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STANDARDIZED CPUE FOR BIGEYE TUNA CAUGHT BY THE JAPANESE TUNA LONGLINE FISHERIES OPERATED IN THE ATLANTIC OCEAN UP TO 2013

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SUMMARY

Japanese longline CPUE on bigeye tuna in the Atlantic Ocean, standardized by GLM applying log-normal error assumption was updated using the latest catch and effort data from 1961 up to 2013. As area definitions, all Atlantic area, three areas divided from all Atlantic, and main fishing ground were applied. Annual and quarterly CPUEs in number and weight bases were calculated, which is the same as previous analyses. As for the environmental factors, sea surface temperature (SST) was applied.

The CPUE in number for all Atlantic area definition, which showed increasing trend from 1961 to 1980, kept relatively high until around 1988, has steadily declined until 2011, and increased after that. The CPUEs in 2011 was the lowest value through the period analyzed. CPUE trend in main fishing ground was basically similar to that of all Atlantic, except that the increasing trend until 1980 was not remarkable. In both area definitions, trends of number and weight based CPUEs were quite similar.

RÉSUMÉ

La CPUE palangrière japonaise du thon obèse dans l'océan Atlantique, standardisée par GLM en appliquant un postulat d'erreur log-normal, a été actualisée à l'aide des dernières données de prise et d'effort de 1961 à 2013. Comme définitions de zone, toute la zone atlantique, trois zones divisées de tout l'Atlantique et une zone de pêche principale ont été appliquées. Les CPUE annuelles et trimestrielles en nombre et poids ont été calculées, ce qui est le même que lors des analyses antérieures. Quant aux facteurs environnementaux, la température à la surface de la mer (SST) a été appliquée.

La CPUE en nombre pour la définition de toute la zone atlantique, qui dégageait une tendance ascendante de 1961 à 1980, s'est maintenue relativement à la hausse jusqu'aux alentours de 1988, a régulièrement chuté jusqu'en 2011, puis a remonté par la suite. En 2011, les CPUE ont affiché la valeur la plus faible de toute la période analysée. La tendance des CPUE dans la principale zone de pêche était fondamentalement similaire à celle de tout l'Atlantique, exception faite du fait que la tendance à la hausse jusqu'en 1980 n'était pas notable. Dans les deux définitions de zones, les tendances du nombre et du poids basées sur les CPUE étaient assez similaires.

RESUMEN

Se ha actualizado la CPUE de patudo de la pesquería palangrera japonesa en el océano Atlántico, estandarizada mediante un GLM con un supuesto de error log-normal, utilizando los últimos datos de captura y esfuerzo de 1961 hasta 2013. Se aplicaron las siguientes definiciones de zona: toda el área del Atlántico, tres zonas divididas en todo el Atlántico y los principales caladeros. Se calcularon las CPUE anuales y trimestrales en número y peso, que està lo mismo que las de análisis anteriores. Como factor medioambiental se aplicó la temperatura de la superficie del mar (SST).

La CPUE en número para la definición de área de todo el Atlántico, que mostraba una tendencia creciente desde aproximadamente desde 1961 hasta 1980, se mantuvo relativamente elevada hasta 1988, descendió de un modo constante hasta 2011, y aumentó después. La CPUE en 2011 fue la más baja de todo el periodo analizado. La tendencia de la CPUE en los principales caladeros fue prácticamente similar a la de todo el Atlántico, con la excepción de que no fue notable la tendencia creciente hasta 1980. En ambas definiciones de área, las tendencias de las CPUE en número y en peso fueron bastante similares.

KEYWORDS

Atlantic, Bigeye, Longline, Catch/effort

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1. Introduction

Longline is the only tuna-fishing gear deployed by Japan at present in the Atlantic Ocean, and bigeye tuna is one of the target species (Anon., 2013). Fishing effort for Japanese longline fishery covers almost entire Atlantic (**Appendix, Figure 1**), and bigeye tuna is mainly caught in the tropical area (**Appendix, Figure 2**).

There are several past studies which provided standardized CPUE for bigeye tuna caught by Japanese longline fishery in the Atlantic Ocean. In Okamoto (2007), Japanese longline CPUE for bigeye was standardized for up to 2005. The model used in that analyses was the same as that used in the CPUE standardization for bigeye assessment in 2004 (Okamoto *et al*., 2004) except that the mixed layer depth (MLD) was removed from environmental factors used in 2004.

In this paper, Japanese longline CPUE up to 2013 for bigeye in the Atlantic Ocean was standardized using GLM with lognormal error assumption in order to provide stock indicator of this species. As no stock assessment of this species is scheduled this year, updated CPUEs which are basically based on the same methods as those in the past studies (Okamoto, 2008, Satoh and Okamoto, 2011) are provided.

2. Materials and methods

The period, time unit (year base or quarter base), data type (number base or weight base) and area definitions used to standardize CPUE for each stock assessment model are shown in **Table 1**. Both number and weight based CPUE were calculated.

Model structures for CPUE standardization used in this paper are similar to that used in 2007 or 2011 analyses (Okamoto, 2008; Satoh and Okamoto, 2011).

2.1 Catch and effort data used

The Japanese longline catch in number and effort statistics from 1961 to 2013 were used to provide CPUE. The catch and effort data set was aggregated by month, 5-degree square, the number of hooks between floats (NHF) and material of main and branch lines. The data sets in which the number of hooks was less than 5000 were not used for analyses. The NHF from 1961 to 1974 when the information was not available was regarded to be 5 for all years and areas. The same data set of catch in weight was also prepared from 1961 to 2013 to observe the trend of weight based CPUE for the comparison with past studies. As the weight in catch data during 1961 through 1970 is not available, the same time and spatial distribution of average weight for 1971 was used to compile the weight based catch and weight statistics from 1961 to 1970 for using in this study.

2.2 Area definition

Two area definitions were applied in this study (**Figure 1**). They were the same as that used in Okamoto *et al*. (2004) or Okamoto (2008). One definition is what covers all Atlantic between 50N and 50S (top of **Figure 1**), and the other is what covers main fishing ground for bigeye in the central part of Atlantic Ocean (bottom of **Figure 1**). Main fishing ground area consists of four sub-areas to standardize spatial deviation in CPUE. Both area definitions were applied to standardize annual and quarterly CPUE in number and weight. In addition to these two sort of area definitions, all Atlantic area was divided into three areas, and quarterly based CPUE in number for each area was separately standardized, which corresponds to the area specific CPUE for Multifan-CL in the last stock assessment.

2.3 Environmental factors

As environmental factor, which is available for the analyzed period from 1961 to 2013, SST (Sea Surface Temperature) was applied. The original SST data, whose resolution is 1-degree latitude and 1-degree longitude by month from 1946 to 2013, was downloaded from NEAR-GOOS Regional Real Time Data Base of Japan Meteorological Agency (JMA).

http://goos.kishou.go.jp/rrtdb/database.html

The original data was recompiled into 5-degree latitude and 5-latitude longitude by month from 1961 to 2013 using the procedures described in Okamoto *et al.* (2001), and used in the analyses. In Satoh and Okamoto (2011), SST was not incorporated because data were not available at the time of analysis. Therefore, the methods in this study are closer to those in Okamoto (2008), which used SST data.

2.4 Gear effects

The number of hooks between floats (NHF) which was divided into 5 classes (NHFCL1: less than 6, NHFCL2: 6-8, NHFCL3: 9-12, NHFCL4: 13-16, NHFCL5: more than 16), and main and branch line materials were categorized into two, 1 = Nylon and 2 = the others. Although this information on the materials has been collected since 1994, the nylon material was started to be used by distant water longliner in around the late 1980s and spread quickly in the early 1990s (Okamoto, 2005). In this study, material of main and branch lines before 1994 was tentatively regarded as 'the others'.

2.5 Model used for standardization

GLM (log-normal error structured model) was applied to standardize CPUE for all the models. Detail of initial models of GLM for each area definition is as follows. GLM procedure of SAS software (version 9.3) was used for this analysis.

The following initial models were applied to standardize annual based CPUE for each area definition of Atlantic Ocean. In order to explain two dimensional distribution of CPUE, the interaction term between latitude and longitude was included in the model as the cubic expression (i.e., $Lat+Lon+(Lat+Lon)^2+(Lat+Lon)^3$). Both latitude and longitude were included as continuous variables.

