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LENGTH-WEIGHT RELATIONSHIP OF ATLANTIC BLUEFIN TUNA CAUGHT BY JAPANESE LONGLINE FISHERIES, BASED UPON JAPAN'S SCIENTIFIC OBSERVER PROGRAM DATA, 2000-2011

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SUMMARY

The length-weight relationship is one of key primary parameters for the stock assessment. The relationships of Atlantic bluefin tuna have been adopted for 30 years with a few descriptions, and a need to review conversions has been noted in the stock assessment. This study examined the length (straight fork length:SFL) and weight (processed and round) relationships by using scientific observer data collected through Japan's observer program between 2000 and 2011. Various models by MCMCglmm were applied to search statistical best models with the optimal separation of seasons. This study finally provided that simple equations to estimate weight from SFL: processed weight=4.2300 x 10^{-5} x $SFL^{2.821755}$, round weight=5.0704 x 10^{-5} x $SFL^{2.812287}$. The similar results were obtained compared to those of existing studies for this species. This study specialized for the Japanese longline fishery, and this would provide more accurate length composition because the processed weight of all of the individual bluefin tuna caught by the fishery have been collected since 2008. The accuracy would be helpful when more complex integrated stock assessment methods apply to Atlantic bluefin tuna.

RÉSUMÉ

La relation longueur-poids est l'un des principaux paramètres pour l'évaluation des stocks. Les relations du thon rouge de l'Atlantique ont été adoptées il y a 30 ans avec quelques descriptions et l'on a constaté dans l'évaluation des stocks la nécessité de passer en revue les conversions. La présente étude a examiné les relations de taille (longueur droite à la fourche : SFL) et de poids (manipulé et vif) à l'aide des données d'observateurs scientifiques recueillies dans le cadre du programme d'observateurs japonais mené entre 2000 et 2011. Divers modèles par MCMCglmm ont été appliqués afin de rechercher les meilleurs modèles statistiques avec la séparation optimale de saisons. Cette étude a finalement fourni cette simple équation pour estimer le poids à partir de la SFL : poids manipulé=4,2300 x 10-5 x SFL2.821755, poids vif=5,0704 x 10-5 x SFL2.812287. Des résultats similaires ont été obtenus par rapport à ceux d'études existantes réalisées pour cette espèce. Cette étude s'est concentrée sur la pêcherie palangrière japonaise et ceci fournirait une composition des tailles plus précise étant donné que le poids manipulé de tous les thons rouges capturés par la pêcherie est recueilli depuis 2008. La précision sera utile lorsque des méthodes d'évaluation des stocks intégrées plus complexes seront appliquées au thon rouge de l'Atlantique.

RESUMEN

La relación talla-peso es uno de los principales parámetros clave de la evaluación de stock. Las relaciones del atún rojo del Atlántico han sido adoptadas hace 30 años con pocas descripciones y en la evaluación de stock se indicó la necesidad de revisar las conversiones. Este estudio examinó las relaciones de talla (longitud recta a la horquilla: SFL) y peso (procesado y vivo) utilizando los datos de observadores científicos recopilados en el programa de observadores de Japón entre 2000 y 2011. Se aplicaron varios modelos mediante MCMCglmm para buscar mejores modelos estadísticos con la separación óptima de temporadas. Este estudio facilitó finalmente estas simples ecuaciones para estimar el peso a partir de SFL: peso procesado =4.2300 x 10-5 x SFL2.821755, peso vivo=5.0704 x 10-5 x SFL2.812287. Se obtuvieron resultados similares en comparación con los de estudios existentes para esta especie. Este estudio se ha centrado en la pesquería de palangre japonesa y esto proporcionaría una composición por tallas más precisa, porque desde 2008 se ha recopilado el peso procesado de todos los ejemplares de atún rojo capturados por la pesquería. Esta precisión sería útil al aplicar al atún rojo del Atlántico métodos de evaluación de stock integrados más complejos.

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KEYWORDS

Bluefin tuna, Conversion factor, Length-weight relationship, Longline fishery, MCMCglmm, Scientific observer

1. Introduction

Japanese longline fishery targeting Atlantic bluefin tuna have been widely conducted in the entire Atlantic Ocean since the 1960s (Kimoto *et al*., 2010 and 2012). This temporal/spatial wide coverage of this fishery makes the information important in providing abundance indices and catch amount for the stock assessment of this species. The Japanese longline fishery has been still one of main fisheries for Atlantic bluefin tuna with some allocations (17.64% in the west of 45°W, and 8.5% in the east of 45°W for the 2013 national quota; ICCAT 2012a), however the fishing patterns and area of fishing for bluefin changed and/or shrank substantially in recent years, due to the introduction of IQ (individual vessels quota) system and limited entry system to the Japanese longline vessels (Japan, 2012).

Japan has continuously conducted its national scientific observer program on Japanese tuna longline vessels in the Atlantic Ocean since 1995, and this program have played a major role in response to the recommendations made by ICCAT since 1996 (Japan, 2012). Various detailed and correct data have been collected through the observer program, and that includes vessel attributes, gear configuration, species identification, biological sampling and various measurements on all observed catches. In total, the scientific observers were monitored about 6,000 operations (more than 130 cruises) on Japanese tuna longline vessels in the entire Atlantic Ocean between 1995 and 2011 (Matsumoto and Miyabe, 1997, 1998, 1999, 2000, 2001; Matsumoto *et al.*, 2002, 2003, 2004, 2005; Matsumoto, 2006; Semba, *et al*. 2007, 2008; Japan, 2011b, 2012).

