SCRS/2014/045 Collect. Vol. Sci. Pap. ICCAT, 71(2): 1059-1097 (2015)

UPDATED STANDARDIZED BLUEFIN CPUE FROM THE JAPANESE LONGLINE FISHERY IN THE ATLANTIC TO 2014 FISHING YEAR

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SUMMARY

Abundance indices of bluefin tuna from the Japanese longline fishery in the West and Northeast Atlantic were provided up to 2014 fishing year (FY). The indices were standardized with delta-lognormal model with random effect. West Atlantic index fluctuated significantly since 2007FY, showing considerably high values since 2012FY. These high indices might be related to 2003 and the following year classes, also may be contributed by recent tendency to target more bigeye. Abundance index in the Northeast Atlantic showed a steep increasing trend since 2009FY, and the size of bluefin caught showed a continuous contribution from 2003 year class. This study also provided the indices in the West and Northeast Atlantic split into two periods in 2010FY, because it was observed very rapid changes in its fishing patterns. The indices in the recent years showed an increasing trend. This strong year class started to migrate into the spawning areas, and it would be beneficial to monitor the other fisheries which target larger fish both in the West and East stocks. It was suggested that careful considerations would be needed for the use of Japanese CPUE series in the stock assessment of both west and east stocks.

RÉSUMÉ

Les indices d'abondance de la pêcherie palangrière japonaise ciblant le thon rouge et opérant dans l'Atlantique Ouest et Nord-Est ont été fournis jusqu'à l'année de pêche 2014. Les indices ont été standardisés au moyen d'un modèle delta-normal avec effet aléatoire. L'indice de l'Atlantique Ouest présente des fluctuations considérables depuis l'année de pêche 2007 et affiche des valeurs considérablement élevées depuis l'année de pêche 2012. Ces indices élevés pourraient être liés à la classe annuelle de 2003 et des années suivantes et pourraient également être influencés par la récente tendance de cibler davantage le thon obèse. L'indice d'abondance de l'Atlantique Nord-Est présentait une tendance marquée à la hausse depuis l'année de pêche 2009 et la taille des thons rouges capturés présentait une contribution continue de la classe d'âge de 2003. Cette étude fournissait également les indices de l'Atlantique Ouest et Nord-Est divisés en deux périodes dans l'année de pêche 2010 car des changements très rapides ont été observés dans les modes de pêche. Les indices des récentes années présentaient une tendance à la hausse. Cette forte classe annuelle a commencé à migrer dans les zones de ponte et il serait judicieux d'effectuer un suivi des autres pêcheries qui ciblent des poissons plus grands dans les stocks Ouest et Est. Il a été suggéré qu'il conviendrait de faire preuve de prudence en utilisant cette série de CPUE dans l'évaluation des stocks de l'Est et de l'Ouest.

RESUMEN

Se facilitan índices de abundancia de atún rojo de la pesquería palangrera japonesa en el Atlántico occidental y nororiental hasta el año pesquero (FY) 2014. Los índices se estandarizaron mediante un modelo delta-lognormal con efectos aleatorios. El índice del Atlántico occidental fluctuó significativamente desde el año pesquero 2007, mostrando valores considerablemente elevados desde el año pesquero 2012. Estos elevados índices podrían estar relacionados con las clases anuales de 2003 y años subsiguientes, y podrían estar influidos por una tendencia reciente de la flota de dirigirse más al patudo. El índice de abundancia del Atlántico nordeste mostraba una marcada tendencia ascendente desde el año pesquero 2009, y la talla del atún rojo capturado mostraba la contribución continua de la clase anual de 2003. Este estudio facilita también los índices en el Atlántico occidental y nororiental separados en dos periodos en el año pesquero 2010, porque se observaron cambios muy rápidos en los patrones de pesca. Los índices en años recientes mostraban una tendencia ascendente. Esta fuerte clase anual empezó a migrar a zonas de reproducción, y sería beneficioso hacer un seguimiento de otras pesquerías que se dirigen a

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peces más grandes tanto en los stocks del este como del oeste. Se sugirió que se requerirá una consideración minuciosa al utilizar estas series de CPUE en la evaluación de stock, tanto de los stocks del este como del oeste.

KEYWORDS

Bluefin tuna, Stock abundance, Catch and effort, CPUE standardization, Delta-lognormal model, Generalized Linear Mixed Model, Long lining, Size

Introduction

Japanese longline fishery data in the North Atlantic are valuable information for studying the bluefin tuna stock in the Atlantic. This fishery covers wide geographical areas in the North Atlantic and the Mediterranean Sea, where bluefin tuna were distributed, for more than five decades (Kimoto *et al*., 2011b). This wide temporal/spacious coverage, together with a good accurate quality of the data is the most important advantages in providing reliable abundance trend for this species.

However, the patterns and areas of fishing by the Japanese longline fishery changed through the history especially in the recent years (**Figures 1 and 2**), due to the introduction of IQ (individual vessels quota) and limited entry system to the Japanese longline vessels, voluntarily since August 2007 and by law August 2009 (Japan, 2011). Because both the amount of catch and the number of vessels have been significantly reduced, the Japanese longline fishery is not a major fishery for bluefin anymore. Although the abundance indices from this fishery are still very reliable and useful, it is strongly recommended to develop valid and reliable indices for other major fisheries (e.g. Mediterranean purse seine) while continued effort in improving Japanese longline standardized CPUE index is also desirable.

For the purpose of maintaining the consistency of the stock assessment, this paper basically provides updated, to 2014 fishing year (FY: e.g. 2014FY refers to the period from August 1, 2013 to July 31, 2014), abundance indices for the bluefin stocks in the Atlantic given in the previous studies (Oshima *et al*., 2008 and 2009, Kimoto *et al*., 2011b, Kimoto *et al*., 2013b, and Kimoto *et al*., 2014). In the east of 45°W, the Japanese longline vessels almost limited their operations solely in the Northeast Atlantic and rarely in the East Atlantic (off Gibraltar and Mediterranean) since 2010FY, due to the IQ system and the small quota for each vessel (**Figures 1 and 2**). Therefore the CPUE series were updated to 2014FY in the West (1976-2014FY) and Northeast Atlantic (1990-2014FY), whereas the CPUE in the East Atlantic was not updated since 2010FY. The CPUE series were standardized by application of Generalized Linear Mixed Modeling technique.

Additionally, the split abundance indices in the West and Northeast Atlantic are provided in order to reduce the uncertainty from the input CPUE series in the stock assessment. In both areas, the CPUEs in the recent years have been affected by the new regulatory measure (IQ system) and strong/good year classes dominated in the Japanese longline catches (Kimoto *et al*., 2011b). The various factors resulted in the concentration of their fishing grounds and fishing seasons (**Figures 1 and 2**). Thus, the authors and the ICCAT Bluefin Tuna Working Group (BFTWG) recommended to split these indices into two periods.

In the West Atlantic, the fishing patterns relatively became stable since 2011FY, after the implementation of the IQ system started in 2008FY voluntarily by the fishermen's association or in 2009FY officially by law. The fishing operation normally started in November before the IQ system, however since 2010FY the fishermen's strategy was changed and nearly half of their operations were mostly occurred in the period between August and October by targeting both bigeye and bluefin tuna in the fishing year (**Figures 1 and 2**). The abundance index in the fishing ground, off Canada (40-50N and 55-45W), between August through January since 2010FY could be used as new separate CPUE time series. This document also provides the early CPUE series up to 2009FY which is the current abundance index in the stock assessment for the West Atlantic.

In the Northeast Atlantic, the CPUE of the Japanese longline fishery has drastically increased in the recent years, and it was recommended to split the CPUE into two series around the implementation of IQ system. It was considered that this increase related to the dominant 2003 strong year class (**Figures 3 and 4**), the introduction of the IQ system, and the reductions of the TAC and the number of vessels (**Figure 5**). To split the CPUE into two series, the optimal split point was statistically selected from two candidates by comparing the AIC values. One candidate following the recommendation by the ICCAT BFTWG was 2008/2009FY (i.e. the early period was 1990-2008FY, and the latter period was 2009-2014FY) due to the introduction of the IQ system in 2009FY. The other was 2009/2010FY, because the operating areas in 2009FY were similar to those before 2008FY, and were wider than 2010FY (**Figure 2**). This study also provides the early and late CPUE series for the Northeast Atlantic with the optimal split point.

Materials and methods

The catch and effort data (individual operation data) of the Japanese longline fishery were obtained from the logbook data compiled by the National Research Institute of Far Seas Fisheries (NRIFSF), and used for the CPUE standardization for the period from 1975 to 2014 fishing years. The fishing years were used in this report; 2014FY refers to the period from August 1, 2013 to July 31, 2014. The logbook data in 2014FY were 100% available, thus the CPUE was updated up to 2014FY. Information on the number of hooks between floats (NHBF) is available since 1975 (indicative of the depth of the line). The catch history by the Japanese longline fishery dates back to much earlier period (back to 1958) but the catches before the mid-1970s mostly came from different areas (mostly tropical waters) from the current fishing grounds. In addition, there were no reliable and sufficient size data available for them. It should be noted that the fleets are very mobile and their operational practice and fishing techniques have been constantly modified during its history (Miyake *et al*, 2010).

The CPUE were standardized respectively for the traditional two areas by applying the same method as previously described by Oshima *et al*. (2008 and 2009) and Kimoto *et al.* (2010b, 2012b, and 2013). These two areas are West Atlantic (off US and Canada, north of 30°N and west of 45°W), and Northeast Atlantic (off Iceland north of 40°N and east of 45°W). The area definitions are shown in **Figures 6 and 7**. Total accumulative numbers of observations (set by set data) throughout the period to 2014FY for the standardized CPUEs are 79,904 in the West Atlantic (**Table 1**), and 86,453 in the Northeast Atlantic (**Table 2**), after eliminating some anomalies due to a technical error.

The size measurement (or composition) data for bluefin tuna caught by the Japanese longline fishery have been collected through the research programs by the NRIFSF and observer program by the Fishery Agency of Japan (Kimoto *et al*., 2011a). In August 2008, Fishery Agency of Japan started to tag of the individual bluefin tuna caught by the Japanese longliners (for identification) and collect their weight (Japan, 2011). Therefore from 2009FY converted size (length) data, using weight-length relationship by ICCAT (Anon, 2011), are available for all fish caught. The number of available size data is shown in **Table 3**. Applying slicing procedures to the size frequencies of bluefin caught by the Japanese longliners, catch at age was estimated for 2009 through 2014FYs from the converted size data. For slicing, the von Bertalanffy growth function estimated by ICCAT (Anon, 2011) was used.

1. Updated standardized CPUE to 2014FY for the West and Northeast Atlantic

In the CPUE standardization, fishing year, month, area, main and branch line material, and the number of hooks between floats were considered as main effects in the model, and interactions between month and area were included as a random effect. The original area stratification of each index was shown in **Figure 6**. Information on materials for main and branch lines is only available since 1994 and classified as either nylon or other materials. The lines used before 1994 were assumed as other materials. In order to keep the interaction in the model (avoiding lack of observations), some adjacent categories (month and area) were aggregated (**Figure 7**). Categories in each main effect adopted in the model are shown in **Table 4-a**. Delta-lognormal model (Lo *et al*., 1992) with binomial distribution to model successful/unsuccessful sets and lognormal for positive catch rate was applied for standardizing CPUE, because the data set includes many zero-catch observations. Model formula of logistic regression model of the 1st step model is as follows,

$$\log\frac{p}{1-p} = \text{Intercept} + (\text{Main effects}) + (\text{Interaction term}) \qquad (1)$$

where $\text{Log}(p/(1-p))$ is logit link function, p indicates ratio of positive catch set and is assumed to binomially distributed. The model formula of lognormal model of the 2nd step is as follows,

$$\text{logCPUE} = \text{Intercept} + (\text{Main effects}) + (\text{Interaction term}) + \text{Error} \qquad (2)$$

where logCPUE indicates natural logarithm of catch rate of positive set, that is the number of bluefin tuna per 1000 hooks, and error is also assumed to be distributed normally. The fitting was conducted by GLIMMIX macro and MIXED procedure of SAS/STAT package (Version 9.3) for the 1st and 2nd steps, respectively. For fixed effects, final model was chosen to include effects which were significant ($p<0.001$) by TYPE III tests among the considered main effects in the 1st and 2nd steps.

In the Northeast Atlantic, the model of the 1st step was not converged with the data in 2013 and 2014FYs, because the ratios of positive catch were 1.0 in the both fishing years (**Figure 8**). To avoid the convergence problem, the model of the 1st step was estimated up to 2012FY, and the output in the 2nd step since 2013FY were directly use for the standardized CPUE.

2. Split standardized CPUE for the West Atlantic

The split CPUE series for the West Atlantic were estimated in the periods between 1976 and 2009FY, and 2010 and 2014FY. In the both periods, the model was same as one used for the entire period with delta-log normal model. In the late period, the data was limited only in the areas 4 and 5 (**Figure 4**) in August through January. The model settings are shown in **Table 4b**. For fixed effects, final model was chosen to include effects which were significant ($p<0.001$) by TYPE III tests among the considered main effects in the 1st and 2nd steps.

3. Split standardized CPUE for the Northeast Atlantic

To split the CPUE into two series, the optimal split point was statistically chosen from two candidates: 2008/2009FY and 2009/2010FY. Delta-lognormal model was applied to obtain the standardized CPUEs for the both early and late periods with each split point (i.e the early period was 1990-2008FY or 1990-2009FY, and the late period was 2009-2014FY or 2008-2014FY). The model setting, shown in **Table 4-c**, in the early period was same as one used for the entire period, and they were slightly modified for the latter model as shown below because of the limitation of their data. The AIC values were calculated for the models of the 1st and the 2nd steps. The summed AIC values of the both periods in each step were compared between the candidates. In each model, only significant factors among the considered main effects in the 1st and 2nd steps were used for the comparison.

The model for the late period was tentatively considered to search the appropriate split point through a statistically objective approach. Because the ratio of positive catch has been close to 1.0 since 2010FY (**Figure 8**), once split point is determined, the recent period model could be much simpler. Since the optimal split point was obtained, the simple GLM model was fitted to the data in the latter period.

$$\log(\mathrm{CPUE} + \mathrm{const.}) = \mathrm{Intercept} + (\mathrm{Main\ effects}) + (\mathrm{Interaction\ term}) + \mathrm{Error} \qquad (3)$$

where constant value was added which was 10% of the minimum observed positive CPUE (0.0278/1000hooks), and error is Gaussian error. Final model was chosen to include effects which were significant ($p<0.001$) by TYPE III tests among the considered main effects. The 95 percentile confidence intervals were calculated based on 5000 replicated data by resampling of the residuals by year.

Results and discussion

It is essential to have reliable adult abundance indices from this fleet for successful stock assessment of Atlantic bluefin tuna stocks. This year's work to update Japanese longline bluefin CPUE both for the West and Northeast Atlantic highlighted the substantial difficulty to provide reliable indices of abundance of adult bluefin tuna. This is primary due to a steep decline of the number of set available to the analysis. This decline of observations was caused by the introduction of IQ system due to total TAC reduction as well as recent increase of both stocks. Current quota available to this fleet is not sufficient to maintain continuous CPUE capable to detect the abundance trend.

1. Updated standardized CPUE to 2014FY for the West and Northeast Atlantic

Results of type III test for positive catch ratio (1st step) and CPUE of positive catch (2nd step) in the base and final models were shown in **Tables 5-a and 5-b**, respectively. The variables of main and branch line materials among the considered main effects were not significant in the model of 1st step for the West and Northeast Atlantic, and they were removed in the final model (**Table 4-a**). In the model of 2nd step, the variable of branch line material was not significant and was excluded in the final model for the both areas.
The final models of 1st and 2nd steps are as follows,

$$\log\frac{p}{1-p} = \mathrm{Intercept} + \mathrm{year} + \mathrm{month} + \mathrm{area} + \mathrm{nhbf} + month * area \qquad (4)$$

$$\text{logCPUE} = \text{Intercept} + \text{year} + \text{month} + \text{area} + \text{nhbf} + \text{main} + month * area \qquad (5)$$

where the interaction term was included as random effect.

Model diagnostics for the West and Northeast Atlantic were shown in **Figures 9 and 10**, respectively. Residual patterns of positive CPUE in the 2nd step were slightly skewed to the right in these areas. Additionally, the residual distribution in the Northeast Atlantic had two modes. There were large annual fluctuations in observed and predicted proportions of positive catch in the West Atlantic, while the proportions in the Northeast Atlantic showed less fluctuations compared to those in the West. Observed CPUE of positive catch in the West Atlantic fluctuated without any trend during 1976-2014FY, and it jumped up sharply in 2007 and 2011FYs in the West. On the other hand, the CPUE in the Northeast Atlantic were stable until 2008FY except for 1996FY, and demonstrated an upward trend since 2010FY.

