Japanese longline CPUE for albacore tuna in the northwestern Pacific Ocean standardized by Generalized Linear Model using operational catch and effort data from 1966 to 2011[1]

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Abstract

Japanese longline CPUE for albacore tuna in the northwestern Pacific Ocean was standardized up to 2011 by GLM (CPUE-LogNormal error structured model). Number of hooks between float (NHF) was applied into the model to standardize the change of the catchability which has been derived by fishing gear configuration. SST (Sea Surface Temperature) was applied in the model as oceanographic factor. Quarter based and year based CPUEs were obtained from lsmeans of year and that of year-quarter interaction.

CPUE in real scale of distant water and offshore longline declined sharply from 8 in 1966 to 4 in 1971, and kept at the same level until 1991 when it increased steeply again and kept at around 11 until 2001. After that, it decreased to 5 in 2003 and 2004, after when it increased again to around 8 with some fluctuation. As for the CPUE of the small longline, it increased from 9 in 1994 to 12 in 1999 after when it has fluctuated between 6 and 9. If these CPUEs are overlaid in the relative scale in which average from 1994 to 2011 is 1.0, they showed similar trends except some differences in small peaks. Using final model selected for Log-normal model was applied to Negative Binomial model for comparison. CPUEs standardized by each model showed very similar trend each other.

By applying vessel identification into log-normal model as explanatory variable, historical change in fishing power was estimated. In the case of distant water and offshore longline, relative fishing power estimated which was around 0.5 in 1979, gradually increased to about 1.2 in 1998 and kept at the similar level thereafter fluctuating between 1.1 and 1.2. Estimated fishing power for small longline has not showed large change and kept in around 1.0 since it has shown very slight increasing trend.

1. Introduction

Japanese longline CPUE for albacore tuna was standardized by Generalized Linear Model up to 2011. In the previous assessment of North Pacific albacore conducted in 2011, Japanese longline CPUE was standardized based on the catch and effort data aggregated to year, month, 5 degree latitude, 5 degree longitude and the number of hooks between float.

By reviewing the last stock assessment, several recommendations were issued to improve this assessment. Since the importance to understand the historical change in catchability was recognized, it is difficult to estimate it. In this study, operational catch and effort data was used to apply vessel identification characteristics into to GLM model in order to estimate the catchability trend. This method was firstly introduced by Hoyle (2009). This method was applied into Japanese longline fishery (Hoyle et al., 2010, Hoyle and Okamoto, 2011) and has utilized for actual BET stock assessment at WCPFC since 2010 (Harley et al., 2010, Davies et al., 2011).

2. Materials and methods

1) Catch and effort data used

Two series of Japanese longline operational based catch and effort statistics, the data for small longlin fishery (10 – 20 GRT) from 1994 to 2011 and that for offshore (principally, 20-

120 GRT) and distant water (larger than 120 GRT) longline fisheries from 1966 to 2011, were used. Analyzed area (Fig. 1) was the same as that used in Ijima et al. (2013) which covers the area ranged from 15°N to 40°N and from 130°E to 180° from which a main albacore catch has been caught at the North Pacific Ocean by Japanese longline fishery. As the back ground information, the number of operation by catch in number per each longline set was presented as histograms in Appendix Fig. 1 by fishery type (distant water and offshore longline and small longline), period of years (1952-1974, 1975-1990, 1991-2002 and 2003-2011) and quarter in 5° latitude by 10° longitude 10 resolution.

Operational based data is data of each longline operation, and includes detail information of each operation (date, noon position, sea surface temperature, catch in number of each species, the number of hooks used, the number of hooks between float, etc.) and that of vessel and cruise (name of vessel, call sign, date of start and end of the cruise, etc.). However, these information does not necessarily cover for all years analyzed. As for the NHF, for example, this information is available from 1975 and call sign which was used as vessel identification is available from 1979.

2) Standardization by GLM (Generalized Linear Model)

CPUE based on the catch in number was used. CPUE is calculated as "the number of caught fish / the number of hooks * 1000" As the model for standardizing CPUE, CPUE-LogNormal error structured model was mainly used. The followings are the full model applied and 10 sorts of models with different combination of explanatory variables were tried.

- Full Model for Year based CPUE standardization in the analyzed area in the North Pacific Ocean from 1966 to 2011 for distant water and offshore longline fishery (from 1994 to 2011 for small longline fishery)

Log (CPUE+const)= μ + YR + QT + F-type + NHFCL + LL5 + SST + YR*QT

Where Log : natural logarithm,

CPUE : catch in number of bigeye per 1000 hooks,

Const : 10% of overall mean of CPUE

μ : overall mean,

YR : effect of year,

QT : effect of fishing season (quarter)

F-type: effect of fishery type (distant water and offshore longline fisheries),

NHFCL : effect of gear type (category of the number of hooks between floats),

LL5 : effect of 5 degree of latitude and 5 degree longitude square as category,

SST: effect of sea surface temperature,

YR*QT : interaction term between year and quarter,

e : error term.

All explanatory variables showed above, were applied into the model as class variable. Basing on the result of ANOVA (type III SS), non-significant effects were removed in step-wise from the initial model based on the F-value ($p<0.05$). In the 10 models tested, the best model was selected based on the AIC value (Akaike's Information Criteria, Akaike 1973).

As environmental factor, which are available for the analyzed period from 1966 to 2011, SST (Sea Surface Temperature) was applied into the model as class variable in 1 degree resolution. This Global Sea Surface Temperatures (COBE-SST) is the data whose resolution is 1-degree latitude and 1-degree longitude by month, and the data from 1966 to 2011 was downloaded from NEAR-GOOS Regional Real Time Data Base of Japan Meteorological Agency (JMA).
http://goos.kishou.go.jp/rrtdb/database.html

The number of hooks between float (NHF) is the important indicator of targeting for longline operation. As this information is available since 1975 as explained before, NHF for the period from 1966 to 1974 is assumed to be 5., Three types of classification of NHF, that is, NHFCL A, B and C were tested using the following model and the best classification to be used for the main analyses was selected by AIC value.

Log (CPUE+const)= μ + YR + QT + NHFCL (Three types)

Where three types of NHFCL tested are

NHFCL_A NHF (number of hooks between float from 5 to 21) was used without classification.

NHFCL_B NHFCL 1: 5-6, NHFCL 2: 7-9, NHFCL 3: 10-13, NHFCL 4: 14-17, NHFCL 5: 18-21

NHFCL_C NHFCL1: 5-10, NHFCL 2: 11-16, NHFCL3: 17-21.

Year based and quarter based CPUE index were obtained from lsmeans output of year and year-quarter interaction, respectively.

3) Estimation of change in catchability

In this paper, a term 'fishing power' is used to represent catchability, but does not include oceanographic effect into the considerations. Historical change in fishing power was estimated by applying vessel identification characteristics into the GLM model as an explanatory variable for distant water and offshore longline from 1979 to 2011 and for small longlin from 1994 to 2011. Used models for this analysis were as follows.

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Std CPUE without vessel effect: Log (CPUE+const) = μ + YR + QT

Std CPUE with vessel effect: Log (CPUE+const) = μ + YR + QT+ Vessel Identification

As the identification of each vessel, call sign (available only from 1979) was used for distant water and offshore longline, and vessel name was used for small longline fleet.

Each index was normalized so as time series average is equal 1.0. By dividing index from model without vessel effect by index from model including vessel effect, historical change in fishing power was estimated. Models which include NHF were also applied to know the effect of NHF in the fishing power estimated by vessel identification.

4) Negative Binomial Model

Negative Binomial error structure assumption was applied for comparison with the result from log-normal model. Same set of explanatory variables with those included in the best model for log-normal model were applied in to the negative binomial model. Basic structure of the model was as follows.

E[Catch] = Effort * exp(Intercept + each explanatory valuables)

where, Catch ~ Negative Binomial(α,β)

3. Results and discussion

1) Selection of NHF classification

Trends of distant water and offshore longline CPUE standardized by the three models with different types of NHFCL (A, B and C) was Shown in Fig. 2. Declining trend from 1966 to 1980 is strongest for NHFCL_B and weakest for NHFCL_C and intermediate for NHFCL_A, and opposite order is true for increasing trend thereafter. In the AIC values derived from models with different type of NHFCL classifications was smallest for NHFCL_A, and largest for NHFCL_C (Table 1), and it was determined to apply NHFCL_A (NHF as it is without classification) for main standardization analyses.

Same analyses were conducted also for small longline fishery. There were not remarkable difference between CPUE trends derived from models in which three difference NHF classifications were applied. As was the case of distant water and offshore longline, AIC value was smallest for the model with NHFCL_A and largest for NHFCL_C. Therefore NHFCL_A was applied for the main CPUE standardization of small longline, too.

The gear configuration is very important factor to standardize targeting in the longline operation. However, this NHF has used in longline operation historically changed depending on change in main target species and development of fishing method and gear including material of them even in the same area and for same target species. Although it was determined that NHF (number of hooks between floats) without classification is applied into the model basing on the results of above analyses, it might be necessary to consider further improve to standardize the targeting.

2) Standardization

The albacore CPUEs (catch in number per 1000 hooks) in year and quarter bases were standardized for the period from 1966 (1994 for small longline) to 2011 by GLM (CPUE-LogNormal error structured model) separately for offshore and distant longline and small longline fisheries. In 10 models listed in Table 2, effects of all explanatory variables included were significant for both fisheries as shown in ANOVA results in Table 3. In the models tested, Model 110 showed smallest value in AIC for both longline fishery groups (Table 2). Therefore, Model 110 was selected as the best model for both fishing groups. Distributions of the standard residual derived from Model 110 were shown in Fig. 3 as histogram and QQ plot and that from all models were shown in Appendix Fig. 2, Distribution of residual of Model 110 did not show remarkable difference from the normal distribution for both of distant water and offshore longline and small longline fisheries.

3) CPUE trend observed

Historical trends of CPUE standardized applying Model 110 were shown in Fig. 4 for distant weater and offshore longlineand small longline fisheries in real and relative scales, overlaying with nominal CPUE. CPUE in real scale of distant water and offshore longline declined sharply from 8 in 1966 to 4 in 1971, and kept at the same level until 1991 when it increased steeply again and kept at around 11 until 2001. After that, it decreased to 5 in 2003 and 2004, after when it increased again to around 8 with some fluctuation. As for the CPUE of the small longline, it increased from 9 in 1994 to 12 in 1999 after when it has fluctuated between 6 and 9. Distant water and offshore longline CPUE and small longline CPUE in relative scale expressing the average from 1994 to 2011 is 1.0 were overlaid in Fig. 5. Both CPUE showed similar trends except some differences in small peaks.

Historical trends of quarter based CPUE standardized using Model 110 were shown in Fig. 6. Since the quarter based CPUE showed strong seasonal oscillation, total trend seems to be similar to that of year based CPUE.

4) Effect of each explanatory variables

Fig. 7 showed trend of standardized CPUE derived each model to observe the effect of each explanatory variable on the standardized CPUE trend. In the case of offshore and distant water longline, Model 100 in which only Year is included showed large difference in CPUE trend before 1985 from nominal CPUE. Before 1985, nominal CPUE showed remarkable declining trend while that of the Model 100 also showed declining trend until 1971 and rather slight increasing trend thereafter.

Model 101 (YR+QT), 102 (YR+QT+F-Type), 104 (YR+QT+LL5), 105 (YR+QT+SST) showed basically similar trend with that of Model 100, that is, increasing trend from 1971 to 1999 and once declined to about half level in 2003 and increased again thereafter. On the other hand, by applying NHF in the model (Model 103), increasing trend was weakened to some extent.

Fig. 8 shows effects of each explanatory variable applied in the model 110 (YR+ QT+ F-Type+ NHF+ LL5+ SST+ YR*QT) for distant water and offshore longline and small longline fishery. As the data of small longline includes only one fishery type (small LL) then there is not figure of F-type. In the fishing season, effect was clearly higher in 1st and 4th quarters than 2nd and 3rd quarters for both of distant water and offshore longline and small longline fisheries. Regarding Fishery type (F-type), offshore longline showed higher effect than distant water longline. This difference in F-type between distant water and offshore longlines would be reasonable because most of longliner which seasonally targeting albacore are offshore and small longline fisheries. In the effect of NHF, basically larger NHF showed higher effect for both fisheries. SST showed peak of effect at 19 and 20°C for distant water and offshore longline, and at 17-19 °C for small longline fisheries. Since quite high peak exist around 13°C, confidence interval is quite wide.