ICCAT SCRS has conducted the stock assessment of Atlantic bluefin tuna with ADAPT VPA (Gavaris 1988, as implemented in VPA-2box) for many years. The most recent assessment was conducted in 2012. It was mentioned in 2012 that the next assessment for bluefin tuna, which will employ new methods and new information, was scheduled for 2015 (ICCAT, 2012b). In the next few years, a move to a statistical assessment model (e.g., MAST, Taylor *et al*., 2011; Stock Synthesis, Methot, 2000; Multifan-CL, Fournier *et al.* 1990) is warranted (Rosenberg *et al*., 2012). For fish stock assessment methods such as VPA or any integrated models, the total number of individuals caught by age and/or size group is required (Sparre, 2000). Therefore, the role of size data (i.e. length composition) becomes more important in the stock assessment.

In order to determine catch-at-size for a fishery, length-weight relationship is routinely used for the stock assessment (Wigley *et al*., 2003). Currently the relationship for Atlantic bluefin tuna is available for both in the east and west of 45°W in management areas. The seasonal length-weight relationship for the west Atlantic bluefin tuna (Parrack and Phares, 1979) has been applied, while the relationship for any seasons in the east Atlantic (Rey and Cort, Unpublished) and in the Mediterranean Sea (Arena, Unpublished) have been adopted separately for the east Atlantic bluefin tuna (ICCAT, 1984). Especially for the west Atlantic, a need to review conversions has been noted since the stock assessment report in 2008 (ICCAT 2009, 2011, 2012c), because the trend of declining condition was implied in southern Gulf of St. Lawrence and the Gulf of Maine (ICCAT,2007; Neilson *et al*., 2009).

Therefore this study reanalyzed the length-weight relationship of Atlantic bluefin tuna, which is one of key essential parameters for the stock assessment. New relationships using the accumulated data collected through Japan's observer program between 2000 and 2011 were provided to diminish the uncertainties in the stock assessment of this species.

2. Materials

This study utilized the accumulated scientific observer data compiled by National Research Institute of Far Seas Fisheries, Japan, for 12 years between 2000 and 2011, where the size information of Atlantic bluefin tuna measured were available. These data contains lengths and weights of individuals with the captured date, location, and vessel name. The scientific observers measured the straight fork length (SFL), which is the straight line from the end of the upper jaw (end of the snout) to the posterior of the shortest caudal ray. The processed or round weight (GWT or RWT) was measured and the processed fish is the gulled, gutted, and tailed. The number of fish measured both its SFL and GWT was 12,932, whereas 2,690 individuals were measured both SFL and RWT (**Table 1**). The sex information was available in about 95% of each data set. The individuals were ranging from 70 to 290cm in SFL and from 7 to 400kg in weight. The individuals ranged from 100 to 235 cm were observed in the 95% of data. The data in March (65 data points) were combined into those in February, and the data between April and June were removed from the analysis due to the small number of data set (0.5% of data set).

3. Methods

To obtain the SFL and GWT relationship, several factors and models were considered using the MCMCglmm package (Hadfield, 2010) in R 2.15.3. The equation of full model is followed;

MCMCglmm(log(GWT)~log(SFL)*(as.factor(se)+as.factor(area)+as.factor(sex))

+random effects(year, ves)+ Gaussian error term)

, where *se* is season, and *ves* is vessel name. Year and vessel name were considered as the random intercepts. All models used the data with sex information (95% of all data set), and were compared and selected using the deviance information criterion (DIC). The burnin was set to be 5,000 in 15,000 iterations, and the result was recorded once every 10 iterations. The median and 95% confidence interval were calculated using the recorded 1,000 iterations.

In the preliminary analyses, optimal area stratification and season separation were sought among all possible combinations. For the area stratification, 2 seasons (December-March, and August-November) were tentatively set based on the locations of each operation. The adequate split in latitude (30°N-60°N) or longitude (15°W-75°W) which had the smallest DIC in the full model were sought. For the season separation, the area stratification with the ICCAT current management boundary: 45°W was considered, and the smallest DIC in the full model were also sought with 2, 3, and 4 seasons.

Based on the preliminary analyses, the statistically suitable model was selected with two areas (east or west of 45°W) and 2 seasons (December-March, and August-November) from various different models (**Table 4**).

After considerations, this study concluded the following simple equation to estimate processed weight from length in a practical manner.

MCMCglmm(log(GWT)~log(SFL)+random effects(year, ves)+ Gaussian error term)

The coefficients were also calculated using the following equations to estimate length from processed weight.

MCMCglmm(log(SFL)~log(GWT)+random effects(year, ves)+ Gaussian error term)

This study also checked the SFL and RWT relationship with the same observer data using the same final model setting as processed weight.