- Initial Model for all Atlantic area definition-

$$\begin{aligned}
&\mathrm{Log\ (CPUEijkl\ +const)}=\mu+YR(i)+QT(j)\\
&+Lat(k)+Lon(l)+Lat^2(m)+Lat*Lon(n)+Lon^2(o)+Lat^3(p)+Lat2*Lon(q)+Lat*Lon^2(r)+Lon^3(s)+NHFCL(t)+SST(u)\\
&+SST^2(v)+SST^3(w)+ML(y)+BL(z)+QT(j)*SST(u)+NHFCL(t)*SST(u)+QT(j)*Lat(k)+QT(j)*Lat^2(m)\\
&+QT(j)*Lat^3(p)+QT(j)*Lon(l)+QT(j)*Lon^2(o)+QT(j)*Lon^3(s)+NHFC(t)*Lat(k)+NHFC(t)*Lat^2(m)\\
&+NHFC(t)*Lat^3(p)+NHFC(t)*Lon(l)+NHFC(t)*Lon^2(o)+NHFC(t)*Lon^3(s)+SST(u)*Lat(k)+SST(u)*Lat^2(m)\\
&+SST(u)*Lat^3(p)+SST(u)*Lon(l)+SST(u)*Lon^2(o)+SST(u)*Lon^3(s)\\
&+e(ijkl....)
\end{aligned}$$

- Initial Model for main fishing ground area definition-

$$\begin{aligned}
&\mathrm{Log\ (CPUEijkl\ +const)}=\mu+YR(i)+QT(j)+Area(k)+NHFCL(l)+SST(m)+SST^2(n)+SST^3(o)+ML(p)+BL(q)+\\
&QT(j)*SST(m)+NHFCL(l)*SST(m)+ML(p)*NHFCL(l)+BL(q)*NHFCL(l)+YR(i)*QT(j)+Area(k)*QT(j)\\
&+Area(k)*NHFCL(l)+Area(k)*SST(m)
\end{aligned}$$

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)
[Lat, Lon, Lat^2, Lat*Lon, Lon^2, Lat^3, Lat^2*Lon, Lat*Lon^2, Lon^3 : interactions between Latitude and Longitude expressed as third order polynomial functions. Latitude and Longitude are included as continuous variables.]
Area: effect of area,
NHFCL : effect of gear type (category of the number of hooks between floats),
SST : effect of SST (as a continuous variable),
SST^2 : effect of SST^2 (=SST x SST, as a continuous variable),
SST^3 : effect of SST^3 (=SST x SST x SST, as a continuous variable),
ML : effect of material of main line,
BL : effect of material of branch line,
QT*SST : interaction term between fishing season and SST,
NHFCL*SST interaction term between gear type and SST,
QT*Lat (*Lat^2,* Lat^3): interaction term between quarter and Latitude,
QT*Lon (*Lon^2,* Lon^3): interaction term between quarter and Longitude,
NHFCL*Lat (*Lat^2,* Lat^3): interaction term between gear type and Latitude,
NHFCL*Lon (*Lon^2,* Lon^3): interaction term between gear type and Longitude,

SST*Lat (*Lat^2,* Lat^3): interaction term between SST and Latitude,
SST*Lon (*Lon^2,* Lon^3): interaction term between SST and Longitude,
ML*NHFCL: interaction term between material of main line and gear type,
BL*NHFCL: interaction term between material of branch line and gear type,
YR*QT : interaction term between year and quarter,
Area*NHFCL : interaction term between area and gear type,
Area*SST : interaction term between area and SST,
e(ijkl…..) : error term.

Based 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 cases in which the factor is not significant as main factor but is significant as interaction with another factor, the main factor was kept in the model. As for the weight based CPUE, the same initial model as for the number based CPUE was used.

In the case of quarter based CPUE, lsmeans of Year-Quarter interaction in the result of above were used to calculate quarterly CPUE for both area definitions. As for the three areas divided from all Atlantic area definition, the model used for all Atlantic was applied.

3. Results and discussion

Number and weight based annual CPUE standardized for all Atlantic area definition is shown in **Figures 2 and 8**. Results of ANOVA and distributions of the standard residual in each analysis are shown in **Table 2** and **Figure 3**, respectively. Distributions of the standard residual did not show remarkable difference from the normal distribution. The trends of both of number based and weight based CPUE are basically similar (**Figure 4**). The CPUE in number, which showed increasing trend from about 5.4 in 1961 to 8.4 in 1980, kept relatively high, around 7.3, until 1987, has steadily declined to around 1.8 after 2011, and increased again after that. The CPUEs in 2011 was the lowest value through the period analyzed.

Standardized annual CPUEs in number and weight for main fishing ground were shown in **Figures 5 and 8**. Results of ANOVA and distributions of the standard residual in each analysis were shown in **Table 3** and **Figure 6**, respectively. As for the results for all Atlantic area definition, there is no notable difference between number based and weight based CPUE trends (**Figure 7**). Although slight increasing CPUE trend was observed in all Atlantic area until around 1980, CPUE of main fishing ground was rather flat and remarkable trend was not observed until 1989 when CPUE started decreasing continuously. CPUE became the lowest (2.1) in 2008, and increased after that.

Quarterly trends of CPUE in number for all Atlantic and those divided into three areas were shown in **Figure 9** overlaying with plots of nominal annual CPUE. Results of ANOVA and distributions of the standard residual in each analysis are shown in **Table 4** and **Figure 10**, respectively. In all areas, seasonal oscillation in standardized CPUE was observed. Although the quarter of highest CPUE is not necessarily fixed through the analyzed period, CPUEs in 1st and 2nd quarters tend to be highest at AREA2, while that in 3rd and 4th quarters seems to be higher at AREA 1 and AREA3. In all three areas, CPUE has declined since around 1979 although that in Area 2 during 1977 through 1980 was rather flat in high CPUE level.

In **Figure 11**, quarterly CPUEs in number for main fishing ground are shown in relative and real scales. Distributions of the standard residual in each analysis were shown **Figure 12**. Its trend is quite similar to that for all Atlantic CPUE.

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Table 1. Period, time unit, data type and area definitions used to standardize CPUE. Stock assessment models shown in the table correspond to those for the last stock assessment.

	Assessment method		
	Production Model	VPA	Multifan-CL
Period	1961-2013	1975-2013	1961-2013
Year or Quarter	Year	Year	Quarter
Type of data	Weight	Number	Number
All Atlantic	+	+	+
Main fishing ground	+	+	+
Three areas	-	-	+

Table 2. Results of ANOVA table of year based CPUE in number and weight for all Atlantic area definition.

AREA ALL		Number				
Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square
Model	281	38406.099	136.6765	320.52	<.0001	0.5855
yr	52	3050.3483	58.66054	137.57	<.0001	
qt	3	28.571778	9.523926	22.33	<.0001	
lt	1	23.703982	23.70398	55.59	<.0001	
ln	1	101.84396	101.844	238.84	<.0001	
lt2	1	2702.8082	2702.808	6338.41	<.0001	
ltln	1	582.82715	582.8271	1366.8	<.0001	
ln2	1	180.98001	180.98	424.42	<.0001	
lt3	1	0.175513	0.175513	0.41	0.5212	
lt2ln	1	115.22453	115.2245	270.22	<.0001	
ltln2	1	254.87429	254.8743	597.71	<.0001	
ln3	1	150.88586	150.8859	353.85	<.0001	
nhfcl	4	88.921308	22.23033	52.13	<.0001	
sst	1	679.64654	679.6465	1593.85	<.0001	
sst2						
sst3						
ml	1	0.000714	0.000714	0	0.9673	
bl						
sst*qt						
sst*nhfcl	4	177.76399	44.441	104.22	<.0001	
yr*qt	156	850.43151	5.451484	12.78	<.0001	
ml*nhfcl	4	44.79579	11.19895	26.26	<.0001	
bl*nhfcl						
lt*qt	3	389.99579	129.9986	304.86	<.0001	
lt2*qt	3	135.42089	45.1403	105.86	<.0001	
lt3*qt	3	333.71346	111.2378	260.87	<.0001	
ln*qt	3	87.839835	29.27995	68.66	<.0001	
ln2*qt	3	7.636402	2.545467	5.97	0.0005	
ln3*qt	3	10.093618	3.364539	7.89	<.0001	
lt*nhfcl	4	72.813969	18.20349	42.69	<.0001	
lt2*nhfcl	4	102.76787	25.69197	60.25	<.0001	
lt3*nhfcl	4	46.413016	11.60325	27.21	<.0001	
ln*nhfcl	4	162.06116	40.51529	95.01	<.0001	
ln2*nhfcl	4	9.513199	2.3783	5.58	0.0002	
ln3*nhfcl	4	23.409905	5.852476	13.72	<.0001	
lt*sst	1	5.953361	5.953361	13.96	0.0002	
lt2*sst	1	524.97295	524.9729	1231.12	<.0001	
lt3*sst	1	10.673152	10.67315	25.03	<.0001	
ln*sst	1	162.77514	162.7751	381.73	<.0001	
ln2*sst	1	162.77514	162.7751	381.73	<.0001	
ln3*sst	1	119.85068	119.8507	281.06	<.0001	

