95% confidence intervals (vertical lines).

Appendices

Supplementary information for the manuscript is provided in this appendices.

Appendix A

Supplemental information about explanatory variables

The effect of the interaction on the standardization of the CPUE was not considered due to the limitation of the computer ability. However, the interaction terms have a potential to improve the fitting of the model to the data. Fig. A1 provides two interactions of each main effect with ratio of positive catch and nominal CPUE based on positive catch, respectively. Weak interactions between two main effects were mostly seen for the ratios of positive catch except for year & quarter and year & area interactions. On the other hands, nominal CPUE based on positive catch showed strong interactions between most of the two main effects except for year & gear. In future work, the introduction of these interactions will be necessary if the computation ability is improved.

An inclusion of sea surface temperature (SST) in the model could be quite informative. In this study, a linear relationship between SST and positive catch was assumed, however, non-linear relationships such as a quadratic relation might be better because shortfin mako shark has optimum temperature (Fig. A2). An additional computations was made using a quadratic relation to compare the effect between a linear and quadratic relations. But the effects was very small and the value of AIC was slightly reduced from 557864.1 to 557842.7.

SST and other main factors such as season, area, and latitude should have a big correlation and such effect should be removed to avoid the issue of collinearity. In this study, variance inflation factor (VIF) was used to remove the explanatory variables with high correlations (Zuur et al. 2009). Latitude of set by resolution of 5 × 5 degree square was removed due to a high degree of collinearity with SST (Table 6). The relationships between latitude and SST showed that the strong negative correlations (Fig. A2).

Impact of each explanatory variables on the standardized CPUE was examined (Fig. A3). Each main effect of the full model was sequentially reduced for binomial model part and negative binomial model part of ZINB model. In compare to the full model (model 1), the other models tends to overestimate the level of CPUE in the period before 2000, and underestimate after 2004. Among the factors except for year, the impacts of area, gear, and fishery were strong and these factors had largely changed the trends of CPUE.

Appendix B

Filtering of the data

Data filtering by prefecture, where the vessels were registered, were conducted to examine the effect of the filtering on the annual trends of the standardized CPUE by zero-inflated negative binomial model. The data with "Thohoku-Hokkaido" areas were selected because the reporting ratio of these vessels were high (see appendix D). These facts might indicate that the fishermen had a tendency to unload shortfin mako sharks without discarding and releasing.

Frequency distribution (Number) of positive shortfin mako catch per operation were shown in Fig. A4. The frequency distributions were quite similar between two data sets of "All area" and "Thohoku-Hokkaido". Annual trends of catch number of "Thohoku-Hokkaido" data and the estimates of annual standardized CPUE were almost same as those of "All data" except for 1994-1996 (Figs. A5 and A6).

Appendix C

Comparisons between two areas

Annual trends of catch, effort (number of hooks), and nominal CPUE of shortfin mako sharks between two areas: "Entire area" and "Taikei area (25-40 ˚N and 140-150 ˚E)", where the same area used for the standardization of CPUE with the survey data (Ohshimo et al 2014), were compared using the logbook data to examine the consistencies of the trends in the different areas. As the consequence, a similar trends of nominal CPUE were observed between "entire areas" and the "Taikei areas" (Fig. A7). These results indicates that the "Taikei area" has a potential to estimate the population indices as a representative of the entire area, and the effects of the fishery dependent data on the standardized CPUE might be small as for the estimates before 2010.

Appendix D

Summaries of Japanese log book data in relation to the shortfin mako sharks

The catches in area-1 were continuously great in number for 1994-2013 (Fig. A8). Plenty of catches in area 5 was observed in the beginning of 1990s with high fishing effort (about 45 million hooks). Historical trends of CPUEs in area 1 and 2 were higher than those in any other areas (Fig. A8).

Number of catch by prefecture indicated that the most common occupation of the catch in whole areas was vessels in Miyagi prefecture (Fig. A9), and the vessels in Northern parts of Japan “Thohoku and Hokkaido” accounted for 88 % catch and the total effort was 53.3 %. Most of the offshore-shallow (HPB < 7) operations were occupied by vessels in Miyagi prefecture, while most of the offshore-deep (HPB > 6) operations were occupied by vessels in Western parts of Japan and Miyagi prefecture (Fig. A10). Distant water fishery mostly comprised deep settings (HPB > 6) and the vessel in Miyagi prefecture occupied the operations (Fig. A10).

Positive catch of shortfin mako was frequently reported for offshore-shallow operations in the North area (northward of 25˚ N) (Fig. A11). Zero-catch was outstanding for offshore-deep operation in South area (southward of 20 ˚ N) (Fig. A12). Positive catch was constantly reported for distant water deep operations in the whole areas, however, the number of positive catch in South (southward of 20 ˚ N) was smaller than that in North (northward of 20˚ N) (Fig. A14). The number of positive catch was entirely large for the vessels in “Tohoku-Hokkaido” excluding the offshore deep operations (Fig. A11-14). Shallow operations have a tendency to catch more shark species than tuna species, while deep operations have a tendency to catch tuna species (Fig. A11-14).

Reporting ratio (number of sets with shortfin mako recorded / total number of sets) was clearly different by the areas (Figs. A15-18). The ratios in areas 1 and 3 were 20-40 %, and the ratios in areas 2 and 4 were 60-80 %. It should be paid attention the interpretation of these values because the numbers of the prefecture and the data used for the calculation were different by areas and latitude. The reporting ratio for distant water shallow operation were about 40-60 % at any areas except for area 5. The variability of the reporting ratio by prefecture where the vessels were registered was not remarkable. The reporting ratio in area 1, 2 and 3 for offshore deep operation were largely different by the prefecture where the vessel was registered, while the reporting ratio of vessels in “Tohoku and Hokkaido” area was higher than those in the western parts of Japan. The reporting ratio of vessels in “Tohoku and Hokkaido” area was almost same among areas except for area 4. The reporting ratio for distant water deep operation were clearly different by the prefecture where the vessel was registered. The reporting ratios in area 1 and 2 (higher latitude) were higher than those in areas 3, 4 (lower latitude) and 5 (west longitude).

The CPUE of shortfin mako shark by fishery, area, and prefecture where the vessel was registered was difficult to summarize the general outline due to the different number of the prefectural data. As the rough tendency of the CPUE, the data of “Tohoku and Hokkaido”, in particular Miyagi prefecture, was enough to estimate the annual trends of CPUE. The CPUEs for deep operation tended to be lower than those of shallow operation. These fact might indicate that the size of the caught sharks were different by the fishery and areas. Larger sharks might have a tendency to inhabit in deeper zone. For the data in Miyagi prefecture which had a great amount of data, nominal CPUE for offshore shallow operation had an increasing trends in whole areas except for area 5. The CPUE of Hokkaido data showed similar trends regarding to areas 1, 2 and 3. The CPUEs for distant water shallow operation had a different trends by the prefecture. The CPUEs for distant water deep operation had a tendency to be low levels and almost constant. It was possible to classify the data in an area into several groups by prefecture.