Standardized CPUE based on the Least Square Mean are shown in **Figure 11 and Table 6**. In the West Atlantic (**Figure 11-a**), the abundance indices showed gradual decline with large fluctuations from 1976FY to the mid-1980s, having reached the lowest in 1986FY. It recovered since then and showed relatively stable until the mid-2000s except for the sudden increase in 1996FY. It exhibited an increase after 2005FY with large fluctuations. The sharp decline in the CPUEs in 2010FY was mainly because of many zero catch data (**Figure 9-e**). This may be related to a good catch rate of bigeye tuna, particularly in 2010FY, and that some vessels targeted bigeye rather than bluefin. The low CPUE in 2010FY were probably caused by the shift of main fishing ground to south (25-35°N and 65-75°W) part of which was outside of the defined area to which CPUE was standardized, and hence large portion of data are not included in the analyses.

Since 2011FY, they showed very high levels, and it possibly related to the good catch of 2003 and the following year classes. Relatively smaller-sized fish (135-150cm in fork length, 50-60kg) were abundant in 2009 and 2011FYs (**Figures 3 and 4**) in the catches off Canada (**Figures 1 and 2**, areas 18-19) in January, which were similar to 2007FY (Kimoto *et al*., 2011a). In addition, the good catch of medium-sized fish (165-185cm, 95-120kg in 2011FY, 180-200cm, 115-165kg in 2012FY, and 195-215cm, 160-195kg in 2013FY) from November to December, which was a similar size range appeared in the Northeast fishing ground between October and November. The large differences since 2012FY were considered to be of less concern, because the magnitude of CPUEs (**Figure 11a**) was large but it remains within the range of variations of constant CV of lognormal error (normal error in the log-scale) (**Figure 12a**). In the recent years, the confidence intervals were very wide, mainly due to the small number of observations.

The CPUE series in the West Atlantic sometimes detected high abundance of relatively small-sized fish (135-150cm, 50-60kg: **Figure 3**). Moreover, the nominal CPUE values of some sets since 2011FY in the West area were as high as those observed in the Northeast, and the size range of fish in the main fishing area and season (40-45°N, 45-55°W, November and December) being similar to the Northeast Atlantic (50-60°N and 15-35°W, October to November), especially in 2012FY (**Figure 13**). These findings possibly suggested migration of fish from the east stock into the western of the stock boundary. However, the possibility of simultaneous appearance of a strong year class of 2003 in the west stock as in the east stock cannot be rejected.

In the Northeast Atlantic (**Figure 11b**), standardized abundance indices have been relatively stable until the mid-2000s except for the sudden increase in 1996FY. It started increasing in 2009FY, reached the highest value in 2012FY, and remained the high levels since then. However, the confidence intervals in the recent years were very wide. In the recent years, the high CPUEs were observed in October and November, in the northern areas: 50-60°N and 15-35°W (**Figure 1 and 2**), where and when the most of the operations are concentrated, because the fish of high quality and value are available. Interestingly, the longline catch since 2010FY were consisted mainly of 2003 year class (**Figures 3 and 4**), while they already appeared in 2009FY catch. Recruitment of the strong 2003 year class to this fishery contributed to the increase in the longline CPUE in that area. It might suggest that younger bluefin is not fully available in the northern fishing ground (north of 50°N). It would be very helpful to understand their migration pattern by age and this issue e.g. by encouraging more electronic tagging studies. At the same time, the introduction of strict IQ system by law possibly has affected the skippers' behavior and efficiency, having also probably contributed this increase of the CPUEs.

2. Split standardized CPUE for the West Atlantic

The CPUE series for the West Atlantic split into two periods, and the standardized CPUEs were calculated in the period between 1976 and 2009FY, and between 2010 and 2014FY. The results of type III test for positive catch ratio (1st step) and CPUE of positive catch (2nd step) in the base and final models were shown in **Tables 7a and 7b**, respectively. Model diagnostics were shown in **Figures 14 and 15**, respectively. Standardized CPUE based on the Least Square Mean are shown in **Figure 16 and Table 8**. Obviously, the final model setting and the results in the early period were similar to those in the entire period.

In the late period, mainly because of the similarity of fishing gears in their operations in the recent years (**Table 1**), the variables of main line materials and NHBF were not significant in the model of 1st step, and were removed in the final model (**Table 4-b**). In the model of 2nd step, the variable of main line material and area were excluded in the final model.

The final models of 1st and 2nd steps are as follows,

$$\log\frac{p}{1-p} = \text{Intercept} + \text{year} + \text{month} + \text{area} + month * area \qquad (6)$$
$$\text{logCPUE} = \text{Intercept} + \text{year} + \text{month} + \text{area} + \text{nhbf} + month * area \qquad (7)$$

where the interaction term was included as random effect.

The estimated standardized CPUE showed an increasing trend since 2010FY. The opposite trend in 2012FY were considered to be of less concern, because it remains within the range of variations of constant CV of lognormal error **(Figure 17**).

3. Split standardized CPUE for the Northeast Atlantic

To split the CPUE series into two periods, the total AIC values were compared between split points (2008/2009FY or 2009/2010FY) for the models of the 1st and the 2nd steps (**Table 9**). For this comparison, delta-lognormal model was used for the both periods, and the final models were shown in **Table 4-c**. It was found that the split point 2009/2010FY gave the minimum total AIC values. Thus, the standardized CPUEs for the Northeast Atlantic were calculated in the period between 1990 and 2009FY, and between 2010 and 2014FY. Delta-log normal and GLM models were applied in the early and late periods, respectively.

The results of type III test in the base and final models were shown for the early and late period in **Tables 10-a and 10-b**, respectively. The model diagnostics were shown in **Figures 18 and 19**, respectively. Standardized CPUE based on the Least Square Mean are shown in **Figure 20** and **Table 11**. Obviously, the results in the early period were similar to those in the entire period.

In the late period, the variables of main and branch line materials and NHBF were not significant in the base model, and were removed from the final model (**Table 4d**).

$$\log(\text{CPUE} + 0.028) = \text{Intercept} + \text{year} + \text{month} + \text{area} + \text{month} * \text{area} + \text{Error} \quad (8)$$

where the interaction term was included as fixed effect.

There are no yearly trends in the residual pattern (**Figure 19**). The estimated standardized CPUE showed a continuous increasing trend since 2010FY (**Figure 20**). This high CPUEs been supported mainly by the strong 2003 year class (**Figure 3**). In the last fishing year, 2014FY, the CPUE was further increased. This might related to the utilization of both 2003 and the following year classes (**Figure 3**), and to the increased skipper's efficiency. The fishing season was shortened in the most recent year (**Table 2**), because the body weight of bluefin tuna caught increased with very high catch rate. Hence the amount of catch can quickly reach to the vessel quota given the current small Japanese quota. Under current small quota, the continued high CPUEs will remain the total fishing efforts reduced substantially and will result in the substantially limited temporal/spacious coverage of efforts. The uncertainty in the stock assessment results could increase, even the CPUE was split into two period. It would be desirable to have more observations (longline sets) to monitor the abundance of bluefin tuna in the Northeast Atlantic in the wide area that had been observed before 2008FY. Currently observed high CPUEs with limited number of longline sets, hence very limited spatial and temporal coverage may possibly over- or under-estimates the year class strength.

The good CPUEs were observed in other fisheries (Anon. 2013) both in the West and East Atlantic. The bluefin currently utilized by the Japanese longliners in the Northeast Atlantic, 2003 year class, have started to migrate into Mediterranean (Gordoa, 2013). The similar phenomenon may affect the CPUE series targeting large fish in the spawning area, and the careful attention would be necessary. It is encouraged to continue to collect and monitor the size information of the catch in each fishery.

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Table 1. Number of longline sets by various strata for the West Atlantic CPUE standardization. Observations were aggregated by month, area (prefixed by A), materials of main line (M1=others, M2=nylon) and branch line (F1=others, F2=nylon), number of hooks between floats (prefixed by B). Area definition is shown in **Figure 6**. Year is fishing year (2014 means August 2013 to July 2014).

Year	Aug	Sep	Oct	Nov	Dec	Jan	Feb	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11
1976	69	112	143	347	322	266	208	10	20	0	0	0	0	0	4	356	223	8
1977	426	497	588	534	522	519	212	52	55	1	0	0	0	0	33	656	869	192
1978	34	96	343	516	559	377	45	0	18	0	1	0	0	0	15	395	249	95
1979	126	218	591	755	680	749	179	4	26	0	0	0	0	0	41	516	819	132
1980	223	358	644	824	777	683	170	0	103	1	0	0	0	0	0	332	341	142
1981	270	601	1201	1513	1512	902	341	0	7	0	0	0	0	0	0	710	583	470
1982	915	1333	2236	1753	846	206	116	0	11	1	3	1	0	0	0	1171	831	407
1983	387	433	561	891	694	623	504	0	5	1	0	0	0	0	0	355	465	245
1984	90	138	314	629	624	572	212	0	1	0	0	0	0	0	0	62	324	86
1985	25	45	310	723	851	655	344	0	0	0	0	0	0	0	0	94	394	66
1986	176	239	420	688	641	551	53	0	0	0	0	0	0	0	0	33	234	88
1987	293	445	658	897	944	710	42	0	41	26	0	21	7	0	0	9	339	288
1988	281	414	751	891	869	651	364	0	1	0	0	0	10	0	0	54	618	591
1989	149	291	517	804	1051	521	247	0	19	54	129	347	51	3	0	3	202	491
1990	85	161	589	663	782	766	296	0	0	5	59	311	84	1	0	0	112	234
1991	0	143	351	516	479	502	154	0	0	0	17	68	123	6	0	0	15	24
1992	30	132	281	310	667	392	2	0	1	0	8	43	21	3	0	4	26	9
1993	16	57	311	664	622	343	53	0	0	0	0	0	0	0	0	0	12	53
1994	0	6	156	336	574	533	92	0	0	0	0	0	0	0	0	0	17	9
1995	0	50	389	235	217	112	1	0	0	0	0	11	11	0	0	0	15	78
1996	0	0	0	38	371	70	0	0	11	0	0	0	0	2	0	0	0	11
1997	0	0	16	73	613	133	0	0	0	0	0	6	34	28	0	0	0	3
1998	0	0	6	31	746	375	33	0	0	17	0	26	5	0	0	0	8	79
1999	51	9	10	316	585	244	127	0	0	3	90	91	40	74	0	0	23	3
2000	11	25	47	347	565	201	153	0	0	0	23	93	32	172	0	0	2	5
2001	129	112	72	190	672	221	134	0	0	1	67	345	123	198	0	0	3	6
2002	22	31	68	638	837	320	395	0	22	7	97	265	425	140	0	0	27	29
2003	0	4	32	163	442	57	106	0	87	10	7	141	37	86	0	0	0	0
2004	1	10	11	41	156	461	167	0	72	2	52	137	72	47	0	0	30	42
2005	0	0	9	10	214	790	761	5	195	0	107	135	108	28	0	0	543	124
2006	0	10	14	0	136	561	368	18	121	4	73	181	154	37	0	0	38	165
2007	0	0	0	6	83	132	149	42	76	0	0	0	0	0	0	0	69	21
2008	0	4	0	0	55	143	40	81	121	0	0	0	0	0	0	0	1	1
2009	4	0	0	7	29	18	0	4	12	0	0	0	0	0	0	0	2	1
2010	12	80	84	89	51	6	0	1	41	10	0	0	0	0	0	0	2	8
2011	42	49	87	99	100	84	2	11	26	0	0	0	0	0	0	2	17	5
2012	15	98	104	102	54	0	0	0	0	0	0	0	0	0	0	0	0	0
2013	14	108	119	121	108	4	0	0	0	0	0	0	0	0	0	0	0	0
2014	15	143	125	47	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	3911	6452	12158	16807	20053	14453	6070	228	1092	143	733	2222	1337	825	93	4752	7453	4211

Table 1. Continued.

Year	A17	A18	A19	A20	A21	A22	A23	A24	M1	M2	F1	F2	B5	B6	B7	B8	B9	B10	B11	B12	B13	Total
1976	26	13	463	32	0	0	3	12	1467	0	1467	0	1199	268	0	0	0	0	0	0	0	1467
1977	238	192	671	162	0	0	0	3	3298	0	3298	0	2670	619	0	9	0	0	0	0	0	3298
1978	186	78	876	24	0	0	2	0	1970	0	1970	0	1764	203	0	0	0	3	0	0	0	1970
1979	481	91	804	143	0	0	0	14	3298	0	3298	0	2653	571	46	0	0	28	0	0	0	3298
1980	984	774	787	71	0	0	0	1	3679	0	3679	0	2958	616	50	28	24	3	0	0	0	3679
1981	1383	756	1464	300	0	0	0	29	6340	0	6340	0	3648	1540	459	178	149	252	86	28	0	6340
1982	1218	675	1950	396	0	0	0	37	7405	0	7405	0	2326	1926	423	371	415	1244	516	184	0	7405
1983	1119	365	1042	111	0	0	0	23	4093	0	4093	0	1024	1601	249	242	127	534	24	210	82	4093
1984	974	272	617	156	0	0	0	8	2579	0	2579	0	470	1700	144	20	17	138	61	6	23	2579
1985	583	193	1245	168	0	0	1	2	2953	0	2953	0	43	1527	1112	11	39	28	3	68	122	2953
1986	329	78	1531	348	0	0	0	21	2768	0	2768	0	21	869	1316	253	5	168	5	0	131	2768
1987	913	432	1408	255	0	0	2	53	3989	0	3989	0	77	1297	1997	383	91	38	0	106	0	3989
1988	1251	479	740	61	0	0	0	26	4221	0	4221	0	5	266	2921	487	78	265	26	64	109	4221
1989	630	651	698	141	0	0	1	26	3580	0	3580	0	20	383	2179	644	14	150	50	80	60	3580
1990	814	601	780	168	0	0	0	45	3342	0	3342	0	0	415	2122	532	26	207	0	40	0	3342
1991	466	184	824	172	0	0	11	87	2145	0	2145	0	43	147	1272	544	25	43	1	25	45	2145
1992	210	354	778	164	0	1	1	156	1814	0	1814	0	0	220	924	512	99	41	0	2	16	1814
1993	471	471	942	75	0	0	0	23	2066	0	2066	0	36	329	1151	369	109	46	20	6	0	2066
1994	316	267	751	286	0	0	0	10	1072	11	1072	72	27	192	1077	276	111	0	0	14	0	1697
1995	292	161	337	83	0	0	0	5	0	139	0	373	33	5	270	293	166	187	48	2	0	1004
1996	52	15	138	177	0	0	0	49	0	328	0	287	0	15	127	237	91	9	0	0	0	479
1997	61	29	258	188	0	0	0	218	0	726	0	630	1	22	169	357	131	53	68	0	34	835
1998	154	39	229	354	0	0	0	246	0	1035	0	1027	0	0	322	645	86	106	32	0	0	1191
1999	15	23	373	393	0	0	0	204	0	1263	0	1149	0	59	159	861	49	140	0	53	21	1342
2000	176	50	499	236	0	0	0	59	0	1310	0	1258	0	3	181	650	258	125	51	33	48	1349
2001	1	5	355	124	0	0	1	296	0	1524	0	1511	1	6	208	963	70	235	20	20	7	1530
2002	14	14	367	235	0	0	0	652	0	2241	0	2142	0	0	63	1493	384	213	2	127	29	2311
2003	2	5	120	209	0	0	0	84	0	804	0	804	0	0	28	366	260	85	1	64	0	804
2004	18	10	64	273	0	0	0	22	0	768	0	815	0	0	105	446	248	48	0	0	0	847
2005	42	91	179	195	0	0	0	1	0	1718	0	1555	0	2	12	711	925	73	0	32	29	1784
2006	119	17	73	72	0	0	0	14	0	1071	0	972	0	0	2	495	431	96	0	48	17	1089
2007	6	63	77	6	0	0	0	2	0	370	0	324	0	0	0	141	203	26	0	0	0	370
2008	12	3	14	8	0	0	0	1	0	199	0	189	0	0	0	26	216	0	0	0	0	242
2009	4	1	25	3	0	0	0	6	0	53	0	53	0	0	0	35	20	3	0	0	0	58
2010	0	30	135	58	0	0	0	35	0	322	0	322	0	0	0	248	60	10	0	4	0	322
2011	1	4	217	96	0	0	0	70	0	463	0	463	0	0	0	82	334	1	0	45	1	463
2012	0	2	200	145	0	0	0	25	0	373	0	373	0	0	0	207	164	0	0	2	0	373
2013	0	0	195	208	0	0	0	71	0	474	0	474	0	0	0	230	240	4	0	0	0	474
2014	0	2	41	144	0	0	0	146	0	269	0	333	0	0	0	194	134	5	0	0	0	333
Total	13561	7490	22267	6440	0	1	22	2782	62079	15461	62079	15126	19019	14801	19088	13539	5799	4607	1014	1263	774	79904

Table 2. Number of longline sets by various strata for the Northeast Atlantic CPUE standardization. Observations were aggregated by month, area (prefixed by A), materials of main line (M1=others, M2=nylon) and branch line (F1=others, F2=nylon), number of hooks between floats (prefixed by B). Area definition is shown in **Figure 6**. Year is fishing year (2014 means August 2013 to July 2014).