AREA ALL		Weight				
Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square
Model	283	23410.431	82.72237	211.65	<.0001	0.501488
yr	52	3085.3813	59.33426	151.81	<.0001	
qt	3	25.905387	8.635129	22.09	<.0001	
lt	1	236.35364	236.3536	604.73	<.0001	
ln	1	83.367886	83.36789	213.3	<.0001	
lt2						
ltln	1	617.52407	617.5241	1579.98	<.0001	
ln2						
lt3	1	22.508552	22.50855	57.59	<.0001	
lt2ln	1	378.85254	378.8525	969.32	<.0001	
ltln2	1	400.00728	400.0073	1023.45	<.0001	
ln3	1	2.328161	2.328161	5.96	0.0147	
nhfcl	4	67.04348	16.76087	42.88	<.0001	
sst	1	37.828144	37.82814	96.79	<.0001	
sst2	1	20.102088	20.10209	51.43	<.0001	
sst3	1	4.494917	4.494917	11.5	0.0007	
ml						
bl						
sst*qt	3	21.910731	7.303577	18.69	<.0001	
sst*nhfcl	4	162.70653	40.67663	104.07	<.0001	
yr*qt	156	737.71178	4.728922	12.1	<.0001	
ml*nhfcl	5	50.158856	10.03177	25.67	<.0001	
bl*nhfcl						
lt*qt	3	252.37859	84.1262	215.24	<.0001	
lt2*qt	3	112.65942	37.55314	96.08	<.0001	
lt3*qt	3	272.00144	90.66715	231.98	<.0001	
ln*qt	3	39.21466	13.07155	33.44	<.0001	
ln2*qt	3	10.181839	3.393946	8.68	<.0001	
ln3*qt	3	42.851233	14.28374	36.55	<.0001	
lt*nhfcl	4	134.26538	33.56635	85.88	<.0001	
lt2*nhfcl	4	48.071833	12.01796	30.75	<.0001	
lt3*nhfcl	4	32.418041	8.10451	20.74	<.0001	
ln*nhfcl	4	113.85513	28.46378	72.83	<.0001	
ln2*nhfcl	4	8.10962	2.027405	5.19	0.0004	
ln3*nhfcl	4	24.109886	6.027471	15.42	<.0001	
lt*sst						
lt2*sst						
lt3*sst						
ln*sst	1	26.246158	26.24616	67.15	<.0001	
ln2*sst						
ln3*sst	1	4.293625	4.293625	10.99	0.0009	

Table 3. Results of ANOVA table of year based CPUE in number and weight for main fishing area definition in the Atlantic Ocean.

Main fishing		Number				
Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square
Model	262	7081.056	27.027	91.830	<.0001	0.396949
yr	52	2174.017	41.808	142.06	<.0001	
qt	3	11.265	3.755	12.76	<.0001	
area	3	45.011	15.004	50.98	<.0001	
nhfcl	4	10.487	2.622	8.91	<.0001	
sst	1	129.125	129.125	438.75	<.0001	
sst2	1	129.167	129.167	438.89	<.0001	
sst3	1	131.043	131.043	445.27	<.0001	
ml	1	3.220	3.220	10.94	0.0009	
bl	1	0.488	0.488	1.66	0.1977	
sst*qt	3	10.426	3.475	11.81	<.0001	
sst*nhfcl	4	76.290	19.072	64.81	<.0001	
ml*nhfcl	4	6.566	1.641	5.58	0.0002	
bl*nhfcl	4	4.497	1.124	3.82	0.0042	
yr*qt	156	472.398	3.028	10.29	<.0001	
qt*area	9	159.350	17.706	60.16	<.0001	
area*nhfcl	12	103.060	8.588	29.18	<.0001	
sst*area	3	33.257	11.086	37.67	<.0001	

Main fishing		Weight				
Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square
Model	262	6636.005	25.328	91.020	<.0001	0.394521
yr	52	2074.797	39.900	143.39	<.0001	
qt	3	24.744	8.248	29.64	<.0001	
area	3	29.479	9.826	35.31	<.0001	
nhfcl	4	34.218	8.554	30.74	<.0001	
sst	1	110.156	110.156	395.87	<.0001	
sst2	1	116.361	116.361	418.17	<.0001	
sst3	1	123.341	123.341	443.25	<.0001	
ml	1	3.601	3.601	12.94	0.0003	
bl	1	1.704	1.704	6.12	0.0133	
sst*qt	3	21.138	7.046	25.32	<.0001	
sst*nhfcl	4	151.925	37.981	136.49	<.0001	
ml*nhfcl	4	3.189	0.797	2.86	0.0219	
bl*nhfcl	4	5.948	1.487	5.34	0.0003	
yr*qt	156	430.827	2.762	9.92	<.0001	
qt*area	9	99.368	11.041	39.68	<.0001	
area*nhfcl	12	118.252	9.854	35.41	<.0001	
sst*area	3	20.896	6.965	25.03	<.0001	

Table 4. Results of ANOVA table of quarterly CPUE in number for each of three areas divided from all Atlantic area definition.

AREA 1

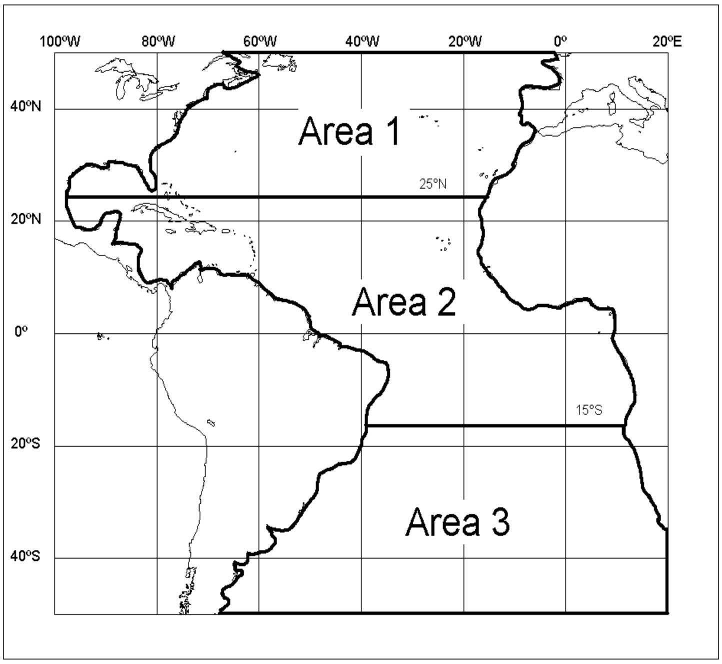
Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square
Model	262	10667.17	40.71	61.30	<.0001	0.560
						CV
yr	51	810.93	15.90	23.94	<.0001	87.224
qt	3	29.70	9.90	14.91	<.0001	
yq						
lt	1	1.57	1.57	2.37	0.124	
ln	1	202.01	202.01	304.15	<.0001	
lt2	1	1.27	1.27	1.91	0.1665	
ltln						
ln2	1	0.49	0.49	0.74	0.3881	
lt3	1	1.17	1.17	1.75	0.1854	
lt2ln	1	65.71	65.71	98.93	<.0001	
ltln2	1	111.45	111.45	167.80	<.0001	
ln3	1	57.62	57.62	86.75	<.0001	
nhfcl	4	14.10	3.52	5.31	0.0003	
sst	1	44.65	44.65	67.23	<.0001	
sst2						
sst3	1	86.21	86.21	129.80	<.0001	
main						
bran						
sst*qt	3	39.04	13.01	19.60	<.0001	
sst*nhfcl	4	47.05	11.76	17.71	<.0001	
ml*nhfcl						
bl*nhfcl						
lt*qt	3	30.88	10.29	15.50	<.0001	
lt2*qt	3	32.85	10.95	16.49	<.0001	
lt3*qt	3	34.47	11.49	17.30	<.0001	
ln*qt	3	57.63	19.21	28.92	<.0001	
ln2*qt	3	126.25	42.08	63.36	<.0001	
ln3*qt	3	168.29	56.10	84.46	<.0001	
lt*nhfcl	4	13.52	3.38	5.09	0.0004	
lt2*nhfcl	4	13.60	3.40	5.12	0.0004	
lt3*nhfcl	4	13.55	3.39	5.10	0.0004	
ln*nhfcl	4	11.90	2.97	4.48	0.0013	
ln2*nhfcl	4	11.90	2.97	4.48	0.0013	
ln3*nhfcl	4	10.07	2.52	3.79	0.0044	
lt*sst						
lt2*sst						
lt3*sst						
ln*sst	1	53.84	53.84	81.06	<.0001	
ln2*sst	1	53.84	53.84	81.06	<.0001	
ln3*sst	1	70.87	70.87	106.70	<.0001	