Appendix table

Table A1 Prefecture, the shortened form of prefecture and the area.

Pref.	Shortened form	Area	Pref.	Shortened form	Area
Hokkaido	HK	Tohoku-Hokkaido	Mie	ME	Others
Aomori	AM	Tohoku-Hokkaido	Wakayama	WK	Others
Iwate	IT	Tohoku-Hokkaido	Kagawa	KA	Others
Miyagi	MG	Tohoku-Hokkaido	Shimane	SN	Western parts of Japan
Fukushima	FS	Tohoku-Hokkaido	Tokushima	TO	Western parts of Japan
Akita	AT	Tohoku-Hokkaido	Kochi	KO	Western parts of Japan
Yamagata	YM	Tohoku-Hokkaido	Ehime	EH	Western parts of Japan
Toyama	TY	Tohoku-Hokkaido	Fukuoka	FO	Western parts of Japan
Ishikawa	IK	Others	Nagasaki	NS	Western parts of Japan
Fukui	FK	Others	Oita	OT	Western parts of Japan
Ibaragi	IG	Others	Miyazaki	MZ	Western parts of Japan
Chiba	CB	Others	Kumamoto	KM	Western parts of Japan
Tokyo	TK	Others	Kagoshima	KG	Western parts of Japan
Kanagawa	KN	Others	Okinawa	ON	Western parts of Japan
Shizuoka	SO	Others			

Appendix figures

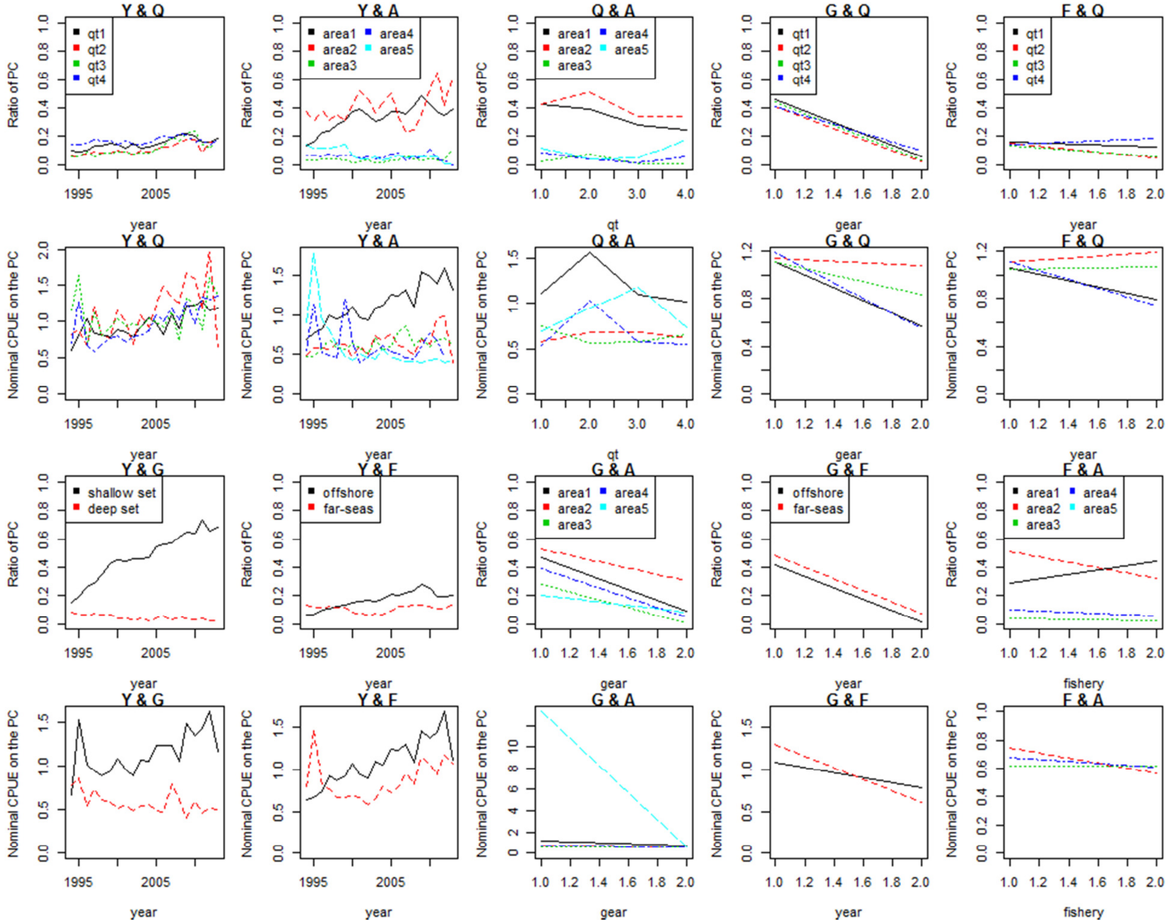


Fig. A1 Two interaction of each main effect for ratio of positive catch (PC) and nominal CPUE based on the PC. Y is year (1994-2013), Q is season (Qt.1-Qt.4), G is gear (shallow set and deep set), A is stratified area (1-5) and F is fishery type (offshore and distant water). Some lines are disappearance due to the missing data.

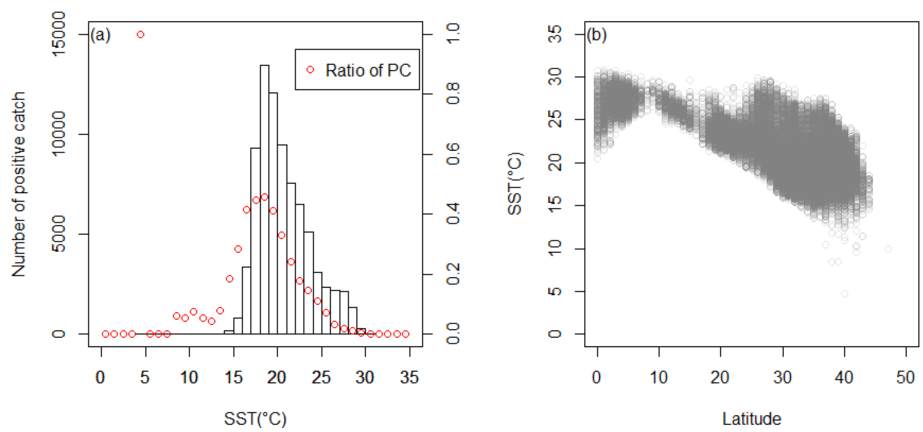


Fig. A2 (a) Number of positive catch for shortfin mako and the ratio of the positive catch against sea surface temperature (SST), (b) Relationships between latitude and SST for positive catch of shortfin mako.