5) Estimation of historical change in fishing power

By applying vessel identification into the model as an explanatory variable, historical change in fishing power was estimated. Effect of vessel identification is thought to be average fishing ability of each vessel existing in each period. If ratio of vessel with high ability is high in one period, averaged fishing power in the period should be high, and vice versa. Standardized CPUEs derived from model with vessel identification and that from model without it for distant water and offshore longline and small longline were shown in Fig. 9 (left). In the Fig. 9 (right), historical change in fishing power estimated as the ratio of CPUEs from models with and without vessel identification was presented. In the case of distant water and offshore longline, relative fishing power estimated which was around 0.5 in 1979, gradually increased to about 1.2 in 1998 and kept at the similar level thereafter fluctuating between 1.1 and 1.2. Estimated fishing power for small longline has not showed remarkable change throughout analyzed period and been kept in around 1.0 since it has shown very slight increasing trend.

Fishing power would change affected by many kind of factors such as fishing devices equipped on the vessel, fishing gear, skill of fishing master, targeting, etc. Especially, targeting is thought to be important factor. In this study, NHF (the number of hooks between float) was applied to standardize the change in catchability derived from change in targeting and gear configuration. Therefore, it is supposed that a part of change in catchability estimated by vessel effect could be explained by NHF. Then, CPUE was standardized by the Models including Year, Quarter, NHF with (Model 203) and without (Model 203) vessel identification were calculated and ratio of these CPUE (Model 103 / Model 203) was also observed (Fig. 10). In the case of distant water and offshore longline, the ratio of both models is around 1.0 throughout the analyzed period fluctuating between 0.9 and 1.1. This ratio was around 1.0 also for small longline fishery. These results indicate that the effects of vessel identification and that of NHF behave very similarly in the standardization, and standardization of catchability by using vessel identification would be able to be achieved by NHF.

Many of factors which affect on the fishing power, for example fishing master and targeting could change in much shorter period than longevity of the vessel. However, as this fishing ability of each vessel was estimated as average from appearing to disappearing of the vessel in the analyzed period, the estimated value of ability of each vessel is fixed through time and does not change in this analysis. It is desirable to develop more flexible indicator to estimate the change in fishing power through the time.

6) Attempt to apply alternative model for standardization

As alternative model, Catch model with Negative Binomial error structure assumption (N-Bin model) was also applied for comparison. Same set of explanatory factors used in Model 110 were applied to N-Bin model. All effects of explanatory variables included in the model were significant for both fishery groups (Table 4). The trends of the standardized CPUE applying N-Bin model were shown in Fig. 11 overlaid with those from Model 110 applying CPUE-LogNormal error structured model for comparison. Their trends were principally very similar each other except for that the fluctuation during the period from 1970 to 1990 for distant water and offshore longlin is stronger in N-Bin model.

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Table 1. AIC values derived from models with different classification of NHFCL (class of the number of hooks between float) for distant water and offshore longline and small longline fisheries.

Types	Model No.		N	AIC
DW & OS	Model_103	YR + QT + NHFCL_A	641920	1898131
DW & OS	Model_103	YR + QT + NHFCL_B	641920	1904571
DW & OS	Model_103	YR + QT + NHFCL_C	641920	1932605
Small	Model_103	YR + QT + NHFCL_A	416837	1107261
Small	Model_103	YR + QT + NHFCL_B	416837	1110411
Small	Model_103	YR + QT + NHFCL_C	416837	1112768

Table 2. Tested models with different combination of explanatory variables and resulted AIC values derived from each model for distant water and offshore longline and small longline fisheries.

Types	Model No.		N	AIC
DW & OS	Model_100	YR	641920	2077186.2
DW & OS	Model_101	YR + QT	641920	1945606.5
DW & OS	Model_102	YR + QT + F-Type	641920	1945562.8
DW & OS	Model_103	YR + QT + NHF	641920	1898131.0
DW & OS	Model_104	YR + QT + LL5	641920	1860606.7
DW & OS	Model_105	YR + QT + SST	641920	1880053.1
DW & OS	Model_106	YR + QT + F-Type + NHF	641920	1898036.6
DW & OS	Model_107	YR + QT + F-Type + NHF + LL5	641920	1819564.4
DW & OS	Model_108	YR + QT + F-Type + NHF + LL5 + SST	641920	1766936.6
DW & OS	Model_109	YR + QT + F-Type + NHF + LL5 + YR*QT	641920	1782117.8
DW & OS	Model_110	YR + QT + F-Type + NHF + LL5 + SST + YR*QT	641920	1732059.7
Small	Model_100	YR	416837	1312883.5
Small	Model_101	YR + QT	416837	1113618.5
Small	Model_103	YR + QT + NHF	416837	1107261.3
Small	Model_104	YR + QT + LL5	416837	1043650.7
Small	Model 005	YR + QT + SST	416837	1047057.6
Small	Model_107	YR + QT + NHF + LL5	416837	1036339.9
Small	Model 108	YR + QT + NHF + LL5 + SST	416837	982357.6
Small	Model_109	YR + QT + NHF + LL5 + YR*QT	416837	1015555.9
Small	Model_110	YR + QT + NHF + LL5 + SST + YR*QT	416837	961270.2

Table 3. Results of ANOVA from all model tested for distant water and offshore longline and small longline fisheries.

Distant water and offshore longline

RUN_100 1966–2011 Year base

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	45	97530.282	2167.340	1455.80	<.0001	R–Square=
Error	641874	955599.642	1.489			0.09261
						CV =
YR	45	97530.282	2167.340	1455.80	<.0001	73.25852

RUN_101 1966–2011 Year base

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	48	274643.604	5721.742	4717.64	<.0001	R–Square=
Error	641871	778486.320	1.213			0.260788
						CV =
YR	45	125999.701	2799.993	2308.63	<.0001	66.12211
QT	3	177113.322	59037.774	48677.30	<.0001	

RUN_102 1966–2011 Year base

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	49	274699.026	5606.103	4622.62	<.0001	R–Square=
Error	641870	778430.897	1.213			0.260841
						CV =
YR	45	126053.621	2801.192	2309.78	<.0001	66.1198
QT	3	176374.366	58791.455	48477.60	<.0001	
F–Type	1	55.423	55.423	45.70	<.0001	

RUN_103 1966–2011 Year base

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	50	290257.846	5805.157	4884.37	<.0001	R–Square=
Error	641869	762872.078	1.189			0.275614
						CV =
YR	45	43147.962	958.844	806.76	<.0001	65.45574
QT	3	176036.981	58678.994	49371.60	<.0001	
NHFCL	2	15614.242	7807.121	6568.79	<.0001	

RUN_104 1966–2011 Year base

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	97	371297.567	3827.810	3603.19	<.0001	R–Square=
Error	641822	681832.357	1.062			0.352566
						CV =
YR	45	96412.551	2142.501	2016.78	<.0001	61.88374
QT	3	116604.441	38868.147	36587.30	<.0001	
LL5	49	96653.963	1972.530	1856.78	<.0001	

RUN_105 1966–2011 Year base

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	67	346222.910	5167.506	4706.98	<.0001	R–Square=
Error	640230	702869.613	1.098			0.330021
						CV =
YR	45	122849.059	2729.979	2486.68	<.0001	62.77837
QT	3	101717.991	33905.997	30884.30	<.0001	
SST	19	73099.342	3847.334	3504.46	<.0001	

RUN_106 1966–2011 Year base

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	65	330286.480	5081.330	4512.00	<.0001	R–Square=
Error	641854	722843.444	1.126			0.313624
						CV =
YR	45	29310.040	651.334	578.36	<.0001	63.71608
QT	3	169089.656	56363.219	50048.10	<.0001	
F–Type	1	108.581	108.581	96.41	<.0001	
NHF	16	55587.454	3474.216	3084.95	<.0001	

RUN_107 1966–2011 Year base

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	114	413561.289	3627.731	3640.42	<.0001	R–Square=
Error	641805	639568.634	0.997			0.392697
						CV =
YR	45	30911.729	686.927	689.33	<.0001	59.93591
QT	3	106996.531	35665.510	35790.20	<.0001	
F–Type	1	564.546	564.546	566.52	<.0001	
NHFCL	16	40564.994	2535.312	2544.18	<.0001	
LL5	49	83274.810	1699.486	1705.43	<.0001	

RUN_108 1966–2011 Year base

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	133	459901.864	3457.909	3757.07	<.0001	R–Square=
Error	640164	589190.659	0.920			0.438381
						CV =
YR	45	30276.373	672.808	731.02	<.0001	57.48082
QT	3	37977.138	12659.046	13754.20	<.0001	
F–Type	1	786.759	786.759	854.82	<.0001	
NHFCL	16	39373.543	2460.846	2673.74	<.0001	
LL5	49	60159.638	1227.748	1333.97	<.0001	
SSTCL	19	49514.10012	2606.005	2831.46	<.0001	

RUN_109 1966–2011 Year base

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	249	450056.983	1807.458	1923.14	<.0001	R–Square=
Error	641670	603072.940	0.940			0.427352
						CV =
YR	45	21828.364	485.075	516.12	<.0001	58.20685
QT	3	60994.740	20331.580	21632.80	<.0001	
F–Type	1	783.326	783.326	833.46	<.0001	
NHFCL	16	34694.444	2168.403	2307.18	<.0001	
LL5	49	79363.534	1619.664	1723.32	<.0001	
YR*QT	135	36495.694	270.338	287.64	<.0001	

RUN_110 1966–2011 Year base

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	268	491294.467	1833.188	2103.44	<.0001	R–Square=
Error	640029	557798.056	0.872			0.468304
						CV =
YR	45	22083.214	490.738	563.08	<.0001	55.93444
QT	3	22629.899	7543.300	8655.34	<.0001	
F–Type	1	1002.035	1002.035	1149.76	<.0001	
NHFCL	16	34337.571	2146.098	2462.48	<.0001	
LL5	49	61434.264	1253.761	1438.59	<.0001	
SST	19	44149.992	2323.684	2666.24	<.0001	
YR*QT	135	31392.603	232.538	266.82	<.0001	

Small longline

RUN_100 1994–2011 Year base

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	17	9821.938	577.761	423.03	<.0001	R–Square=
Error	416819	569275.561	1.366			0.016961
						CV =
YR	17	9821.938	577.761	423.03	<.0001	50.59013

RUN_101 1994–2011 Year base

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	20	226153.429	11307.671	13354.00	<.0001	R–Square=
Error	416816	352944.070	0.847			0.390527
						CV =
YR	17	12993.386	764.317	902.63	<.0001	39.83447
QT	3	216331.491	72110.497	85160.30	<.0001	

RUN_103 1994–2011 Year base

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	22	226876.029	10312.547	12203.70	<.0001	R–Square=
Error	416814	352221.470	0.845			0.391775
						CV =
YR	17	13685.522	805.031	952.66	<.0001	39.79377
QT	3	215193.662	71731.221	84885.70	<.0001	
NHFCL	2	722.600	361.300	427.56	<.0001	

RUN_104 1994–2011 Year base

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	60	280748.613	4679.144	6536.49	<.0001	R–Square=
Error	416776	298348.887	0.716			0.484804
						CV =
YR	17	11125.478	654.440	914.21	<.0001	36.62597
QT	3	65293.689	21764.563	30403.80	<.0001	
LL5	40	54595.184	1364.880	1906.66	<.0001	

RUN_105 1994–2011 Year base

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	39	278023.424	7128.806	9873.72	<.0001	R–Square=
Error	416660	300827.722	0.722			0.480302
						CV =
YR	17	14807.432	871.025	1206.41	<.0001	36.78233
QT	3	105044.097	35014.699	48496.90	<.0001	
SST	19	51944.137	2733.902	3786.58	<.0001	

RUN_107 1994–2011 Year base

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	76	285958.136	3762.607	5349.35	<.0001	R–Square=
Error	416760	293139.363	0.703			0.4938
						CV =
YR	17	11650.753	685.338	974.35	<.0001	36.3055
QT	3	61697.794	20565.931	29238.80	<.0001	
NHFCL	16	5209.523	325.595	462.90	<.0001	
LL5	40	54436.142	1360.904	1934.81	<.0001	

RUN_108 1966–2011 Year base

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	95	321342.748	3382.555	5472.390	<.0001	R–Square=
Error	416604	257508.398	0.618			0.555139
						CV =
YR	17	13795.929	811.525	1312.910	<.0001	34.03339
QT	3	14966.212	4988.737	8070.910	<.0001	
NHFCL	16	3777.839	236.115	381.990	<.0001	
LL5	40	38792.511	969.813	1568.990	<.0001	
SST	19	35457.89004	1866.205	3019.2	<.0001	

RUN_109 1994–2011 Year base

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	127	300284.228	2364.443	3533.85	<.0001	R–Square=
Error	416709	278813.271	0.669			0.518538
						CV =
YR	17	10630.657	625.333	934.61	<.0001	35.4094
QT	3	59754.226	19918.075	29769.20	<.0001	
NHFCL	16	5219.010	326.188	487.51	<.0001	
LL5	40	54388.727	1359.718	2032.21	<.0001	
YR*QT	51	14326.092	280.904	419.83	<.0001	

RUN_110 1994–2011 Year base

Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Model	146	334105.728	2288.395	3894.810	<.0001	R–Square=
Error	416553	244745.418	0.588			0.577188
						CV =
YR	17	12919.005	759.941	1293.410	<.0001	33.1813
QT	3	16060.035	5353.345	9111.310	<.0001	
NHFCL	16	3743.941	233.996	398.260	<.0001	
LL5	40	38832.467	970.812	1652.310	<.0001	
SST	19	33899.127	1784.165	3036.620	<.0001	
YR*QT	51	12762.981	250.255	425.930	<.0001	

Table 4. Results of ANOVA from Negative Binomial model tested for distant water and offshore longline and small longline fisheries.