Year	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	A31	A32	A33	A34	A35	M1	M2	F1	F2	B4	B5	B6	B7	B8	B9	B10	B11	B12	Total
1990	0	0	21	136	245	155	56	6	613	0	6	0	0	619	0	619	0	0	6	304	230	38	30	11	0	0	619
1991	0	32	233	734	1100	312	86	25	2519	0	3	0	0	2522	0	2522	0	0	85	887	920	373	78	107	55	17	2522
1992	0	58	724	1738	1289	477	103	11	4288	97	15	0	0	4400	0	4400	0	79	170	2149	1409	443	34	91	0	25	4400
1993	16	341	1219	1366	869	323	39	0	1250	2592	77	254	0	4173	0	4173	0	29	93	3421	473	22	26	30	6	73	4173
1994	0	24	458	902	738	350	116	8	1438	1157	1	0	0	2122	21	2122	110	0	16	2079	365	5	0	0	0	131	2596
1995	0	105	282	646	459	108	18	0	254	259	232	873	0	0	348	0	791	0	68	740	419	278	113	0	0	0	1618
1996	61	610	1227	910	233	0	0	0	245	454	3	2339	0	0	2109	0	2061	0	0	156	1625	1065	195	0	0	0	3041
1997	122	2044	1660	1555	3	0	0	0	800	1062	45	3477	0	0	4499	0	4243	0	0	249	3004	1946	184	1	0	0	5384
1998	651	1469	2296	1849	6	0	0	0	251	928	8	5020	64	0	5596	0	5552	0	59	5	4351	1685	166	2	2	1	6271
1999	1163	1774	1878	614	90	3	0	0	177	692	4	4330	319	0	5139	0	4561	0	1	183	2452	2787	52	47	0	0	5522
2000	877	1510	1836	1594	1149	10	0	0	1802	939	79	3974	182	0	6415	0	6493	0	1	76	2685	3955	254	4	0	1	6976
2001	637	1230	1685	1679	105	88	49	59	741	1282	15	3447	47	0	5235	0	5206	0	0	49	2052	3128	196	31	5	71	5532
2002	473	1063	1623	806	67	23	21	7	908	678	22	2357	118	0	3895	0	3668	0	0	0	620	3307	143	3	10	0	4083
2003	270	941	1390	949	14	0	0	0	99	141	39	3255	30	0	3439	0	3370	0	1	1	333	2957	272	0	0	0	3564
2004	591	1233	1611	1513	1160	16	0	0	331	310	866	4615	2	0	5704	0	5764	0	0	1	706	4618	670	124	5	0	6124
2005	262	1113	1723	1947	1427	117	0	2	713	135	2569	3174	0	0	6229	0	5987	0	7	2	392	5231	910	49	0	0	6591
2006	256	826	1502	1514	1100	52	3	0	851	375	979	3048	0	0	5027	0	4661	0	0	0	366	3954	837	89	4	3	5253
2007	68	393	989	774	696	226	17	0	327	117	1396	1323	0	0	3040	0	2872	0	0	0	0	2943	220	0	0	0	3163
2008	51	482	790	665	539	204	5	0	313	48	848	1527	0	0	2659	0	2382	0	0	0	73	2639	24	0	0	0	2736
2009	186	731	872	846	384	33	0	0	444	534	229	1845	0	120	2854	120	2854	0	0	0	1	2720	325	6	0	0	3052
2010	0	217	789	429	46	1	0	0	23	87	5	1367	0	68	1288	26	1413	0	0	0	0	1373	109	0	0	0	1482
2011	0	16	488	178	0	0	0	0	1	95	0	586	0	27	603	27	623	0	0	0	0	638	44	0	0	0	682
2012	0	5	343	14	0	0	0	0	2	7	0	353	0	24	329	24	315	0	0	0	0	336	26	0	0	0	362
2013	0	0	311	89	0	0	0	0	0	66	0	334	0	0	388	0	388	0	0	0	0	349	51	0	0	0	400
2014	0	1	249	57	0	0	0	0	0	1	0	306	0	0	282	0	264	0	0	0	0	254	53	0	0	0	307
Total	5684	16218	26199	23504	11719	2498	513	118	18390	12056	7441	47804	762	14075	65099	14033	63578	108	507	10302	22476	47044	5012	595	87	322	86453

Table 3. The number of available measured size data for bluefin tuna caught by the Japanese longline fishery.

Fishing year	West Atlantic	East Atlantic
2009	3869	19582
2010	1607	16292
2011	4017	9509
2012	1770	7679
2013	1937	6887
2014	1373	7033

Table 4. Categories in each main effect in the standardized CPUE for the West and/or Northeast Atlantic, and the adopted effects (✓) in the final models. The model settings for (a) the updated standardized CPUE for the West and Northeast Atlantic in the entire period to 2014FY, (b) the split standardized CPUE series for the West Atlantic, (c) consideration of the consideration of the optimal split point for the Northeast Atlantic, and (d) the split standardized CPUE series for the Northeast Atlantic.

a) Main effect / Area	West Atlantic			Northeast Atlantic		
Stock	West			East		
Model	Delta-lognormal	1st step	2nd step	Delta-lognormal	1st step	2nd step
Fishing Year	1976-2014	✓	✓	1990-2014	✓	✓
Month	Nov, Dec, Jan, Feb	✓	✓	Aug-Oct, Nov, Dec, Jan-Mar	✓	✓
Area (**Figure 4**)	5 areas	✓	✓	4 areas	✓	✓
Material of main line (main)	Nylon, others (since 1994)	-	✓	Nylon, others (since 1994)	-	✓
Material of branch line (bran)	Nylon, others (since 1994)	-	-	Nylon, others (since 1994)	-	-
Hooks between floats (nhbf)	5– 13 (individual)	✓	✓	4 - 7, 8 - 12 hooks	✓	✓
Area*month	Random effect	✓	✓	Random effect	✓	✓

b) Main effect / Area	Early: West Atlantic			Late: West Atlantic		
Stock	West			West		
Model	Delta-lognormal	1st step	2nd step	Delta-lognormal	1st step	2nd step
Fishing Year	1976-2009	✓	✓	2010-2014	✓	✓
Month	Aug-Oct, Nov, Dec, Jan-Mar	✓	✓	Aug-Oct, Nov, Dec-Mar	✓	✓
Area (**Figure 4**)	4 areas	✓	✓	2 areas (4 and 5)	✓	✓
Material of main line (main)	Nylon, others (since 1994)	-	✓	Nylon, others (since 1994)	-	-
Material of branch line (bran)	Nylon, others (since 1994)	-	-	Removed (only Nylon)	-	-
Hooks between floats (nhbf)	5– 13 (individual)	✓	✓	8, 9- 10 hooks	-	✓
Area*month	Random effect	✓	✓	Random effect	✓	✓

c) Main effect / Area	Early: Northeast Atlantic			Late: Northeast Atlantic		
Stock	East			East		
Model	Delta-lognormal	1st step	2nd step	Delta-lognormal	1st step	2nd step
Fishing Year	1990-2008 or 2009	✓	✓	2009 or 2010-2014	✓	✓
Month	Aug-Oct, Nov, Dec, Jan-Mar	✓	✓	Aug-Oct, Nov, Dec-Mar	✓	✓

Area (**Figure 4**)	4 areas	✓	✓	2 areas (31+32, 33+34)	✓	✓
Material of main line (main)	Nylon, others (since 1994)	-	✓	Nylon, others (since 1994)	-	✓
Material of branch line (bran)	Nylon, others (since 1994)	-	-	Nylon, others (since 1994)	-	-
Hooks between floats (nhbf)	4 - 7, 8 - 12 hooks	✓	✓	7 - 8, 9 - 10 hooks	-	-
Area*month	Random effect	✓	✓	Not included	-	-

d) Main effect / Area	Early: Northeast Atlantic			Late: Northeast Atlantic	
Stock	East			East	
Model	Delta-lognormal	1st step	2nd step	GLM	final
Fishing Year	1990-2009	✓	✓	2010-2014	✓
Month	Aug-Oct, Nov, Dec, Jan-Mar	✓	✓	Aug-Oct, Nov, Dec-Mar	✓
Area (**Figure 4**)	4 areas	✓	✓	2 areas (31+32, 33+34)	✓
Material of main line (main)	Nylon, others (since 1994)	-	✓	Nylon, others (since 1994)	-
Material of branch line (bran)	Nylon, others (since 1994)	-	-	Nylon, others (since 1994)	-
Hooks between floats (nhbf)	4 - 7, 8 - 12 hooks	✓	✓	7 - 8, 9 - 10 hooks	-
Area*month	Random effect	✓	✓	Fixed effect	✓

Table 5. Statistical results from GLMM analysis for positive catch ratio (1st step) and CPUE of positive catch (2nd step) for the updated standardized CPUEs to 2014FY for the West and Northeast Atlantic, (a) in the base model and (b) in the final model.

(a) base model

West Atlantic (1976-2014)

Type 3 test of fixed effect for proportion of positive catch (1st step)

Effect	DF	DF	Chi-square	F Value	Pr > ChiSq	Pr > F
year	38	510	148.42	3.91	<.0001	<.0001
month	3	510	139.18	46.39	<.0001	<.0001
area	4	510	130.82	32.7	<.0001	<.0001
nhbf	8	1144	198.59	24.82	<.0001	<.0001
main	1	1144	0.02	0.02	0.9024	0.9024
bran	1	1144	1.52	1.52	0.2184	0.2186

Type 3 test of fixed effect for LogCPUE with positive catch (2nd step)

Effect	DF	DF	F Value	Pr > F
year	38	424	3.14	<.0001
month	3	424	87.73	<.0001
area	4	424	8.41	<.0001
nhbf	8	30000	15.84	<.0001
main	1	30000	23.09	<.0001
bran	1	30000	0.03	0.8533

Northeast Atlantic (1990-2014)

Type 3 test of fixed effect for proportion of positive catch (1st step)

Effect	DF	DF	Chi-square	F Value	Pr > ChiSq	Pr > F
year	22	220	191.63	8.71	<.0001	<.0001
month	3	220	146.03	48.68	<.0001	<.0001
area	3	220	33.13	11.04	<.0001	<.0001
nhbf	1	496	14.35	14.35	0.0002	0.0002
main	1	496	0.28	0.28	0.5961	0.5963
bran	1	496	1.77	1.77	0.184	0.1846

Type 3 test of fixed effect for LogCPUE with positive catch (2nd step)

Effect	DF	DF	F Value	Pr > F
year	24	214	14.7	<.0001
month	3	214	35.1	<.0001
area	3	214	2.07	0.1051
nhbf	1	65000	12.54	0.0004
main	1	65000	69.64	<.0001
bran	1	65000	0.41	0.5236

(b) final model

West Atlantic (1976-2014)

Type 3 test of fixed effect for proportion of positive catch (1st step)

Effect	DF	DF	Chi-square	F Value	Pr > ChiSq	Pr > F
year	38	513	148.55	3.91	<.0001	<.0001
month	3	513	139.14	46.38	<.0001	<.0001
area	4	513	130.91	32.73	<.0001	<.0001
nhbf	8	949	192.38	24.05	<.0001	<.0001

Type 3 test of fixed effect for LogCPUE with positive catch (2nd step)

Effect	DF	DF	F Value	Pr > F
year	38	424	3.14	<.0001
month	3	424	87.76	<.0001
area	4	424	8.41	<.0001
nhbf	8	30000	15.84	<.0001
main	1	30000	29.96	<.0001

Northeast Atlantic (1990-2014)

Type 3 test of fixed effect for proportion of positive catch (1st step)

Effect	DF	DF	Chi-square	F Value	Pr > ChiSq	Pr > F
year	22	219	220.29	10.01	<.0001	<.0001
month	3	219	153.72	51.24	<.0001	<.0001
area	3	219	30.62	10.21	<.0001	<.0001
nhbf	1	136	10.12	10.12	0.0015	0.0018

Type 3 test of fixed effect for LogCPUE with positive catch (2nd step)

Effect	DF	DF	F Value	Pr > F
year	24	214	14.71	<.0001
month	3	214	35.08	<.0001
area	3	214	2.08	0.1043
nhbf	1	65000	12.52	0.0004
main	1	65000	107.86	<.0001

Table 6. Nominal CPUE, number of sets, and abundance index statistics for the updated standardized CPUE to 2014FY for the West and Northeast Atlantic.

West Atlantic

Year	Sets	Nominal CPUE	Lower 95% CI	Upper 95% CI	Std. CPUE	CV
1976	1143	3.162	0.074	0.386	0.609	0.432
1977	1787	6.412	0.428	1.001	2.362	0.215
1978	1497	4.091	0.179	0.556	1.140	0.289
1979	2363	1.311	0.131	0.357	0.782	0.254
1980	2454	2.335	0.272	0.623	1.487	0.209
1981	4268	2.996	0.393	0.728	1.932	0.155
1982	2921	0.694	0.120	0.320	0.708	0.248
1983	2712	1.036	0.065	0.222	0.434	0.315
1984	2037	1.722	0.184	0.432	1.017	0.216
1985	2573	2.924	0.217	0.495	1.184	0.208
1986	1933	0.399	0.008	0.073	0.088	0.598
1987	2593	1.835	0.129	0.364	0.782	0.264
1988	2775	2.109	0.218	0.490	1.179	0.205
1989	2623	1.145	0.180	0.419	0.991	0.214
1990	2507	1.072	0.140	0.365	0.818	0.243
1991	1651	0.988	0.136	0.377	0.818	0.259
1992	1371	1.854	0.228	0.528	1.252	0.212
1993	1682	1.241	0.218	0.533	1.229	0.227
1994	1535	2.114	0.204	0.486	1.136	0.220
1995	565	1.046	0.133	0.410	0.842	0.288
1996	479	4.150	0.390	0.873	2.105	0.204
1997	819	2.325	0.220	0.594	1.304	0.252
1998	1185	1.413	0.096	0.300	0.614	0.290
1999	1272	1.178	0.100	0.332	0.657	0.308
2000	1266	1.495	0.133	0.387	0.820	0.272
2001	1217	0.704	0.066	0.311	0.519	0.401
2002	2190	0.560	0.092	0.306	0.606	0.307
2003	768	0.869	0.077	0.354	0.597	0.395
2004	825	2.051	0.070	0.309	0.529	0.385
2005	1775	1.209	0.113	0.278	0.640	0.228
2006	1065	1.596	0.194	0.479	1.100	0.229
2007	370	5.224	0.298	0.735	1.690	0.229
2008	238	1.479	0.102	0.396	0.726	0.349
2009	54	2.200	0.242	0.889	1.675	0.334
2010	146	0.343	0.083	0.342	0.607	0.366
2011	285	5.211	0.447	1.150	2.588	0.240
2012	156	2.751	0.561	1.783	3.610	0.295
2013	233	2.595	0.432	1.217	2.618	0.263
2014	50	1.083	0.259	0.948	1.788	0.333

Northeast Atlantic

Year	Sets	Nominal CPUE	Lower 95% CI	Upper 95% CI	Std. CPUE	CV
1990	619	0.840	0.023	0.081	0.401	0.318
1991	2522	0.901	0.032	0.093	0.504	0.271
1992	4400	1.055	0.067	0.128	0.857	0.164
1993	4173	0.951	0.070	0.119	0.843	0.136
1994	2596	1.496	0.079	0.150	1.008	0.159
1995	1618	1.724	0.085	0.145	1.030	0.134
1996	3041	2.520	0.215	0.362	2.582	0.130
1997	5384	1.332	0.135	0.225	1.611	0.128
1998	6271	0.960	0.067	0.126	0.848	0.160
1999	5522	1.031	0.097	0.174	1.202	0.147
2000	6976	1.025	0.104	0.165	1.209	0.116
2001	5532	1.359	0.122	0.199	1.441	0.122
2002	4083	0.859	0.093	0.153	1.104	0.126
2003	3564	1.141	0.092	0.163	1.134	0.142
2004	6124	0.976	0.087	0.139	1.015	0.118
2005	6591	0.763	0.063	0.100	0.733	0.115
2006	5253	0.951	0.074	0.118	0.866	0.115
2007	3163	0.976	0.076	0.121	0.887	0.116
2008	2736	1.320	0.089	0.141	1.035	0.115
2009	3052	2.026	0.132	0.208	1.529	0.114
2010	1482	3.516	0.208	0.348	2.486	0.129
2011	682	4.649	0.326	0.634	4.204	0.168
2012	362	7.378	0.655	1.527	9.253	0.214
2013	400	6.285	0.590	1.190	7.751	0.177
2014	307	8.944	0.582	1.425	8.423	0.227

Table 7. Statistical results from GLMM analysis for positive catch ratio (1st step) and CPUE of positive catch (2nd step) for the split standardized CPUEs to 2014FY for the West Atlantic, (a) in the base model and (b) in the final model.