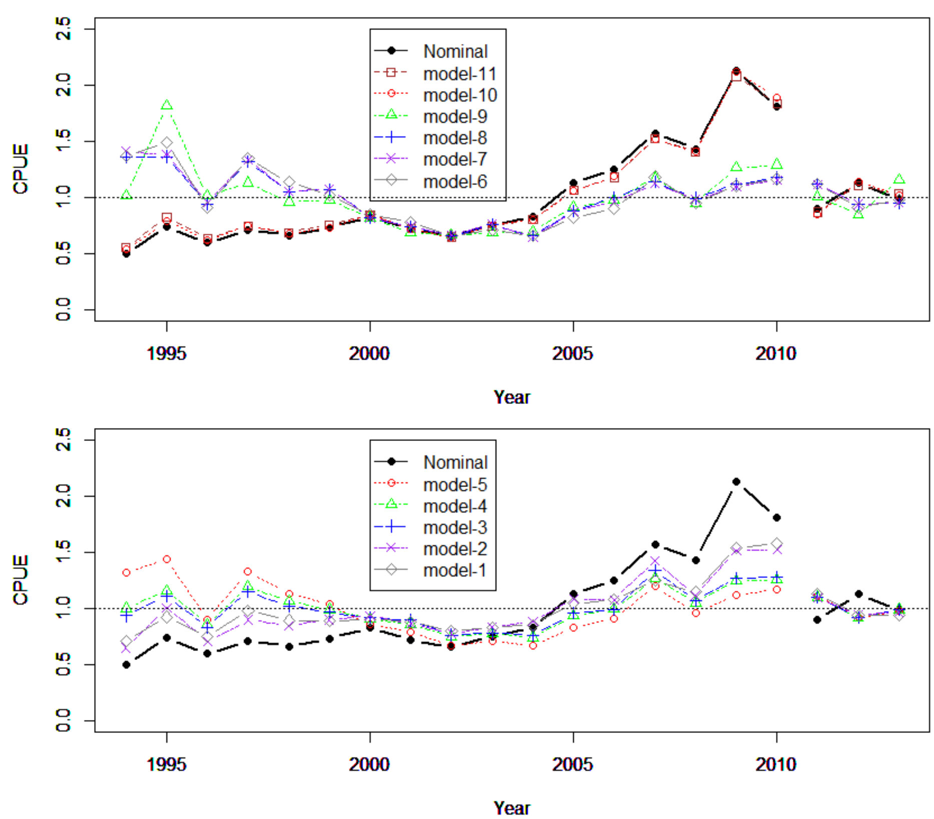


Fig. A3 Impacts of each explanatory variables of ZINB model on standardized CPUE of shortfin mako. Y axis denotes the relative CPUE. Model 1 – 11 corresponds to the models in Table 2.

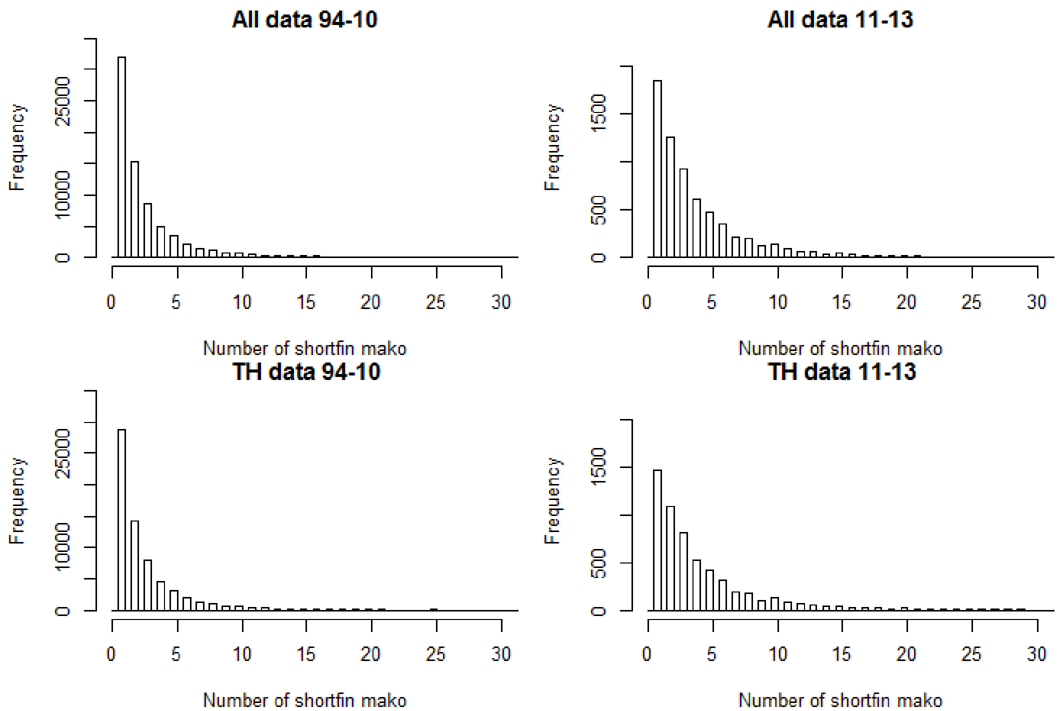


Fig. A4 Frequency distribution (Number) of positive catch per operation for "All data" and "Thohoku-Hokkaido (TH) data" for 1994-2010 and 2011-2013, respectively.

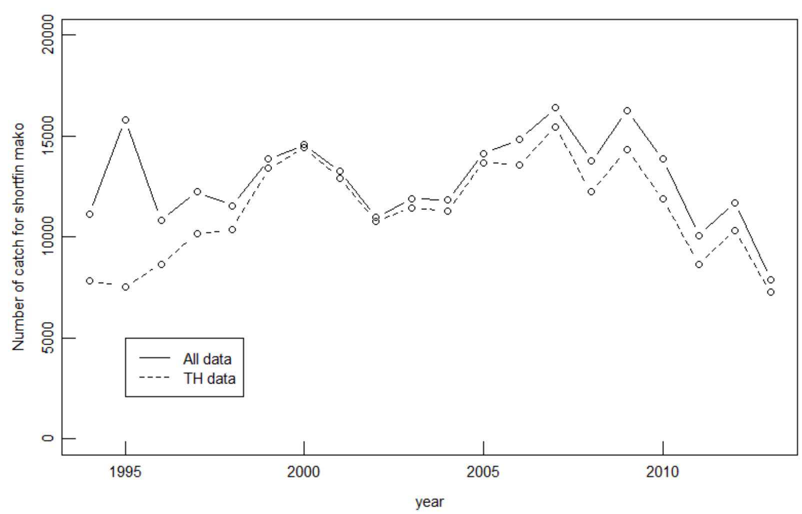


Fig. A5 Comparisons of annual trends of catch number for shortfin mako between two data sets: "All data" and "Thohoku-Hokkaido data".

