ISC/18/SHARKWG- 3/1

Preliminary analysis of blue shark catches in the Japanese high seas squid driftnet fishery in the North Pacific Ocean from 1981 to 1992[1]

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[1] Working document submitted to the ISC Shark Working Group Workshop, 8-14 November 2018, National Kaohsiung University of Science and Technology, Kaohsiung 811, Taiwan.

Abstract
This working paper predicted annual catch of blue shark (*Prionace glauca*) caught by Japanese high seas squid driftnet fishery in the North Pacific during 1981 and 1992. Since the logbook data from 1981 to 1992 have no species-specific information about sharks, the annual catch of blue shark was predicted using generalized linear model and generalized additive model with scientific observer data in 1990 and 1991 as well as the logbook data. The coefficients of explanatory variables estimated from the four models with scientific observer data and the relevant information about factors of logbook data were used to predict the catches. The predicted catches of blue shark by factors were aggregated to calculate the annual catch. The predicted annual catch of blue shark tended to increase since the early 1980s and peaked around 1988-1989, and subsequently decreased.

Introduction
The Japanese high seas driftnet fisheries consist of “the large mesh driftnet fishery” which targeted striped marlin (*Kajikia audax*) and albacore (*Thunnus alalonga*) (Nakano et al., 1993) and “the squid driftnet fishery” which targeted flying squid (*Ommastrephes bartrami*) (Yatsu et al., 1993). A substantial number of sharks were caught by these fisheries as non-target species, especially blue shark, (*Prionace glauca*) in 1980s and the beginning of 1990s (McKinnell and Seki, 1998).

In the stock assessment of North Pacific blue shark (ISC, 2017), the historical catches of blue shark caught by the squid driftnet fishery from 1981 to 1992 were used. However, the annual catches had a large uncertainty because the annual catches from 1981 to 1988 were a constant value (13,331 tons). It is therefore necessary to predict more accurately the historical catches of blue shark.

Catch is an essential information for the stock assessments of sharks. However, logbook data reported by fisherman is frequently lacking a detailed information such as a species-specific name of sharks and the accuracy of the catch record is low due to an underreporting. Although the scientific observer data have a problem of the lower data coverage compared to logbook data (Yatsu et al., 1993), the observer data is more useful to validate the reporting rates of the logbook data and to estimate accurately the catch rates (i.e. catch per unit effort; CPUE) of blue shark. It is therefore possible to estimate accurately the annual catch of blue shark through multiplying the annual catch rate of observer data by the annual fishing effort collected by logbook data.

The objective of this document paper is to predict the catches of blue shark caught by Japanese squid driftnet fishery from 1981 to 1992 using the logbook data and scientific observer data.

Materials and methods

Data source

1. Logbook data

This data aggregated by 10 days from 1981 to 1992 contains the following information; number of operations; fishing time (year and month); latitude and longitude by 1×1 degrees; fishing effort in number of "tans" per operation; and catch in weight (kg) of several species. The "tan" is a unit of net in Japanese and the standard length of one "tan" is approximately 50 m. A large number of "tans" (approximately 70-200 tans) are connected to form "section" and the driftnet used in an operation normally consists of 7-10 "sections" (Yatsu et al., 1993). The "species" comprises of the flying squid, Pacific pomfret (*Brama japonica*), sharks (no species-specific), skipjack tuna (*Katsuwonus pelamis*), yellowtail (*Seriola dumerlli*) and billfishes. The zero-catch ratio of sharks was considerably high (80%) on a basis of fishing operations for 10 days.

Since the regulation for squid driftnet fishery (restricted the fishing period to 7 months from June 1 to December 31 and the fishing area to 20-46^{o}N and 170^{o}E-145^{o}W) was established by Japanese government in 1981 (Yatsu et al., 1993), the operational area was changed seasonally from southern water (mainly 35-40^{o}N in quarter 2; May-June) to northern water (mainly 40-45 ^{0}N in quarters 3 and 4; July-December) (Fig. 1). Therefore, the quarters (Qt) were separated into two seasons of Qt1 (May-June) and Qt2 (July-December) in accordance with the shifts of the operational area. The fishing effort (total length of "tans") was calculated as the number of "tans" multiplied by length of one tan (50 m).

2. Scientific observer data

This data was collected by observer on board in 1990 and 1991. This data contains detailed information on each set; fishing date (year, month, day, time), fishing area (latitude and longitude), environmental condition (sea surface temperature and oceanic condition) for each driftnet deployment and retrieval, gear configurations (mesh size, number of deployed "tans", length of one "tan", and number of "section") and catch in number of all species caught by the driftnet fishery.

As with the logbook data, the quarters were separated into two quarters (Qt1: May and June, Qt2: July to December, Fig. 2). The zero-catch ratio of blue sharks was high (46%) on a basis of "section".

Catch estimation

Catches in number of blue sharks caught by the Japanese squid driftnet fishery during 1981 and 1992 were predicted using generalized additive model (GAM) and generalized linear model (GLM) with logbook data from 1981 to 1992 and scientific observer data in 1990 and 1991. The procedures (Fig. 3) are as follows;

I. Since the zero-catch ratio of observer data was high and the count data was over-dispersion, the single model with negative binomial error distribution and the two-step model with binomial and negative binomial error distributions were used. Four different structured models were constructed to estimate the catch rates of blue shark for different combination of factors.

✓ Single model

$\text{Catch} \cong \text{NB}(\mu, \theta)$

$\text{Model1}: \log(\mu) = intercept + factor(Qt) + s(lat, lon) + offset(effort) + error$

$\text{Model 2}: \log(\mu) = intercept + s(lat, lon) + offset(effort) + error$

$\text{Model 3}: \log(\mu) = intercept + factor(Qt) + offset(effort) + error$

$\text{Model 4}: \log(\mu) = intercept + offset(effort) + error$

where Catch is catch in number, NB is a negative binomial model (error) with the mean μ and variance θ, the link function is log, the quarter (Qt) was given as a fixed effect, the interaction of latitude (lat) and longitude (lon) was given using spline function and fishing effort (the number of "tans") were given as an offset term after transforming logarithm.