Negative Binomial Model 110

Distant watewr and offshore longline

	d.f.	Chi-square	Pr > ChiSq
YR	45	31682.8	<.0001
QT	3	26898.1	<.0001
F-Type	1	183.42	<.0001
NHFCL	16	33667.6	<.0001
LL5	49	48713.5	<.0001
SST	19	42583.5	<.0001
YR*QT	135	38525.4	<.0001

Small longline

	d.f.	Chi-square	Pr > ChiSq
YR	17	24280.1	<.0001
QT	3	26942.3	<.0001
NHFCL	16	3372.51	<.0001
LL5	40	57832.7	<.0001
SST	19	48717.2	<.0001
YR*QT	51	25451.3	<.0001

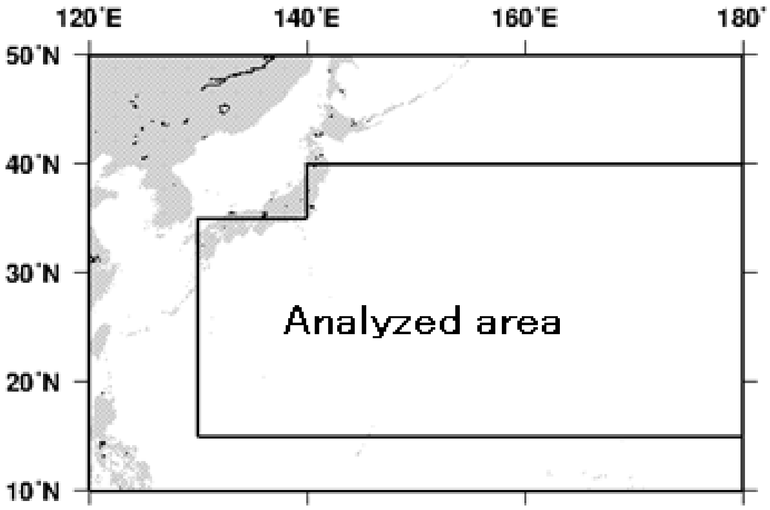


Fig. 1. Analysis area used in this study.

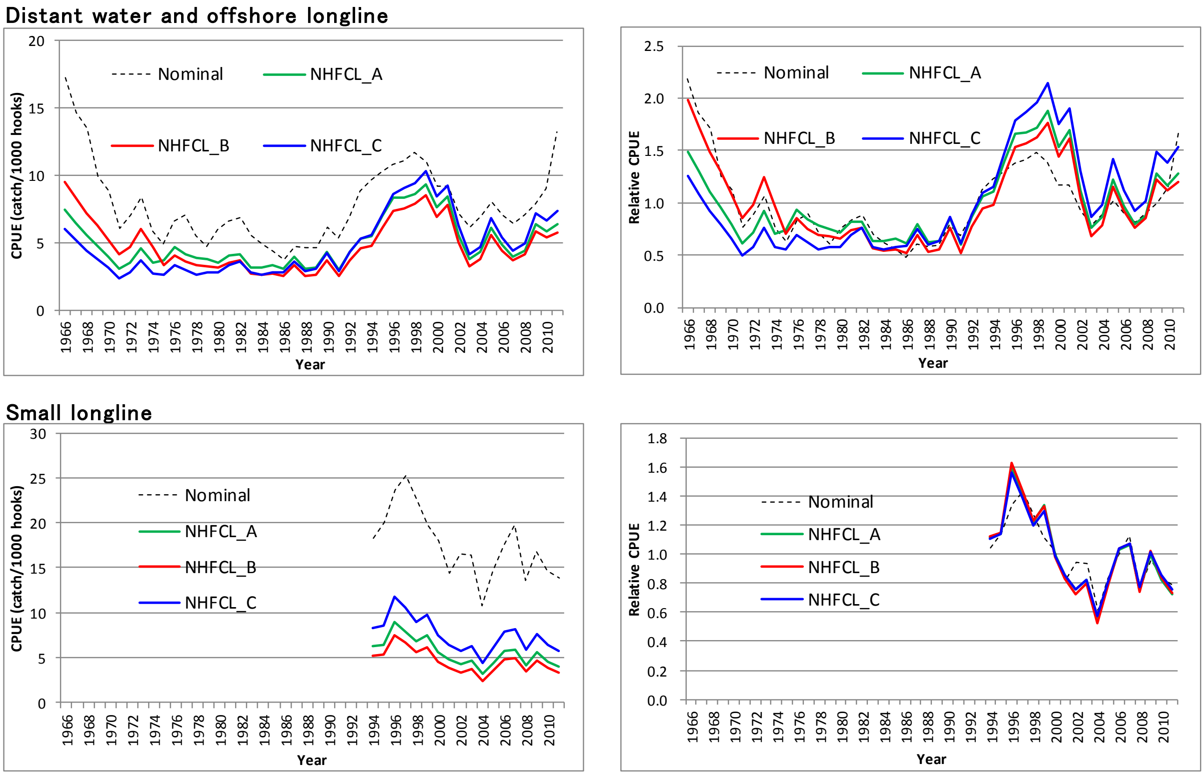


Fig. 2. Annual based CPUE in number standardized using L5, L1 and fine (set by set) data sets from 1960 to 2009 for main fishing ground (top) and whole (bottom) Indian Ocean expressed in relative (left figure) and real (right figure) scale overlaid with nominal CPUE.

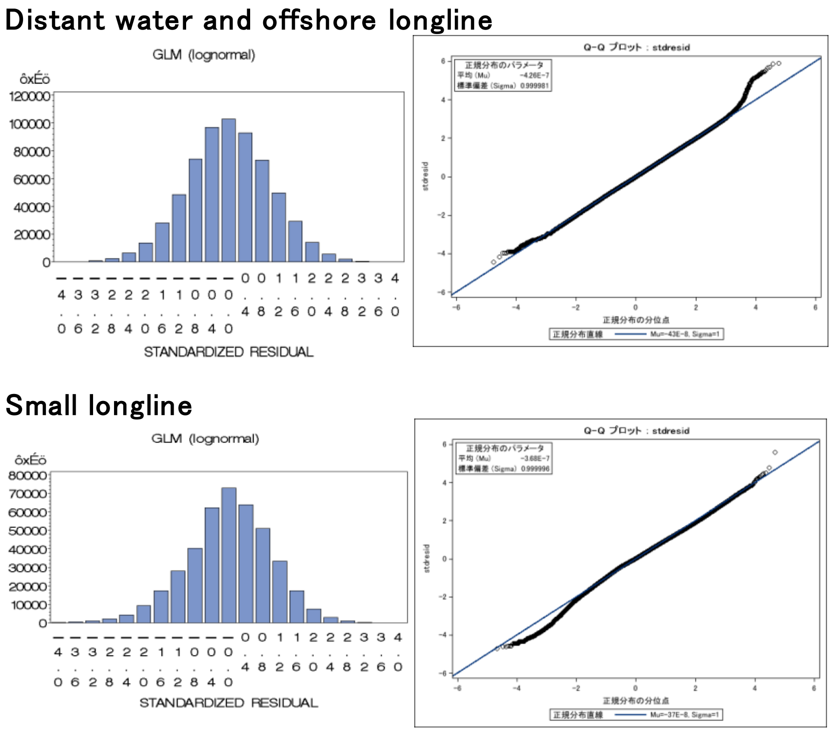


Fig. 3 Standardized residuals of annual based CPUE standardization using Model 110 for Distant water and offshore longline and small longline fisheries.

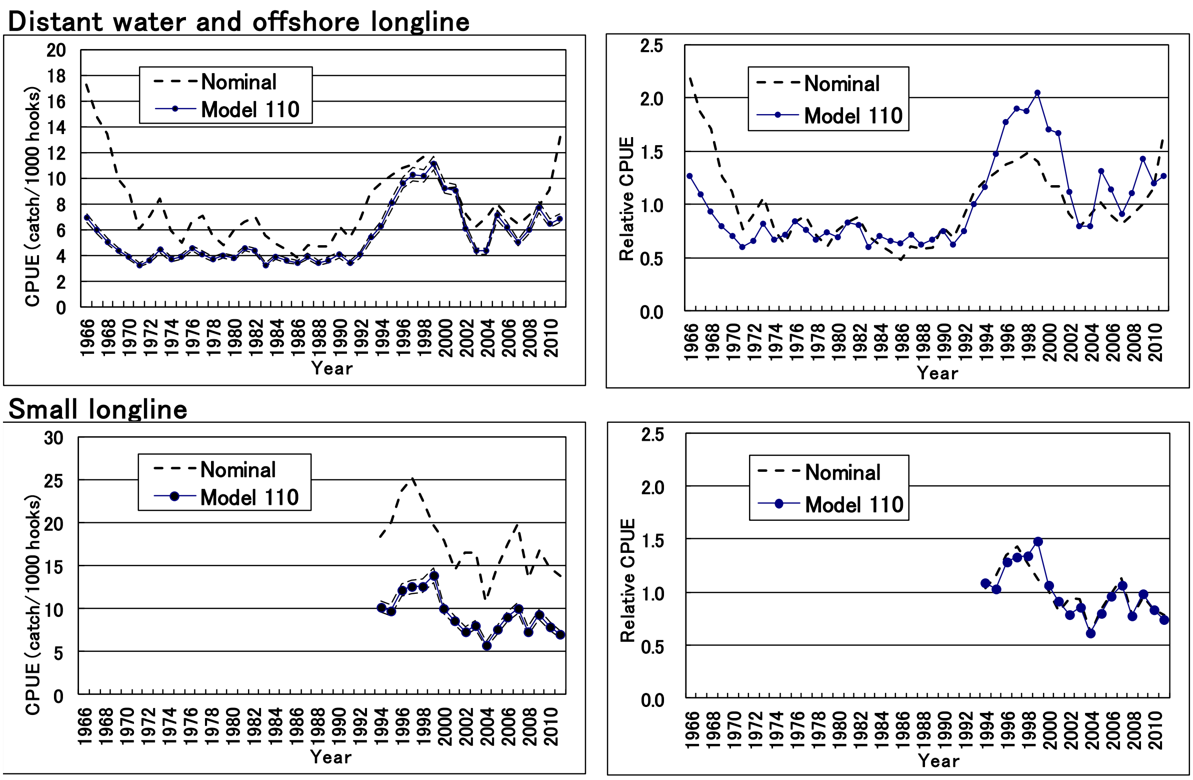


Fig. 4. Standardized CPUE in real (left) and relative scale by applying Model 110 for distant water and offshore longline and small longline fisheries overlaying with nominal CPUE..

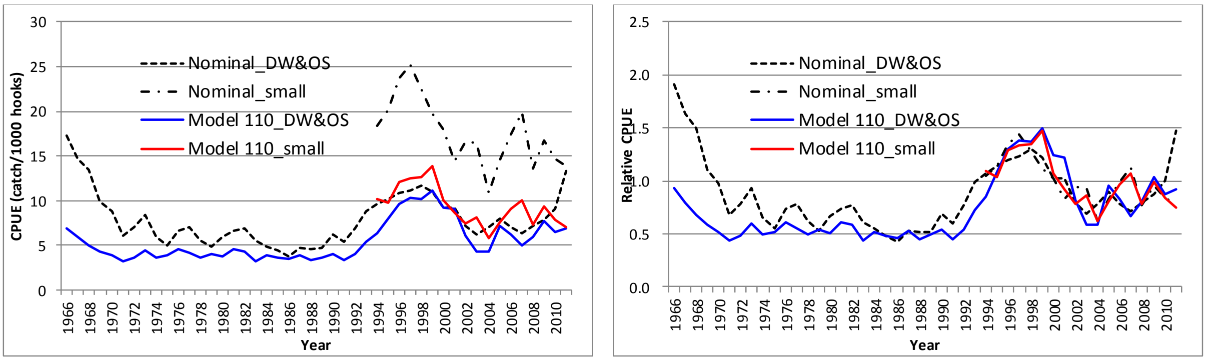


Fig. 5. Comparison of standardized CPUEs between distant water and offshore longline and small longline fisheries in real scale (left) and relative scale (right), overlaying with nominal CPUE of both fishery groups.