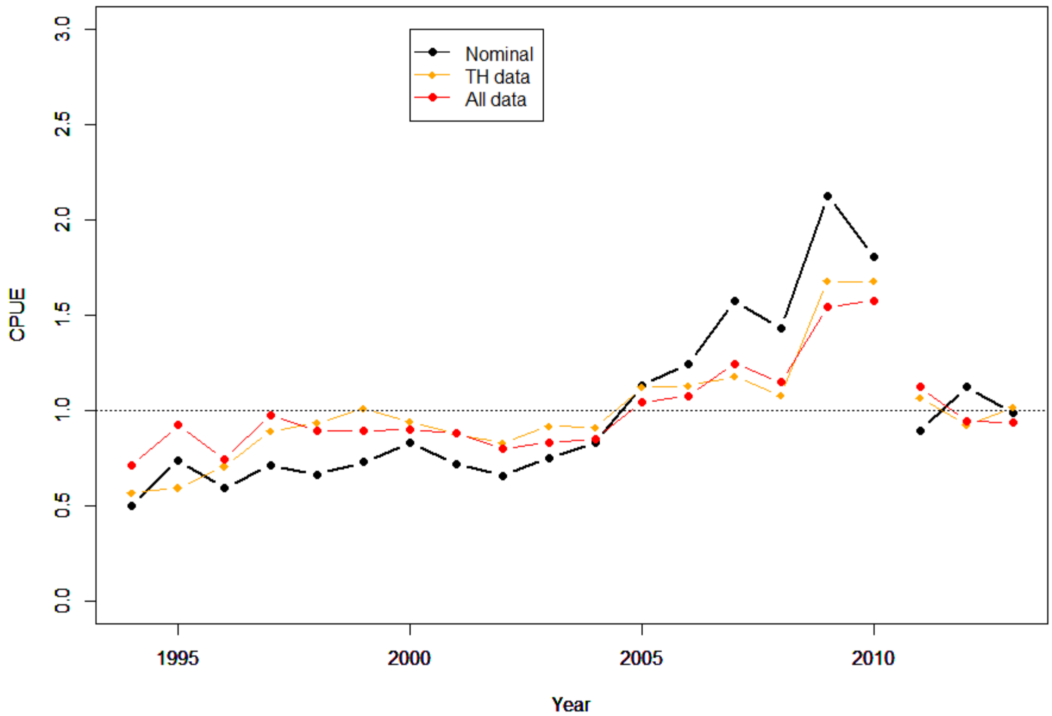


Fig. A6 Comparisons of estimates of annual standardized CPUE (least squares means) for shortfin mako for the full model (Zero-Inflated Negative Binomial) between two data sets: “All data” and “Thohoku-Hokkaido data”.

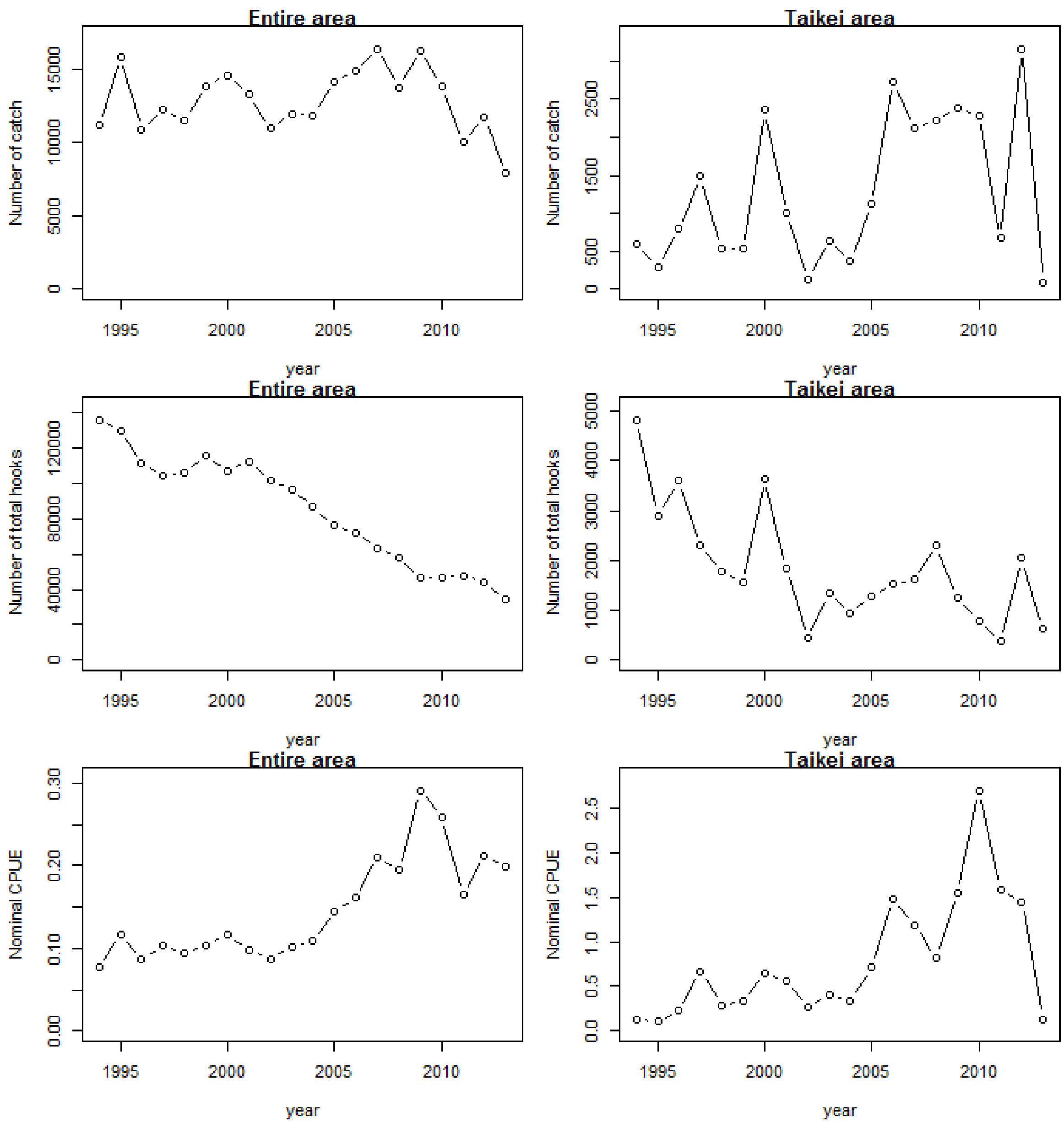


Fig. A7 Annual changes in number of catch for shortfin mako (upper figure), number of total hooks (×1000) (middle figure), and nominal cpue (per 1000 hooks) (lower figure) between entire North Pacific and Taikei area (25-40 ˚N and 140-150 ˚E).