MCMCglmm(log(RWT)~log(SFL)+random effects(year, ves)+ Gaussian error term)

MCMCglmm(log(SFL)~log(RWT)+random effects(year, ves)+ Gaussian error term)

Finally, the SFL and RWT relationships were compared among this studies (SFL-GWT and SFL-RWT relationships) and current ICCAT equations for the East Atlantic (ICCAT, 1984) and for the West Atlantic (Parrack and Phares, 1979) in any season. The relationship was further compared to Rodriguez-Roda (1964). The conversion factor 1.16 (ICCAT, 2006-2013) was used to estimate RWT from GWT. Coefficients (a and b) in the final models were expressed by the equation: Weight = a*Length^b, or Length = a*Weight^b.

4. Results

A number of lengths (straight fork length) and weights (processed or round weight) measured by the scientific observers for 12 years between 2000 and 2011 were used for this study (**Table 1**). The data have been collected in the most of fishing areas for Japanese longliners. Fishing season for Japanese longliners for bluefin usually starts in August in the Northeast Atlantic Area. The fishing area in the East Atlantic shifts towards west in Oct-Dec, 40°-60°N, and in January, around 45°N (Kimoto *et al*., 2012). Thus, the lengths and weights were measured on board mainly off Iceland in October and November (**Table 1** and **Figure 1**).

In the preliminary analyses, the optimal area stratification and season separation were sought. Although the smallest DIC was obtained when the area was divided with 20°W (**Table 2**), the number of data set in December-March in the east of 20°W became very small (5 data points). Instead of the area stratification with the smallest DIC method, the ICCAT current management boundary: 45°W was considered for further analyses. For the season separation, it was found that smaller DIC was obtained by increasing the number of season separations (ns, **Table 3**). The smaller DIC was obtained with 3 or 4 seasons (ns=3 or 4), but the number of data set in the west of 45°W was also biased. Thus, this study considered that the optimal season was divided into December-March, and August-November (2 seasons) for further analyses.

Following the results of the preliminary analyses, the statistically best model was selected with 2 areas (east or west of 45°W) and 2 seasons (December-March, and August-November), and the full model was chosen with the smallest DIC (**Table 4**). The estimated SFL and GWT relationships by season, area, and sex were shown in **Figure 2.** Similar relationships were obtained regardless of season, area, and sex. The differences of estimated GWT with a particular length among predicted relationships mostly were less than 3kg, which could be considered as measurement errors. Though the estimated GWT with over 250cm in December-March were slightly larger than those in August-November, this also would be considered as observation errors due to its small number of data set over 250cm in both seasons (1.4% of data in Dec-Mar, and 0.7% of data in Aug-Sep). The differences of estimated GWT between seasons were 4-8kg at 250cm.

Because the statistically best model showed the similar relationships among season, area, and sex, this study concluded to use the simple equation between SFL and GWT with only random effects (year and vessel name) to estimate the GWT from a particular SFL in a practical manner. The estimated parameters were available in **Tables 5** and **6,** and the relationship was shown in **Figure 3**. The predicted GWT with the simple equation was 19, 58, 132, and 247kg at 100, 150, 200, and 250cm, respectively. The 95% confidence interval obviously was wider at large individuals. The traces and densities of Intercept and ln(SFL) were provided in **Figure 4** for the final model of SFL-GWT relationship.

This study also provided SFL and RWT relationship, and compared the estimated SFL and GWT relationships multiplied 1.16 conversion factor. The estimated parameters were available in **Table 5**, and the traces and densities of Intercept and ln(SFL) for SFL-RWT relationship were provided in **Figure 6**. Similar formulas were obtained between two relationships (**Figure 5**). The 95% confidence interval became wider in SFL and RWT relationship than those in SFL and GWT relationship multiplied 1.16. These relationships were also compared to the existing studies included the current ICCAT equations (**Figure 7).** The relationships obtained in this study appeared similar to one by Rodriguez-Roda (1964), and to one in the west Atlantic (any season) at the SFL below 200cm. The ICCAT equation in the west Atlantic predicted larger round weight at the length over 200cm than those of this study. The smaller round weight in the entire range of length were observed by using ICCAT equation in the east Atlantic compared to this study.

5. Discussions

This study reanalyzed the length-weight relationship of Atlantic bluefin tuna, which is one of key parameters for the stock assessment, with the accumulated data measured by Japan's scientific observers. Our observer data widely covers its temporal/spatial distribution of Atlantic bluefin tuna in the entire Atlantic. These data fully reflected Japanese longline fishery targeting this species. Compared to other studies, this study contained a number of individuals measured in the recent 12 years, and widely covered the fish between 100 and 300cm in any seasons except the spawning period. The broad-ranging length was corresponded to ages between 3 and about 30 applying the von Bertalanffy growth curves (Restrepo *et al.*, 2011; Cort, 1991). This study achieved a comprehensive understanding of the length-weight relationship in their feeding period.

The length-weight relationships were compared between this study and the existing studies, and mostly similar results were obtained in this study. This study was close to Rodriguez-Roda (1964), and it was mainly because their samples (N= 326, 130-249 cm) were post-spawning with the similar size range and were come from the Spanish traps in the Straits of Gibraltar which caught the fish moved from east to west in July and August. On the other hand, the equation by Rey and Cort (unpublished) in ICCAT (1984), which has been presently adopted in the stock assessment, estimated smaller weight than this study. Though some information was restricted for comparison, the differences were about 15 and 25kg in RWT at 200 and 250cm in SFL, respectively.