✓ Two-step model

At the first step, the proportion of zero-catch was estimated using binomial generalized additive (or linear) model with logit link function. At the second step, positive catch was estimated using negative binominal model with log link function.

First step

$\text{r} \cong \text{Bin}(1, \text{p})$

$$\text{Model 1a}: \log\left[\frac{p}{1-p}\right] = intercept + factor(Qt) + s(lat, lon) + error$$

$$\text{Model 2a}: \log\left[\frac{p}{1-p}\right] = intercept + s(lat, lon) + error$$

$$\text{Model 3a}: \log\left[\frac{p}{1-p}\right] = intercept + factor(Qt) + error$$

$$\text{Model 4a}: \log\left[\frac{p}{1-p}\right] = intercept + error$$

where *r* is response variable on presence (=1) or absence (=0) of the blue shark, and *p* represents the encounter probability.

Second step

$pcatch \cong \mathrm{NB}(\mu, \theta)$

Model 1b: $\log(pcatch) = intercept + factor(Qt) + s(lat, lon) + offset(effort) + error$

Model 2b: $\log(pcatch) = intercept + s(lat, lon) + offset(effort) + error$

Model 3b: $\log(pcatch) = intercept + factor(Qt) + offset(effort) + error$

Model 4b: $\log(pcatch) = intercept + offset(effort) + error$

where $pcatch$ represents positive catch in number.

II. The models were run using the R (version 3.3.0). For single model and two-step model, Akaike Information Criterions (AIC) and Bayesian Information Criterions (BIC) were calculated to select the best and better models from four models. The goodness-of-fits for the best models were also investigated using the residual plots to evaluate the fitting the model to the data. The estimated coefficients of intercept and explanatory variables (quarter, and latitude and longitude) from scientific observer data and those with fishing effort from logbook data during 1981 to 1992 were used to predict the catches of blue shark.

III. The best model was basically used to predict the catch. However, the remaining models were also used to predict the catch if the fishing area and/or time of logbook data was not covered by scientific observer data because the spatiotemporal coverage of logbook data is higher than that of scientific observer data. Here, the model is referred to "prediction model".

IV. The predicted catches of blue sharks from the multiple models were aggregated by year.

Evaluation of prediction model

Annual catches of scientific observer data in 1990 and 1991 were predicted using both models (single model and two-step model) with the scientific observer data to evaluate the accuracy of the prediction model. The predicted annual catches in 1990 and 1991 were compared with the observed annual catches (91,233 and 95,567 in 1990 and 1991, respectively) to select the best model. The best model was used to predict the annual catches of blue shark from 1981 to 1992.

Results and discussion

A total of eleven shark species were reported by scientific observer during 1990 and 1991. The catch of blue shark was accounted for 92.5% (*n*=91,233) and 95.4% (*n*=95,567) of the total catch for sharks in 1990 and 1991, respectively. The overall (upper figure), quarter-specific (qts.2-4, lower figures) and monthly-specific spatial distribution of catch in number collected by scientific observer shows that blue shark was mainly caught, especially at June and July in the western water of the operational area (37-42^{o}N and 150-170^{o}W) (Fig. 4, 5).

For both models (i.e. single model and two-step model), both AIC and BIC selected the full model including quarter (Qt) and latitude (lat) and longitude (lon) (Model 1 in Table 1 and Model 1a, b in Tables 2) as the best model. In addition, the AIC and BIC of the remaining models showed that the performance of more complicated model was better than that of simpler model (Tables 1, 2). In the evaluation of two prediction model, the accuracy of the two-step model was better than that of single model. The predicted catches of the single model and two-step model in 1990 and 1991 were 103,200 and 92,524, and 96,529 and 91,887, respectively. Based on these results, two-step model was selected to predict the annual catches of blue shark during 1981 and 1992. The operation numbers of logbook data for each prediction model and its rates showed that 89.4 % of operation number were applicable to model 1, 1a and 1b (qt, latitude, longitude), while there was no data allocated to model 4, 4a and 4b (intercept) (Table 3).

The predicted catches of blue sharks tended to increase since the early 1980s and peaked around 1988-1989, and then decreased (Table 4, Fig. 6). Catch in 1981 was much lower than that in other year because the deployed "tans" in 1981 was extremely low compared to that of other year (1.9 million "tans" in 1981, 15.7-33.4 million "tans" in other years). Yatsu et al. (1993) reported that there was no reliable data of deployed "tans" in logbook data from 1978 to 1981; thus, the predicted catches in 1981 is probably under-predicted. Similarly, the reason why the catch levels decreased rapidly in 1990 would also come from deployed "tans" because they substantially decreased from 33.4 million "tans" in 1989 to 22.7 million "tans" in 1990. Yatsu et al. (1993) reported a considerable decline of deployed "tans" in 1990 resulted from 1) a decrease in the number of actual vessels operated and 2) high CPUE of flying squid.

Compared with the annual catch number of blue sharks caught by squid driftnet fishery in 1989 and 1990 calculated by Yatsu et al. (1993), the decreasing trends in the catch was similar, however the annual catch in this study was slightly higher than that reported by Yatsu et al. (1993) (Table 4). Our prediction method seems to be better than that of Yatsu (1993) because their estimation methods assumed that the operations with scientific observer were randomly sampled from the operations by commercial fishery. This means that spatial and temporal conditions were not directory considered in the previous study. Moreover, the previous study provided catch estimation only in 1989 and 1990, whereas our method provided those during the overall period when the logbook data are available (1981-1992). In the near future, the annual catches of blue sharks caught by Japanese large-mesh driftnet fishery is necessary to predict using the same prediction method applied in this study.

Acknowledgements

We deeply grateful to Dr. T. Ichii, National Research Institute of Far Seas Fishery in Japan, for kindly provided us valuable data of Japanese high seas squid driftnet fishery and helpful comments. We also thank Dr. Y. Semba, National Research Institute of Far Seas Fishery in Japan, for her valuable suggestions on our study. Finally, the driftnet observer data were produced through the combined efforts of many fishing crews, observers, and scientists at the National Research Institute of Far Seas Fisheries in Japan, the National Marine Fisheries Service in USA and Fisheries and Oceans Canada.