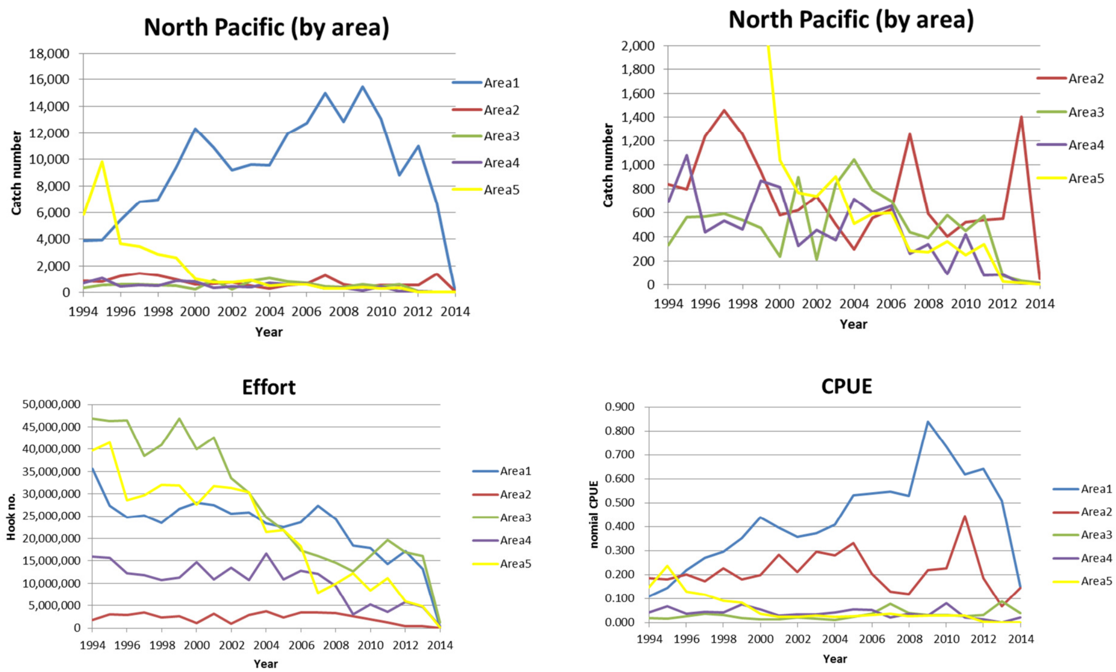
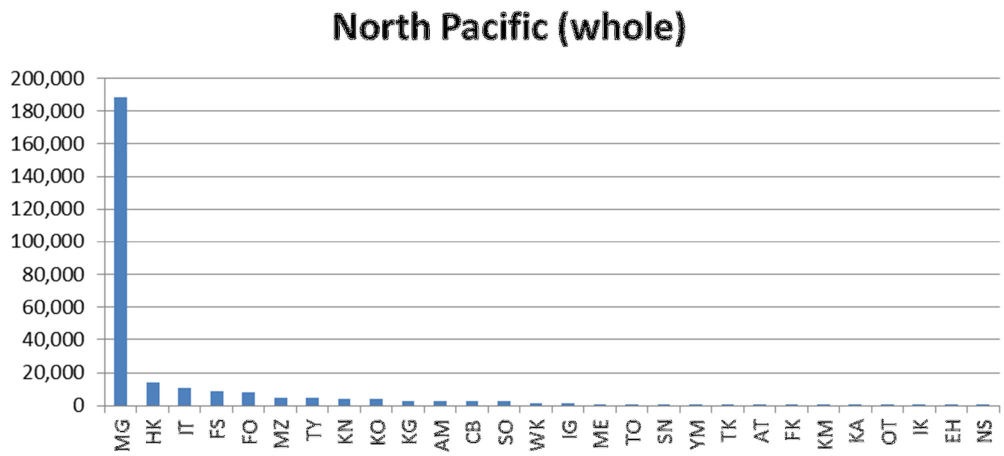


Fig. A8 Annual trends of catch number, effort (number of hooks) and nominal CPUE of shortfin mako by areas. Y axis is truncated by 2000 for the upper right figure.



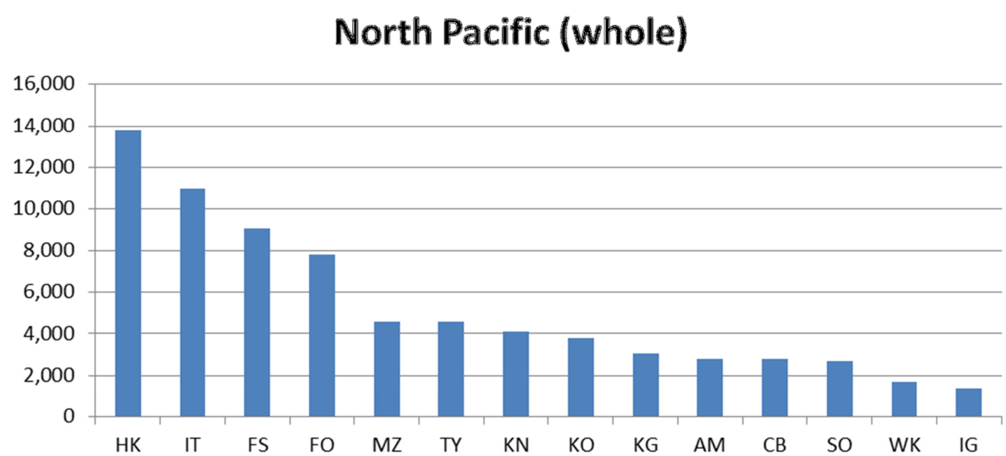


Fig. A9 Total catch number by prefecture. Y axis is truncated by 16,000 for lower figure. “MG” denotes the Miyagi prefecture. Other shortened form are summarized in Table A1.