This study was also similar to the length-weight relationship in the west Atlantic (Parrack and Phares, 1979) for the length below 200cm. The sampling areas possibly were overlapped because they analyzed mark-recapture data collected by the U.S.A. from 1974-1977 (N=3545 in May-Oct, 20-372cm, and 2-545kg). However the sampling seasons were slightly overlapped (September and October), and this might cause the differences of the relationships. Given these results, it is suggested that the length-weight relationships both in the east and west Atlantic for the current stock assessment were reviewed.

This study specialized for the Japanese longline fishery. The data depended on its fishing grounds, and the most of fish were measured the processed weight. The scientific observers measured Atlantic bluefin tuna mainly in between September and December (mostly in October and November) in the east Atlantic, whereas they were in December and January in the west Atlantic. This study does not provide the relationship in all distributional areas, seasons, and sizes of Atlantic bluefin tuna, especially in spawning seasons and in the Mediterranean Sea.

The size data for bluefin tuna caught by the Japanese longline fishery have been fully improved since 2008. Since August 2008, Fishery Agency of Japan has started to tag (for identification) and collect the processed weight of all of the individual bluefin tuna caught by the Japanese longliners (Japan, 2011a), which achieved 100% coverage of size of the recaptures in weight. Utilizing the outcome of this study, processed weight of all products caught by Japanese longliners would be converted into length. More accurate length composition of this fishery would contribute to the improvement of the stock assessment. Furthermore, age-specific abundance indices of this fishery possibly would be available with accumulating these data.

In this study, the conversion factor 1.16 from processed weight to round weight was chosen to compare SFL-GWT and SFL-RWT relationships. The comparison between the two relationships in this study showed similar results, while there were small differences (5kg at 250cm). More precise conversion factor would be available when the round and processed weight relationship was examined. In a practical manner, this study implied that 1.16 would be reasonable for the conversion factor.

Currently, in the stock assessment of Atlantic bluefin tuna, catch at size and catch at age have been generating for VPA (ICCAT, 2012c). There remained uncertainties in this process, while the catch at size for several fisheries was raised by the method agreed by the working group with its small coverage of size samples. Since 2008, the size information has been improved for the Japanese longline fishery, and the more precise catch at size by using the result of this study would be provided in near future. The similar exercises in the length-weight relationship for other fisheries are encouraged, while improving the size information. When one applies this study to other fishery, it is suggested to check a detail on the data beforehand, especially needs a caution that this study did not include the spawning seasons.

This study provided the length-weight relationships of Atlantic bluefin tuna specialized for Japanese longline fishery. This study fully covered the fishing grounds and its seasons, and could estimate more accurate length composition for the fishery. These accuracies would be helpful when more complex integrated stock assessment methods apply to Atlantic bluefin tuna. This study provided various analysis methods, which would be also helpful for other fisheries.

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Table 1. The number of fish measured both straight fork length and processed weight, or straight fork length and round weight with the range of the length (cm) by month, area (east or west of 45°W), and sex (Male:M, or Female:F). March was combined into February.

	Length and Processed weight						Length and Round weight					
	East of 45°W			West of 45°W			East of 45°W			West of 45°W		
Month	Total	(M,F)	length	Total	(M,F)	length	Total	(M,F)	length	Total	(M,F)	length
Jan	93	(54,31)	94-235	1327	(696,555)	77-288	25	(4,6)	66-185	506	(238,176)	77-275
Feb-Mar	0	-	-	610	(205,125)	91-250	0	-	-	48	(27,15)	91-230
Aug	34	(19,14)	121-260	0	-	-	21	(15,6)	167-242	0	-	-
Sep	814	(469,336)	140-263	107	(83,21)	174-289	371	(224,146)	140-245	0	-	-
Oct	4703	(2616,2045)	104-269	59	(46,11)	165-278	966	(533,430)	114-250	6	(3,3)	165-278
Nov	3562	(1900,1591)	73-281	174	(114,52)	96-263	450	(255,184)	71-271	24	(16,6)	67-263
Dec	693	(367,313)	75-280	756	(423,282)	103-275	68	(41,22)	71-233	205	(100,97)	70-263

Table 2. Preliminary analysis of searching optimal area stratification by considering two-area separation with several splits in the North Atlantic Ocean. The DIC value and the number of data set by area and season.

		East of the split		West of the split	
Split	DIC	Dec-Mar	Aug-Nov	Dec-Mar	Aug-Nov
75W	-19750.44	3024	9317	27	0
70W	-19849.68	2376	9314	675	3
65W	-19760.40	2289	9313	762	4
60W	-19756.62	2241	9313	810	4
55W	-19745.08	1848	9313	1203	4
50W	-19760.88	1466	9168	1585	149
45W	-19750.09	765	8990	2286	327
40W	-19753.89	414	8578	2637	739
35W	-19764.26	325	8255	2726	1062
30W	-19840.58	285	7264	2766	2053
25W	-19853.79	150	5563	2901	3754
20W	-19885.88	5	3204	3046	6113
15W	-19756.25	0	189	3051	9128

		North of the split		South of the split	
Split	DIC	Dec-Mar	Aug-Nov	Dec-Mar	Aug-Nov
30N	-19794.61	2471	9317	580	0
35N	-19835.90	2359	9313	692	4
40N	-19759.19	2289	9313	762	4
45N	-19746.83	915	9054	2136	263
50N	-19758.73	114	8359	2937	958
55N	-19821.44	7	5464	3044	3853
60N	-19753.64	0	259	3051	9058

Table 3. Preliminary analysis of searching optimal season separation with two areas (east or west of 45°W). The DIC value and the number of data set by area and season were shown with two, three, four seasons (ns=2, 3, 4).