References

ISC (2017). Stock assessment and future projections of blue shark in the North Pacific Ocean through 2015. Annex-13. Report of the Shark Working Group. (International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean: Vancouver, Canada).

McKinnell, S., Seki, MP. (1998). Shark bycatch in the Japanese high seas squid driftnet fishery in the North Pacific Ocean. Fish. Res. 39: 127-138.

Nakano, H., Okada, K., Watanabe, Y., Uosaki, K. (1993). Outline of the large-mesh driftnet fishery of Japan. Int. N. Pac. Fish. Comm. Bull. 53: 25-37.

Yatsu, A., Hiramatsu, K., Hayase, S. (1993). Outline of Japanese squid driftnet fishery with notes on the by-catch. Int. N. Pac. Fish. Comm. Bull. 53: 5-24.

Table 1. AIC and BIC for four single methods (negative binomial models).

Model	Added explanatory variables	AIC	BIC
1	+ qt+ latitude + longitude	157713.4	157983.8
2	+ latitude + longitude	158165.7	158427.7
3	+ qt	164867.9	164893.4
4	Intercept	165739.5	165756.4

Table 2. AIC and BIC for four delta-type two step models.

1. Binomial model (First step)

Model	Added explanatory variables	AIC	BIC
1a	+ qt+ latitude + longitude	41014.8	41276.1
2a	+ latitude + longitude	41362.4	41615.1
3a	+ qt	47567.2	47584.1
4a	Intercept	49684.2	49692.6

2. Negative binomial model (Second step)

Model	Added explanatory variables	AIC	BIC
1b	+ qt+ latitude + longitude	122099.7	122349.6
2b	+ latitude + longitude	122214.8	122457.1
3b	+ qt	126781.5	126805.1
4b	Intercept	126968.7	126984.4

Table 3. Operation numbers of logbook data for each prediction model and its rates.

Model	**Model 1** (qt, latitude, longitude)	**Model 2** (latitude, longitude)	**Model 3** (qt)	**Model 4** (Intercept)
Number	278,859	11,389	21,597	0
Rate (%)	89.4	3.7	6.9	0.0

Table 4. Predicted catches in number of blue sharks caught by the Japanese high seas squid drift from 1981 to 1992.

Year	This study NB method	This study Modified delta-type two step method	Yatsu et al., (1993)
1981	72,897.6	72,928.1	-
1982	973,946.2	952,992.0	-
1983	1,332,978.3	1,247,961.8	-
1984	1,600,182.2	1,452,946.0	-
1985	1,776,298.6	1,642,119.9	-
1986	1,913,245.9	1,726,690.9	-
1987	1,765,202.6	1,588,648.5	-
1988	2,364,736.9	2,080,969.1	-
1989	2,150,840.8	2,077,212.7	1,439,581
1990	1,020,945.6	982,451.0	723,933
1991	940,798.0	918,222.5	-
1992	654,431.3	630,610.6	-

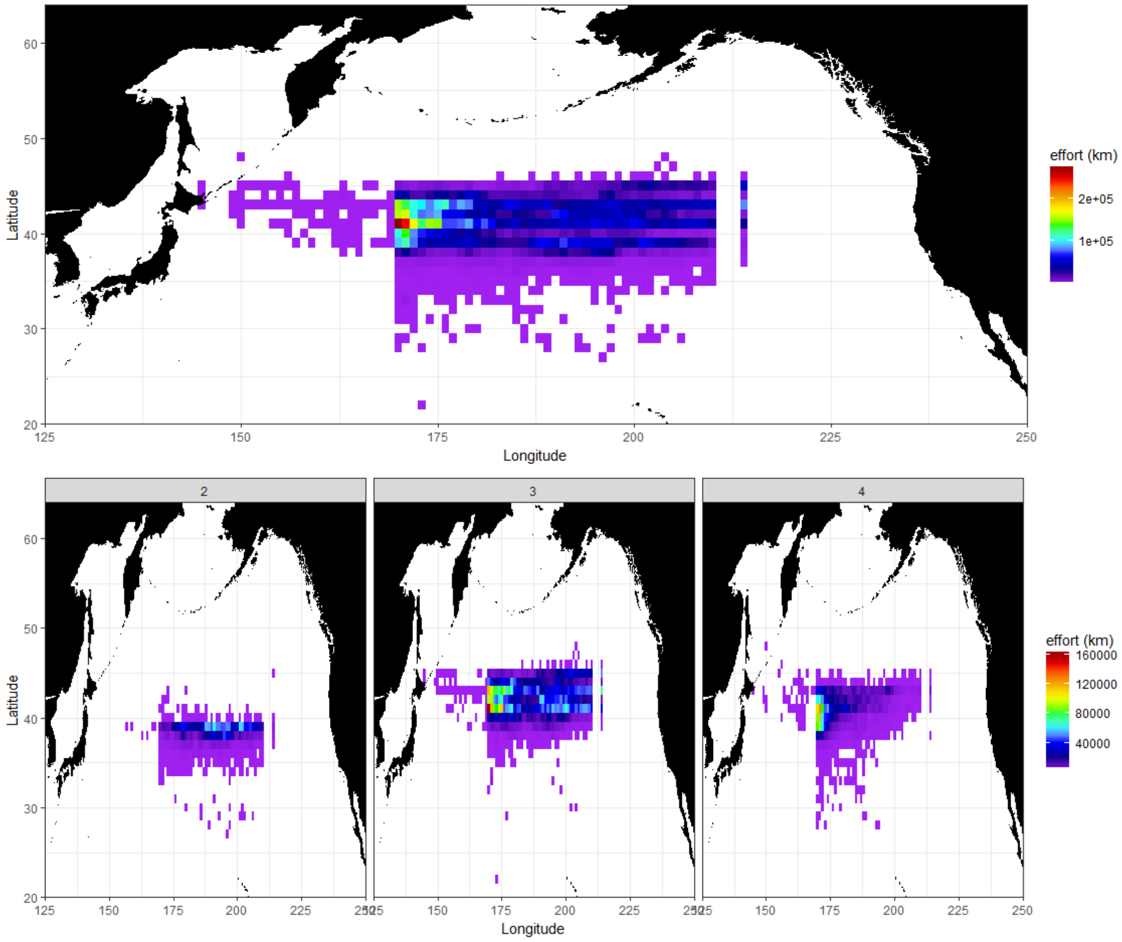


Fig. 1. Spatial distribution of fishing effort for the Japanese high seas squid driftnet fishery. Overall (upper figure) and quarter-specific (qts.2-4, lower figures) logbook data collected from 1981 to 1992.