AREA 2

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square
Model	286	13588.16	47.51	163.60	<.0001	0.537
						CV
yr	52	2157.42	41.49	142.87	<.0001	28.535
qt	3	17.90	5.97	20.54	<.0001	
yq						
lt	1	111.05	111.05	382.41	<.0001	
ln	1	2.00	2.00	6.88	0.0087	
lt2	1	67.17	67.17	231.31	<.0001	
ltln						
ln2	1	4.50	4.50	15.48	<.0001	
lt3	1	9.09	9.09	31.30	<.0001	
lt2ln	1	180.65	180.65	622.07	<.0001	
ltln2	1	204.22	204.22	703.23	<.0001	
ln3	1	7.35	7.35	25.30	<.0001	
nhfcl	4	40.23	10.06	34.63	<.0001	
sst	1	5.56	5.56	19.14	<.0001	
sst2	1	4.90	4.90	16.86	<.0001	
sst3	1	4.95	4.95	17.03	<.0001	
main						
bran						
sst*qt	3	18.05	6.02	20.72	<.0001	
sst*nhfcl	4	98.91	24.73	85.15	<.0001	
ml*nhfcl						
bl*nhfcl	4	18.07	4.52	15.55	<.0001	
lt*qt	3	104.70	34.90	120.18	<.0001	
lt2*qt	3	53.12	17.71	60.98	<.0001	
lt3*qt	3	62.32	20.77	71.54	<.0001	
ln*qt	3	35.17	11.72	40.37	<.0001	
ln2*qt	3	5.18	1.73	5.95	0.0005	
ln3*qt	3	5.45	1.82	6.26	0.0003	
lt*nhfcl	4	93.15	23.29	80.19	<.0001	
lt2*nhfcl	4	20.59	5.15	17.72	<.0001	
lt3*nhfcl	4	14.01	3.50	12.06	<.0001	
ln*nhfcl	4	65.09	16.27	56.04	<.0001	
ln2*nhfcl	4	42.00	10.50	36.16	<.0001	
ln3*nhfcl	4	73.08	18.27	62.91	<.0001	
lt*sst	1	137.56	137.56	473.69	<.0001	
lt2*sst	1	79.06	79.06	272.25	<.0001	
lt3*sst						
ln*sst	1	5.84	5.84	20.09	<.0001	
ln2*sst	1	4.52	4.52	15.55	<.0001	
ln3*sst	1	2.35	2.35	8.08	0.0045	

AREA 3

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square
Model	275	14211.12	51.68	143.94	<.0001	0.790
						CV
yr	52	249.97	4.81	13.39	<.0001	63.035
qt	3	6.58	2.19	6.11	0.0004	
yq						
lt	1	0.68	0.68	1.90	0.1677	
ln	1	4.56	4.56	12.70	0.0004	
lt2	1	2.64	2.64	7.35	0.0067	
ltln	1	5.30	5.30	14.75	0.0001	
ln2	1	17.35	17.35	48.32	<.0001	
lt3	1	4.77	4.77	13.28	0.0003	
lt2ln	1	6.37	6.37	17.75	<.0001	
ltln2	1	12.15	12.15	33.86	<.0001	
ln3	1	10.36	10.36	28.87	<.0001	
nhfcl	4	9.19	2.30	6.40	<.0001	
sst	1	9.18	9.18	25.57	<.0001	
sst2						
sst3	1	1.89	1.89	5.28	0.0216	
main						
bran						
sst*qt	3	25.55	8.52	23.73	<.0001	
sst*nhfcl	4	20.87	5.22	14.54	<.0001	
ml*nhfcl						
bl*nhfcl						
lt*qt	3	7.76	2.59	7.20	<.0001	
lt2*qt	3	10.72	3.57	9.96	<.0001	
lt3*qt	3	14.60	4.87	13.55	<.0001	
ln*qt	3	16.49	5.50	15.31	<.0001	
ln2*qt	3	18.12	6.04	16.83	<.0001	
ln3*qt	3	6.02	2.01	5.59	0.0008	
lt*nhfcl	4	5.86	1.47	4.08	0.0026	
lt2*nhfcl	4	5.93	1.48	4.13	0.0024	
lt3*nhfcl	4	6.81	1.70	4.75	0.0008	
ln*nhfcl	4	25.71	6.43	17.90	<.0001	
ln2*nhfcl	4	44.87	11.22	31.25	<.0001	
ln3*nhfcl						
lt*sst	1	16.03	16.03	44.65	<.0001	
lt2*sst	1	30.86	30.86	85.97	<.0001	
lt3*sst	1	55.03	55.03	153.29	<.0001	
ln*sst	1	57.37	57.37	159.81	<.0001	
ln2*sst	1	43.43	43.43	120.98	<.0001	
ln3*sst						



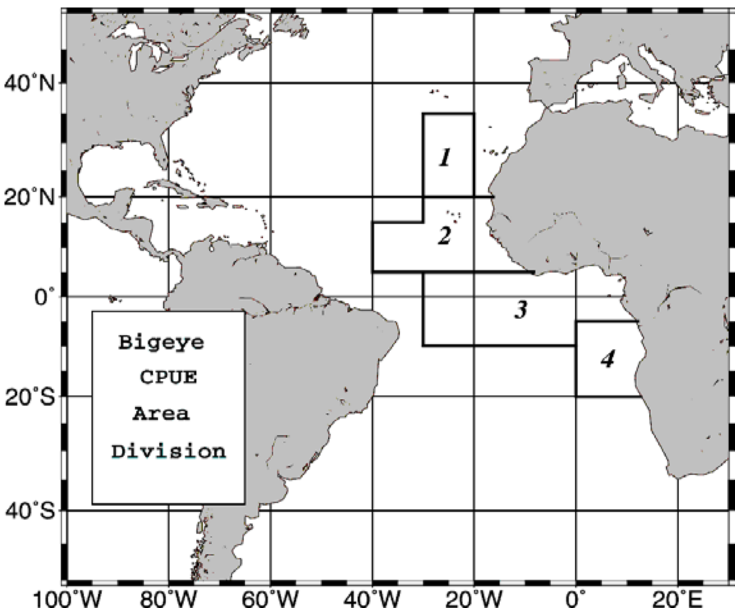


Figure 1. Two area definitions used in this study. All Atlantic area (top) and main fishing ground area (bottom) definitions.

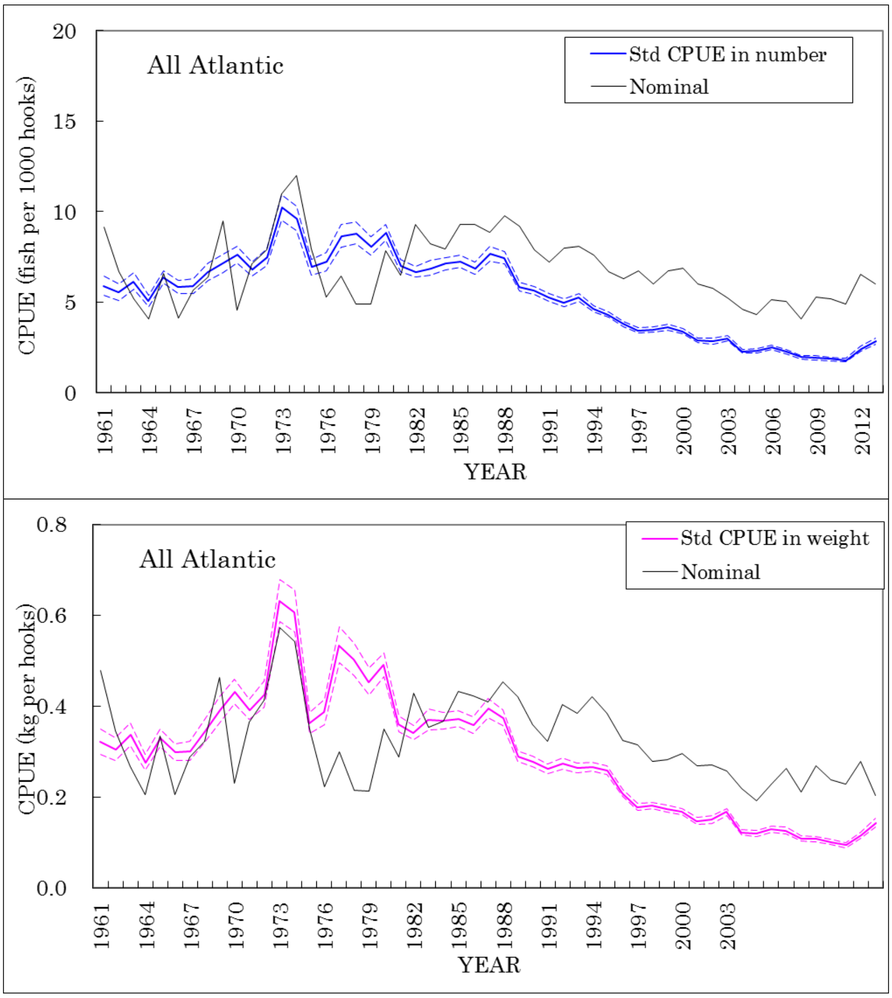


Figure 2. Standardized CPUE for all Atlantic area definition in number (top figure) and in weight (bottom figure) expressed in real scale overlaid with nominal CPUE.