						Number of data in the east of 45°W				Number of data in the west of 45°W			
ns	Season1	Season2	Season3	Season4	DIC	Season1	Season2	Season3	Season4	Season1	Season2	Season3	Season4
2	Jan	Mar-Dec	-	-	-19643.74	85	9670	-	-	1251	1362	-	-
2	Jan-Mar	Aug-Dec	-	-	-19695.04	85	9670	-	-	1581	1032	-	-
2	Jan-Aug	Sep-Dec	-	-	-19692.13	118	9637	-	-	1581	1032	-	-
2	Jan-Sep	Oct-Dec	-	-	-19675.76	923	8832	-	-	1685	928	-	-
2	Jan-Oct	Nov-Dec	-	-	-19669.09	5584	4171	-	-	1742	871	-	-
2	Jan-Nov	Dec	-	-	-19676.01	9075	680	-	-	1908	705	-	-
2	Aug-Jan	Feb-Mar	-	-	-19668.86	9755	0	-	-	2283	330	-	-
2	Sep-Jan	Feb-Aug	-	-	-19667.46	9722	33	-	-	2283	330	-	-
2	Oct-Jan	Feb-Sep	-	-	-19663.74	8917	838	-	-	2179	434	-	-
2	Nov-Jan	Feb-Oct	-	-	-19686.39	4256	5499	-	-	2122	491	-	-
2	Dec-Jan	Feb-Nov	-	-	-19657.02	765	8990	-	-	1956	657	-	-
2	Sep-Mar	Aug	-	-	-19623.19	9722	33	-	-	2613	0	-	-
2	Oct-Mar	Aug-Sep	-	-	-19636.10	8917	838	-	-	2509	104	-	-
2	Nov-Mar	Aug-Oct	-	-	-19704.89	4256	5499	-	-	2452	161	-	-
2	Dec-Mar	Aug-Nov	-	-	-19749.96	765	8990	-	-	2286	327	-	-
2	Oct-Aug	Sep	-	-	-19632.81	8950	805	-	-	2509	104	-	-
2	Nov-Aug	Sep-Oct	-	-	-19698.92	4289	5466	-	-	2452	161	-	-
2	Dec-Aug	Sep-Nov	-	-	-19749.39	798	8957	-	-	2286	327	-	-
2	Nov-Sep	Oct	-	-	-19670.37	5094	4661	-	-	2556	57	-	-
2	Dec-Sep	Oct-Nov	-	-	-19746.12	1603	8152	-	-	2390	223	-	-
2	Dec-Oct	Nov	-	-	-19725.38	6264	3491	-	-	2447	166	-	-
3	Dec	Jan-Mar	Aug-Nov	-	-19783.99	680	85	8990	-	705	1581	327	-
3	Dec-Jan	Feb-Mar	Aug-Nov	-	-19791.15	765	0	8990	-	1956	330	327	-
3	Dec-Mar	Aug	Sep-Nov	-	-19748.59	765	33	8957	-	2286	0	327	-
3	Dec-Mar	Aug-Sep	Oct-Nov	-	-19761.63	765	838	8152	-	2286	104	223	-
3	Dec-Mar	Aug-Oct	Nov	-	-19811.85	765	5499	3491	-	2286	161	166	-
4	Dec	Jan-Mar	Aug-Oct	Nov	-19843.25	680	85	5499	3491	705	1581	161	166
4	Dec-Jan	Feb-Mar	Aug-Oct	Nov	-19852.30	765	0	5499	3491	1956	330	161	166
4	Dec-Mar	Aug	Sep-Oct	Nov	-19810.37	765	33	5466	3491	2286	0	161	166
4	Dec-Mar	Aug-Sep	Oct	Nov	-19817.97	765	838	4661	3491	2286	104	57	166

Table 4. Model selection: the DIC value in various models with two areas (east or west of 45°W) and two seasons (Dec-Mar, and Aug-Nov).