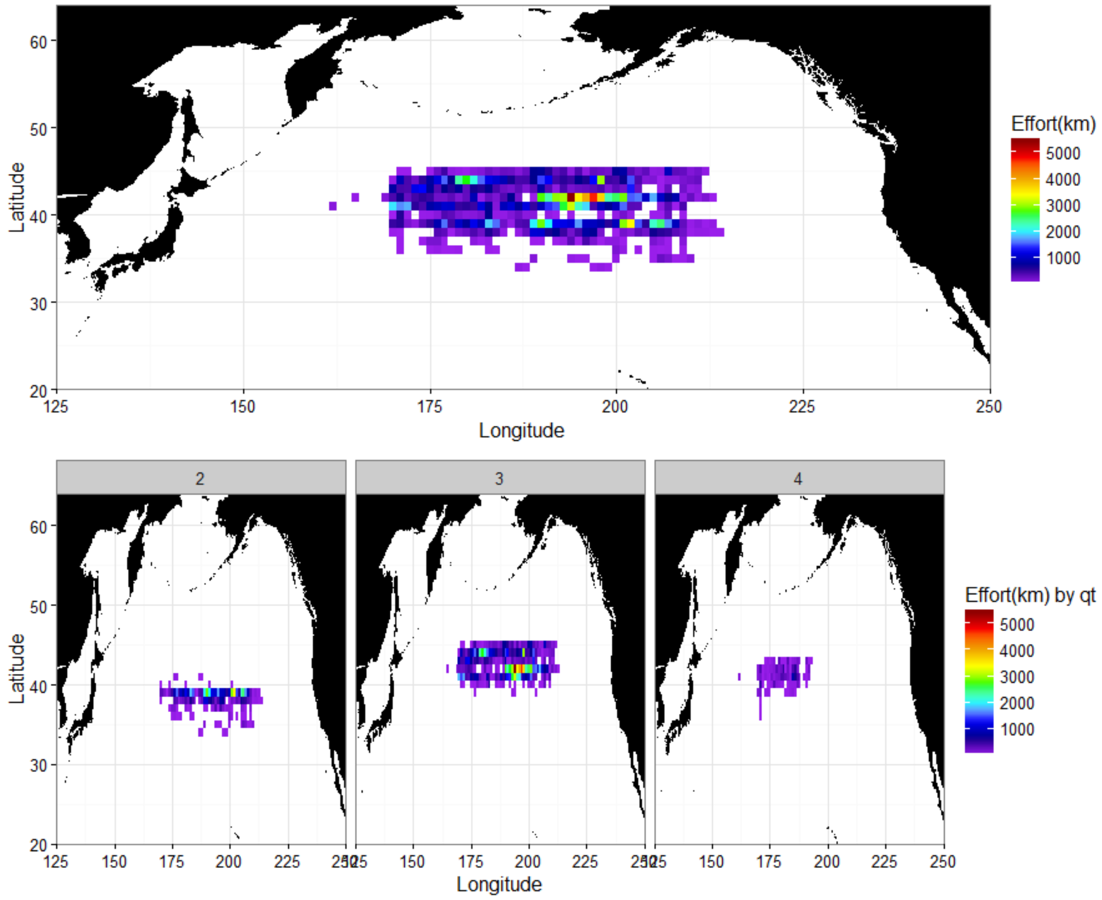


Fig. 2. Spatial distribution of fishing effort for the Japanese high seas squid driftnet fishery. The overall (upper figure) and quarter-specific (qts.2-4, lower figures) scientific observer data collected in 1990 and 1991.