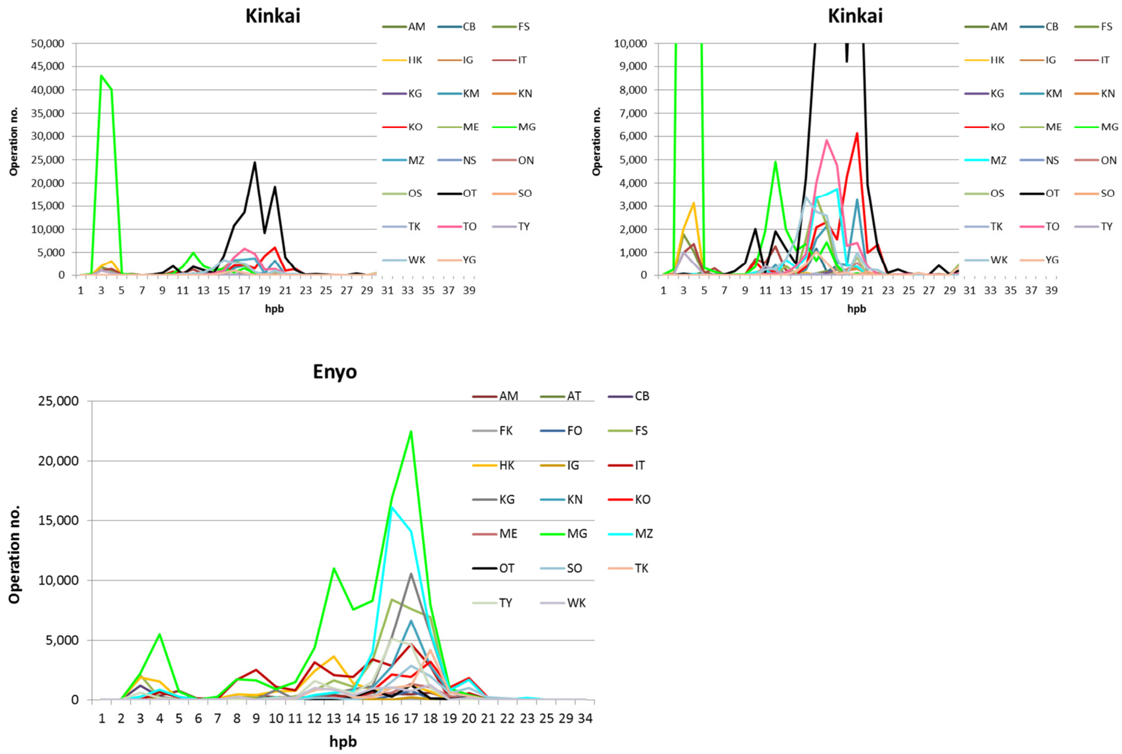


Fig. A10 Prefectural operation number against hooks per basket (HPB) for offshore (Kinkai) and distant water (Enyo) fisheries.

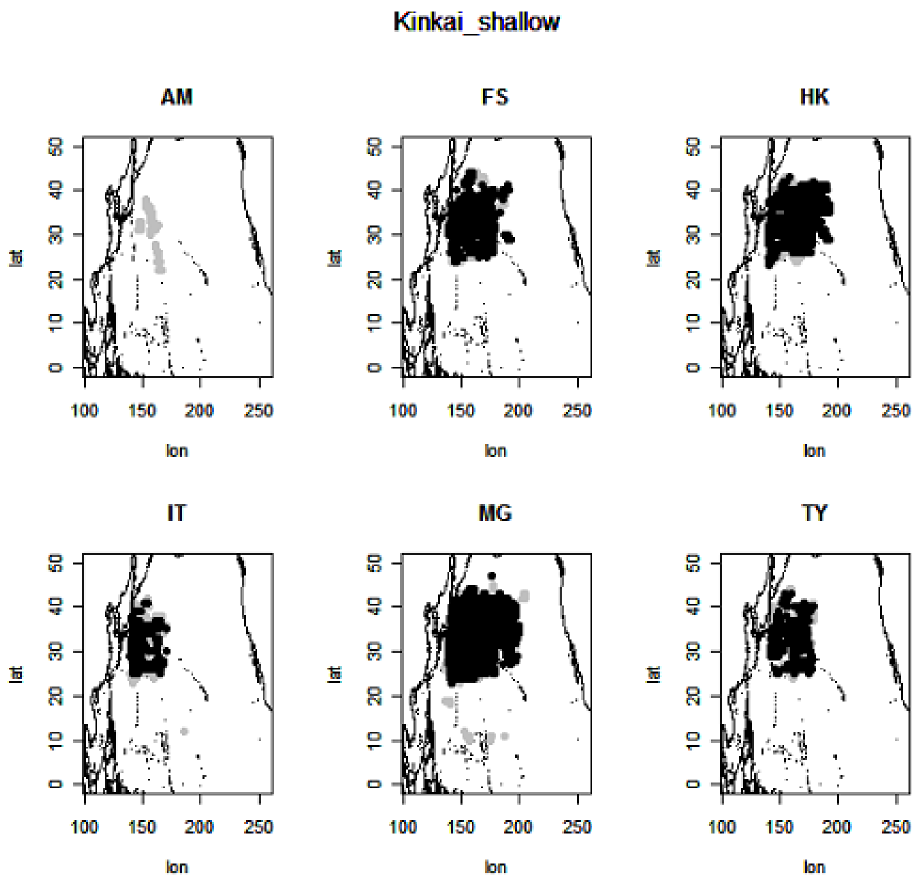


Fig. A11 Location of the operation by prefecture where the vessel is registered (Black circle) and the positive catch of shortfin mako (grey circle) for offshore shallow fishery.

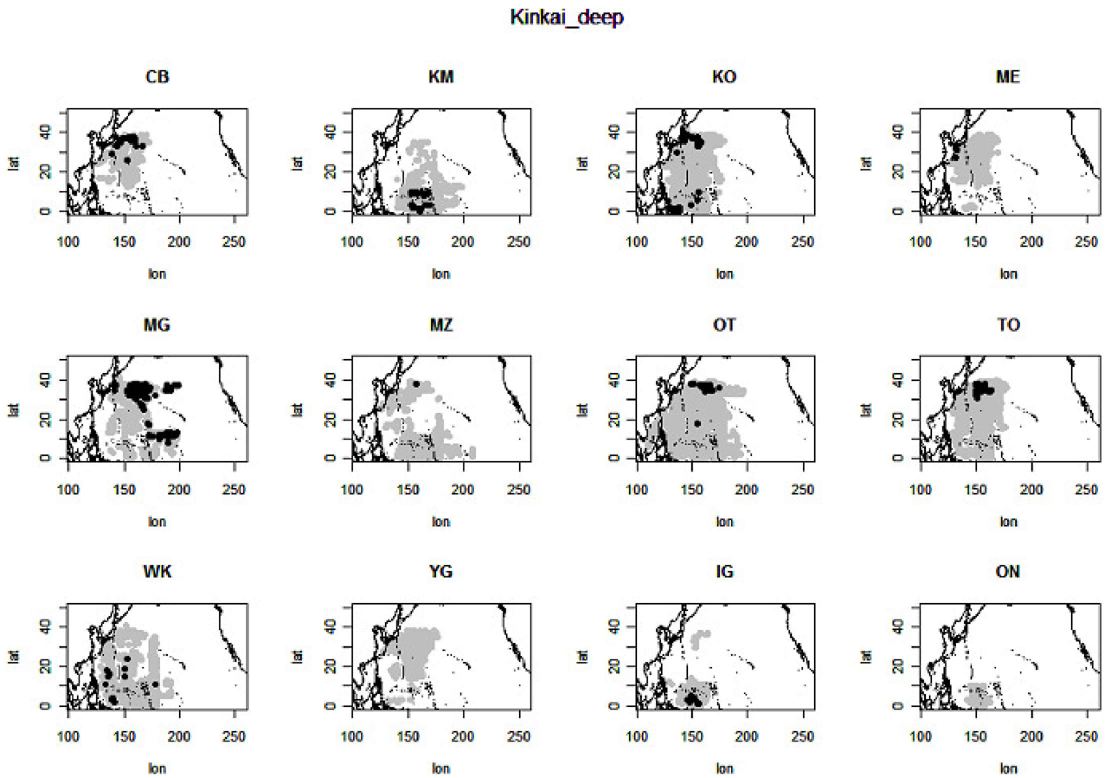


Fig. A12 Location of the operation by prefecture where the vessel is registered (Black circle) and the positive catch of shortfin mako (grey circle) for offshore deep fishery.