Model	DIC
ln(GWT)~ln(SFL)*(se +ew +sex)+random(yr,ves)	-19749.96
ln(GWT)~ln(SFL)*(se +sex)+random(yr,ves)	-19749.20
ln(GWT)~ln(SFL)*(ew +sex)+random(yr,ves)	-19623.88
ln(GWT)~ln(SFL)*(se +ew)+random(yr,ves)	-19746.79
ln(GWT)~ln(SFL)*(se)+random(yr,ves)	-19746.56
ln(GWT)~ln(SFL)*(ew)+random(yr,ves)	-19621.06
ln(GWT)~ln(SFL)*(sex)+random(yr,ves)	-19608.32

Table 5. Coefficients for straight fork length and weight relationships with the medians and the 95% confidence intervals for the intercept (a) and the slope (b). The standard equation is: Weight = a*Length^b, where weight and length are in kg and in cm, respectively.

	a			b			Reference
	median	95% confidence interval		median	95% confidence interval		
Processed weight	4.230E-05	3.878E-05	4.581E-05	2.821755	2.806536	2.837652	This study
Round weight	5.070E-05	4.498E-05	5.724E-05	2.812287	2.788670	2.835821	This study
West Atlantic (any season)	2.861E-05			2.929000			ICCAT,1984: Parrack and Phares, 1979
East Atlantic	2.950E-05			2.898958			ICCAT,1984: Rey and Cort, unpublished
Str. Gibraltar	0.000053			2.8			Rodriguez-Roda, 1964

Table 6. Coefficients for weight and straight fork length relationships with the medians and the 95% confidence intervals for the intercept (a) and the slope (b). The standard equation is: Length= a*Weight^b, where weight and straight fork length are in kg and in cm, respectively.

	a			b		
	median	95% confidence interval		median	95% confidence interval	
Processed weight	4.250E-05	4.153E-05	4.064E-05	2.823204	2.826021	2.828658
Round weight	5.119E-05	5.062E-05	6.036E-05	2.810061	2.813737	2.780217

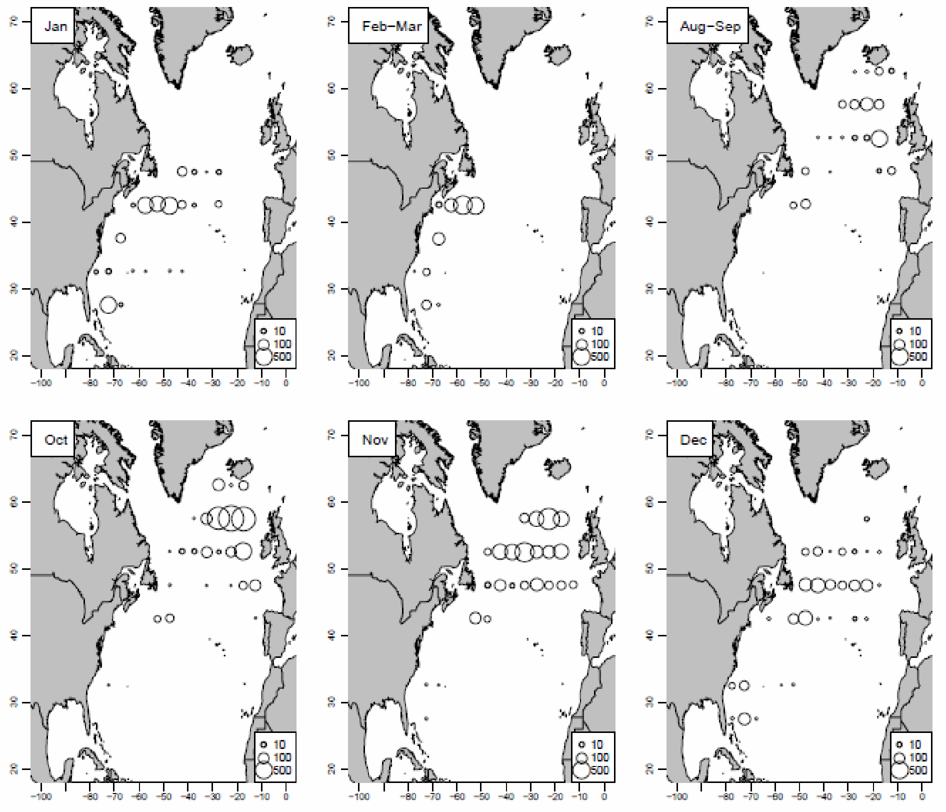

Figure 1. Monthly distributions of accumulative bluefin tuna in number by 5x5 degree area where straight fork length and weight were measured by scientific observes on Japanese longline vessels in the north Atlantic Ocean.

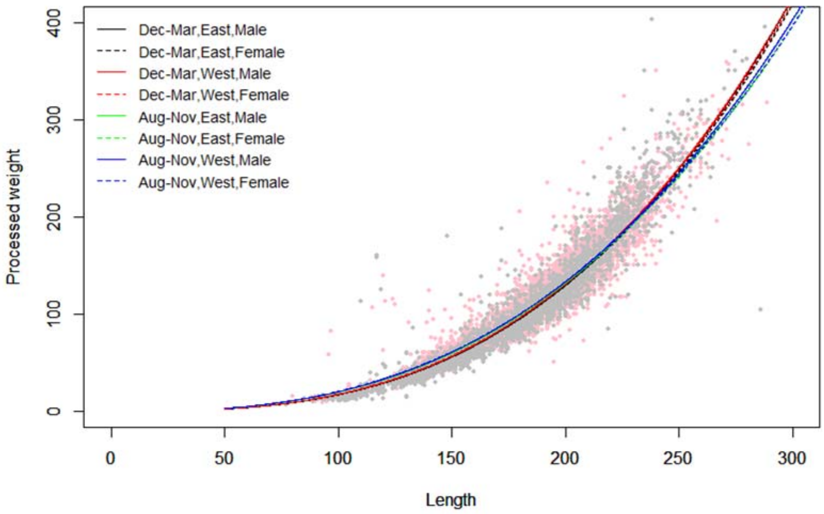

Figure 2. The straight fork length (cm) and processed weight (kg) relationship by area (east or west of 45°W), season (Dec-Mar, and Aug-Sep), and sex (male and female) of the statistical best model. Each observations in Dec-Mar and in Aug-Nov were colored as gray and pink, respectively.