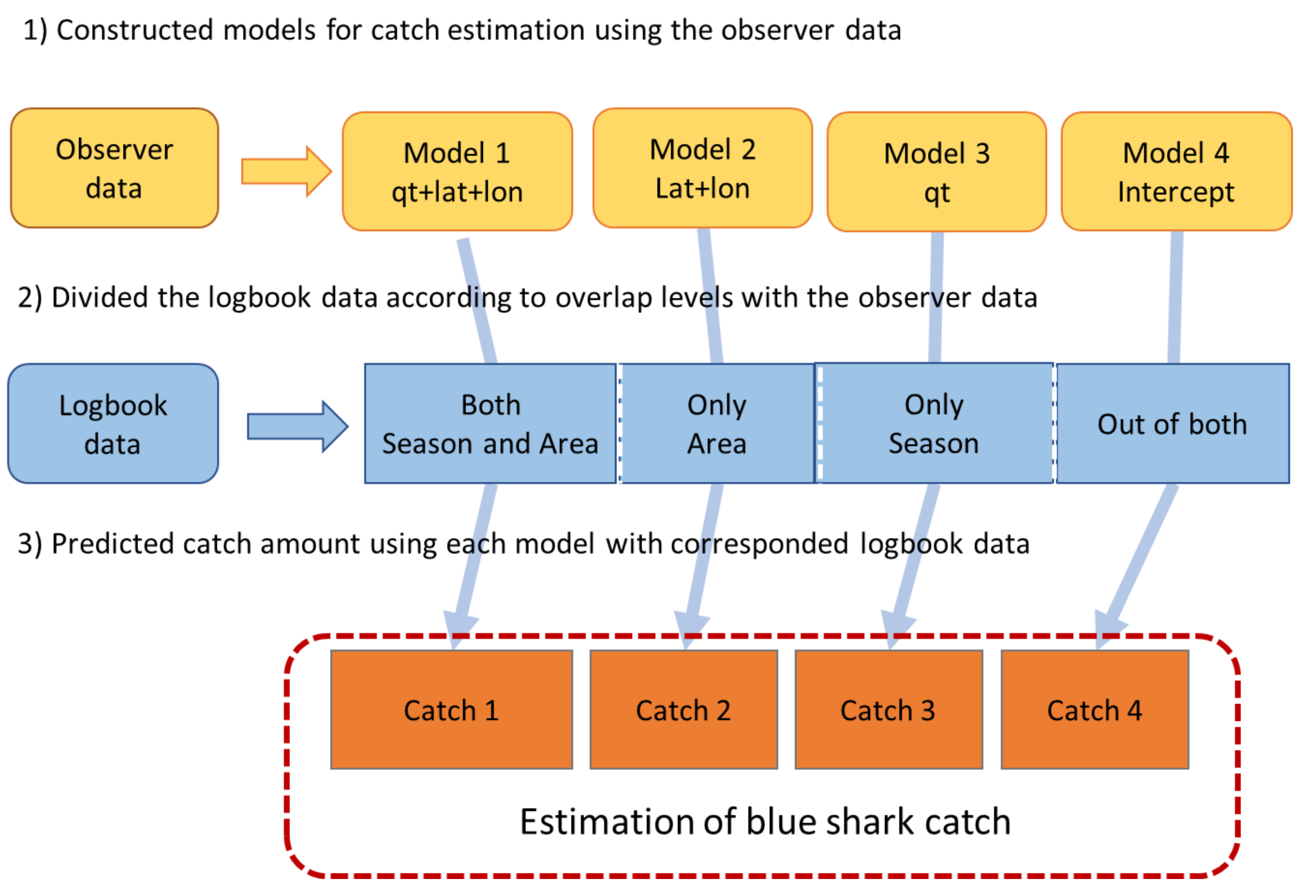


Fig. 3. Procedures of catch prediction for blue shark (*Prionace glauca*) caught by the Japanese high seas squid driftnet fishery.

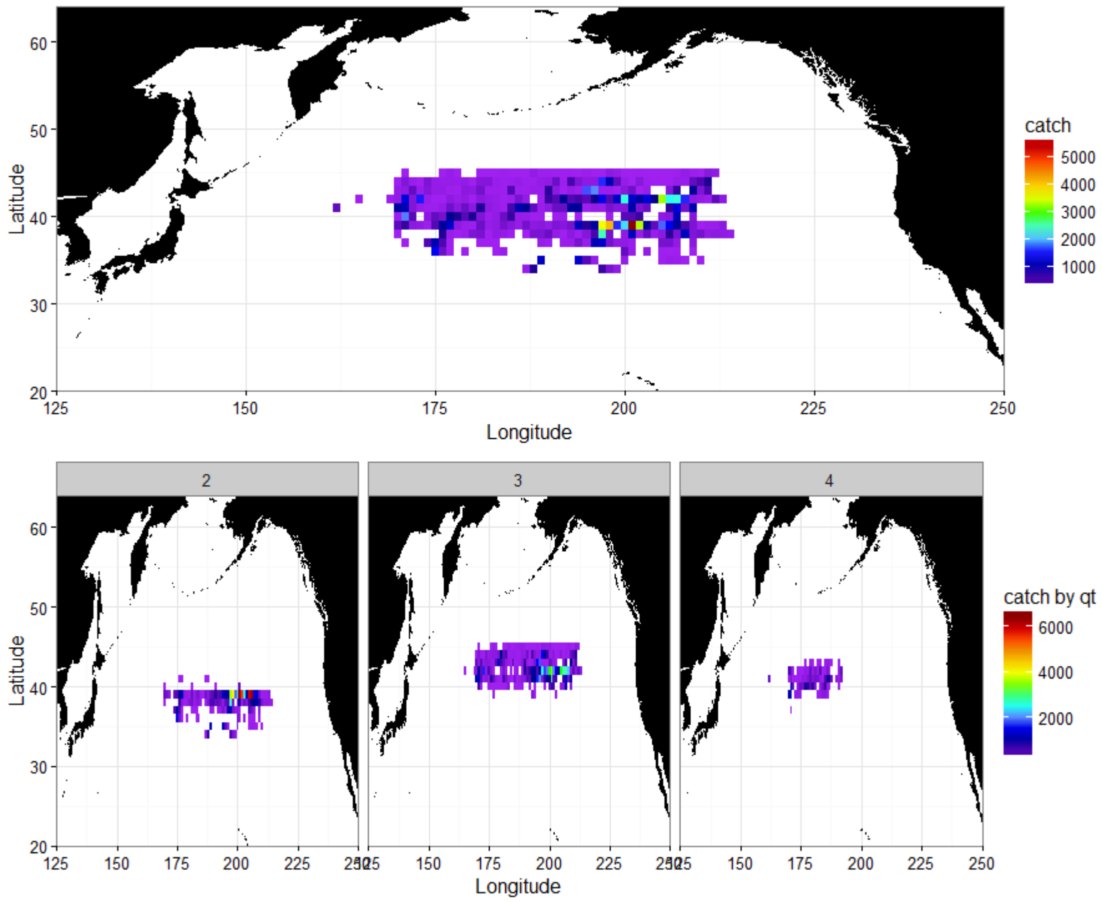
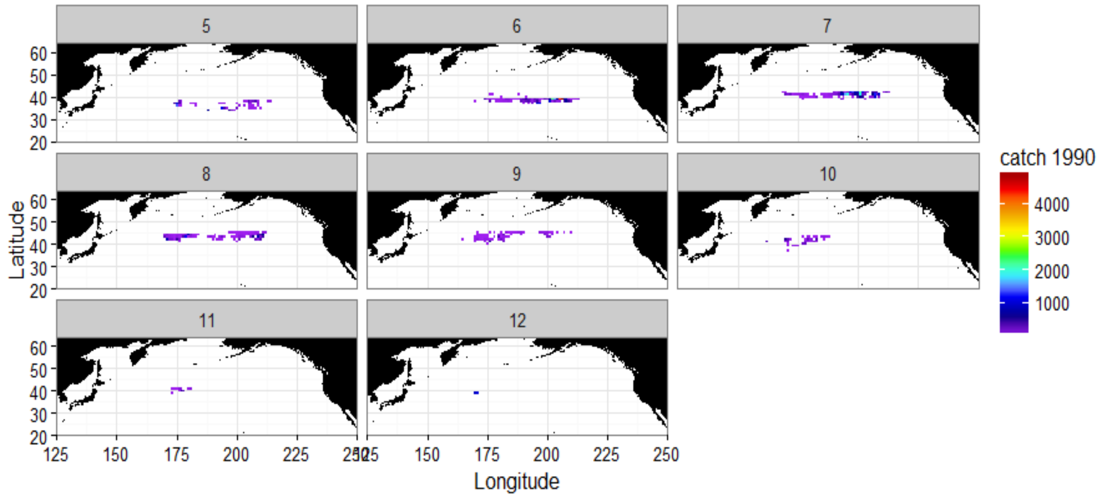