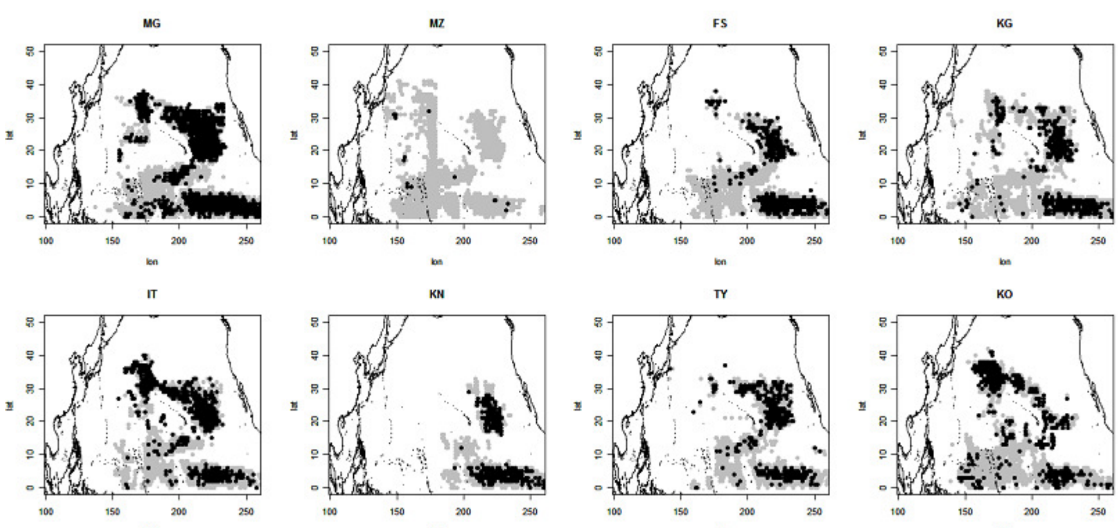


Fig. A13 Location of the operation by prefecture where the vessel is registered (Black circle) and the positive catch of shortfin mako (grey circle) for distant water shallow fishery.

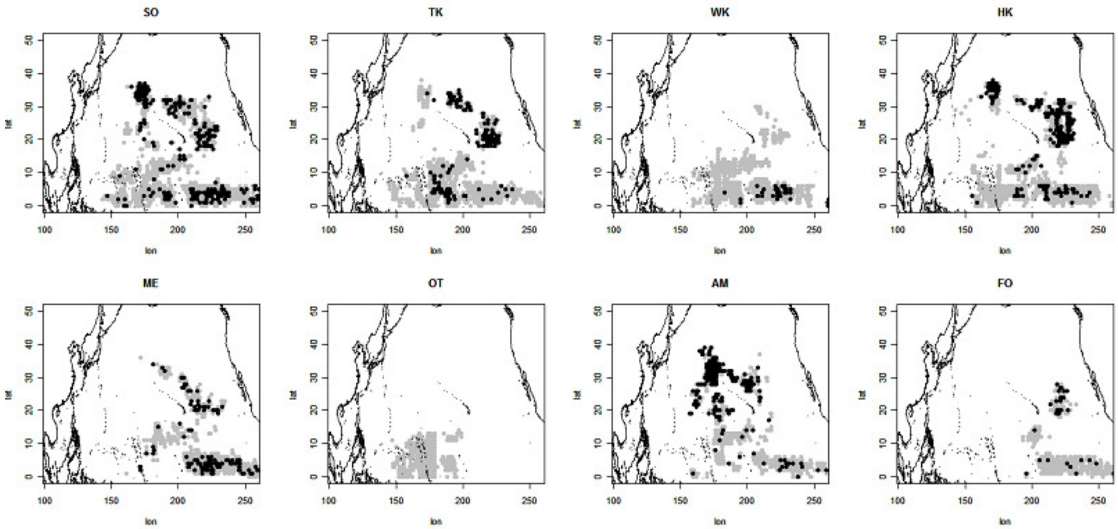


Fig. A14 Location of the operation by prefecture where the vessel is registered (Black circle) and the positive catch of shortfin mako (grey circle) for distant water deep fishery.

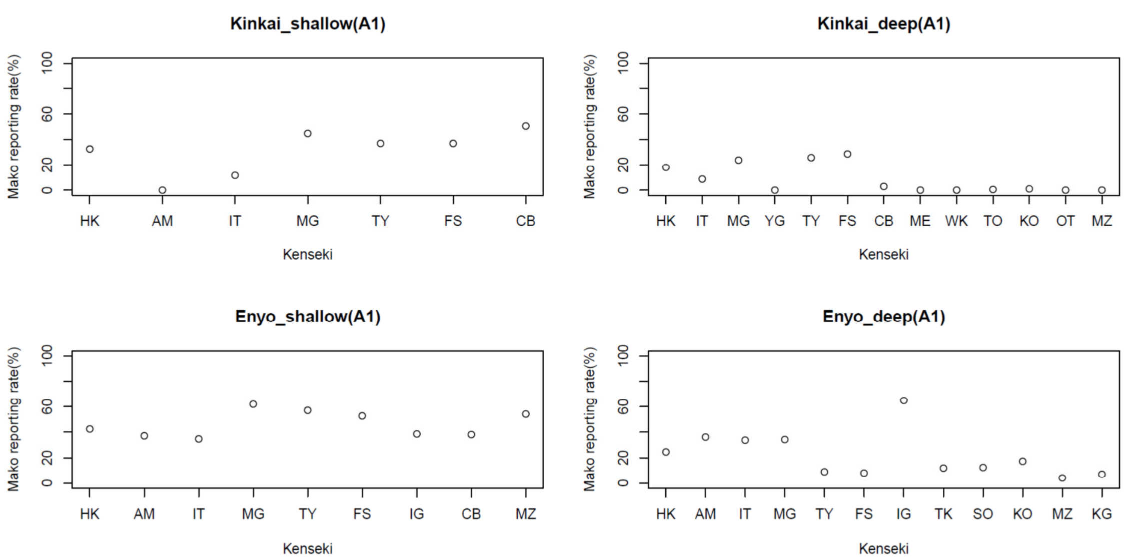


Fig. A15 Reporting ratio of shortfin mako catch by prefecture for fishery, gears, and area 1.