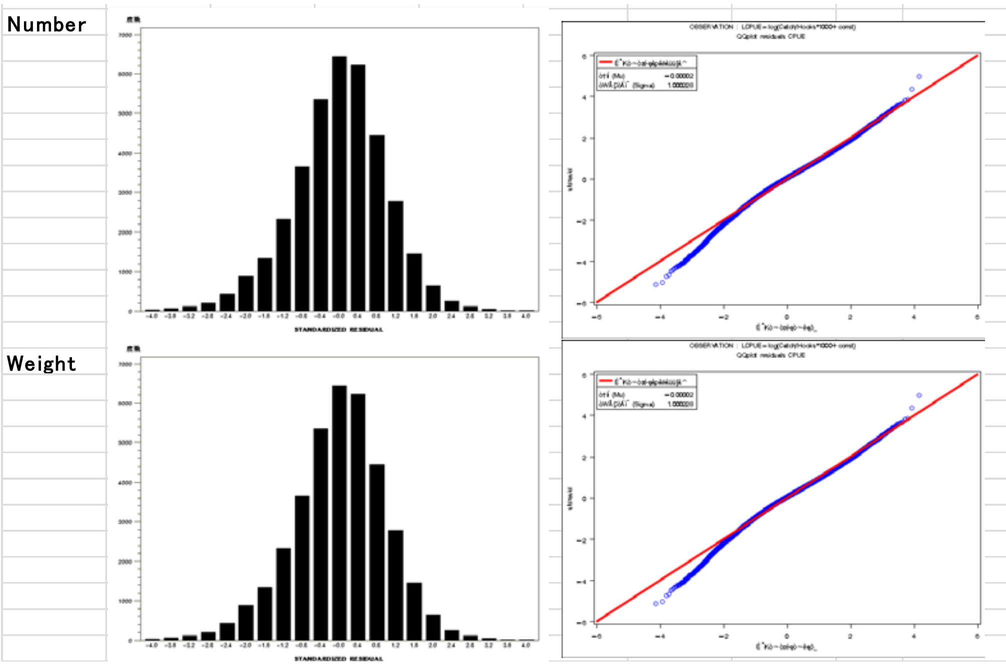


Figure 3. Overall histogram and QQ-plot of standard residuals from the GLM analyses for bigeye CPUE in number (top figures) and weight (bottom figures) for main fishing ground area definition.

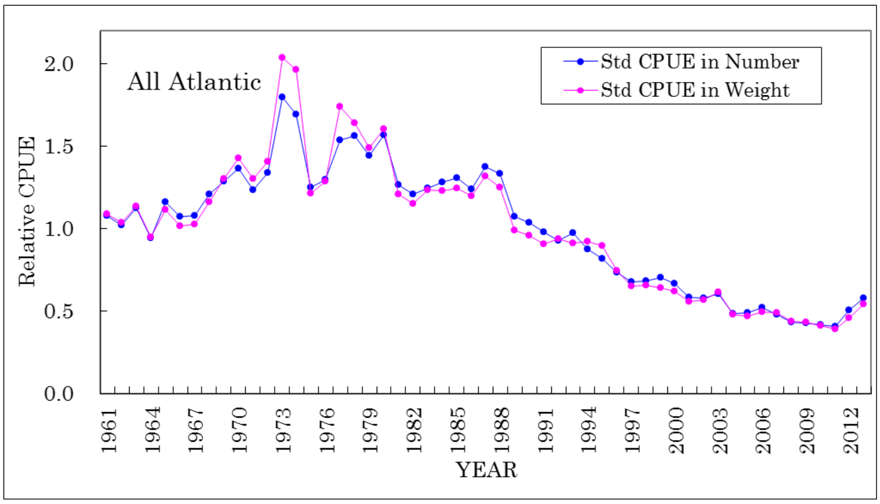


Figure 4. Standardized CPUE for all Atlantic area definition in number and in weight expressed in relative scale.

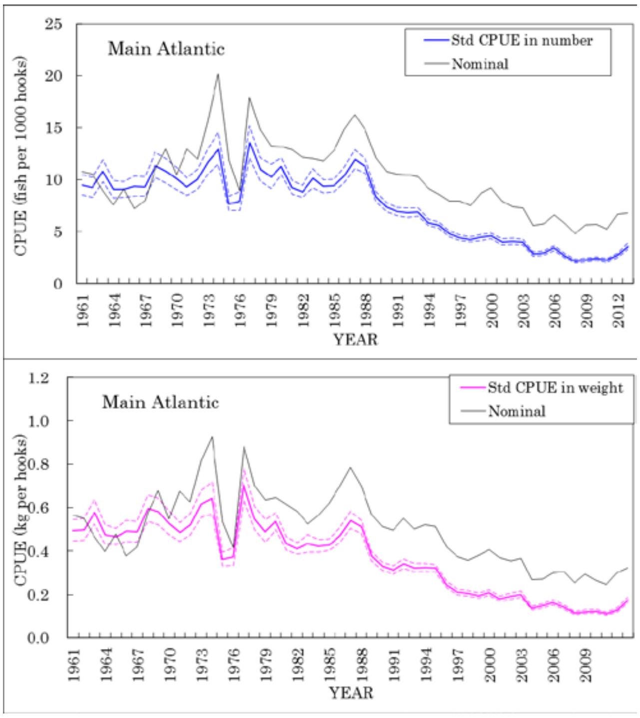


Figure 5. Standardized CPUE for main fishing ground area definition in number (top figure) and in weight (bottom figure) expressed in real scale overlaid with nominal CPUE.

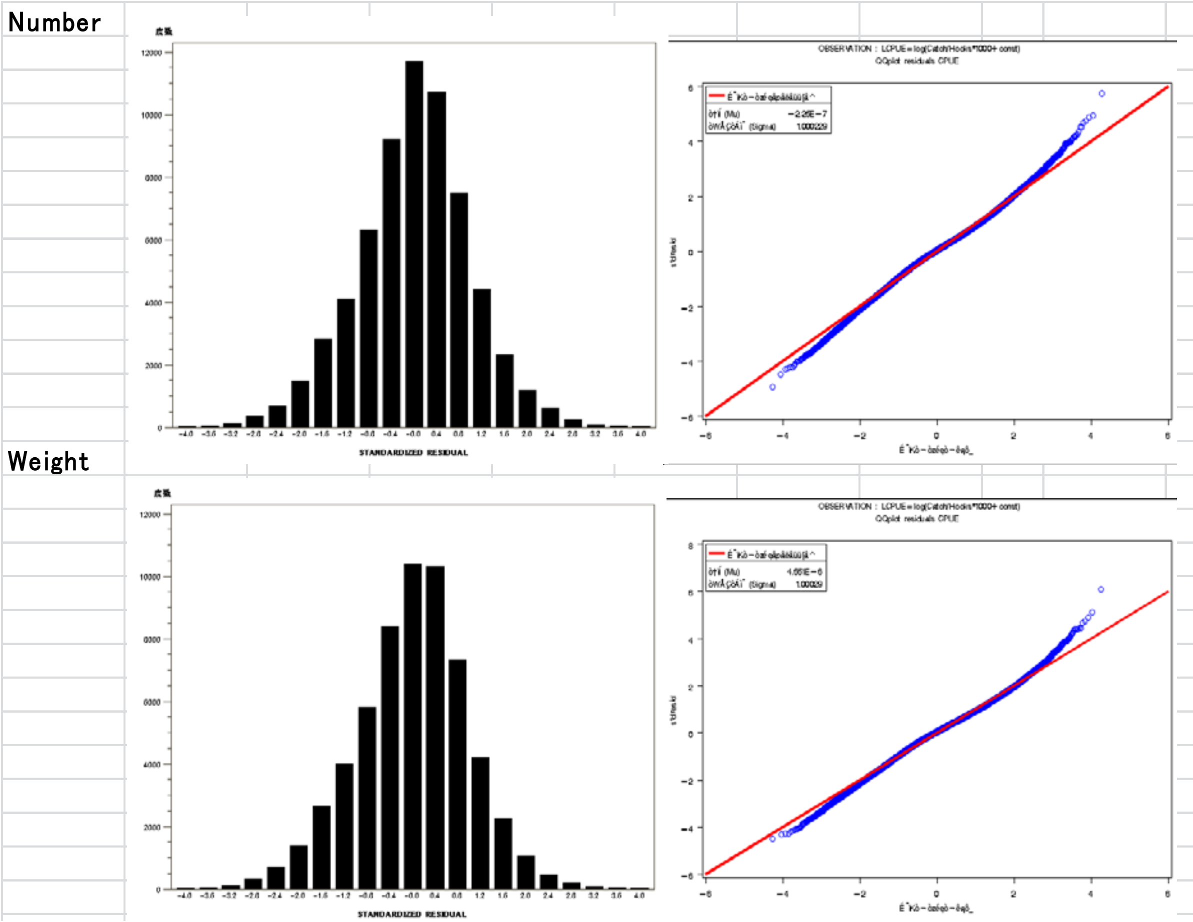


Figure 6. Overall histogram and QQ-plot of standard residuals from the GLM analyses for bigeye CPUE in number (top figures) and weight (bottom figures) for all Atlantic area definition.