Fig. 4. Spatial distribution of catch in number for the Japanese high seas squid driftnet fishery. The overall (upper figure) and quarter-specific (qts.2-4, lower figures) scientific observer data collected in 1990 and 1991.



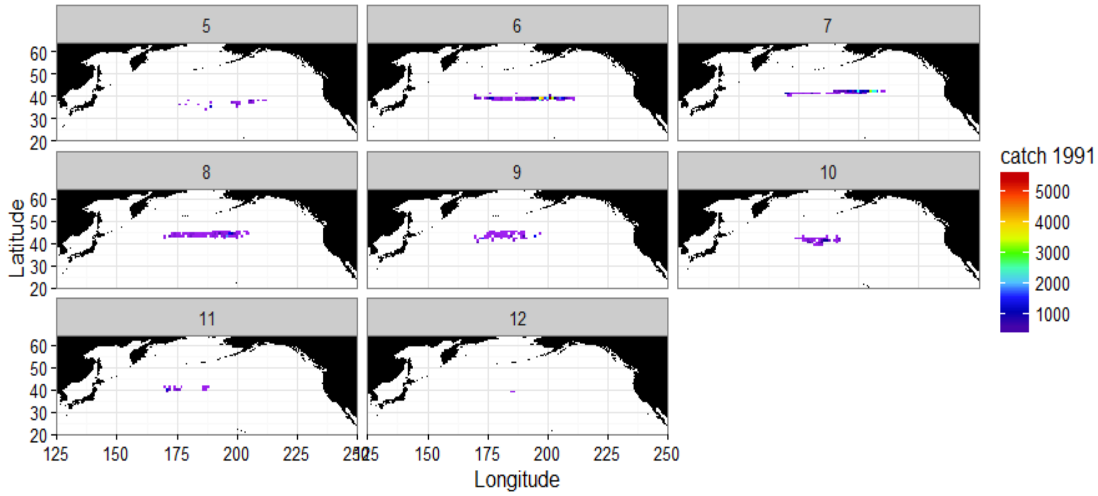


Fig. 5. Spatial distribution of monthly catch in number for the Japanese high seas squid driftnet fishery in 1990 (upper figures) and 1991 (lower figures).

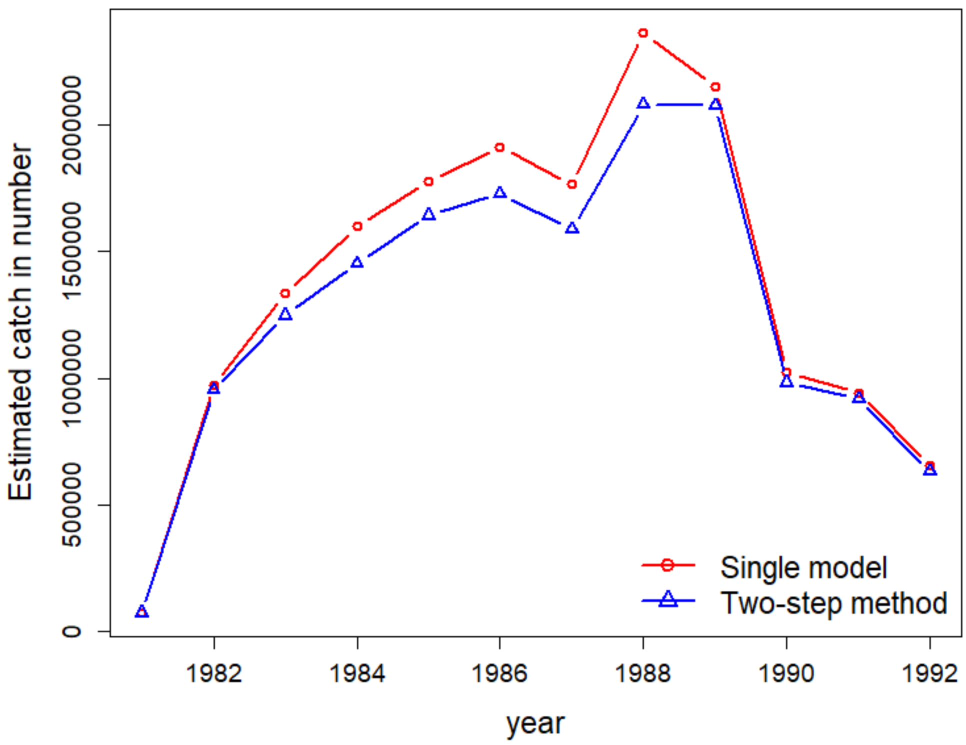


Fig. 6. Comparisons of predicted catches in number of blue sharks caught by the Japanese high seas squid driftnet fishery from 1981 to 1992 between single model (red line with open circle) and two-step model (blue line with open triangle).