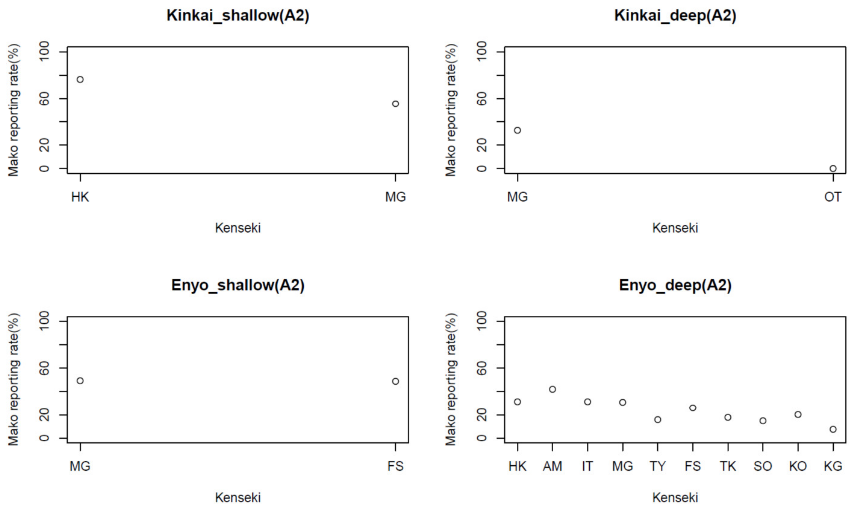


Fig. A16 Reporting ratio of shortfin mako catch by prefecture for fishery, gears, and area2.

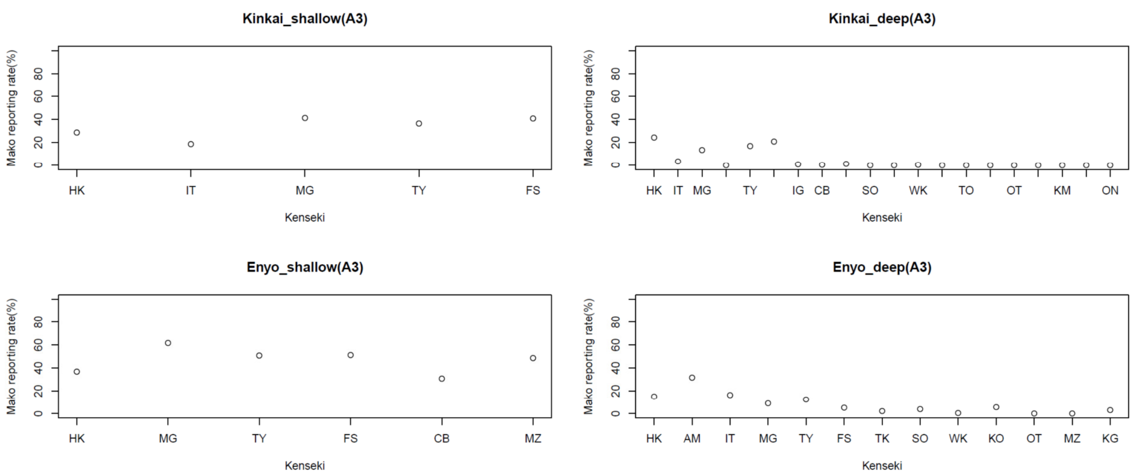


Fig. A17 Reporting ratio of shortfin mako catch by prefecture for fishery, gears, and area 3.

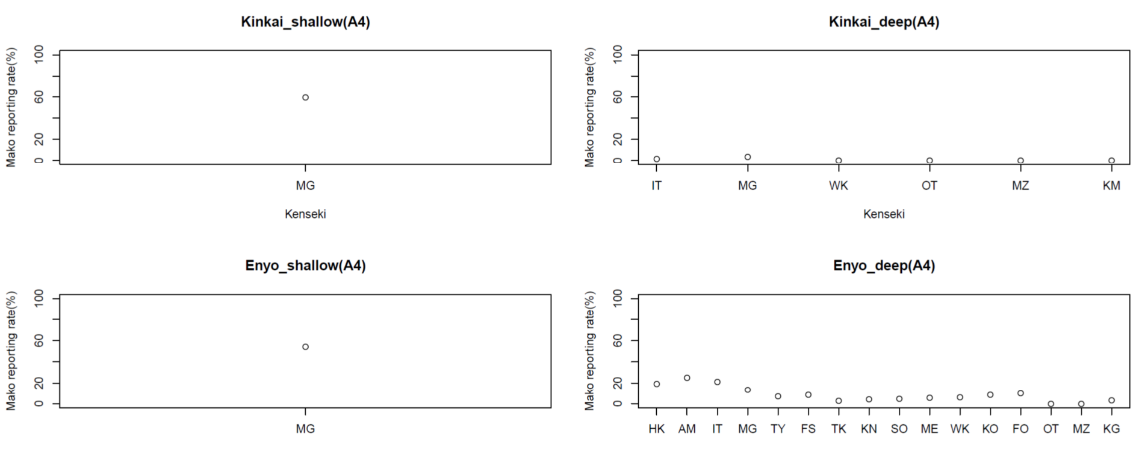


Fig. A18 Reporting ratio of shortfin mako catch by prefecture for fishery, gears, and area 4.

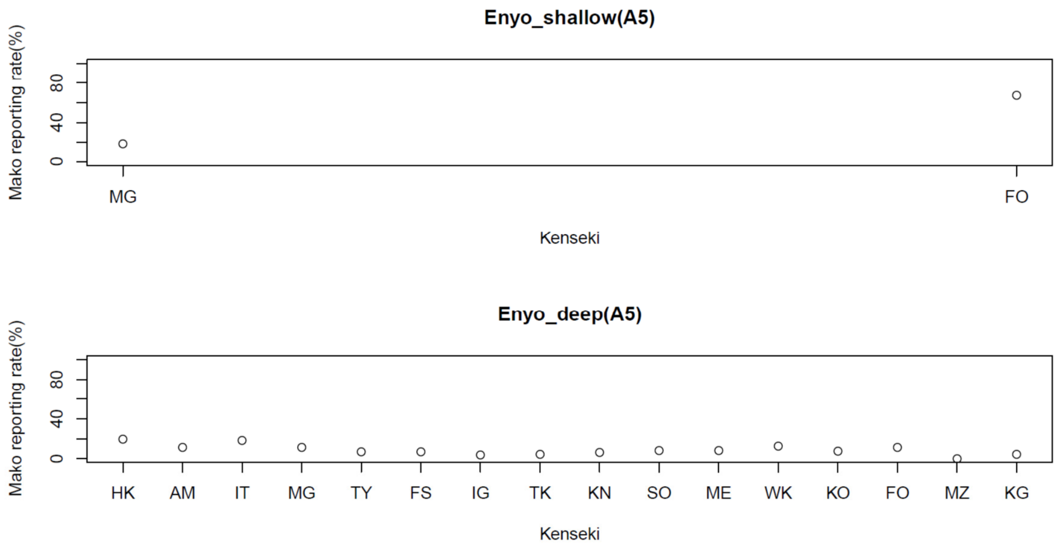


Fig. A18 Reporting ratio of shortfin mako catch by prefecture for fishery, gears, and area 5.