(a) base model

West Atlantic (1976-2009)

Type 3 test of fixed effect for proportion of positive catch (1st step)

Effect	DF	DF	Chi-square	F Value	Pr > ChiSq	Pr > F
year	33	485	124.32	3.77	<.0001	<.0001
month	3	485	127.58	42.53	<.0001	<.0001
area	4	485	126.64	31.66	<.0001	<.0001
nhbf	8	1123	195.1	24.39	<.0001	<.0001
main	1	1123	0	0	0.9554	0.9554
bran	1	1123	1.55	1.55	0.2125	0.2128

Type 3 test of fixed effect for LogCPUE with positive catch (2nd step)

Effect	DF	DF	F Value	Pr > F
year	33	398	2.81	<.0001
month	3	398	86.44	<.0001
area	4	398	7.69	<.0001
nhbf	8	30000	15.84	<.0001
main	1	30000	24.89	<.0001
bran	1	30000	0	0.9467

West Atlantic (1976-2009)

Type 3 test of fixed effect for proportion of positive catch (1st step)

Effect	DF	DF	Chi-square	F Value	Pr > ChiSq	Pr > F
year	4	28	37.81	9.45	<.0001	<.0001
month	3	28	58.98	19.66	<.0001	<.0001
area	1	28	14.03	14.03	0.0002	0.0008
nhbf	1	28	6.13	6.13	0.0133	0.0196
main	1	28	1.74	1.74	0.1873	0.1979

Type 3 test of fixed effect for LogCPUE with positive catch (2nd step)

Effect	DF	DF	F Value	Pr > F
year	4	25	3.91	0.0134
month	3	25	7.51	0.001
area	1	25	4.13	0.0528
nhbf	1	1039	12.16	0.0005
main	1	1039	2.67	0.1023

(b) final model

West Atlantic (1976-2014)

Type 3 test of fixed effect for proportion of positive catch (1st step)

Effect	DF	DF	Chi-square	F Value	Pr > ChiSq	Pr > F
year	33	484	124.06	3.76	<.0001	<.0001
month	3	484	127.67	42.56	<.0001	<.0001
area	4	484	126.7	31.67	<.0001	<.0001
nhbf	8	933	188.53	23.57	<.0001	<.0001

Type 3 test of fixed effect for LogCPUE with positive catch (2nd step)

Effect	DF	DF	F Value	Pr > F
year	33	398	2.82	<.0001
month	3	398	86.46	<.0001
area	4	398	7.69	<.0001
nhbf	8	30000	15.84	<.0001
main	1	30000	31.65	<.0001

West Atlantic (2010-2014)

Type 3 test of fixed effect for proportion of positive catch (1st step)

Effect	DF	DF	Chi-square	F Value	Pr > ChiSq	Pr > F
year	4	28	35.89	8.97	<.0001	<.0001
month	3	28	59.07	19.69	<.0001	<.0001
area	1	28	14	14	0.0002	0.0008

Type 3 test of fixed effect for LogCPUE with positive catch (2nd step)

Effect	DF	DF	F Value	Pr > F
year	4	25	3.83	0.0145
month	3	25	7.62	0.0009
area	1	25	4.12	0.0531
nhbf	1	1040	10.21	0.0014

Table 8. Nominal CPUE, number of sets, and abundance index statistics for the split standardized CPUE to 2014FY for the West Atlantic.

West Atlantic (1976-2009)

Year	Sets	Nominal CPUE	Lower 95% CI	Upper 95% CI	Std. CPUE	CV
1976	1143	3.162278	0.114	0.579	0.612	0.423
1977	1787	6.412	0.658	1.520	2.383	0.212
1978	1497	4.091	0.274	0.836	1.141	0.284
1979	2363	1.311	0.203	0.541	0.790	0.249
1980	2454	2.335	0.417	0.940	1.491	0.206
1981	4268	2.996	0.606	1.106	1.950	0.151
1982	2921	0.694	0.186	0.484	0.715	0.242
1983	2712	1.036	0.101	0.334	0.438	0.306
1984	2037	1.722	0.283	0.653	1.025	0.211
1985	2573	2.924	0.336	0.755	1.200	0.204
1986	1933	0.399	0.014	0.107	0.091	0.550
1987	2593	1.835	0.198	0.548	0.786	0.259
1988	2775	2.109	0.335	0.742	1.188	0.200
1989	2623	1.145	0.277	0.633	0.997	0.209
1990	2507	1.072	0.216	0.552	0.824	0.237
1991	1651	0.988	0.211	0.571	0.827	0.253
1992	1371	1.854	0.353	0.804	1.270	0.208
1993	1682	1.241	0.333	0.804	1.233	0.223
1994	1535	2.114	0.316	0.742	1.154	0.216
1995	565	1.046	0.204	0.619	0.848	0.282
1996	479	4.150	0.600	1.319	2.119	0.199
1997	819	2.325	0.340	0.901	1.318	0.248
1998	1185	1.413	0.151	0.455	0.623	0.282
1999	1272	1.178	0.157	0.509	0.674	0.300
2000	1266	1.495	0.204	0.581	0.821	0.266
2001	1217	0.704	0.105	0.469	0.528	0.389
2002	2190	0.560	0.141	0.455	0.604	0.299
2003	768	0.869	0.119	0.529	0.599	0.385
2004	825	2.051	0.110	0.470	0.543	0.374
2005	1775	1.209	0.174	0.418	0.643	0.222
2006	1065	1.596	0.297	0.720	1.102	0.224
2007	370	5.224	0.451	1.097	1.677	0.225
2008	238	1.479	0.154	0.579	0.711	0.341
2009	54	2.200	0.368	1.321	1.660	0.328

West Atlantic (2010-2014)

Year	Sets	Nominal CPUE	Lower 95% CI	Upper 95% CI	Std. CPUE	CV
2010	225	0.152	0.044	0.279	0.247	0.485
2011	373	3.839	0.270	0.903	1.096	0.309
2012	369	1.781	0.647	1.545	2.219	0.220
2013	474	1.567	0.317	0.842	1.147	0.248
2014	331	1.434	0.463	1.300	1.721	0.263

Table 9. The comparison of AIC values to obtain the optimal split point for Northeast Atlantic. Delta-lognormal model was applied.

	AIC 1st step total	AIC 2nd step total	AIC 1st step early	AIC 2nd step early	AIC 1st step late	AIC 2nd step late
Without split	1315.8	155558.4	-	-	-	-
split 08/09	1228.6	155713.5	1129.5	141125.9	99.1	14587.6
split 09/10	1218.6	155555.4	1173.2	148206.7	45.4	7348.7

Table 10. Statistical results from GLMM analysis for positive catch ratio (1st step) and CPUE of positive catch (2nd step) in the period between 1990 and 2009 for the Northeast Atlantic, and results from GLM analysis in the period between 2010 and 2014, (a) in the base model and (b) in the final model.

(a) base model

Northeast Atlantic (1990-2009)

Type 3 test of fixed effect for proportion of positive catch (1st step)

Effect	DF	DF	Chi-square	F Value	Pr > ChiSq	Pr > F
year	19	200	150.7	7.93	<.0001	<.0001
month	3	200	148.15	49.38	<.0001	<.0001
area	3	200	32.16	10.72	<.0001	<.0001
nhbf	1	483	14.7	14.7	0.0001	0.0001
main	1	483	0.32	0.32	0.5742	0.5745
bran	1	483	1.89	1.89	0.1692	0.1698

Type 3 test of fixed effect for LogCPUE with positive catch (2nd step)

Effect	DF	DF	F Value	Pr > F
year	19	192	4.54	<.0001
month	3	192	36.76	<.0001
area	3	192	1.85	0.1394
nhbf	1	62000	11.65	0.0006
main	1	62000	90.84	<.0001
bran	1	62000	0.34	0.5618

Northeast Atlantic (2009-2014)

Analysis of Deviance Table (Type III tests)

Response: lcpue

	LR Chisq	Df	Pr(>Chisq)	
as.factor(year)	613.56	4	< 2.2e-16	***
as.factor(month)	13.52	2	0.00116	**
as.factor(area)	39.12	1	3.994e-10	***
as.factor(nhbf)	1.29	1	0.25542	
as.factor(main)	2.30	1	0.12925	
as.factor(bran)	1.43	1	0.23156	
as.factor(month):as.factor(area)	11.67	2	0.00293	**

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

(b) final model

Northeast Atlantic (1990-2009)

Type 3 test of fixed effect for proportion of positive catch (1st step)

Effect	DF	DF	Chi-square	F Value	Pr > ChiSq	Pr > F
year	19	201	187.39	9.86	<.0001	<.0001
month	3	201	154.97	51.66	<.0001	<.0001
area	3	201	30.3	10.1	<.0001	<.0001
nhbf	1	136	10.53	10.53	0.0012	0.0015

Type 3 test of fixed effect for LogCPUE with positive catch (2nd step)

Effect	DF	DF	F Value	Pr > F
year	19	192	4.54	<.0001
month	3	192	36.74	<.0001
area	3	192	1.86	0.1385
nhbf	1	62000	11.63	0.0006
main	1	62000	137.52	<.0001

Northeast Atlantic (2009-2014)

Analysis of Deviance Table (Type III tests)

Response: lcpue

as.factor(year)	646.07	4	< 2.2e-16	***
as.factor(month)	13.35	2	0.001264	**
as.factor(area)	39.50	1	3.282e-10	***
as.factor(month):as.factor(area)	12.08	2	0.002378	**

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

Table 11. Nominal CPUE, number of sets, and abundance index statistics for the split standardized CPUE to 2014FY for the Northeast Atlantic.

Northeast Atlantic (1990-2009)

Year	Sets	Nominal CPUE	Lower 95% CI	Upper 95% CI	Std. CPUE	CV
1990	619	0.840	0.087	0.276	0.395	0.294
1991	2522	0.901	0.118	0.322	0.494	0.255
1992	4400	1.055	0.244	0.458	0.849	0.159
1993	4173	0.951	0.255	0.429	0.839	0.131
1994	2596	1.496	0.288	0.534	0.996	0.155
1995	1618	1.724	0.312	0.524	1.027	0.130
1996	3041	2.520	0.772	1.295	2.538	0.130
1997	5384	1.332	0.488	0.810	1.596	0.127
1998	6271	0.960	0.243	0.451	0.839	0.156
1999	5522	0.994	0.349	0.620	1.180	0.144
2000	6976	1.025	0.372	0.587	1.187	0.114
2001	5532	1.359	0.439	0.709	1.417	0.120
2002	4083	0.859	0.335	0.548	1.088	0.123
2003	3564	1.141	0.334	0.585	1.123	0.140
2004	6124	0.976	0.313	0.495	0.999	0.115
2005	6591	0.763	0.227	0.355	0.721	0.112
2006	5253	0.951	0.268	0.419	0.851	0.112
2007	3163	0.976	0.275	0.431	0.874	0.112
2008	2736	1.320	0.319	0.502	1.017	0.113
2009	3052	2.026	0.472	0.742	1.502	0.113

Northeast Atlantic (2010-2014)

Year	Sets	Nominal CPUE	Lower 95% CI	Upper 95% CI	Std. CPUE	CV
2010	1482	3.516	1.771	2.060	1.922	0.045
2011	682	4.649	2.446	2.925	2.696	0.052
2012	362	7.378	4.010	4.918	4.483	0.060
2013	400	6.285	3.740	4.492	4.133	0.054
2014	307	8.944	5.306	6.372	5.858	0.054

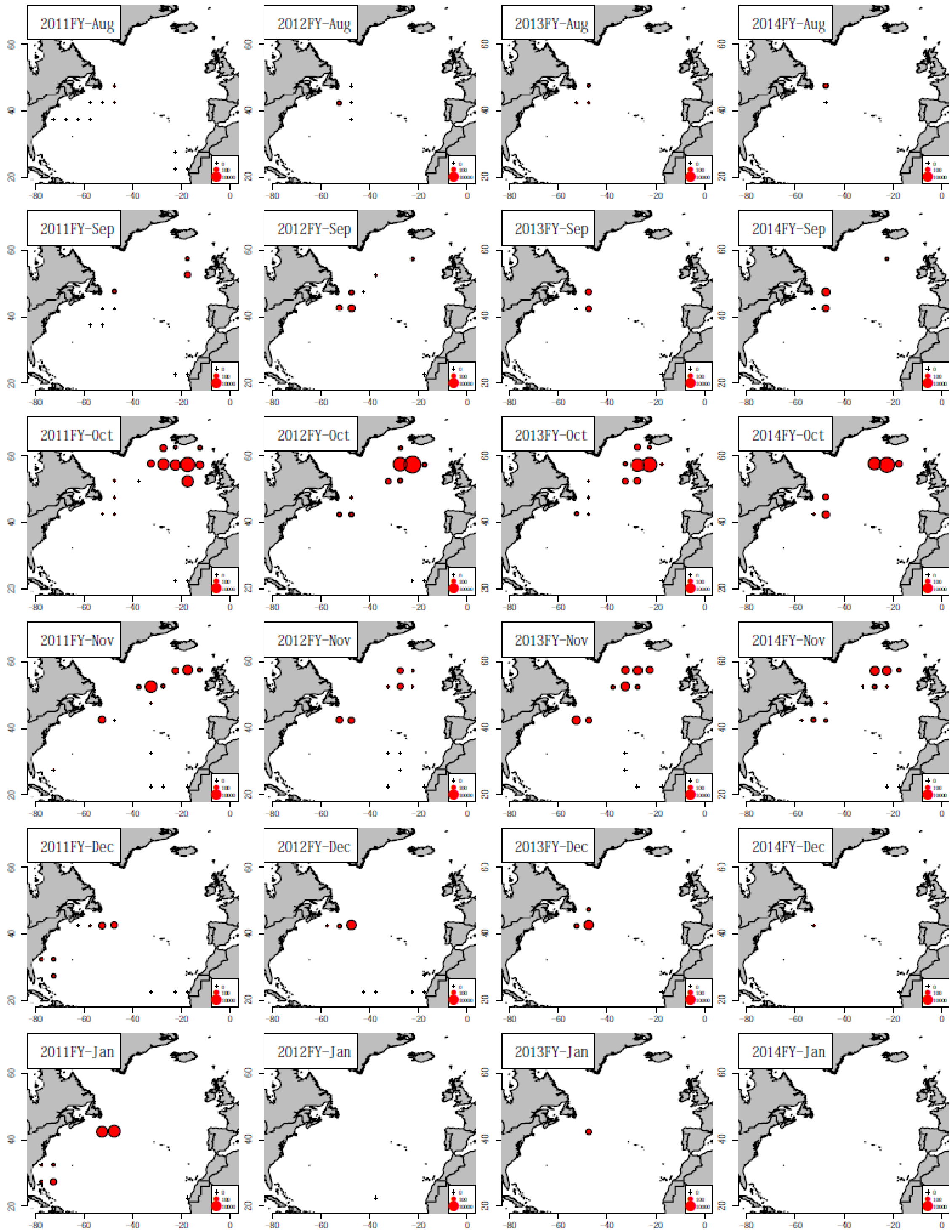


Figure 1. Monthly distributions of accumulative bluefin catch in number by Japanese longliners by 5x5 degree area in the main season (August-January: top to bottom) in the period between 2011 and 2014 FYs (left to right).