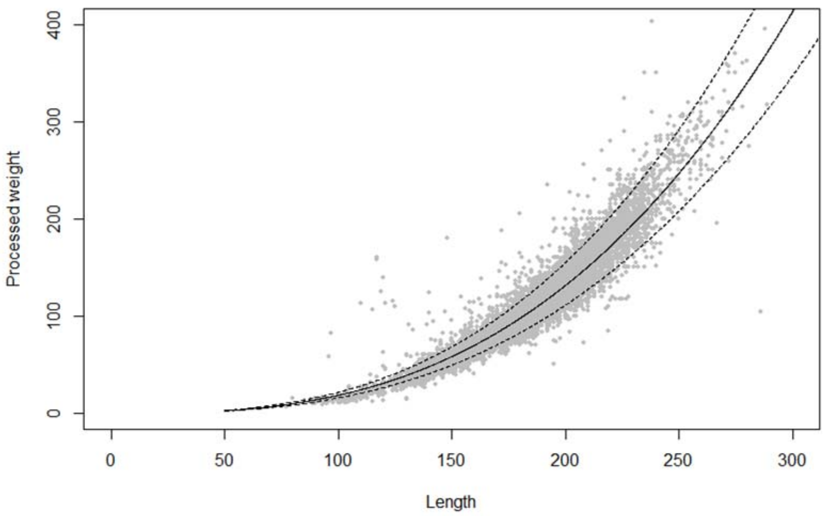

Figure 3. The final straight fork length (cm) and processed weight (kg) relationship with the 95% confidence interval.

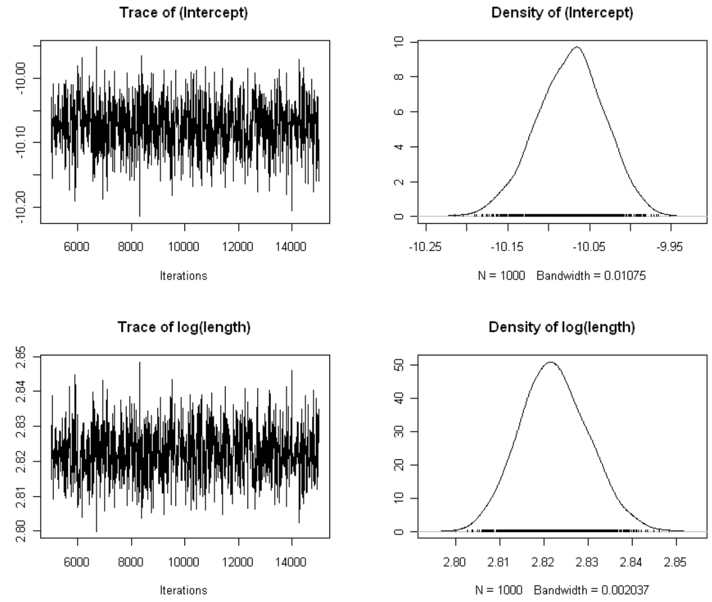

Figure 4. Traces and densities of Intercept and ln(SFL) for the final model of SFL-GWT relationship.

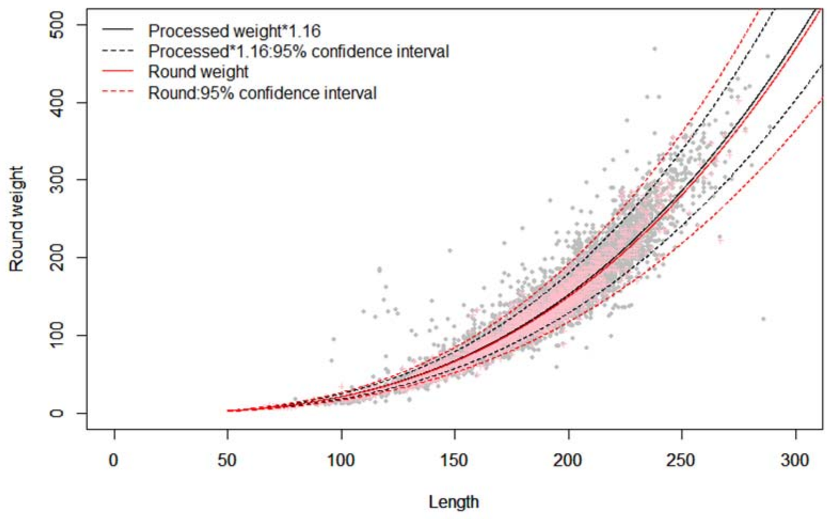

Figure 5. The comparison of straight fork length (cm) and round weight (kg) relationships with the 95% confidence interval. Black line and gray points show the final length and processed weight multiplied 1.16, and red line and pink points show the length (cm) and round weight (kg) relationship.