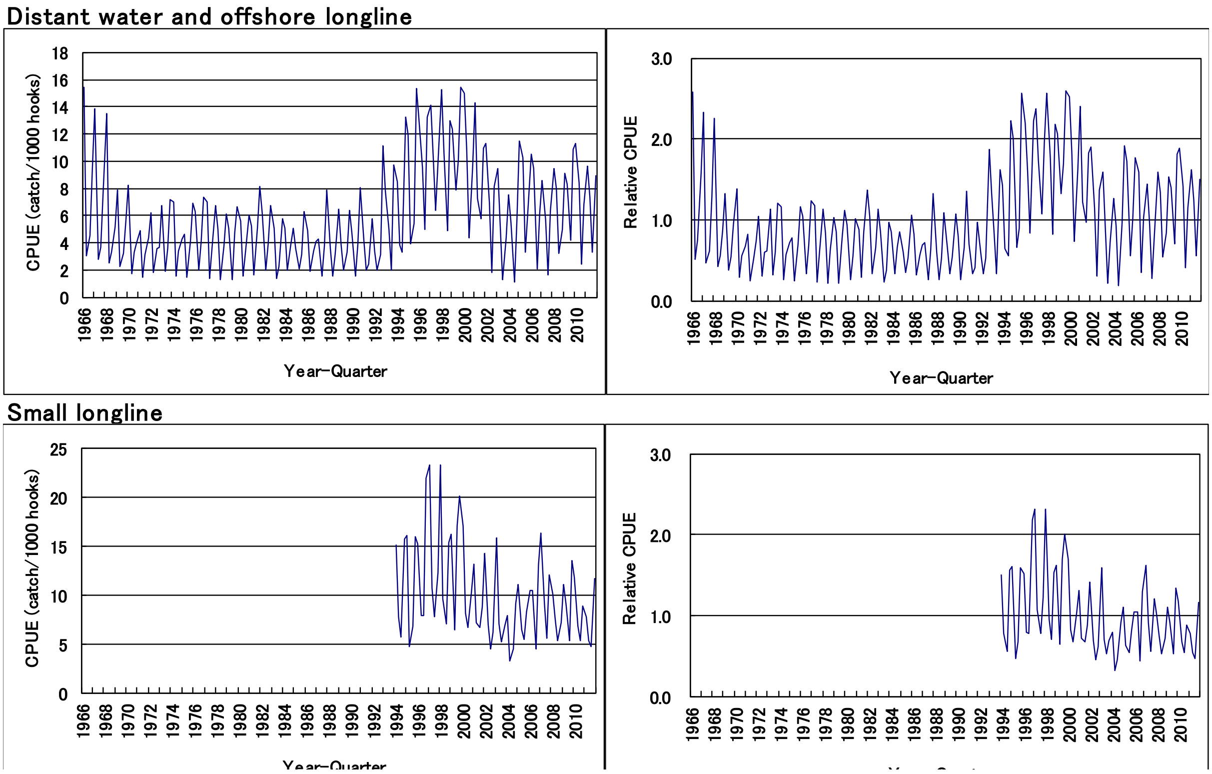


Fig. 6. Standardized CPUE in real (left) and relative scale by applying Model 110 for distant water and offshore longline and small longline fisheries overlaying with nominal CPUE..

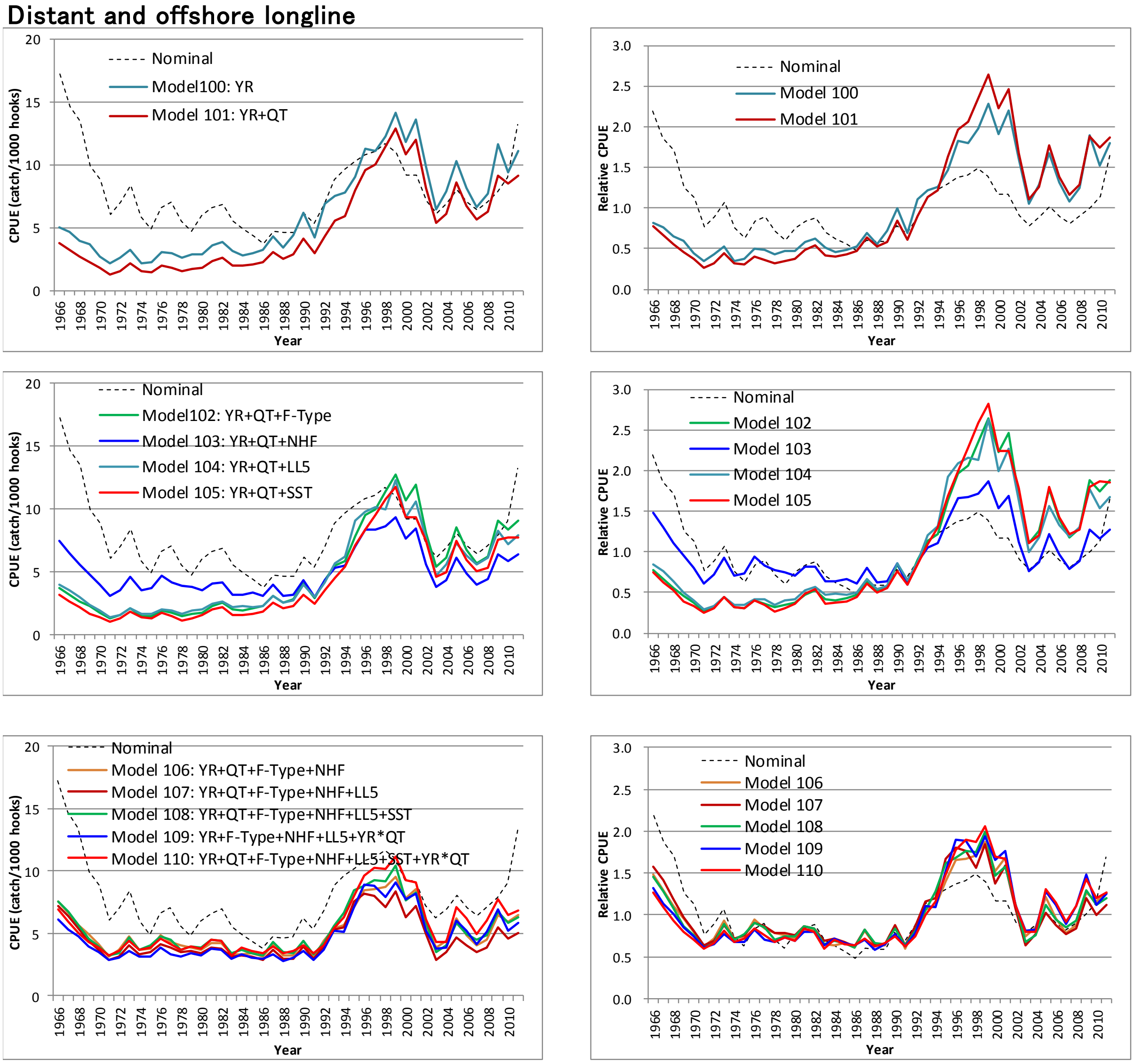


Fig. 7. Observation of the effect of each explanatory variable on the standardized CPUE trend, for distant and offshore longline and small longline fisheries by overlaying CPUEs derived from each model.

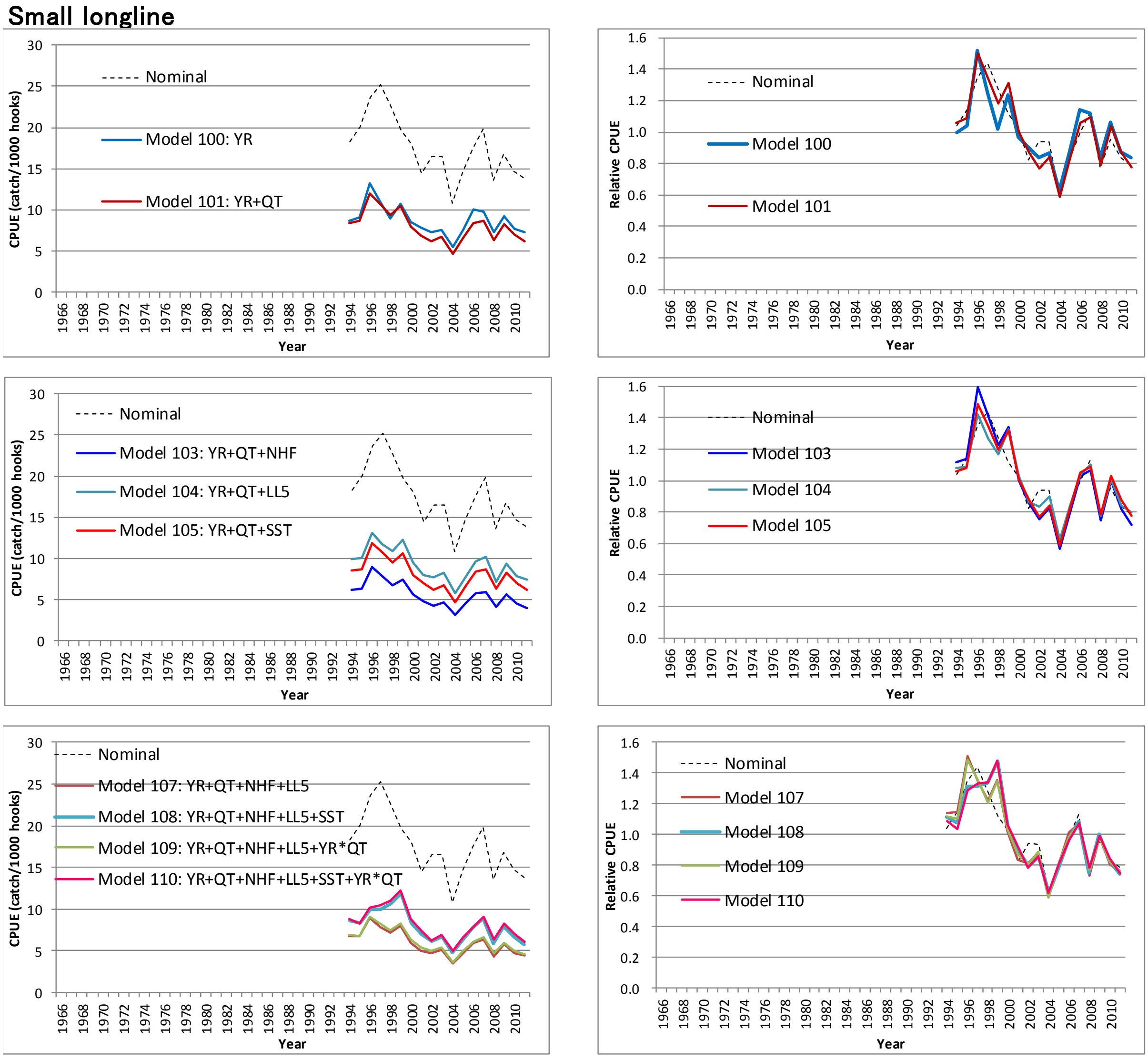


Fig. 7. Continued.