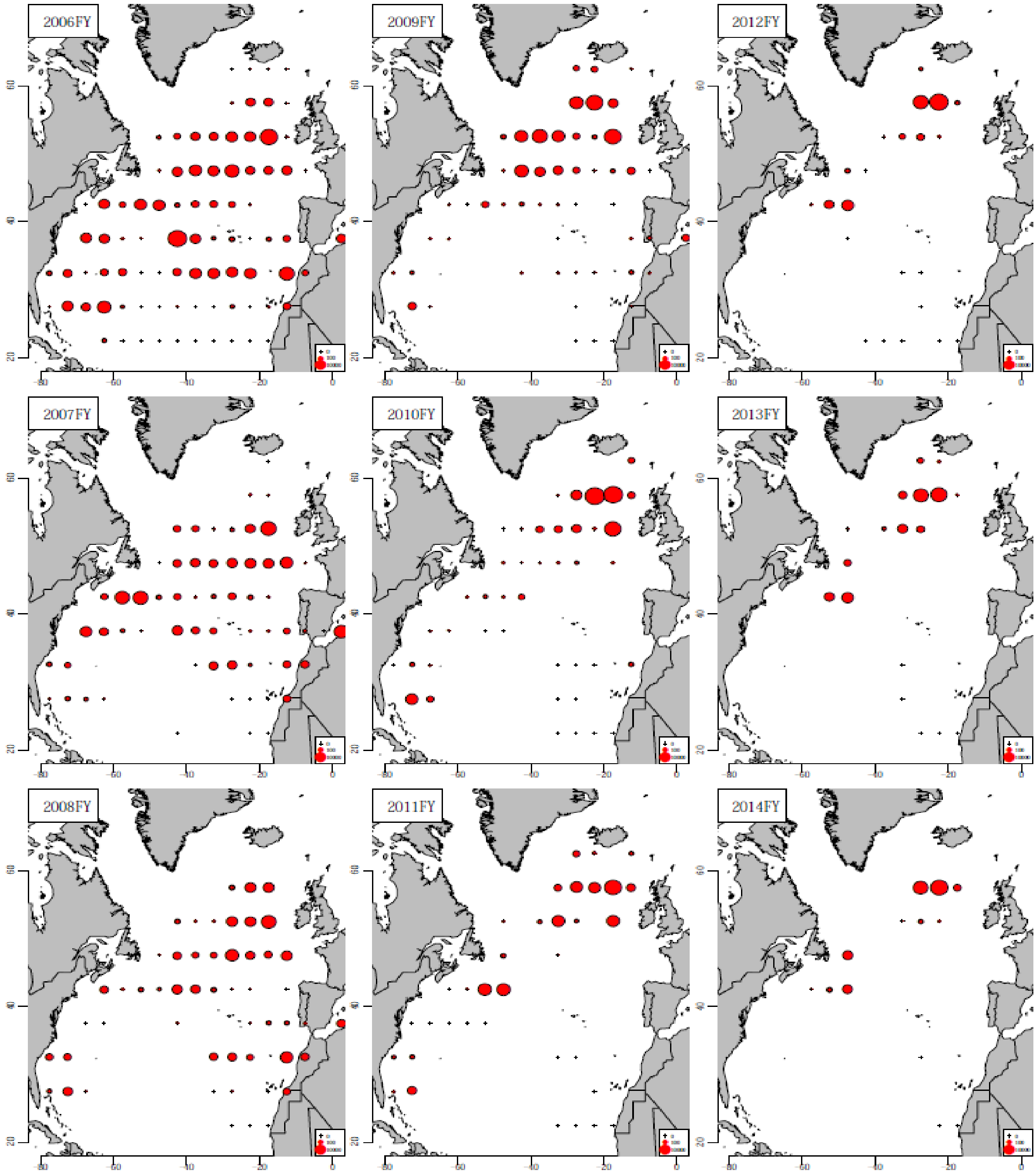


Figure 2. Yearly distributions of accumulative bluefin catch in number by Japanese longliners by 5x5 degree area in the period between 2006 and 2014 FYs.

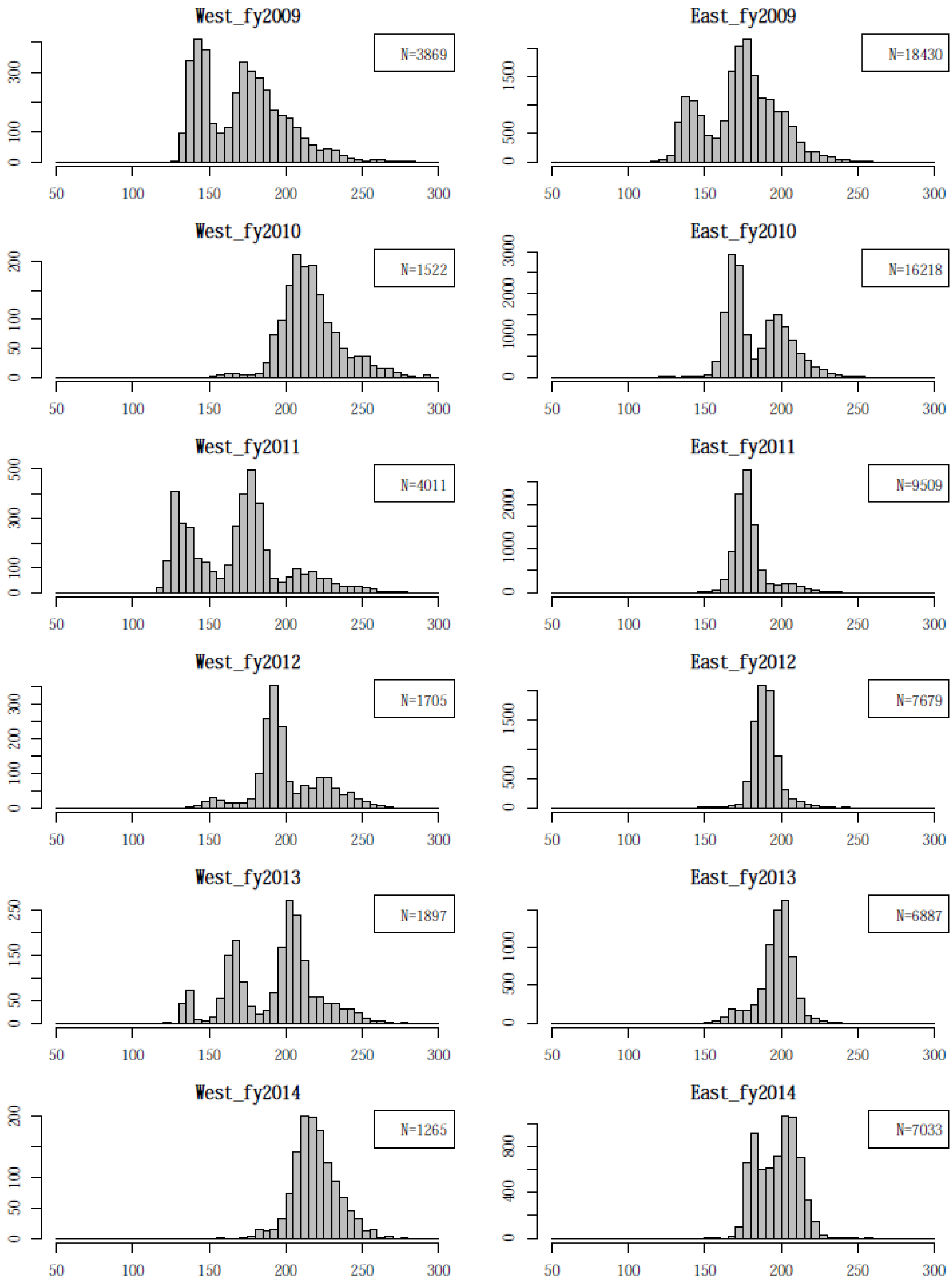
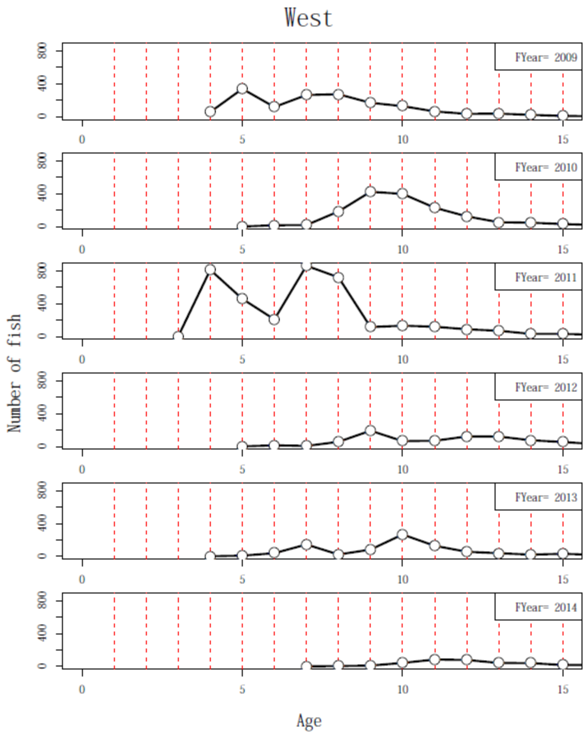


Figure 3. Converted fork length frequencies using the length-weight conversion factors (Anon, 2011) from 2009 to 2014FY measured by on board size measurement program in the west Atlantic (left panel) and the Northeast Atlantic (right panel).



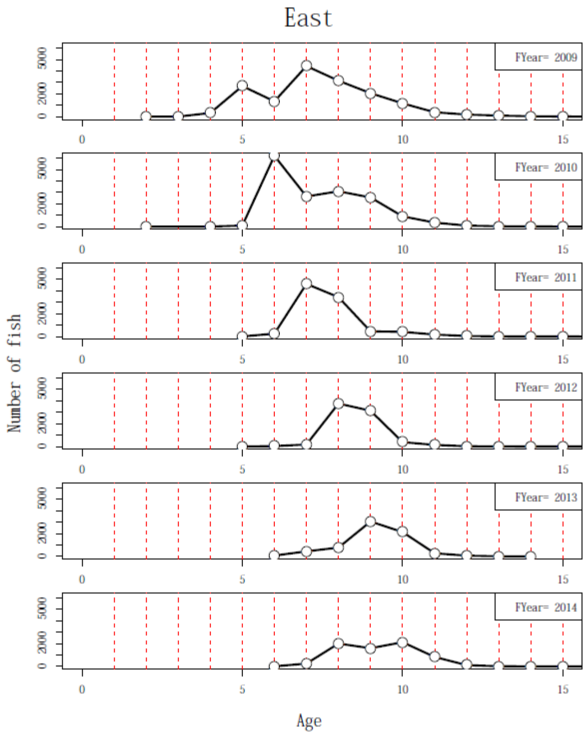


Figure 4. Catch at age was estimated for 2009 through 2014FYs from the converted size data in the West (left panel) and Northeast Atlantic (right panel), applying slicing procedures to the size frequencies of bluefin caught by the Japanese longliners.

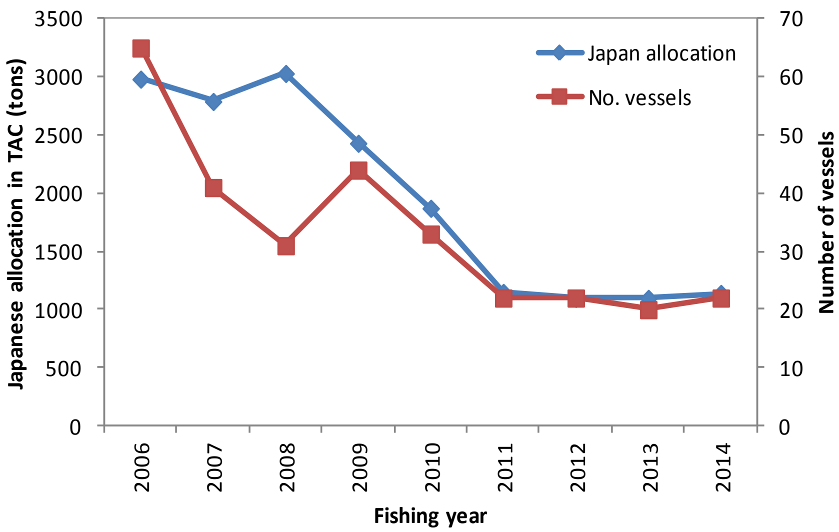


Figure 5. The allocated Japanese TAC for the eastern bluefin tuna (blue line) and the number of operating vessels in the east of 45W (red line) since 2007 fishing year. Fishing year 2014 means August 2013 to July 2014.

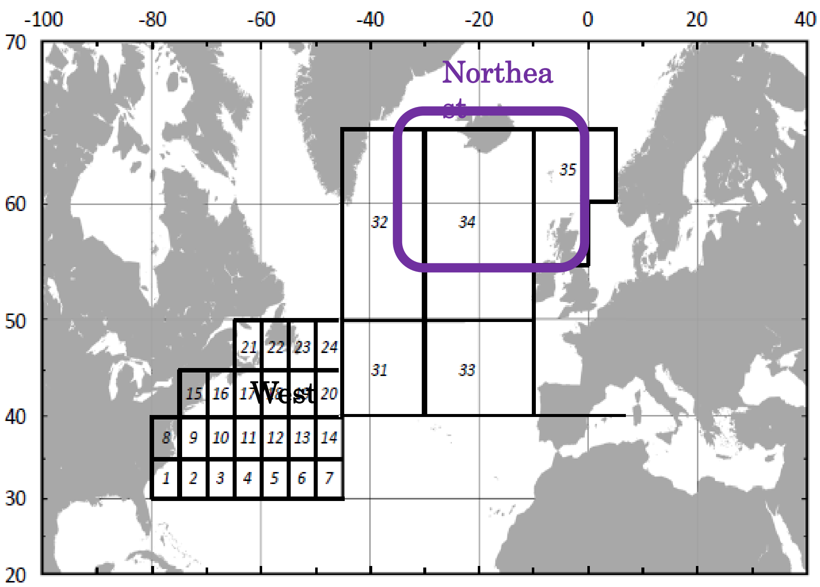


Figure 6. Original area stratification considered in the CPUE standardization for the West and Northeast Atlantic. Numbers from 1 through 24 and from 31 through 35 denote for the West and the Northeast Atlantic, respectively. Numbers indicate original area stratification used in **Tables 1-2**.

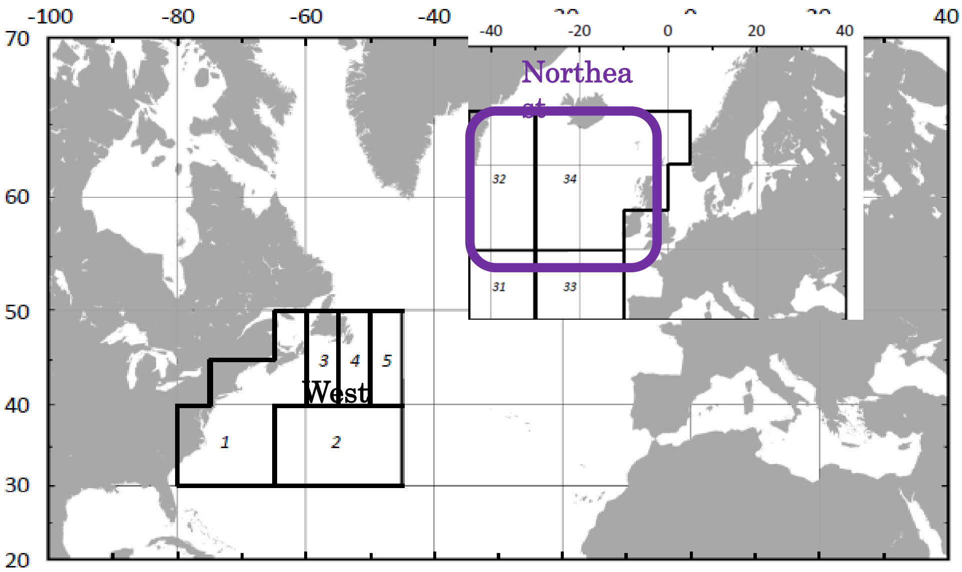


Figure 7. Combined areas used in the CPUE standardization for the West and the Northeast Atlantic. Numbers from 1 through 5 and from 31 through 34 denote for the West and the Northeast Atlantic, respectively. For the split CPUE in the Northeast Atlantic, the combined areas (31-32, and 33-34) were used for the analysis.