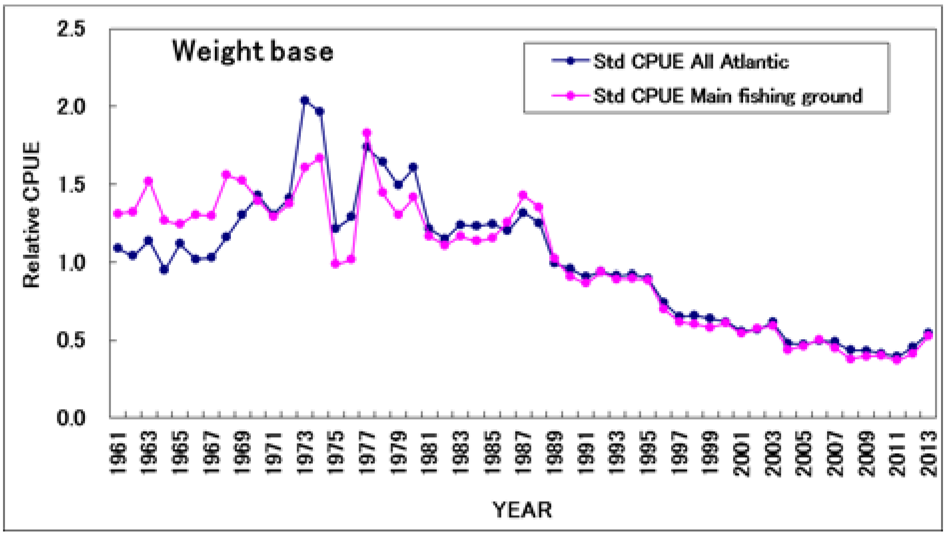


Figure 7. Standardized CPUE for main fishing ground area definition in number and in weight expressed in relative scale.

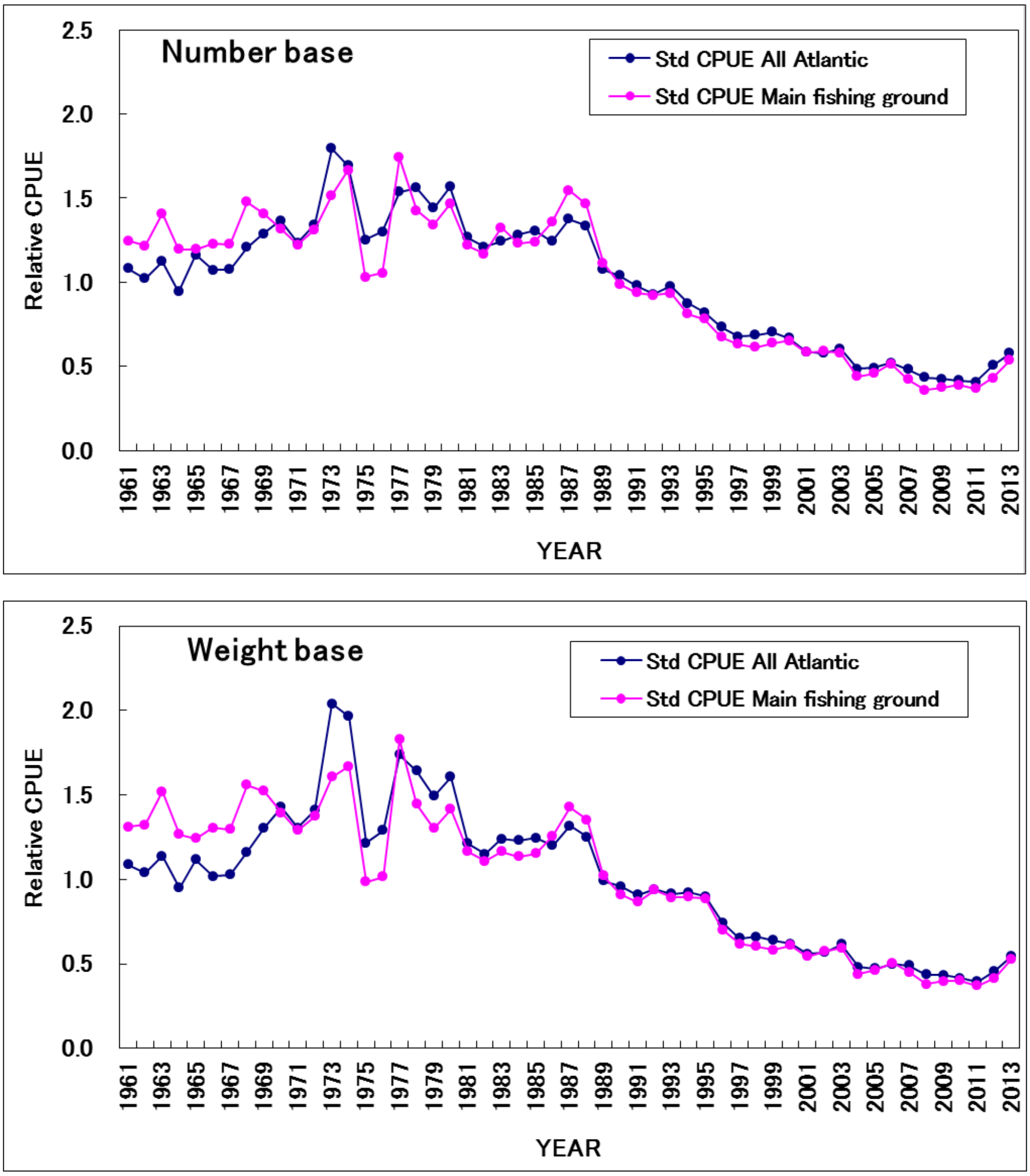


Figure 8. Standardized CPUE for all Atlantic and main fishing ground area definitions in number (top figure) and in weight (bottom figure) expressed in relative scale.

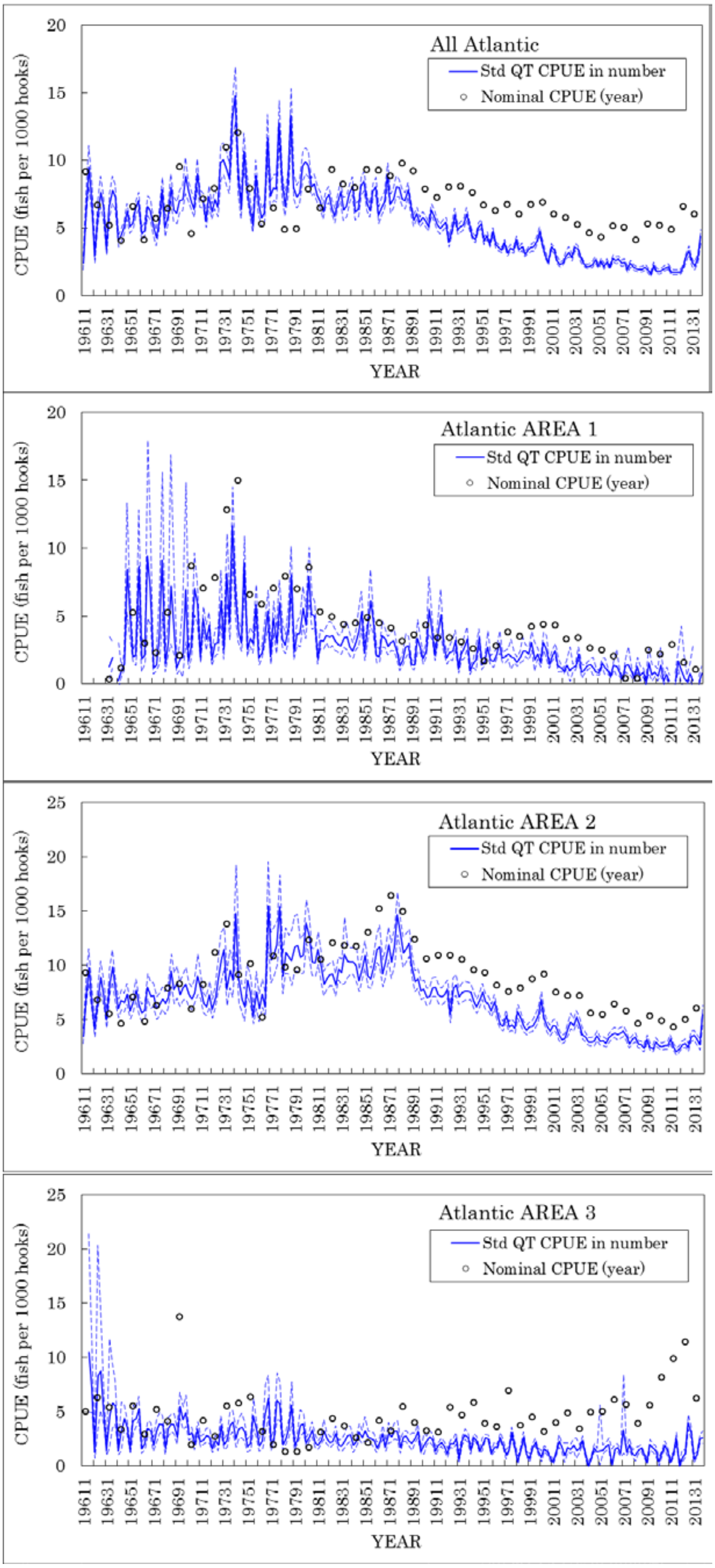


Figure 9. Standardized quarterly CPUE in number for whole and each of three divided area of all Atlantic area definition expressed in real scale.