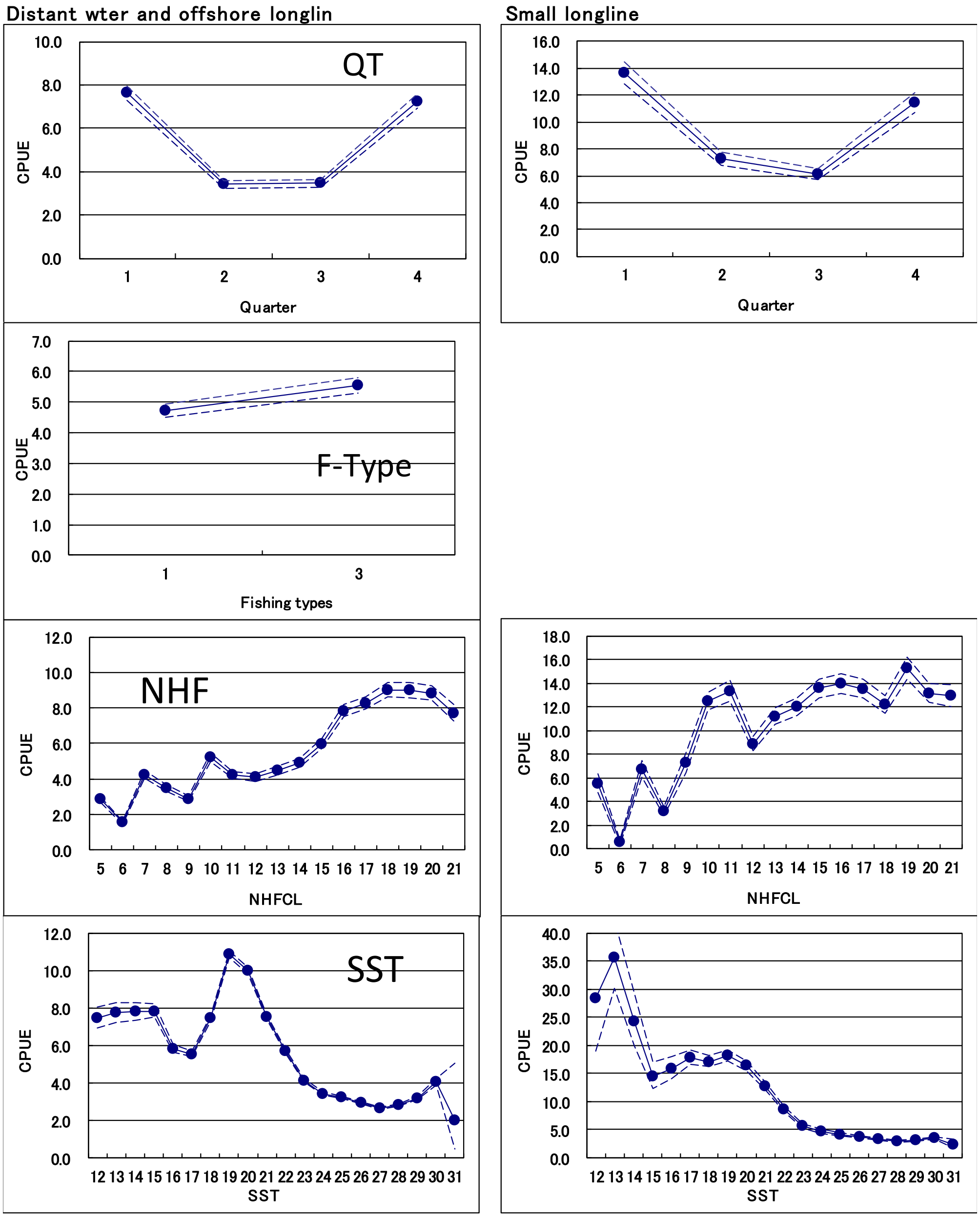


Fig. 8. Effect of main variables (QT: quarter, F-Type: distant water longline or offshore longline, NHF: Number of hooks between float, SST: sea surface temperature) applied in Model 110 for distant and offshore longline and small longline fisheries.

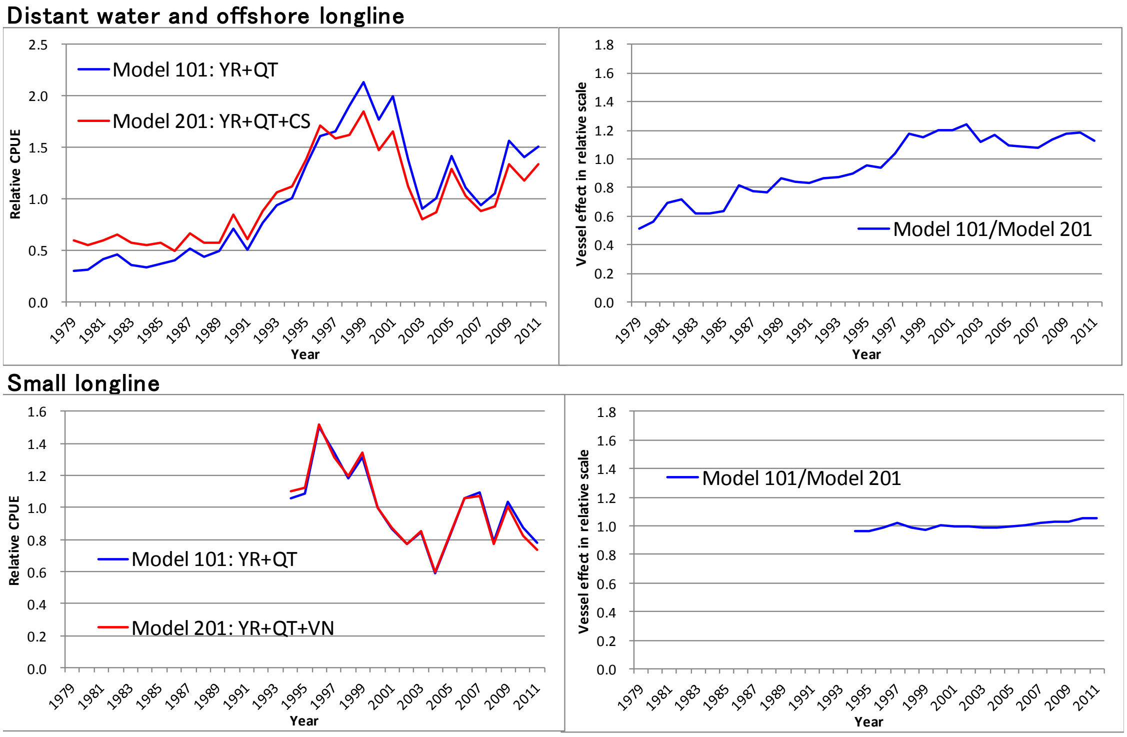


Fig. 9. Standardized CPUEs applying models without (Model 101: YR+QT) and with vessel identification (Model 201: YR+QT +call sign or + vessel name) (left). Right figures ware historical trend of fishing power (right) estimated as the ratio of these index.(Model101/Model201).

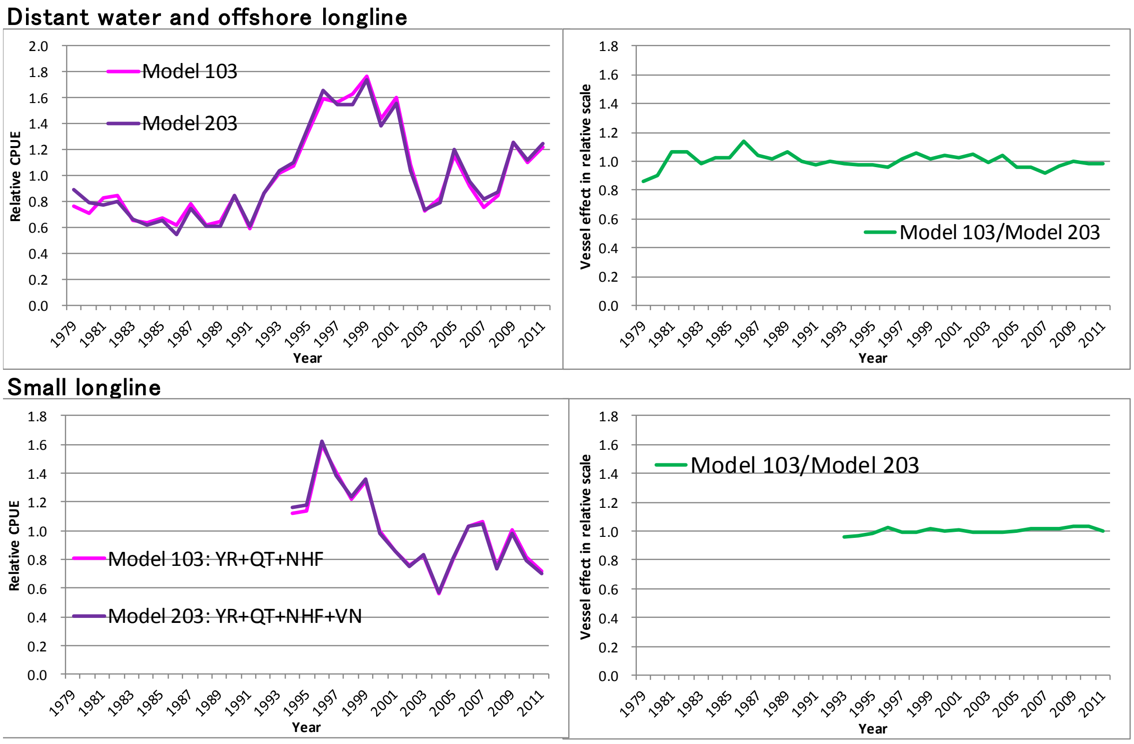


Fig. 10. Standardized CPUEs applying models without (Model 103: YR+QT+NHF) and with vessel identification (Model 203: YR+QT+NHF +call sign or + vessel name) (left). Right figures ware historical trend of fishing power (right) estimated as the ratio of these index.(Model103/Model203).