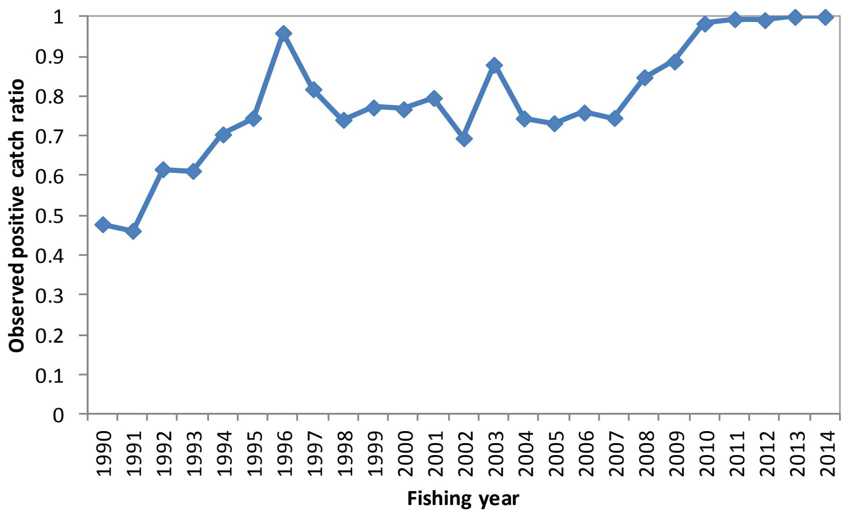
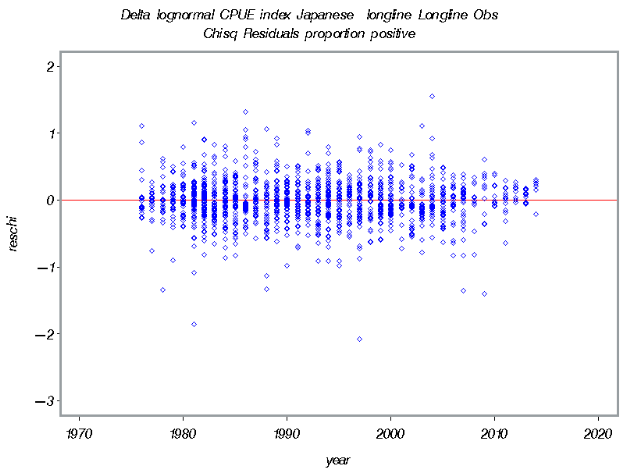
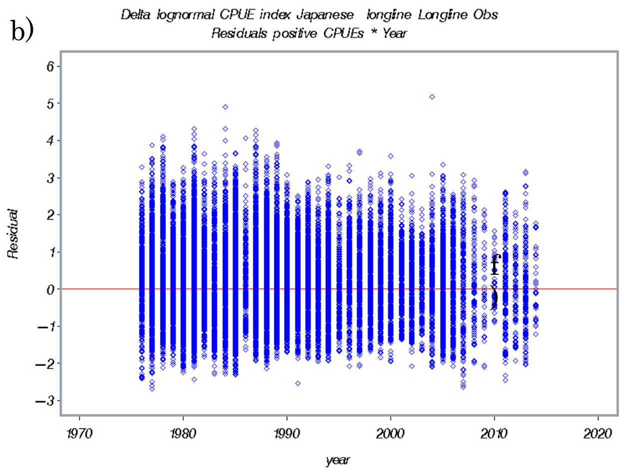


Figure 8. The positive catch ratio in the Northeast Atlantic in the entire analyzed period.

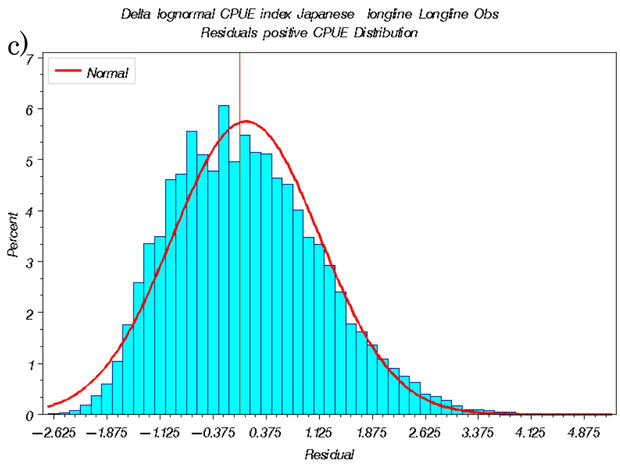
a)


Delta lognormal CPUE index Japanese longline Longline Obs
Chisq Residuals proportion positive
reschi
year
1970
1980
1990
2000
2010
2020

b)


Delta lognormal CPUE index Japanese longline Longline Obs
Residuals positive CPUEs * Year
Residual
year
1970
1980
1990
2000
2010
2020

c)


Delta lognormal CPUE index Japanese longline Longline Obs
Residuals positive CPUE Distribution
Normal
Percent
Residual
−2.625
−1.875
−1.125
−0.375
0.375
1.125
1.875
2.625
3.375
4.125
4.875

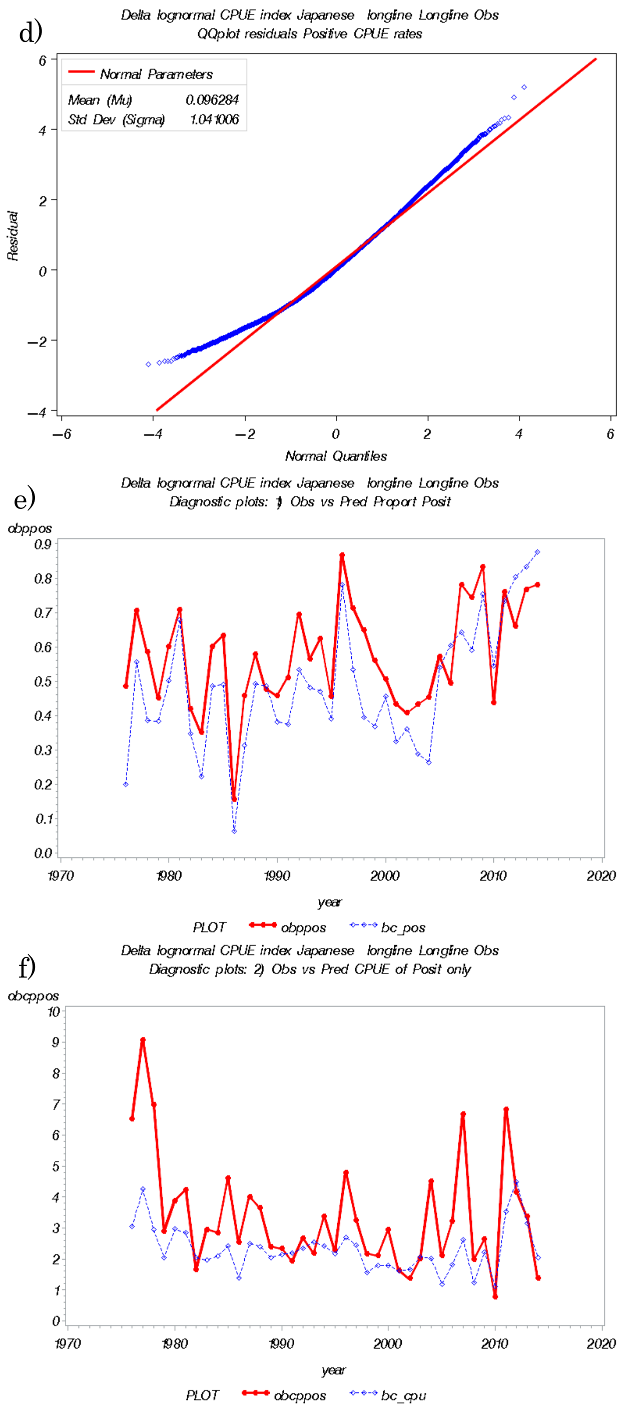
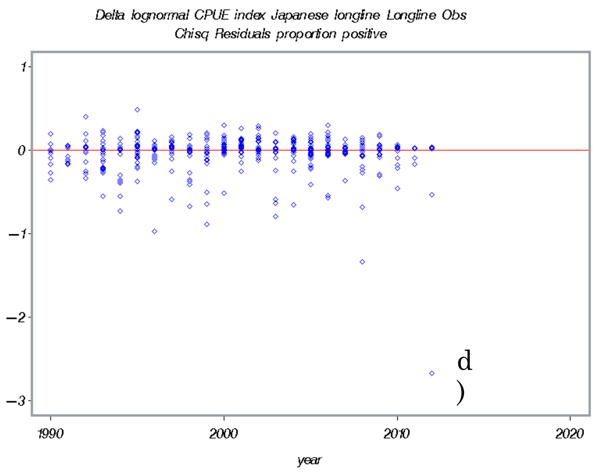
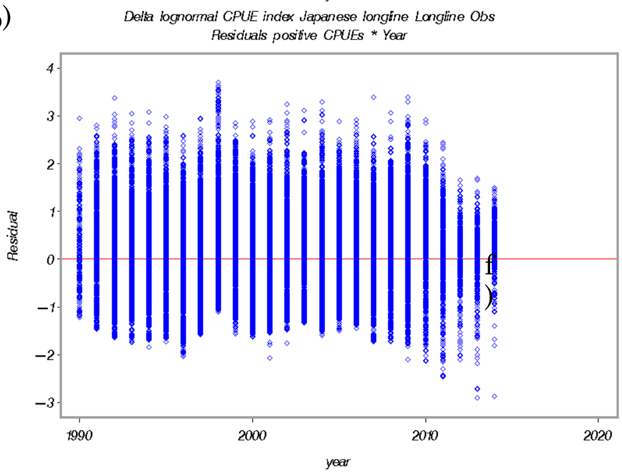


Figure 9. Model diagnostics of the CPUE in the period between 1976 and 2014FY for the West Atlantic: residual distributions in the (a)1st and (b)2nd steps of CPUE standardization, (c)distribution and (d)qqplot of the residuals for the positive CPUE, (e)observed (red line) and predicted (blue line) proportion of positive catch observation, and (f)observed (red line) and predicted (blue line) CPUE of positive catch set using delta-lognormal model.

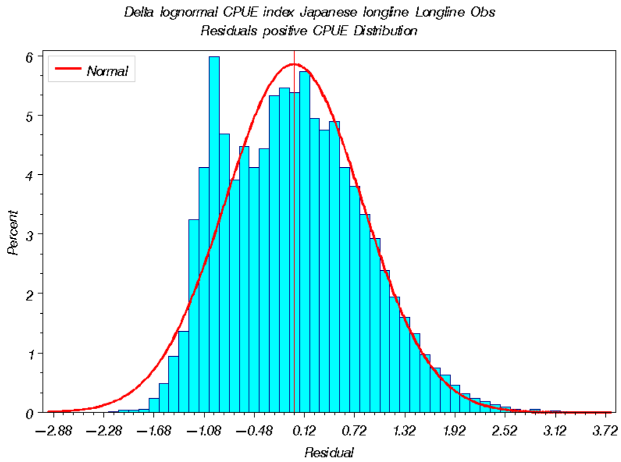
a)


Delta lognormal CPUE index Japanese longline Longline Obs
Chisq Residuals proportion positive
reschi
year
d
)

b)


Delta lognormal CPUE index Japanese longline Longline Obs
Residuals positive CPUEs * Year
Residual
year
f
)

c)


Delta lognormal CPUE index Japanese longline Longline Obs
Residuals positive CPUE Distribution
Normal
Percent
Residual

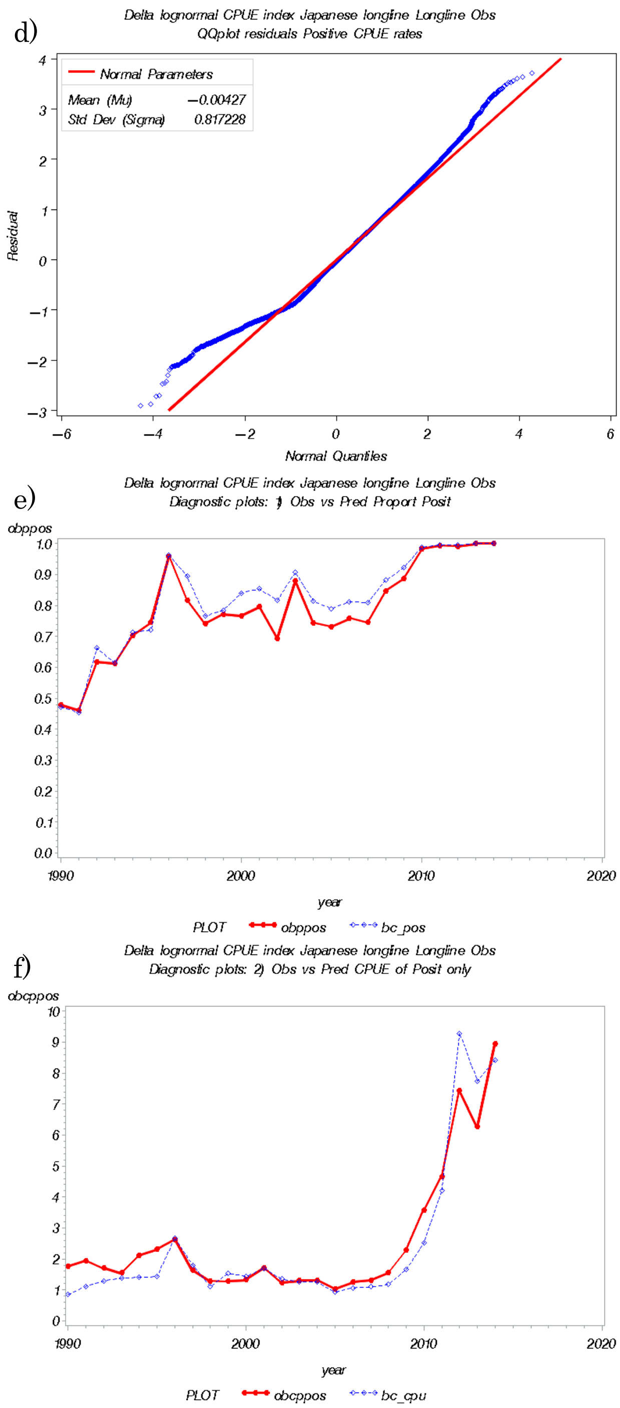
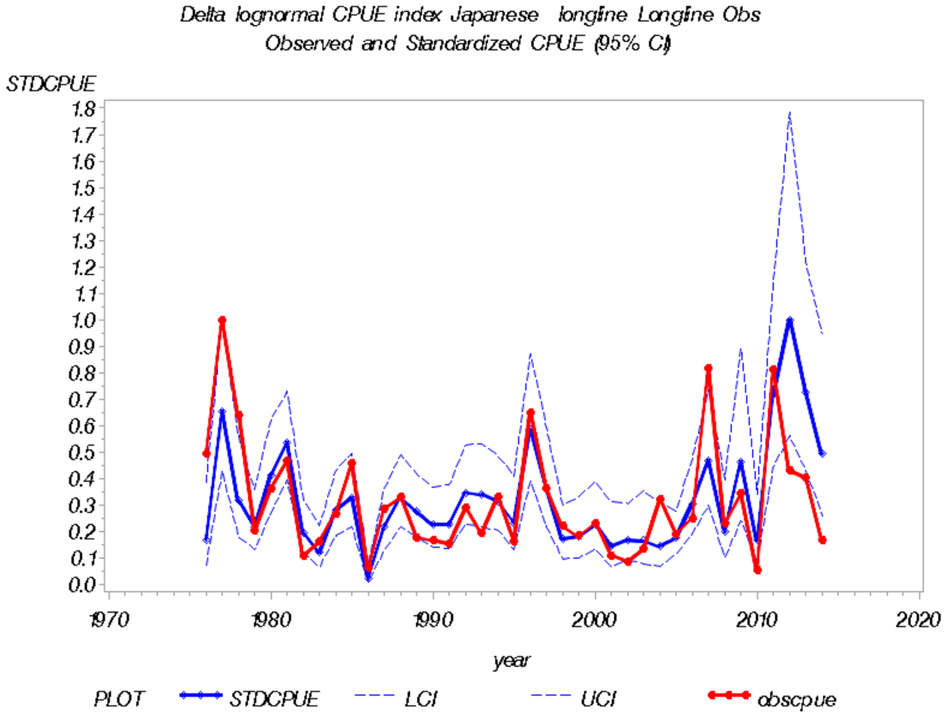


Figure 10. Model diagnostics of the CPUE in the period between 1990 and 2014FY for the Northeast Atlantic: residual distributions in the (a)1st and (b)2nd steps of CPUE standardization, (c)distribution and (d)qqplot of the residuals for the positive CPUE, (e)observed (red line) and predicted (blue line) proportion of positive catch observation, and (f)observed (red line) and predicted (blue line) CPUE of positive catch set using delta-lognormal model.

