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SIZE-WEIGHT RELATIONSHIPS OF THE BIGEYE TUNA (*THUNNUS OBESUS*) FROM NORTH ATLANTIC AREAS USING LINEAR AND NON-LINEAR FITS

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SUMMARY

*Linear and non-linear fits of 1501 observations of size (FL cm) and live-weight (RW kg) of bigeye (*Thunnus obesus*) obtained in the NE Atlantic over recent years were tested. Results were compared among themselves and with those considered as a reference for this species-stock. The equations obtained from linear and non-linear fits ($RW=5.29919E^{-05} * FL^{2.8211264}$ and $RW=6.0568^{-05} * FL^{2.79379}$, respectively) showed a minor difference in predicting individual weight by size class. The non-linear fit parameters slightly increase the predicted mean weight of the whole sample in around +0.2% compared to the linear fit parameters suggesting that the type of fit would have a negligible impact on both the predictive individual mean weight and the whole sample mean weights. The comparison of results obtained with both types of fits versus the equation considered as a reference also showed minor differences in the estimated average individual weight from size. However, the average weight of the whole sample analysed would increase by over 4% in relation to that obtained when using the reference equation. A review of the literature on size-weight relationships for this species is also included suggesting a considerable diversity of results probably due to diverse factors that are discussed.*

RÉSUMÉ

*On a testé des ajustements linéaires et non linéaires de 1.501 observations de taille (cm FL) et de poids vif (RW kg) du thon obèse (*Thunnus obesus*) obtenues dans l'Atlantique Nord-Est au cours de ces dernières années. Les résultats ont été comparés entre eux et avec ceux considérés comme une référence pour cette espèce-stock. Les équations obtenues des ajustements linéaires et non linéaires (RW =5,29919E-05 * FL 2,8211264 et RW = 6,0568-05 * FL 2,79379, respectivement) ont montré une différence mineure dans la prédiction des poids individuels par classe de taille. Les paramètres des ajustements non linéaires augmentent légèrement le poids moyen prédit de la totalité de l'échantillon d'environ + 0,2 % par rapport aux paramètres des ajustements linéaires, ce qui suggère que le type d'ajustement aurait un impact négligeable sur le poids moyen individuel prédit et sur les poids moyens de l'ensemble de l'échantillon. La comparaison des résultats obtenus avec les deux types d'ajustements par rapport à l'équation considérée comme une référence a également montré des différences mineures dans l'estimation du poids individuel moyen à partir de la taille. Cependant, le poids moyen de l'ensemble de l'échantillon analysé augmenterait de plus de 4 % par rapport à celui obtenu lors de l'utilisation de l'équation de référence. Un examen des publications sur la relation taille-poids pour cette espèce est aussi inclus, ce qui suggère une diversité considérable des résultats probablement due à divers facteurs qui sont discutés.*

RESUMEN

*Ajustes lineales y no-lineales fueron ensayados con 1501 observaciones de talla (FL cm)-peso (RW kg) de atún patudo (*Thunnus obesus*) obtenidas en el Atlántico NE durante años recientes. Los resultados fueron comparados entre sí y con los aportados por otro autor considerados como referencia para esta especie-stock. Las ecuaciones obtenidas de ambos ajustes lineal y no-lineal ($RW=5.29919E^{-05} * FL^{2.8211264}$ y $RW=6.0568^{-05} * FL^{2.79379}$, respectivamente) mostraron una escasa diferencia en la predicción del peso individual por clase de talla. El ajuste no-lineal incrementaría levemente la estimación del peso medio del conjunto de esta muestra analizada en sólo un +0.2% en relación al peso medio obtenido usando los parámetros del ajuste lineal lo que sugiere que el tipo de ajuste tendría un impacto despreciable en la estimación del peso individual y del conjunto de la muestra. La comparación de los resultados obtenidos mediante ambos tipos de ajustes frente a la ecuación considerada como referencia*

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mostró diferencias menores en la estimación de peso medio individual a partir de la talla. Sin embargo, el peso medio del conjunto de la muestra analizada se incrementaría sobre un 4% en relación al obtenido usando la ecuación de referencia. Una revisión de la bibliografía disponible sobre relaciones talla-peso de esta especie sugiere una gran diversidad de resultados probablemente debida a factores diversos que son discutidos.

KEYWORDS

Bigeye tuna and Length-weight relationship

Introduction

Bigeye tuna (*Thunnus obesus*) is a highly migratory, epi-mesopelagic oceanic species that preferentially moves in tropical and subtropical waters in the Atlantic, Indian and Pacific oceans and, occasionally or seasonally, can reach temperature waters, either forming schools or, sporadically, even mixing some individuals with schools of other species such as albacore (*Thunnus alalunga*). The geographical limits of its distribution have been located between 55º-60ºN and 45º-50ºS, and it has been described as being absent in the Mediterranean Sea (Collette and Nauen 1983).

Its physiological characteristics allow it a highly active, swift swimming capacity, making use of a propulsion system characterized by a slight ondulating movement of the body and a swift oscillation of its caudal fin, typical of tunas and unique among the teleosts (Graham and Dickson 2004). Its behaviour of forming epipelagic banks during the initial stages of life make it susceptible to being caught especially by surface orientated fishing methods, which take advantage of its tendency to aggregate, forming banks.

Conversely, adult individuals may migrate vertically hundreds of metres, between day and night, until reaching depths at the tolerance limit of dissolved oxygen concentration. These large individuals are susceptible to being caught by deepwater longliners and, sporadically, by surface longliners. This species is classified under the category termed as "tropical tuna", which also includes yellowfin and skipjack tuna. Its large eyes relative to those in other tuna species, its sturdily-built body and the length of the pectoral fins are some of the more visible external morphological characteristics.