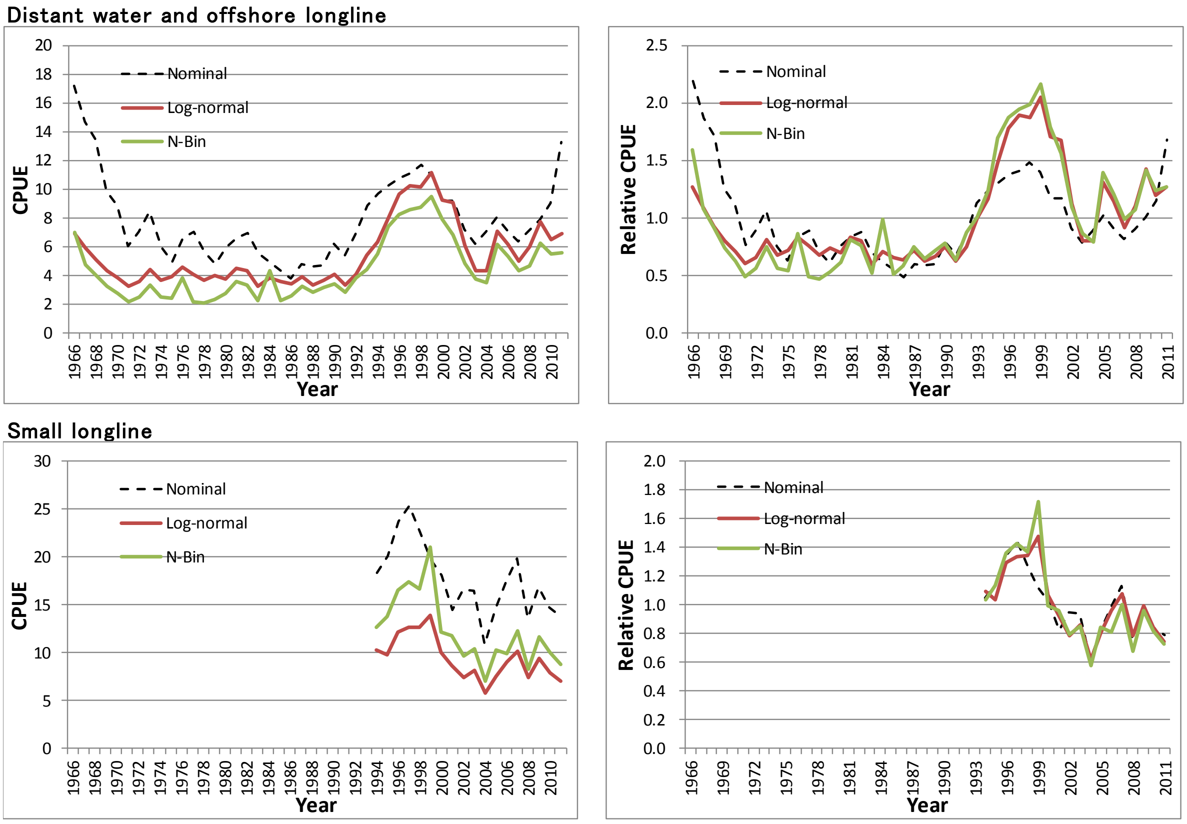
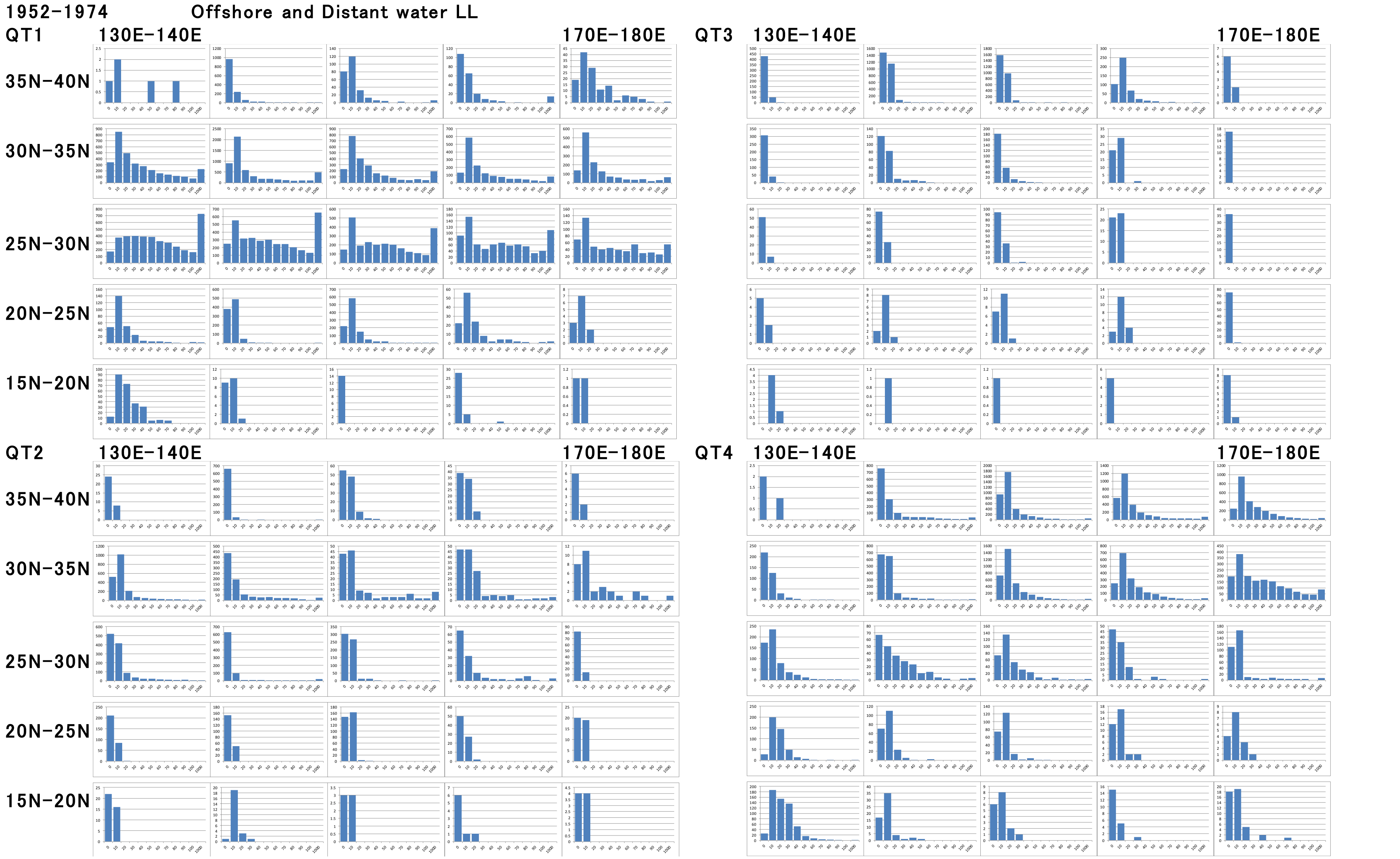
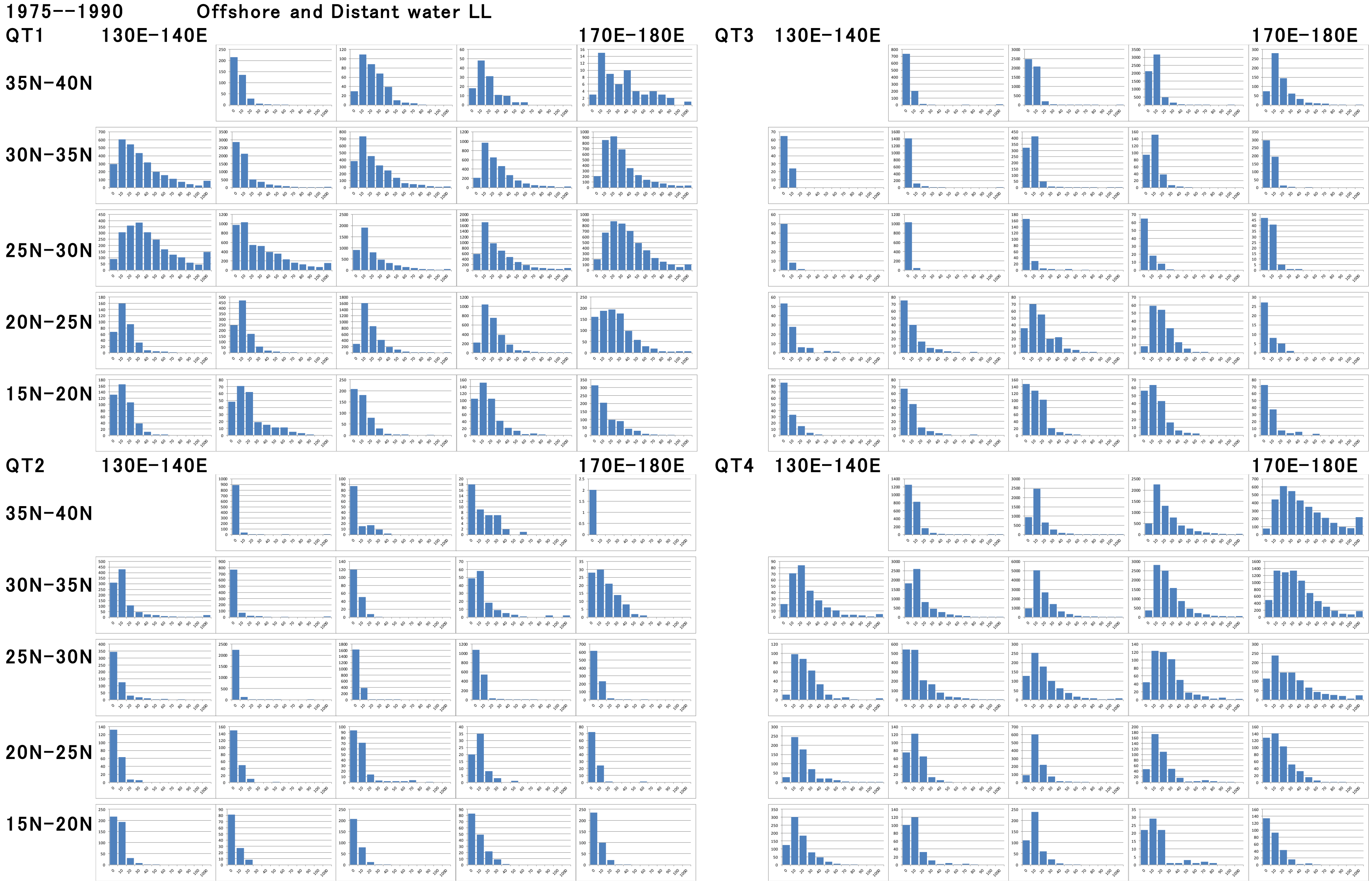


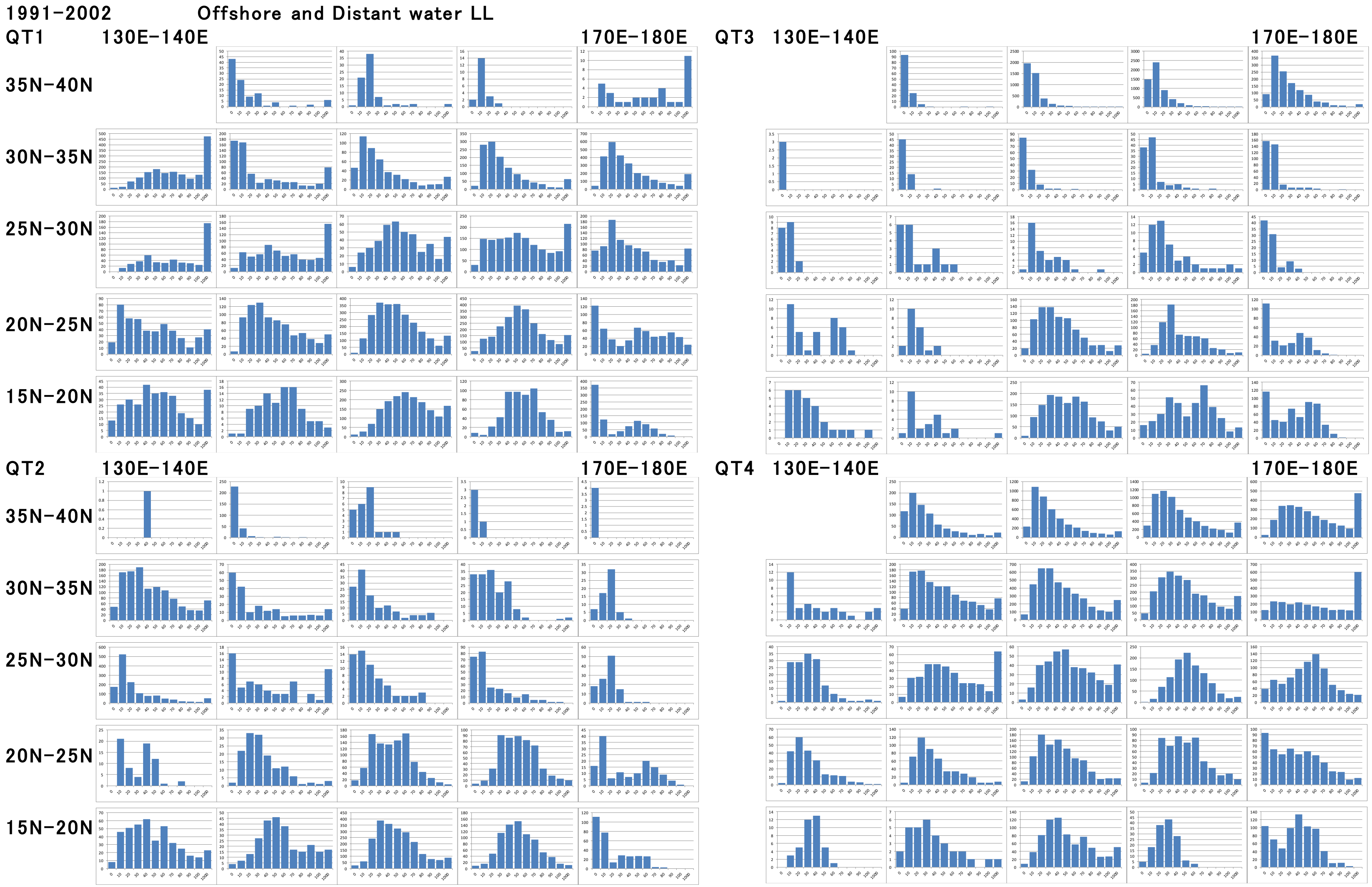
Fig. 11. Comparison of standardized CPUE by Log-normal model and Negative-binomial model, in which the same set of explanatory variables as Model 110 were included.