(a) West Atlantic



(b) Northeast Atlantic

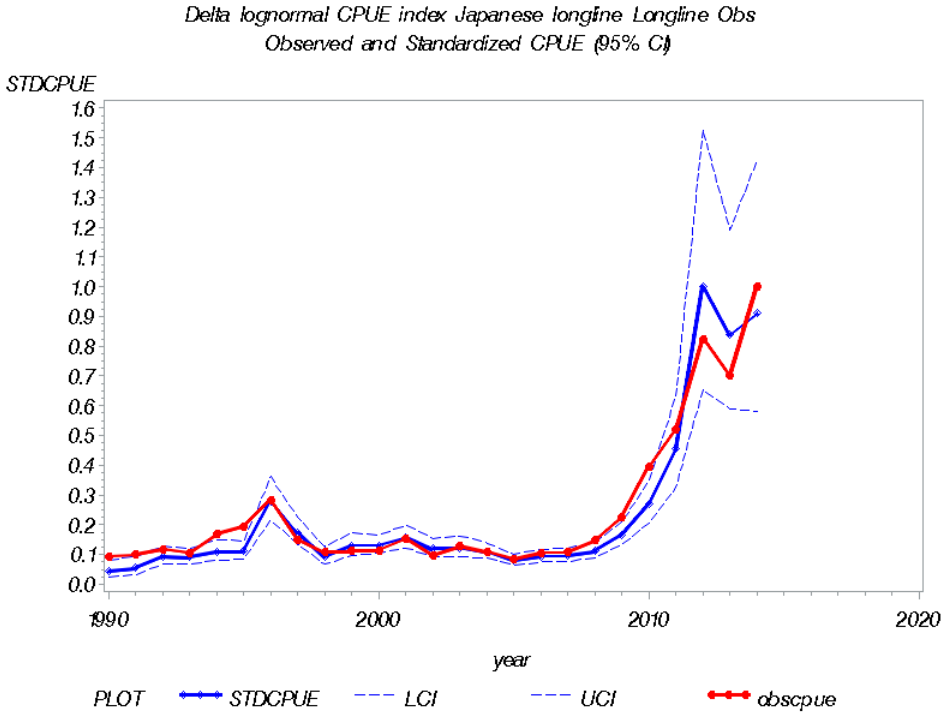
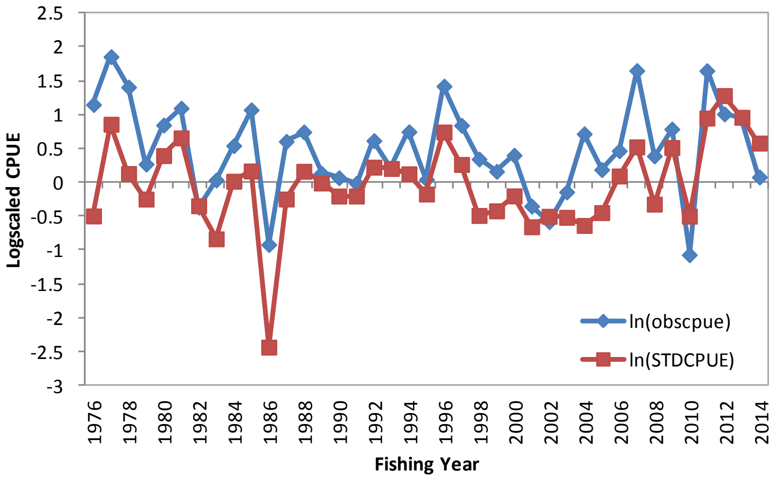


Figure 11. Standardized CPUE (blue line) with 95% confidence intervals and nominal CPUE (red line) for (a) the West Atlantic and (b) the Northeast Atlantic.

(a) West Atlantic



(b) Northeast Atlantic

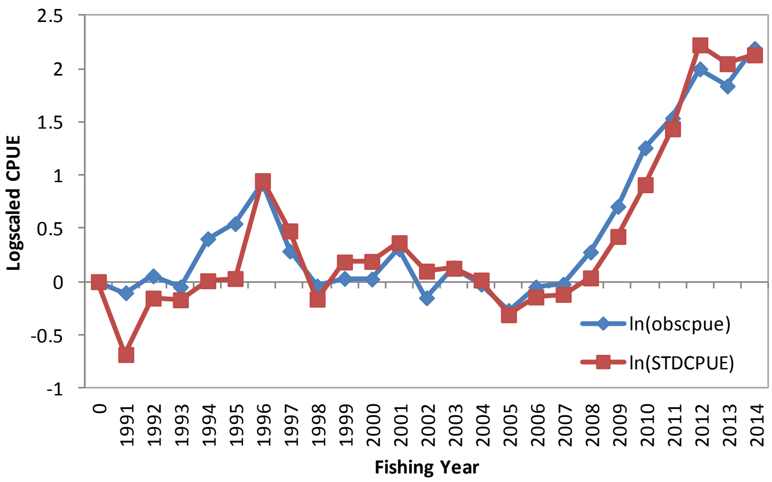


Figure 12. Standardized CPUE and nominal CPUE in logarithmic scale with 95% confidence intervals and nominal CPUE for (a) the West Atlantic and (b) the Northeast Atlantic.

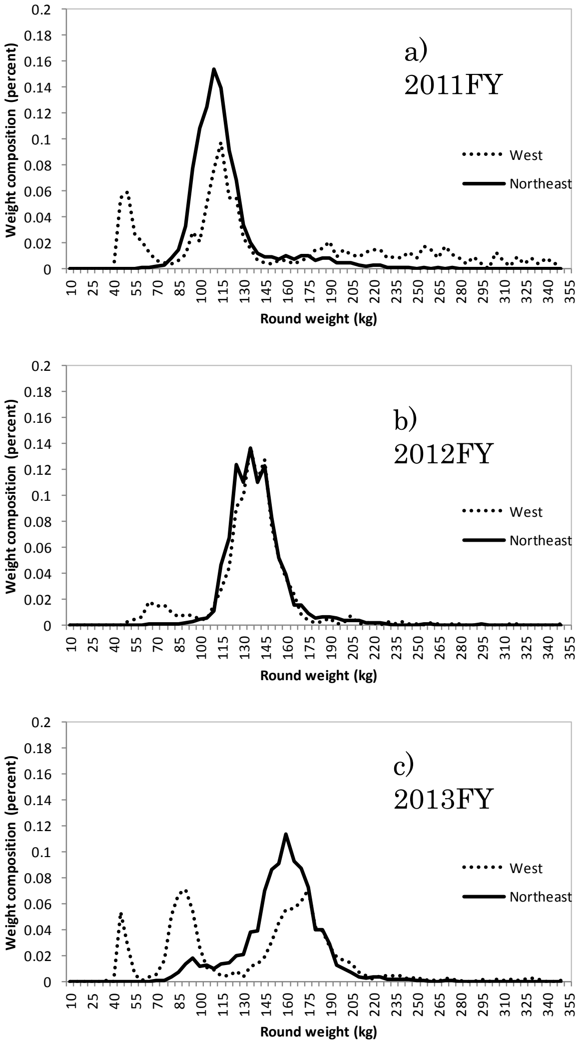


Figure 13. The weight composition (kg) in the main fishing area and season in the West (40-45°N, 45-55°W, in November and December, dotted line) and Northeast Atlantic (50-60°N and 15-35°W, in October and November, solid line) in (a)2011, (b)2012, and (c)2013FYs.

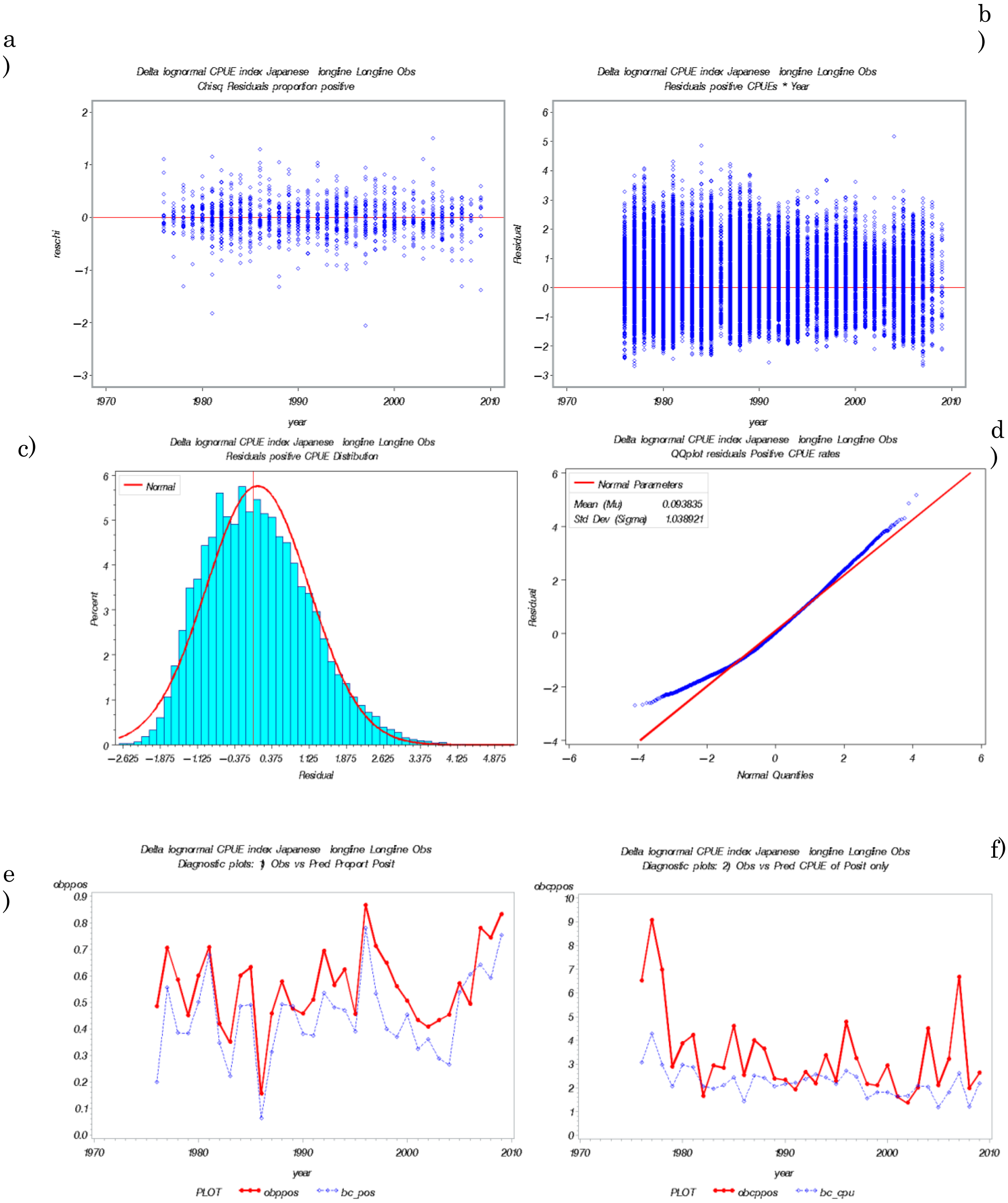


Figure 14. Model diagnostics of the CPUE in the period between 1976 and 2009FY for the West Atlantic: residual distributions in the (a)1st and (b)2nd steps of CPUE standardization, (c)distribution and (d)qqplot of the residuals for the positive CPUE, (e)observed (red line) and predicted (blue line) proportion of positive catch observation, and (f)observed (red line) and predicted (blue line) CPUE of positive catch set using delta-lognormal model.

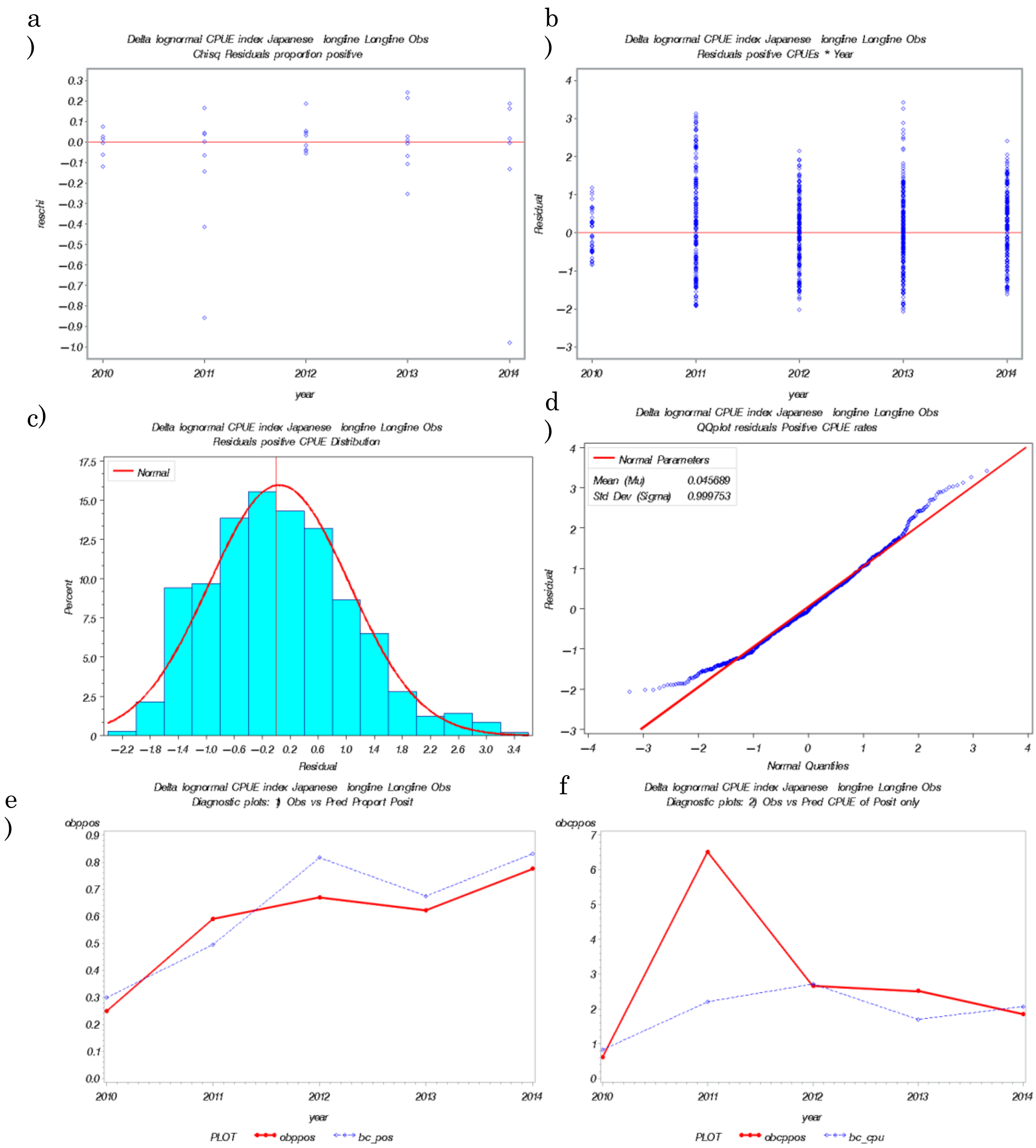
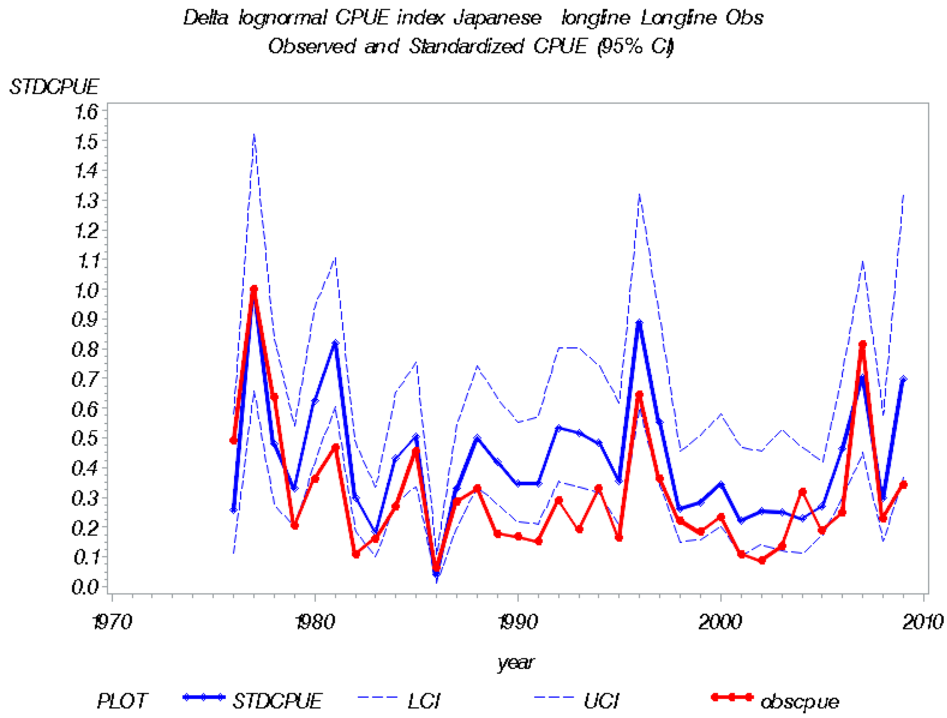


Figure 15. Model diagnostics of the CPUE in the period between 2010 and 2014FY for the West Atlantic: residual distributions in the (a)1st and (b)2nd steps of CPUE standardization, (c)distribution and (d)qqplot of the residuals for the positive CPUE, (e)observed (red line) and predicted (blue line) proportion of positive catch observation, and (f)observed (red line) and predicted (blue line) CPUE of positive catch set using delta-lognormal model.