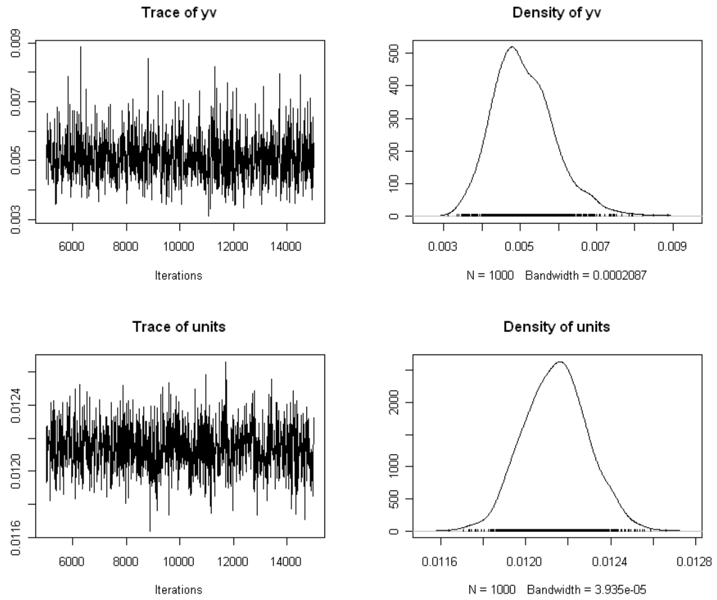

Figure 6. Traces and densities of Intercept and ln(SFL) for the final model of SFL-RWT relationship.

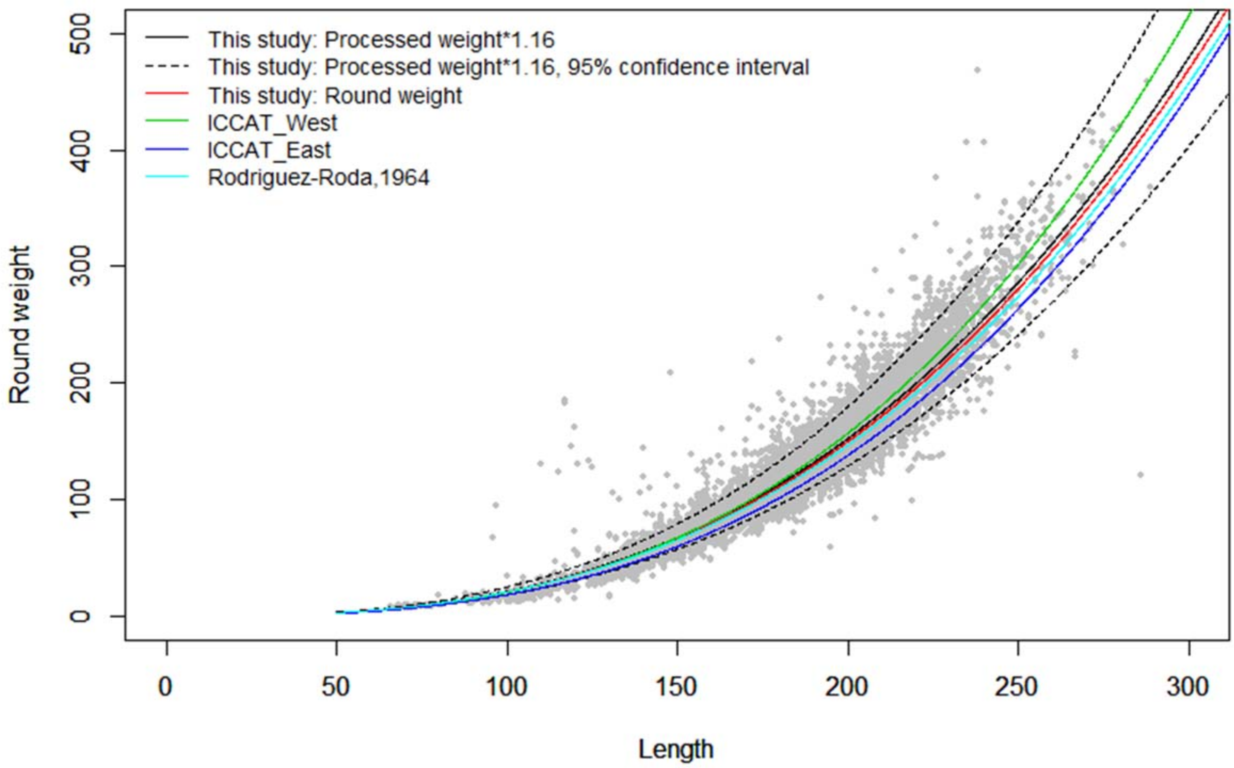

Figure 7. The comparison of straight fork length (cm) and round weight (kg) relationship between this study and the existing studies. Black solid, black dashed, red, green, blue, and sky-blue lines represent the final length and processed weight multiplied 1.16 in this study, its 95% confidence interval, ICCAT in the west Atlantic (Parrack and Phares, 1979), ICCAT in the east Atlantic (ICCAT, 1984), and Rodriguez-Roda (1964) relationships, respectively.