Appendix: Summary of goodness-of-fits for the outputs of GAM analyses from R

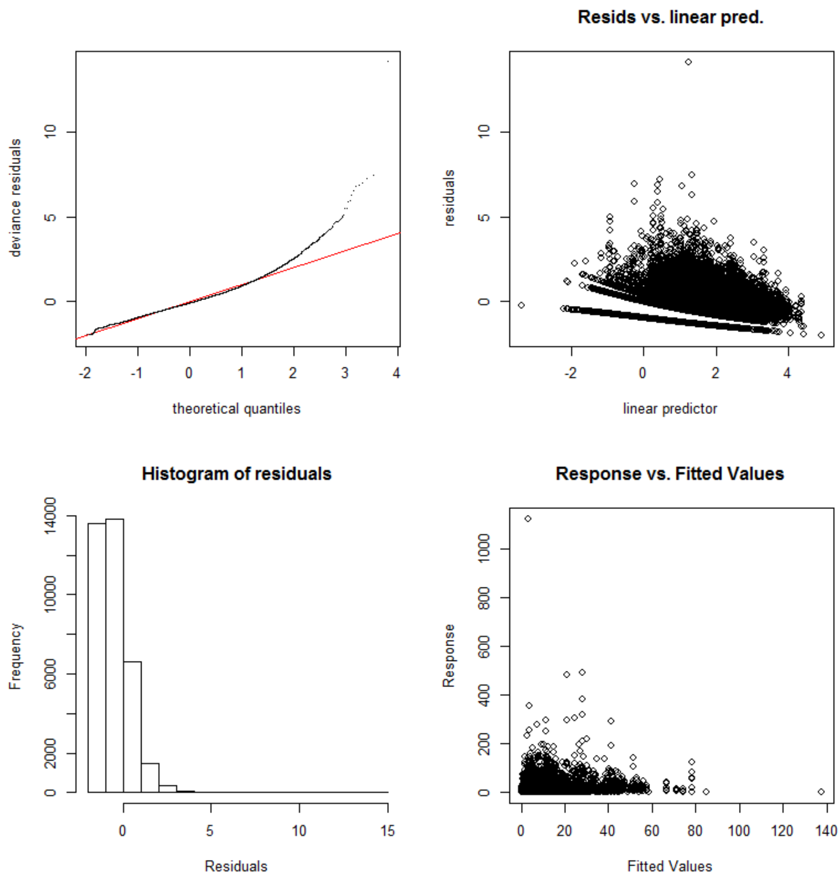


Figure A1. Diagnostics of the goodness-of-fits for the best model from the GAM analysis (single model with negative binomial error distribution).

Family: Negative Binomial (0.328)

Link function: log

Formula:

t. catch.102 ~ factor(qt) + s (Lon, Lat) + offset(log(effort))

Parametric coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-8.35769	0.04025	-207.65	<2e-16	***
factor(qt)3	1.07483	0.05399	19.91	<2e-16	***

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

Approximate significance of smooth terms:

	edf	Ref.df	Chi.sq	p-value	
s(Lon,Lat)	28.81	29	8328	<2e-16	***

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

R-sq.(adj) = 0.0649 Deviance explained = 22.3%

-REML = 78948 Scale est. = 1 n = 35968

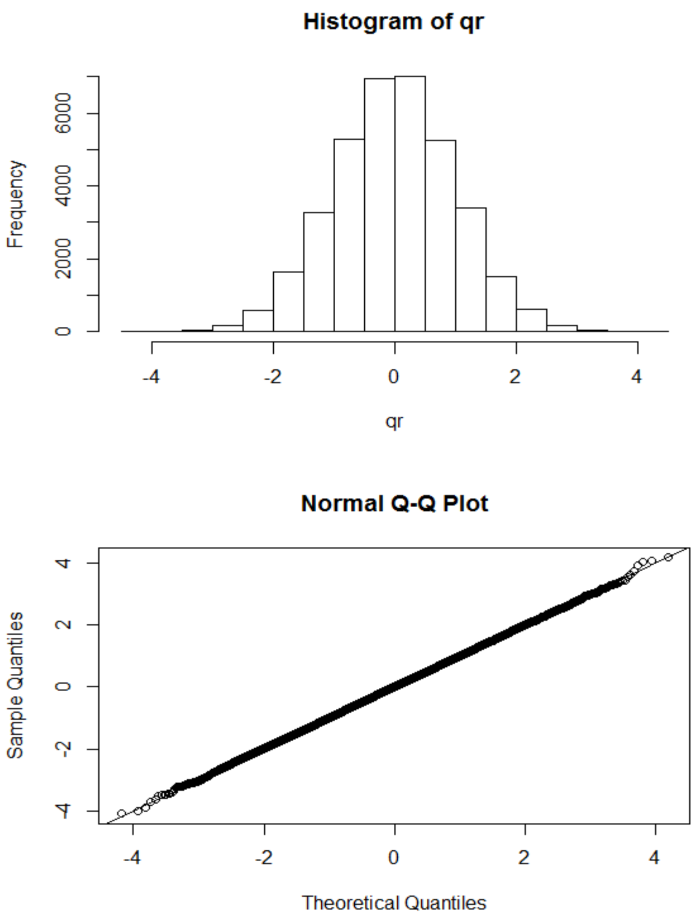


Figure A2. Diagnostics of the goodness-of-fits for the best model from the binomial part of GAM analysis (two-step model with binomial and negative binomial error distributions).