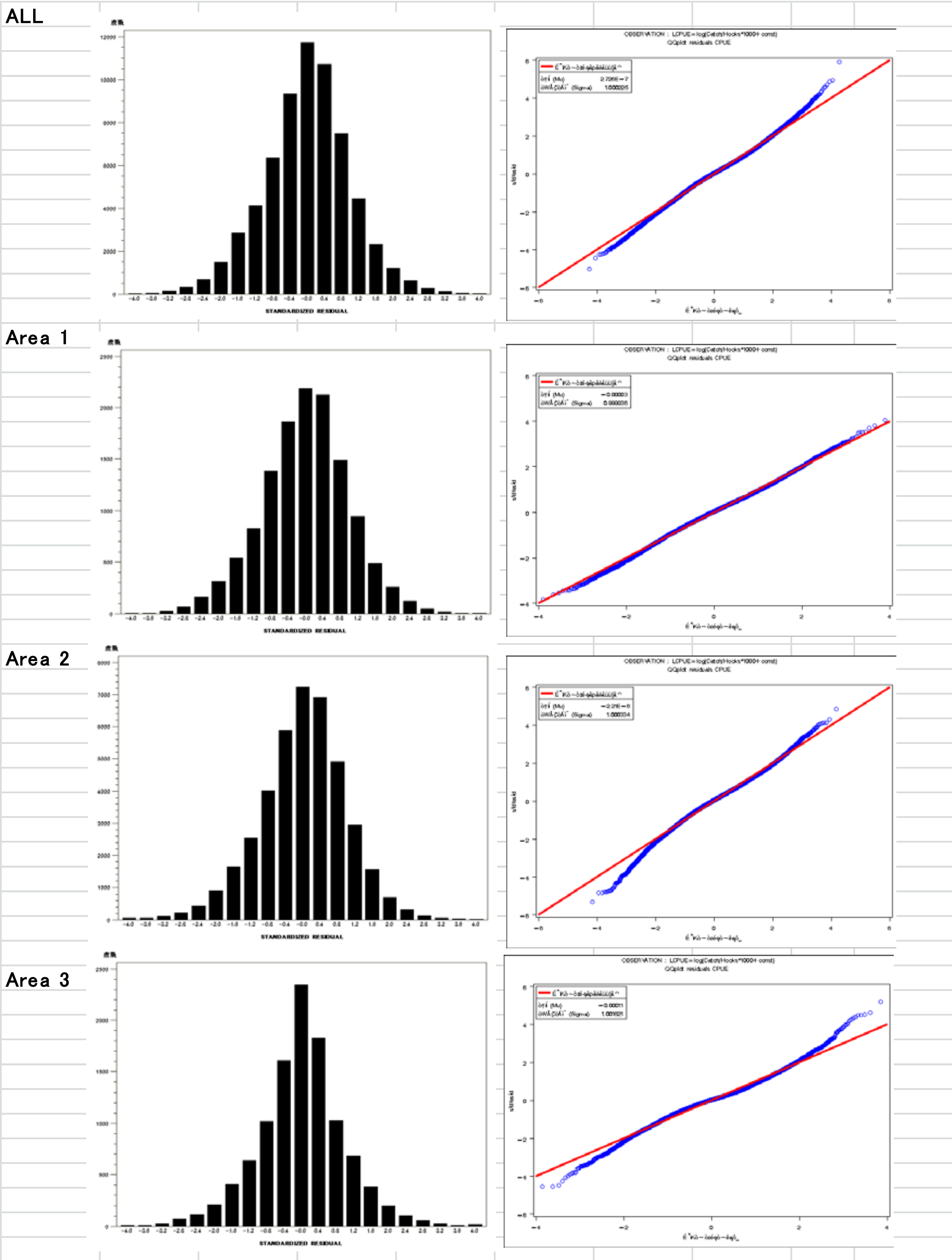


Figure 10. Overall histogram and QQ-plot of standard residuals from the GLM analyses for quarterly CPUE in number for whole and each of divided three areas of all Atlantic area definition.

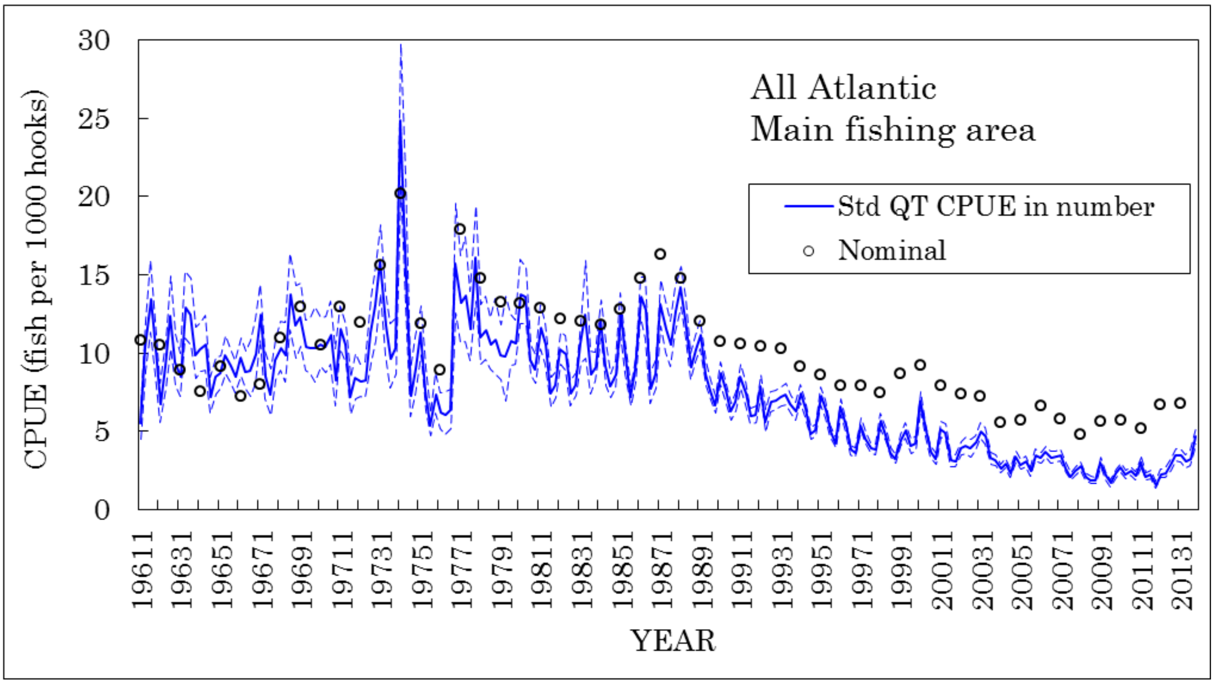


Figure 11. Standardized quarterly CPUE in number for main fishing ground area definition expressed in real scale.

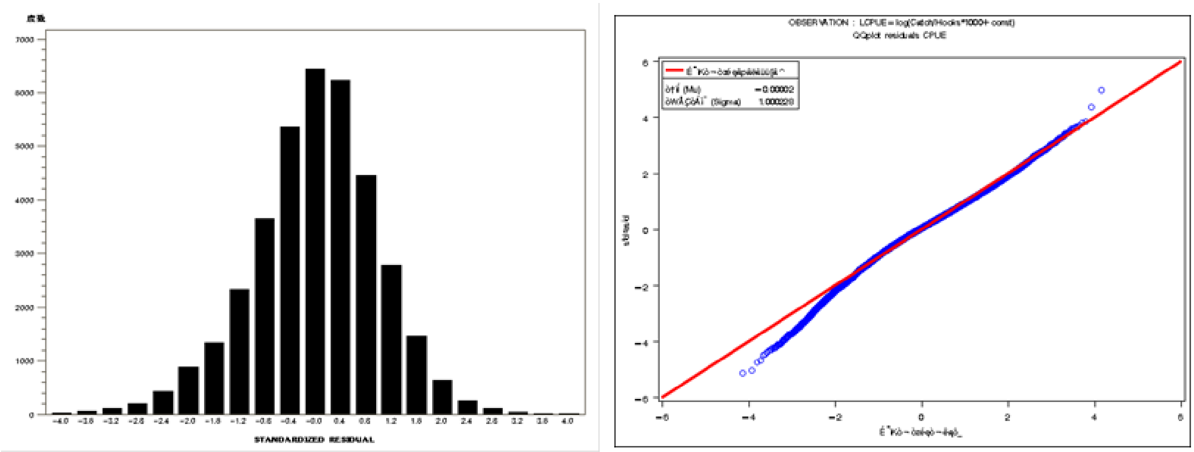


Figure 12. Overall histogram and QQ-plot of standard residuals from the GLM analyses for quarterly CPUE in number for main fishing ground area definition.