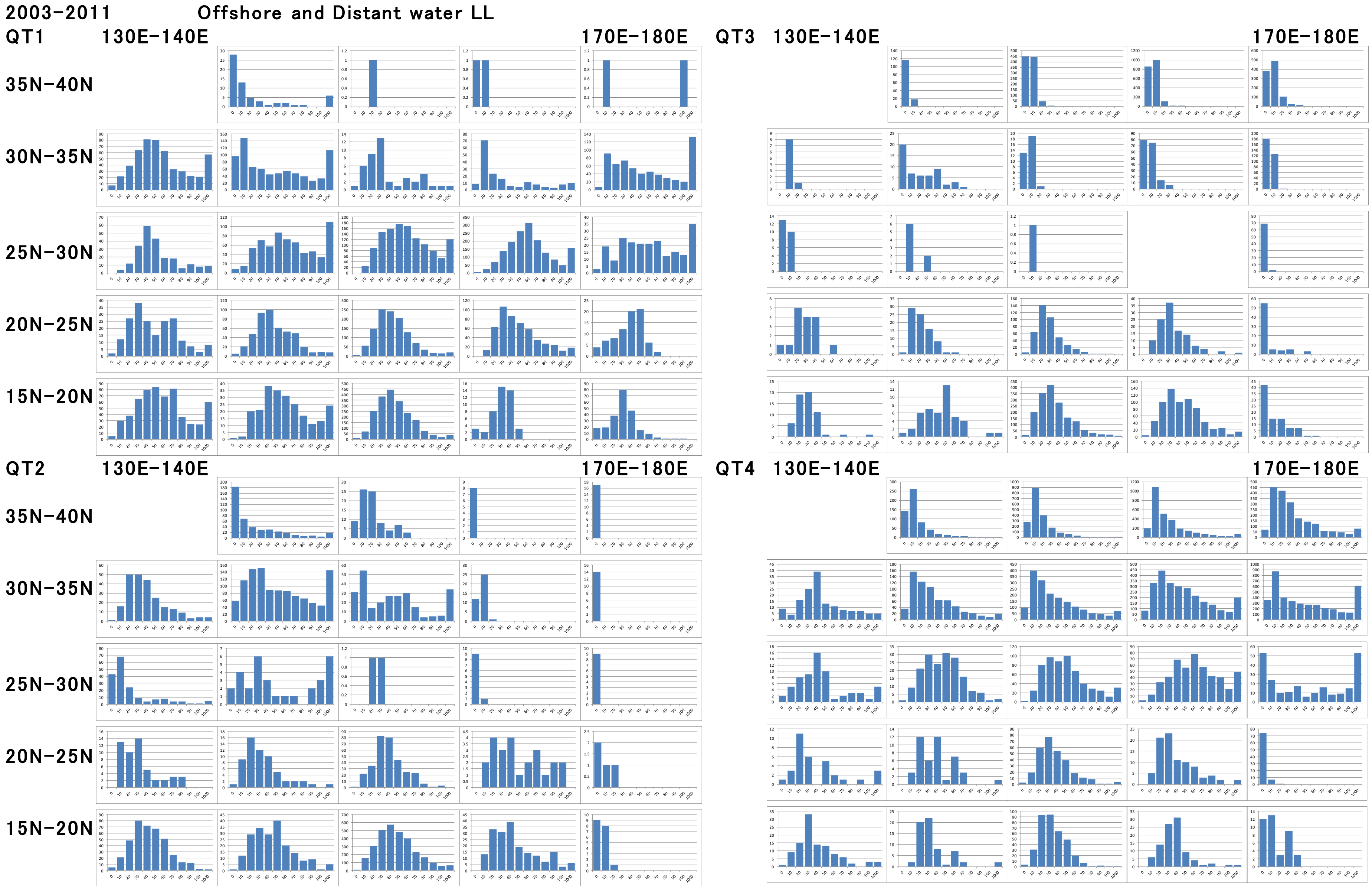
Appendix Fig. 1. Histograms of the number of longline set by catch in number per set, by fishery type (distant water and offshore longline and small longline), period of years (1952-1974, 1975-1990, 1991-2002 and 2003-2011) and quarter in 5° latitude by 10° longitude 10 resolution.



Appendix Fig. 1. Continued.

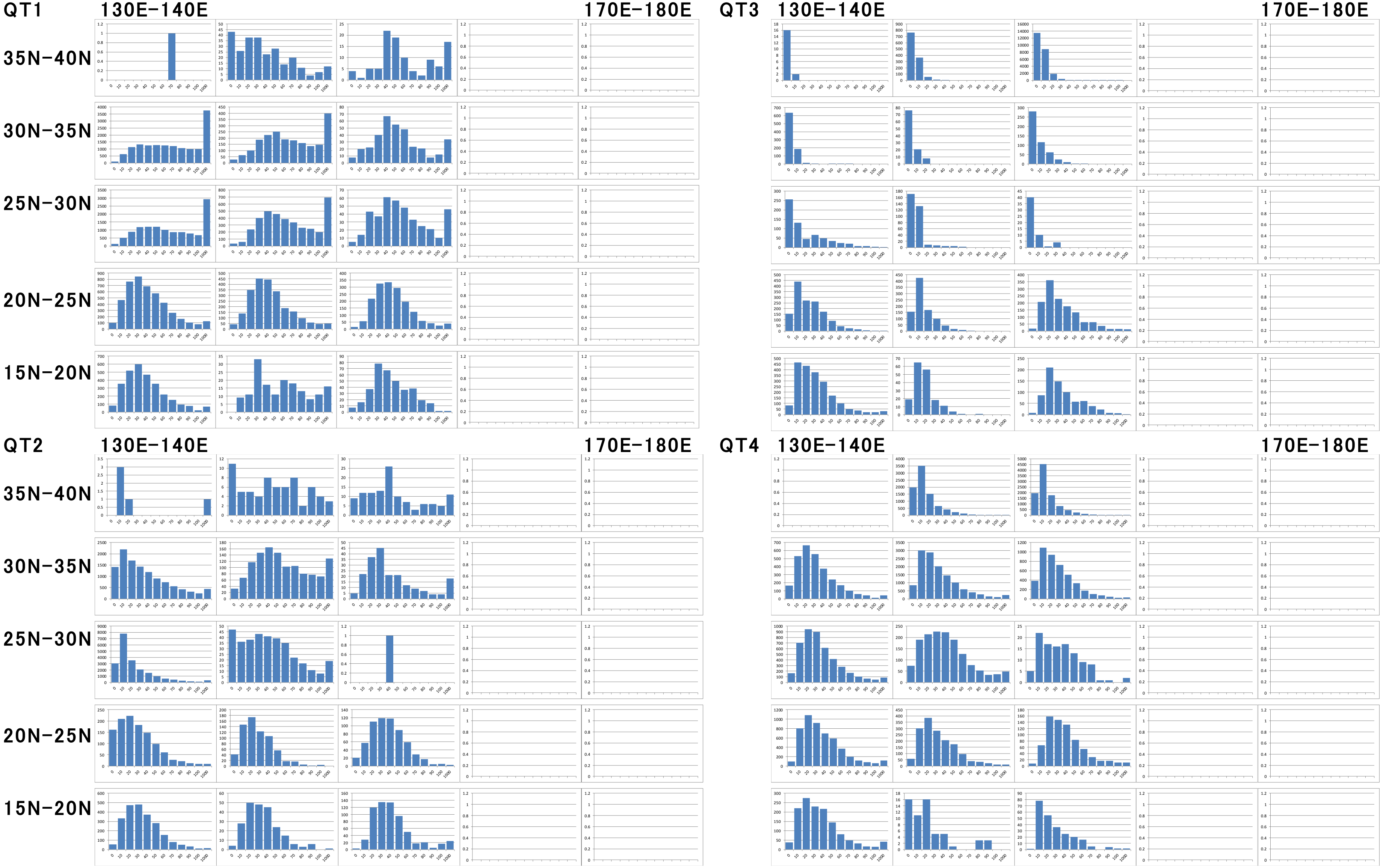


Appendix Fig. 1. Continued.

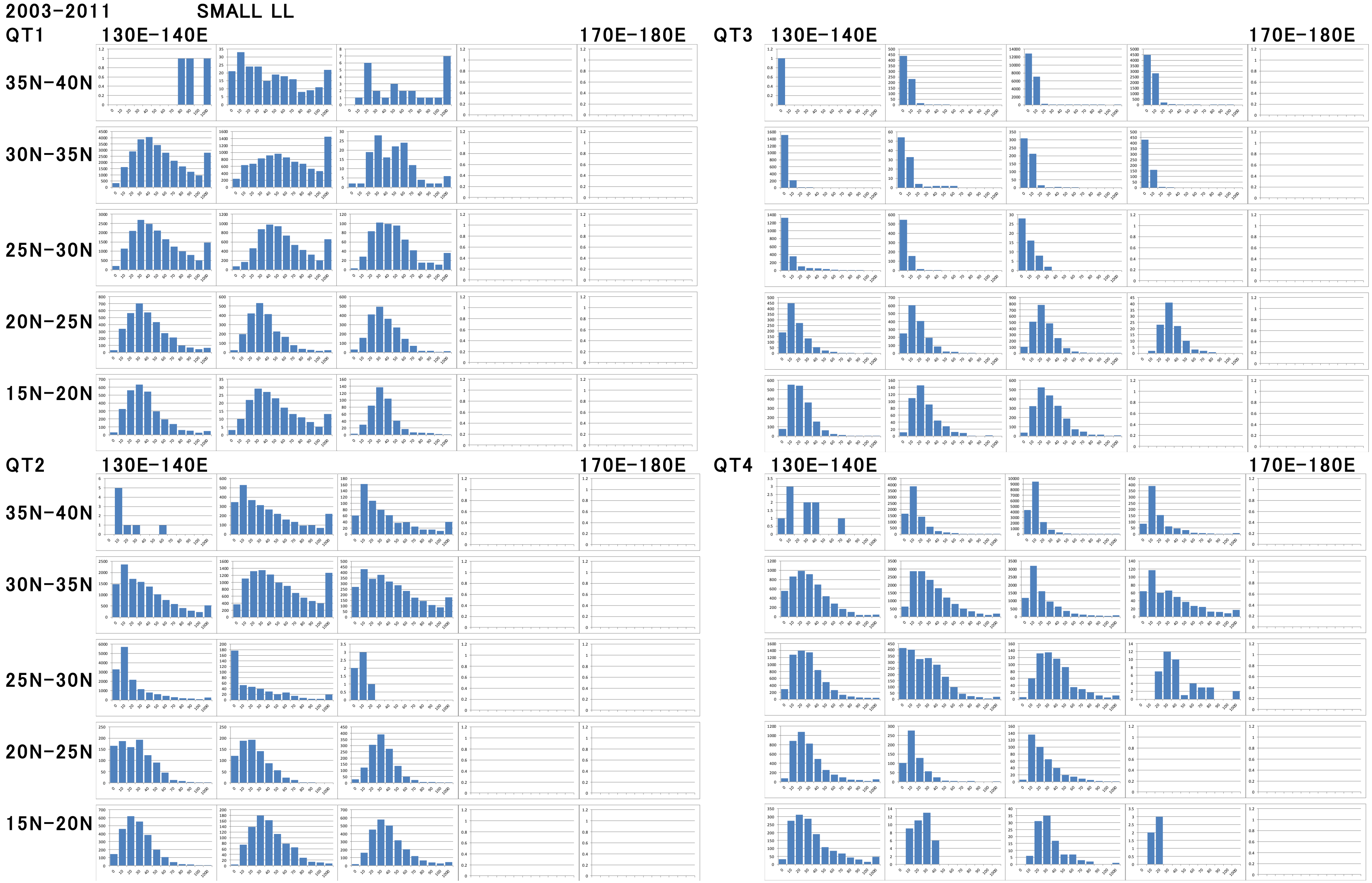


Appendix Fig. 1. Continued.