West Atlantic 1979-2009



West Atlantic 2010-2014

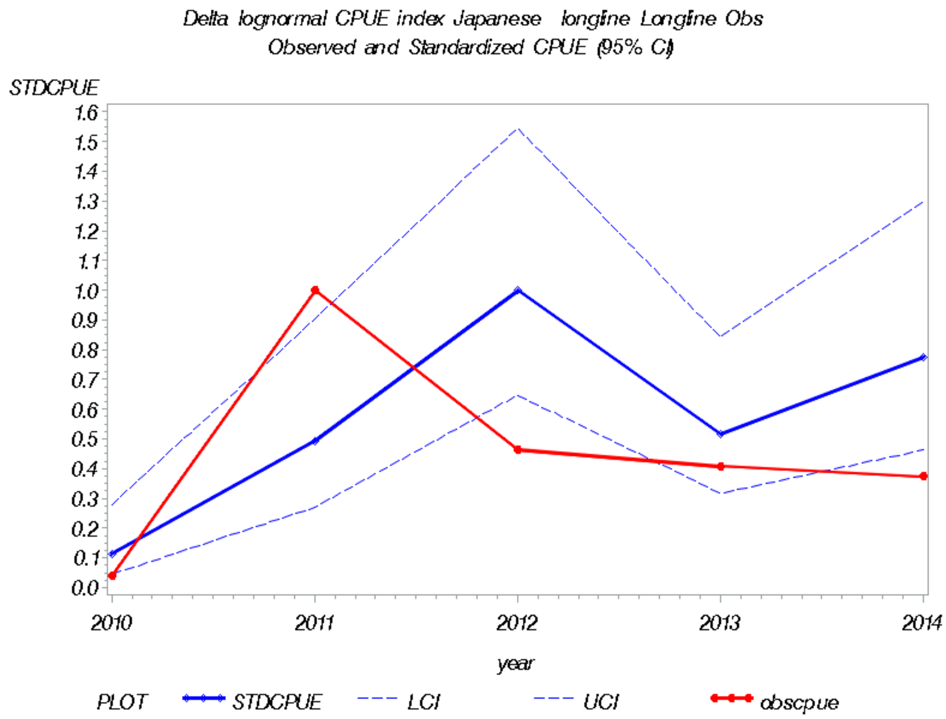


Figure 16. Standardized CPUE (blue line) with 95% confidence intervals and nominal CPUE (red line) for the CPUE series for the West Atlantic in the period between 1976 and 2009FY (Upper panel) and between 2010 and 2014FY (lower panel).

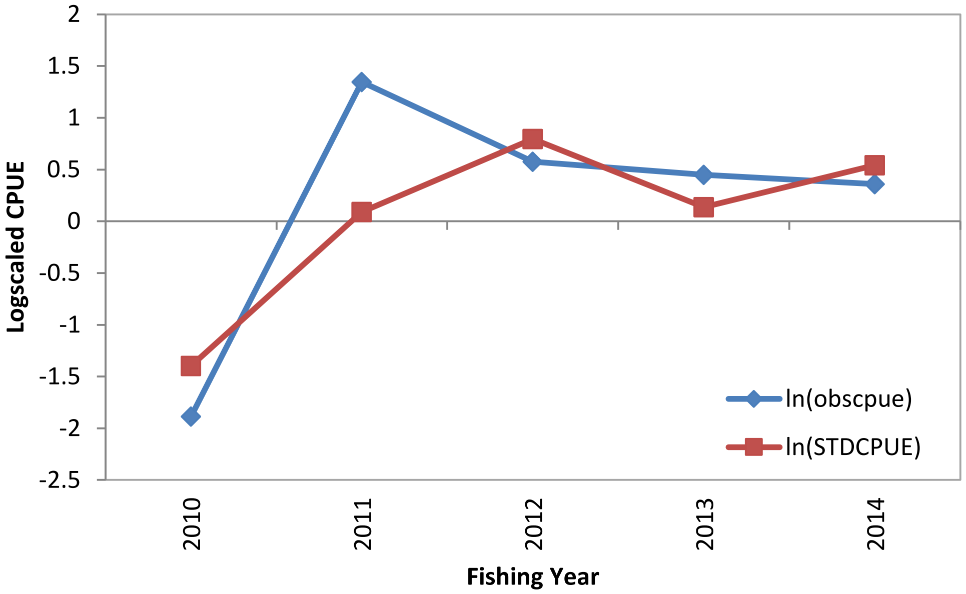


Figure 17. Standardized CPUE and nominal CPUE in logarithmic scale with 95% confidence intervals and nominal CPUE in the period between 2010 and 2014FY for the West Atlantic.

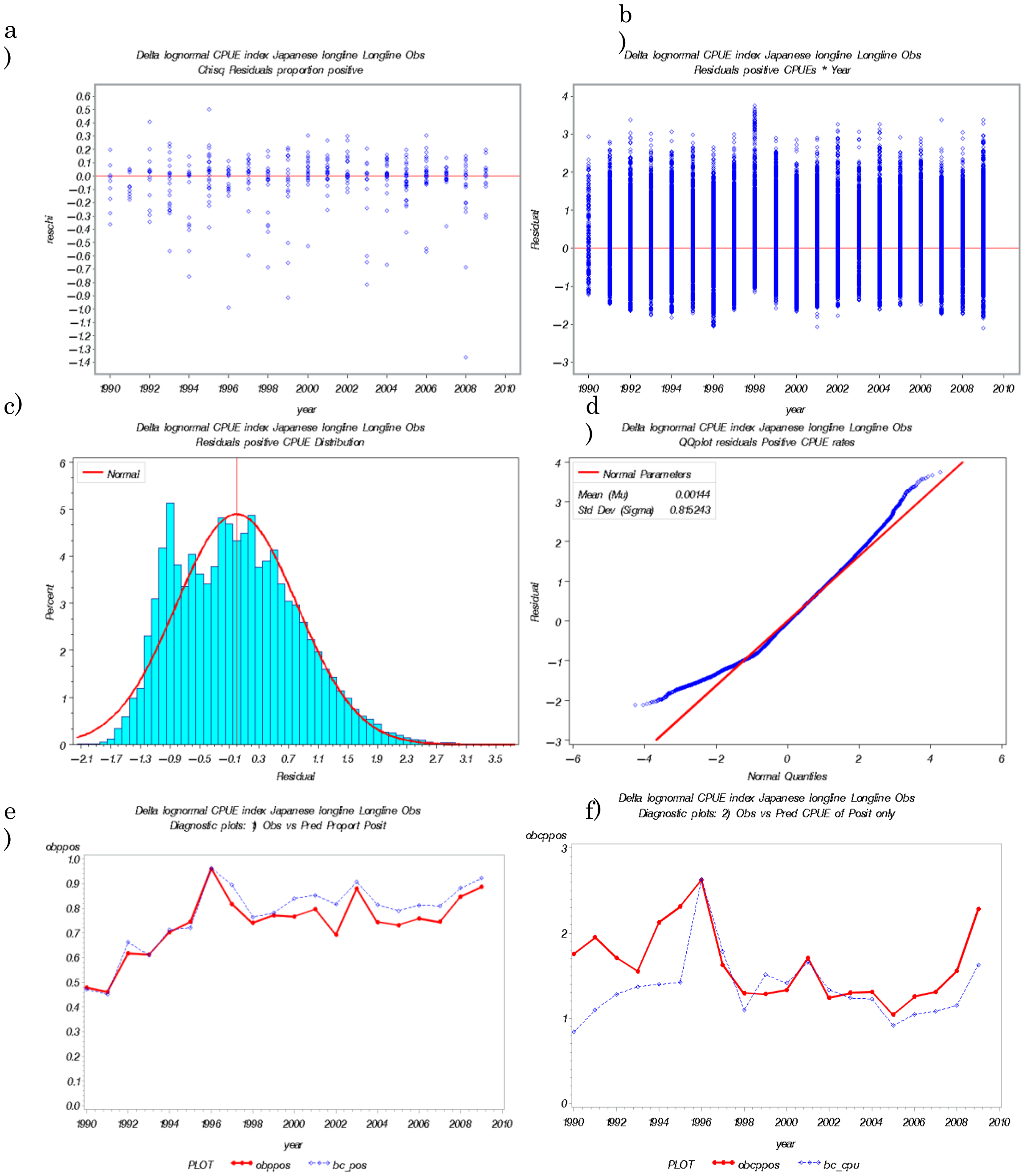


Figure 18. Model diagnostics of the CPUE in the period between 1990 and 2009FY for the Northeast Atlantic: residual distributions in the (a)1st and (b)2nd steps of CPUE standardization, (c)distribution and (d)qqplot of the residuals for the positive CPUE, (e)observed (red line) and predicted (blue line) proportion of positive catch observation, and (f)observed (red line) and predicted (blue line) CPUE of positive catch set using delta-lognormal model.

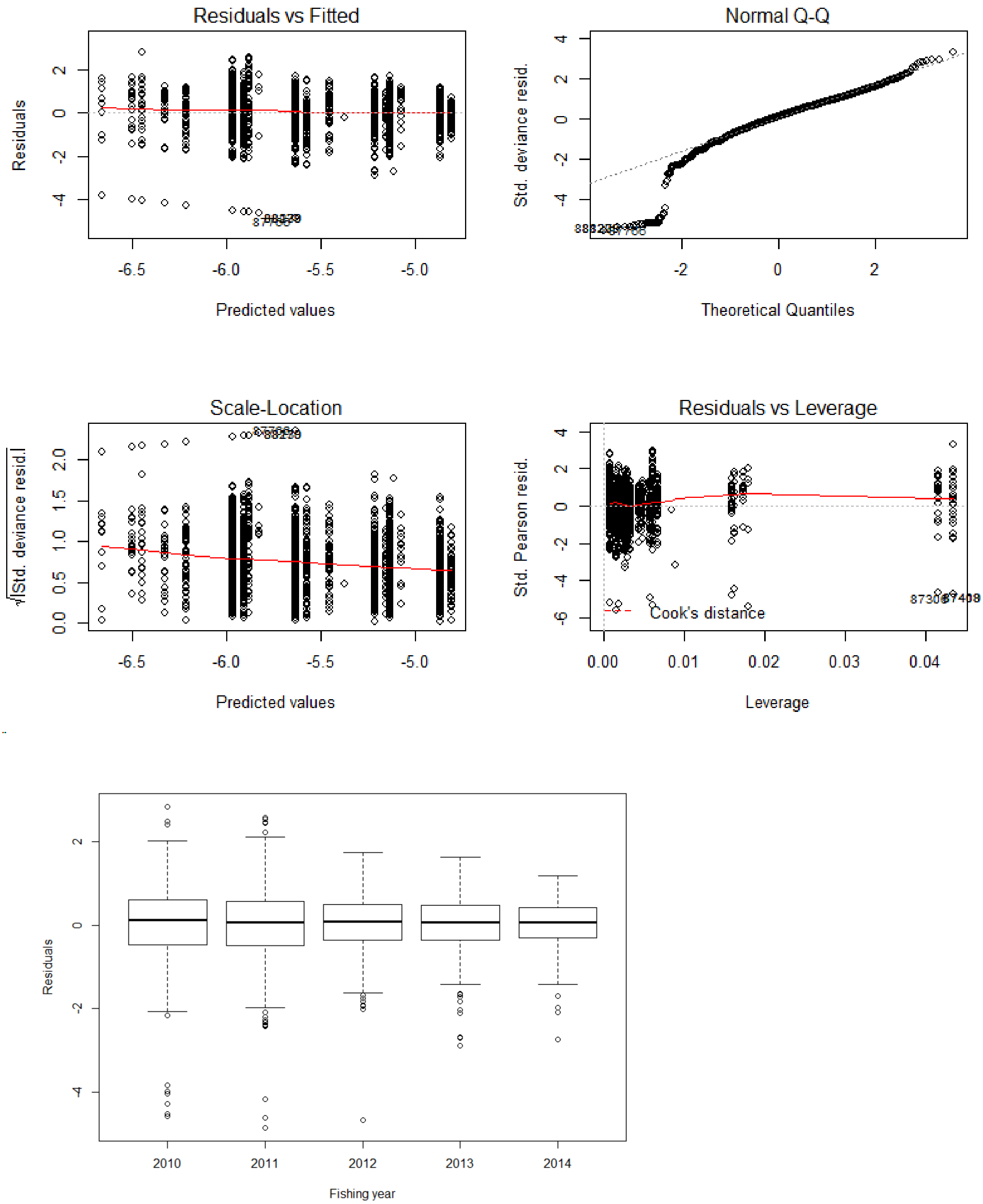
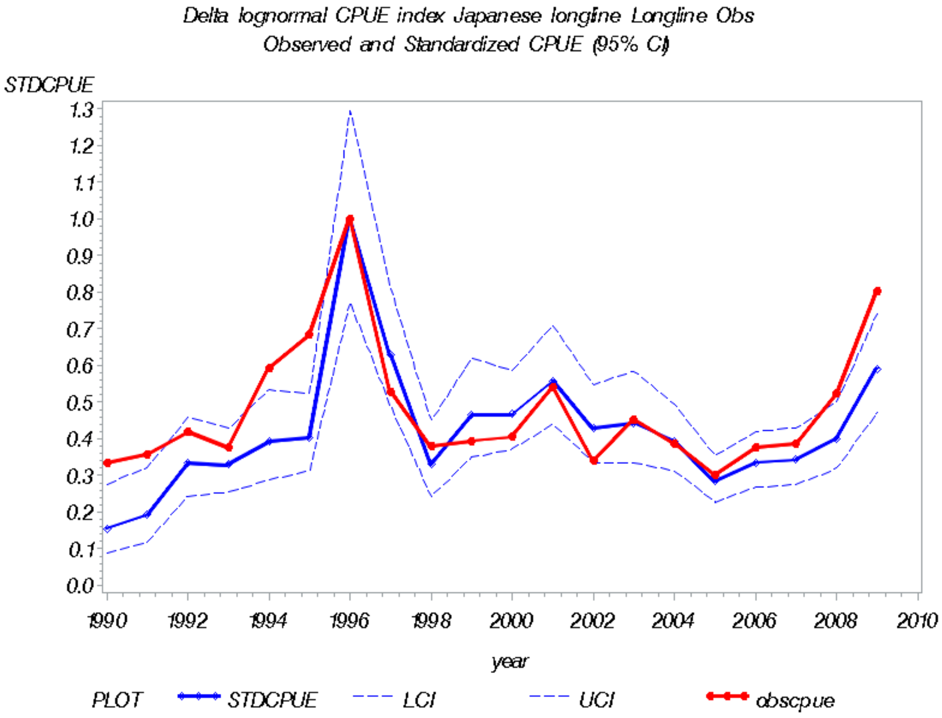


Figure 19. Model diagnostics (upper panel) and the yearly residual patterns (lower panel) of the CPUE in the period between 2010 and 2014FY.

Northeast Atlantic 1990-2009



Northeast Atlantic 2009-2014

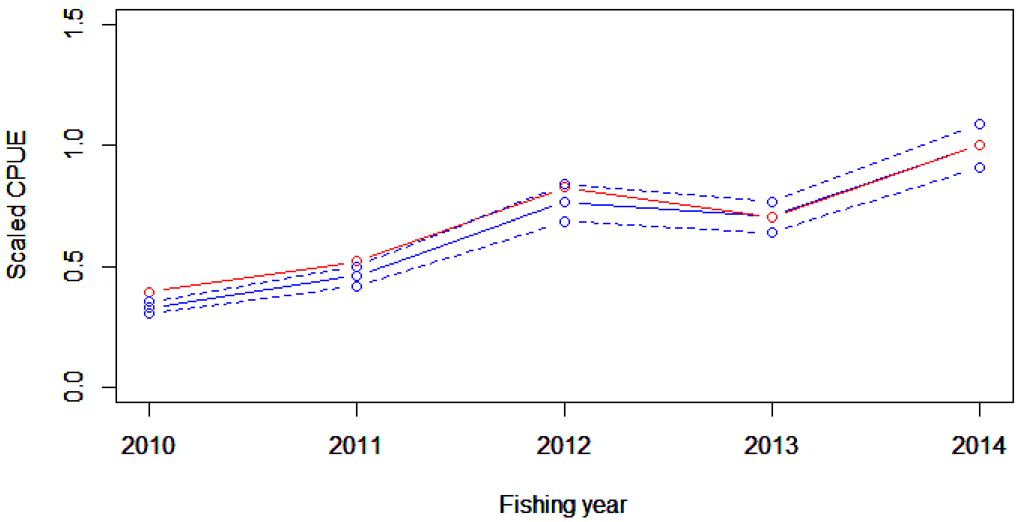


Figure 20. Standardized CPUE (blue line) with 95 percentile confidence intervals and nominal CPUE (red line) for the CPUE series for the Northeast Atlantic in the period between 1990 and 2009FY (Upper panel) and between 2010 and 2014FY (lower panel).