Appendix

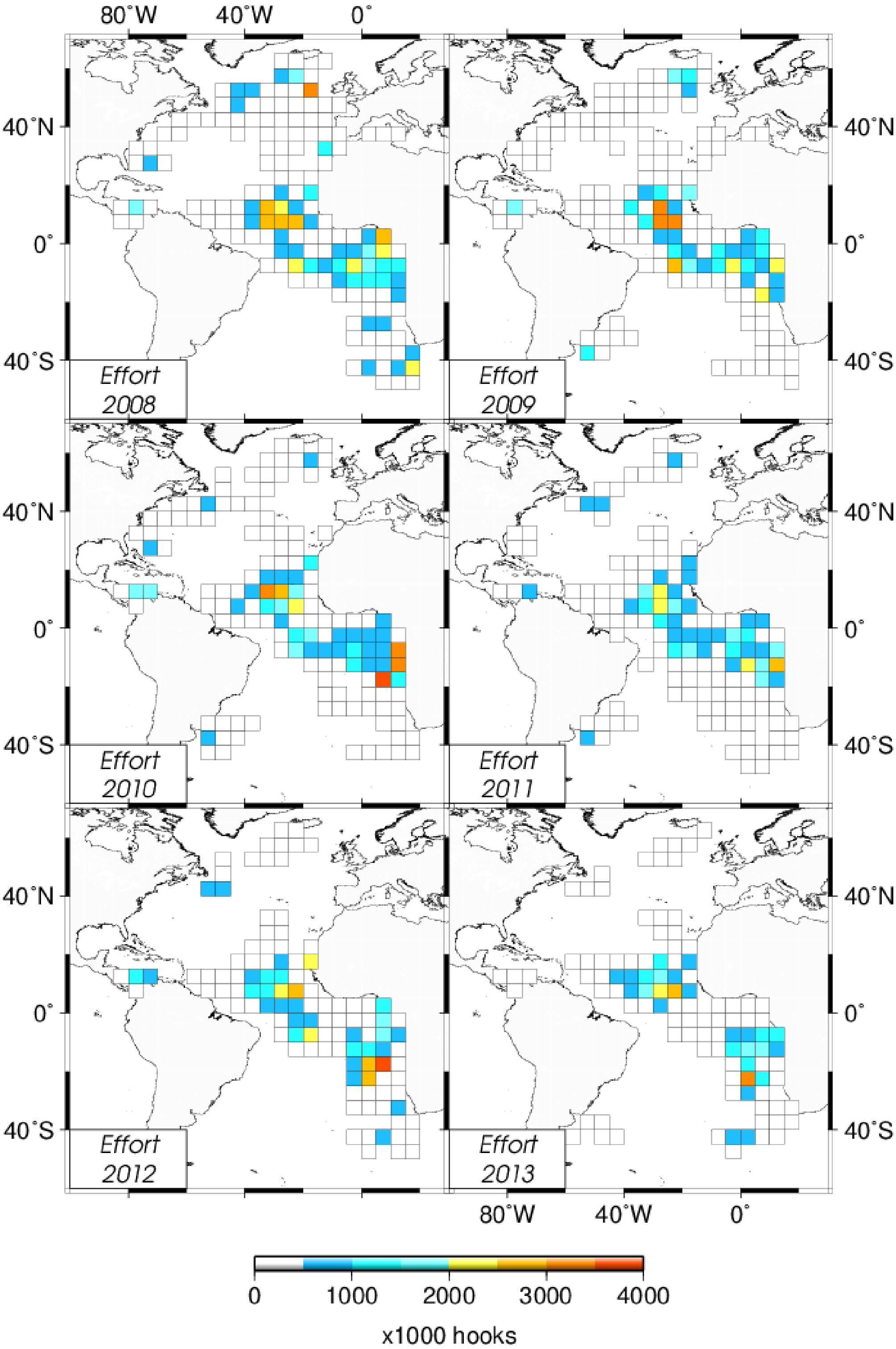


Figure 1. Geographical distribution of fishing effort for Japanese longline fishery in recent years.

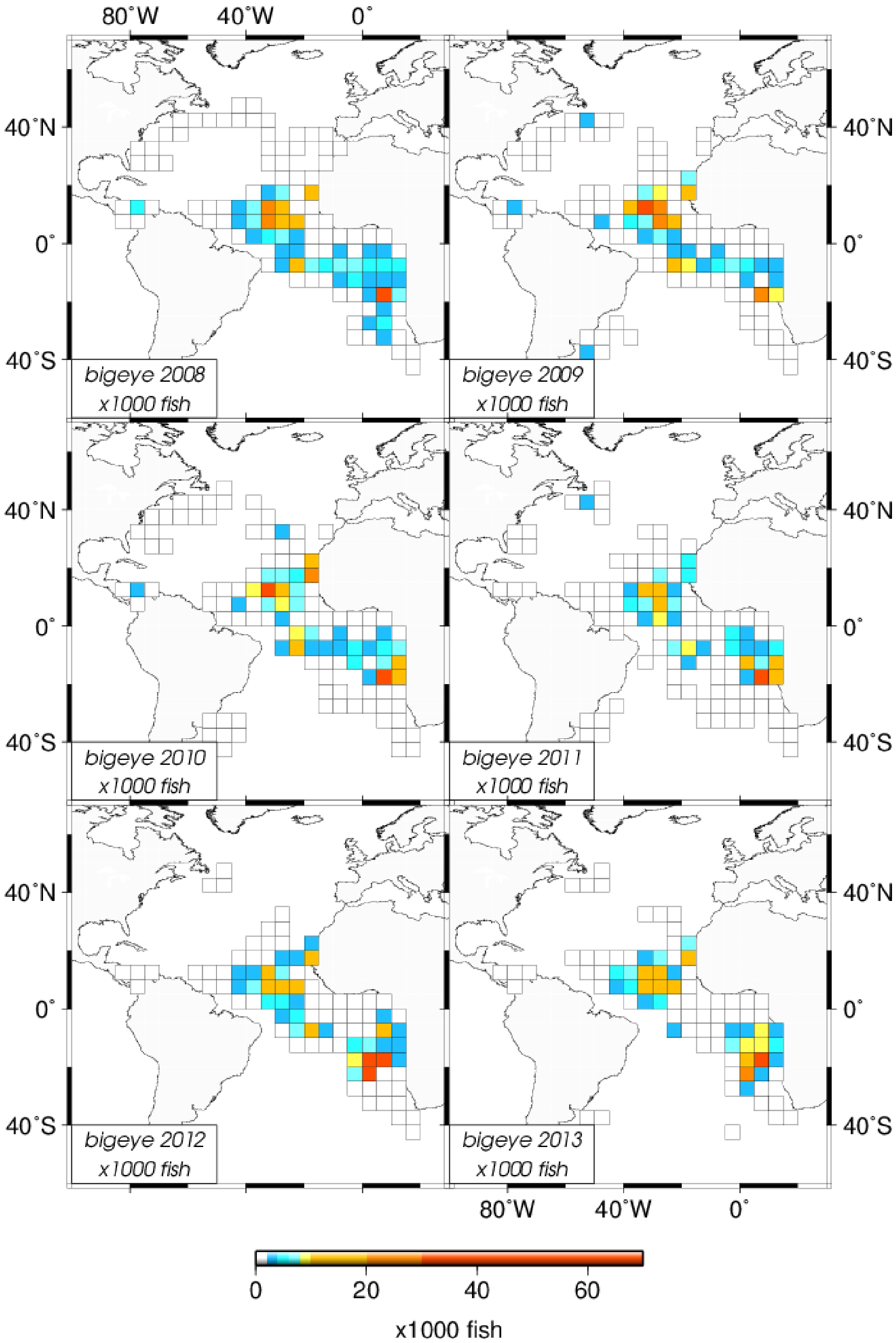


Figure 2. Geographical distribution of bigeye catch by Japanese longline fishery in recent years.