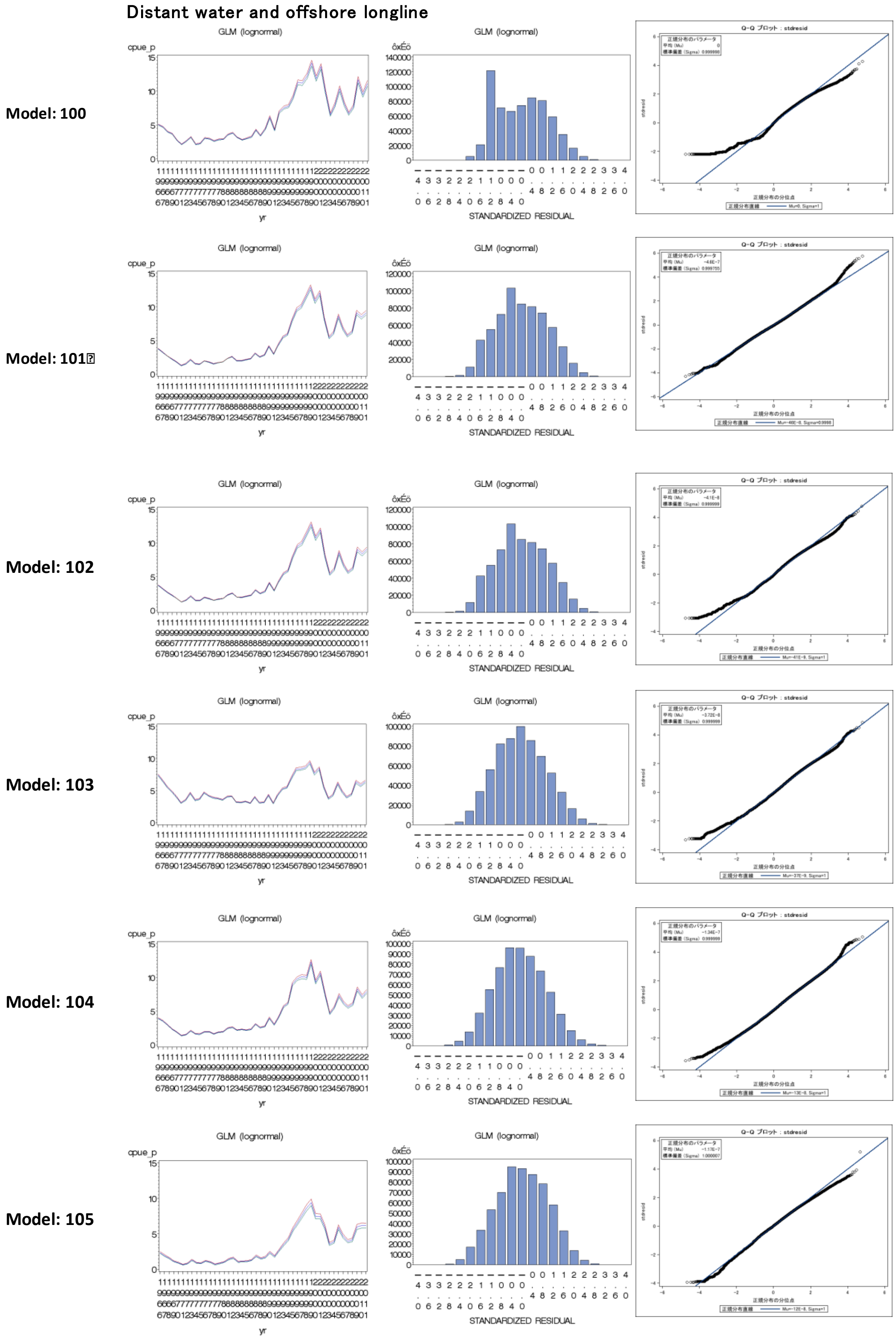
1994-2002 SMALL LL



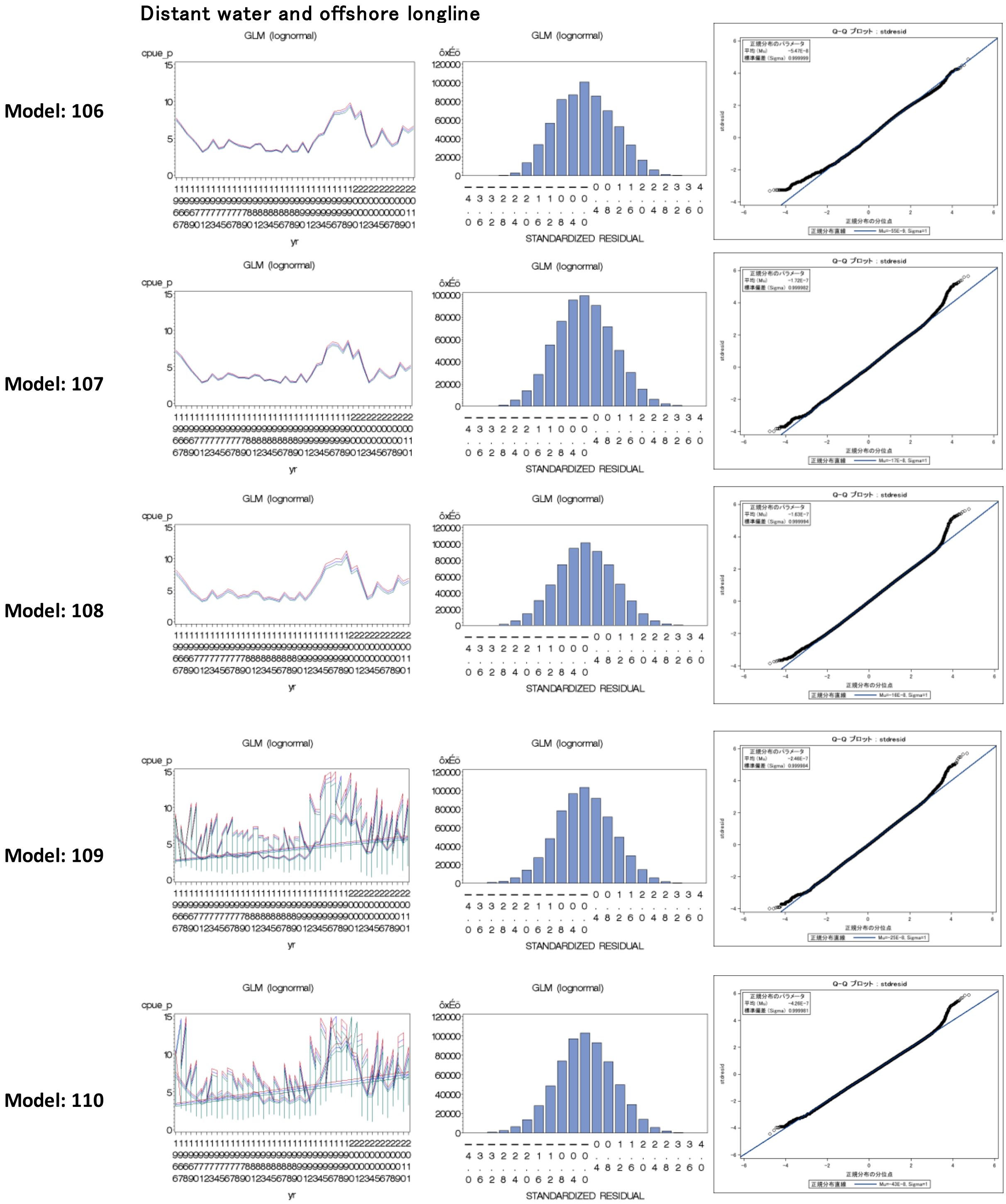
Appendix Fig. 1. Continued.



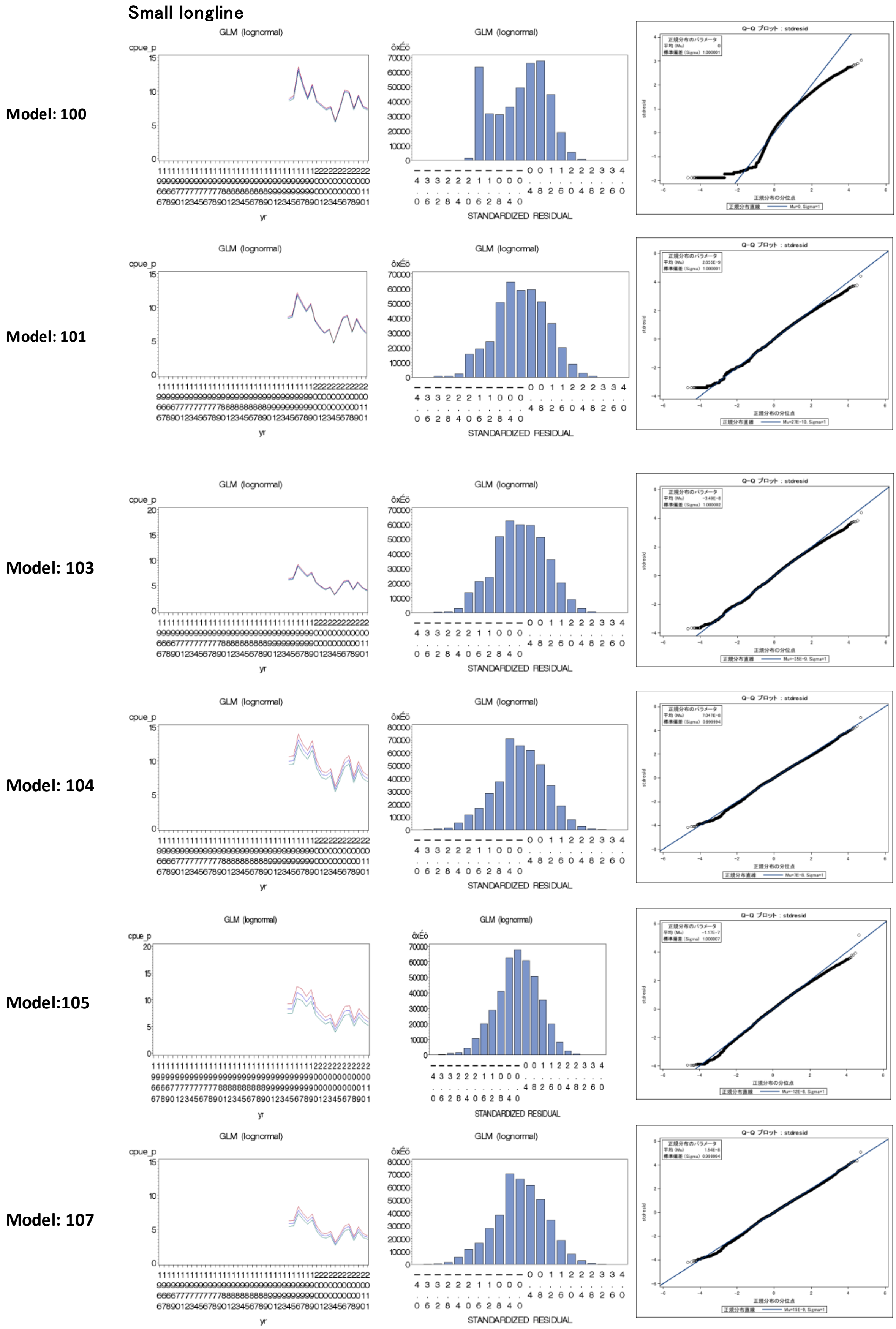
Appendix Fig. 1. Continued.



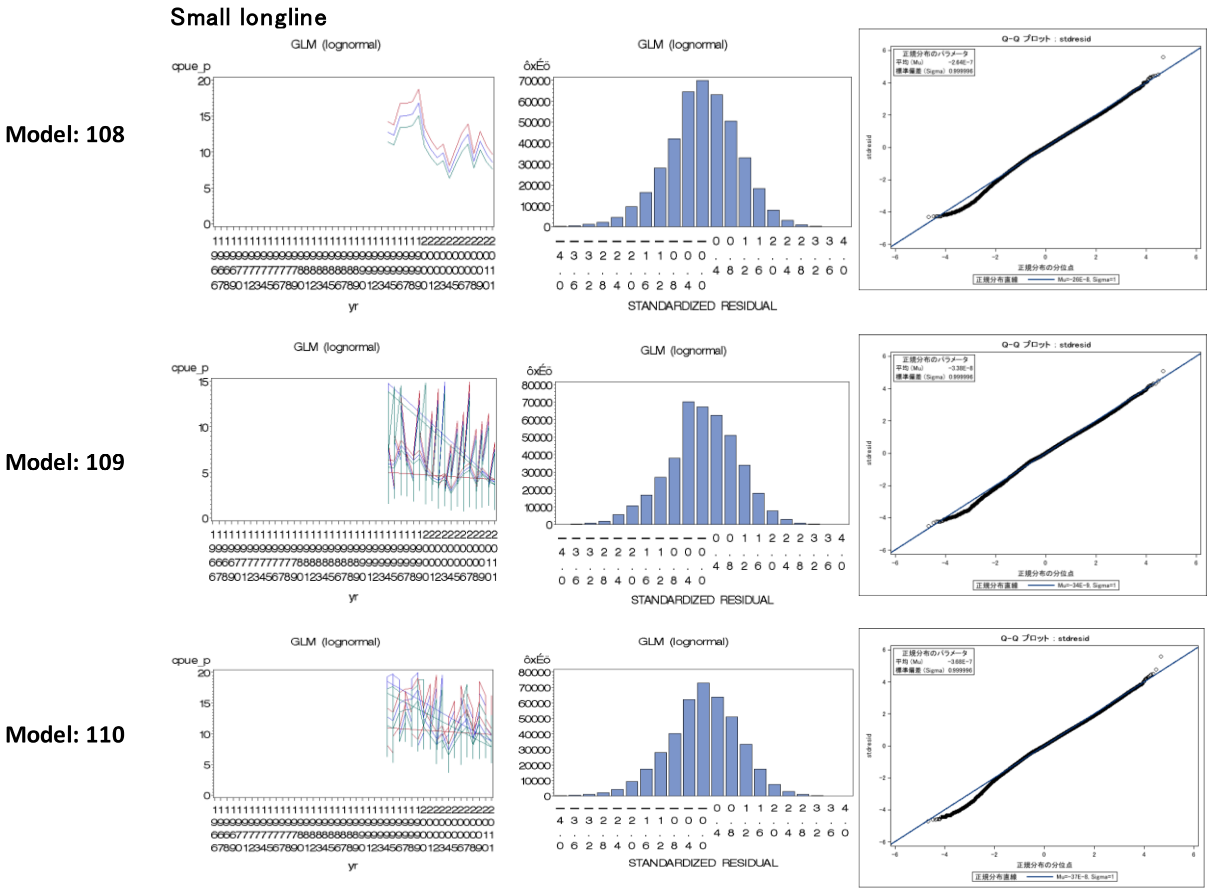
Appendix Fig. 2. Standardized CPUE and standardized residuals derived from all models applied for distant water and offshore longline and small longline fisheries.



Appendix Fig. 2. Continued.



Appendix Fig. 2. Continued.



Appendix Fig. 2. Continued.