First step

Family: binomial
Link function: logit

Formula:
pcatch ~ factor(qt) + s (Lat, Lon)

Parametric coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-0.78248	0.05957	-13.14	<2e-16	***
factor(qt)3	1.49013	0.08197	18.18	<2e-16	***

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

Approximate significance of smooth terms:

	edf	Ref.df	Chi.sq	p-value	
s(Lat,Lon)	28.77	29	4588	<2e-16	***

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

R-sq.(adj) = 0.218   Deviance explained = 17.6%
UBRE = 0.14031 Scale est. = 1   n = 35968

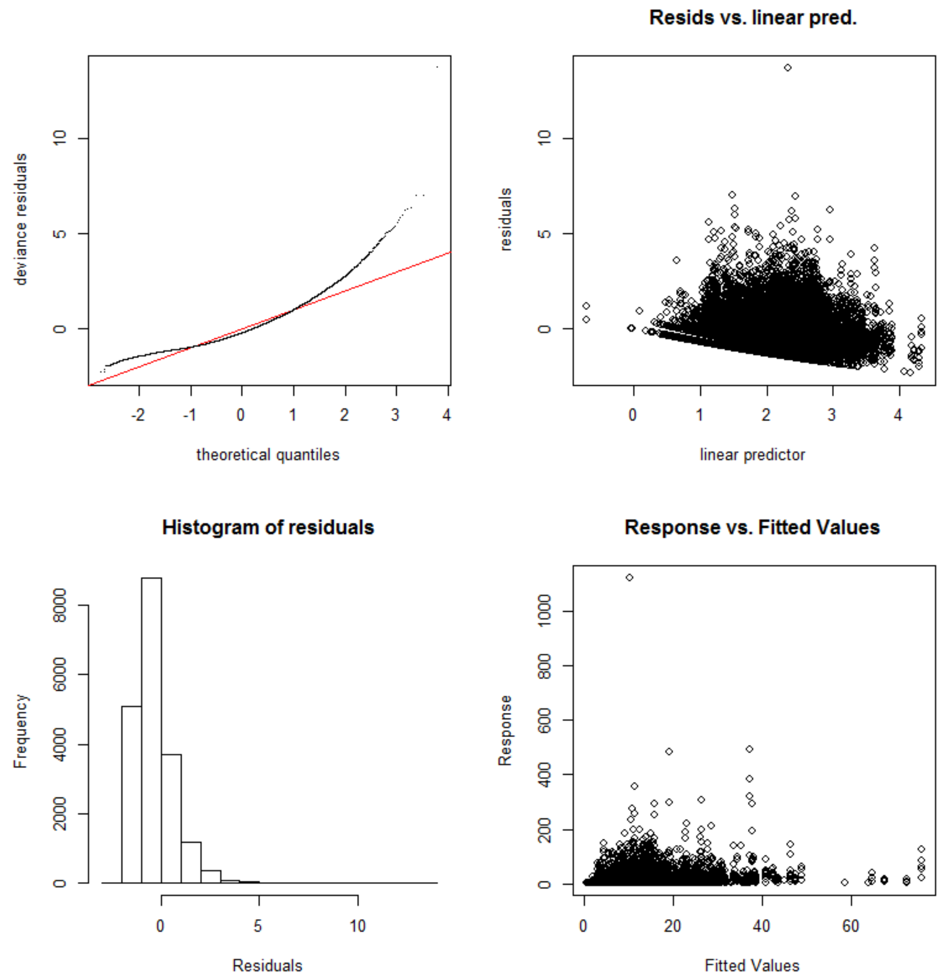


Figure A3. Diagnostics of the goodness-of-fits for the best model from the positive catch part of GAM analysis (two-step model with binomial and negative binomial error distributions).

Second step

Family: Negative Binomial (0.95)

Link function: log

Formula:

t. catch.102 ~ factor(qt) + s (Lon, Lat) + offset(log(effort))

Parametric coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-7.01036	0.03062	-228.9	<2e-16 ***

factor(qt)3 0.52332 0.04759 11.0 <2e-16 ***

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

Approximate significance of smooth terms:

	edf	Ref.df	Chi.sq	p-value
s(Lon,Lat)	28.74	29	5461	<2e-16 ***

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

R-sq.(adj) = 0.0724 Deviance explained = 21.7%

-REML = 61119 Scale est. = 1 n = 19256

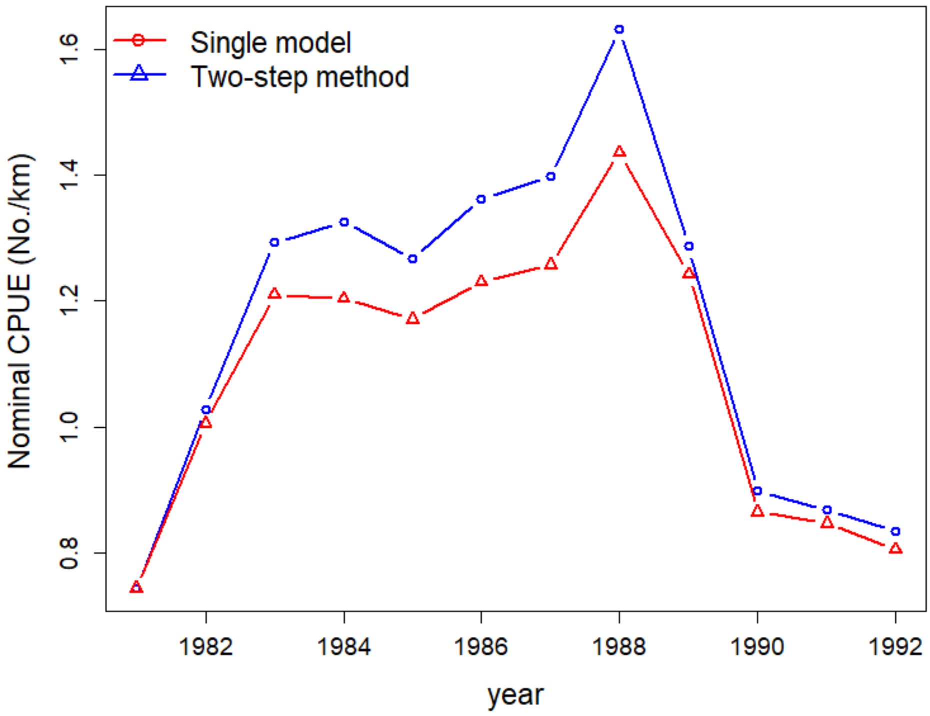


Figure A4. Comparisons of nominal CPUE (number of catches / km) for blue sharks caught by Japanese high seas squid driftnet fishery from 1981 to 1992 between single model (red line with open circle) and two-step model (blue line with open triangle).