One of the larger tuna species, it can reach a larger size, along with yellowfin tuna and, in any case, after Bluefin tuna. Although its broad geographical distribution and its evolution as a species dates back millions of years, and therefore, it is to be expected that it would have been historically caught by indigenous-coastal living communities over the past few thousand years, it is believed that this species was described scientifically, for the first time, in the 19th century, based on observations made on the Isle of Madeira (Lowe 1839).

Evaluation and management involved accepting the hypothesis of a single stock for the entire Atlantic. But however, other possible alternatives should not be discarded (Anon. 2005[a]). Study of its biological parameters is highly beneficial for gaining knowledge of the species and population structure, as well as for the evaluation and management of the stock/s since it is also a valuable and highly appreciated fisheries resource on the international markets.

Size-weight relationship is an important biological parameter as it is involved in estimating average weight based on size and provides parameters for defining individual growth in weight. Therefore, this size-weight relationship has an impact on the resulting CAS-CAA matrices for the purposes of evaluation and exerts an influence in estimating the demographic-biomass distribution of the stock. Reducing any possible uncertainty regarding this parameter will contribute to reducing the uncertainty in the evaluations.

Size-weight relationship in bigeye tuna has been studied by numerous authors in the Atlantic (i.e. De Jaeger 1963, Morita 1973, Lenarz 1974, Choo 1976, Chur and Krasovskaya 1980, Parks *et al*. 1982, Lins-Oliveira *et al*. 2005, Song Liming *et al*. 2005, Xu *et al*. 2006, Chang *et al*. 2008, Zhu *et al*. 2009) in the Pacific (i.e. Iversen 1955, Ronquillo 1963, Kume and Shiohama 1964, Nakamura and Uchiyama 1966, Morita 1973, Sun *et al*. 2001, Wang *et al*. 2002, Zhu *et al*. 2008) and in the Indian Ocean (i.e. Morita 1973, Cort 1986, Poreeyanond 1994, Chantawong *et al*. 1999, Uchiyama and Kazama 2003, Zhu *et al*. 2008). Some of these works suggest that there could be significant differences between them due to the different fishing zones-seasons, gender, or due to other reasons such as the type of size-weight used, the availability of data in each study, the quality of the same or the analysis methods applied in each case, etc.

This work sets out to contribute to providing recent size-weight relationships in order to be able to compare them and regularly validate the relationships used in evaluating the Atlantic stock, as well as reviewing the status of the matter in view of the large number of relationships available, considering the recent recommendations by the Working Group in the ICCAT in this regard.

Material and methods

Samples of bigeye tuna (*Thunnus obesus*) were obtained from landings made in North Atlantic ports during years 2007-2014. Size data (FL cm) were measured with an ichthiometer to the nearest lower centimetre and its corresponding weight (kg live weight – RW) was recorded along with the landing date. Gender could not be identified since the individuals were marketed whole in live-round weight.

A preliminary analysis using GLM was conducted to test the significance and importance of the factors Ln (size), year and month, in order to explain variability in Ln (weight). The relationship between size and weight of the type RW= a*FL^ b was obtained by two different types of fit. An initial approximation by linear fit (linearization) based on the logarithmic transformation of the size and weight variables: Ln RW= Ln a + b * Ln FL, where "*a*" and "*b*" are the constants for establishing this linear relationship (Sparre and Venema 1997). A second approximation was conducted using a non-linear Gauss-Newton type model (Anon. 2009). The results obtained were compared between each other and with those obtained by other authors. Additionally, the quantitative impact of using one or other relationships was evaluated in order to estimate the average catch weight based on the size data available.

Results and discussion

A total of 1501 size-weight observations on bigeye tuna, on sizes 61-194 cm (weights 5-104 kg) were available for analysis, besides their year and month landing variables. **Tables 1** and **2** summarize the data available on size and weight for the analyses. The average size and average weight of the observations were 114 cm (Std.= 0.556) and 37 kg (Std.= 0.512), respectively. **Figure 1** shows the size distribution available for the analyses. The range of sizes analysed represents the most frequently observed sizes in bigeye catches for all the fishing methods as a whole (Anon. 2006).

Analysis by GLM indicated that the size variable is the most important significant factor in explaining weight variability in individuals. The year and month variables were not significant so that the fits were focused on years and months combined.

The model using a linear fit was highly significant and explained 98% of the weight variability in terms of size (**Table 3**). The resulting equation was: RW=5.29919E$^{\mathbf{-05}}$ * FL $^{\mathbf{2.8211264}}$. Bivariate lineal fit of the RW by FL and of the Ln RW by Ln FL -and their 95% confidence intervals- are presented (**Figure 2**). Residuals by predicted plot of Ln RW as well as actual by predicted plot of Ln RW are provided (**Figure 3)**. Residual normal quantile plot of Ln RW is also provided (**Figure 4**). All diagnostics achieved suggested high representativeness of this relationship to accurately predict weight from size within this size interval.

The resulting equation of the non-linear fit RW=6.0568E$^{\mathbf{-05}}$ * FL $^{\mathbf{2.79379}}$ (**Table 4, Figure 5**) slightly improved the linear fit, especially in the case of the large sizes that are poorly represented in the sample and that are less frequent in the catch. The value of the constants "*a*" and "*b*" obtained by linear fit would be outside the 95% confidence limit estimated by non-linear fit. But however, the impact of using one or another equation seems to be negligible to estimate the individual average weight by size class (**Figure 6**) and the average weight for the whole sample analysed. In the case of a sample with a size distribution such as that used in this analysis (**Figure 1**), non-linear fit would very slightly increase the estimate of the average weight of the whole sample in just +0.2% relative to that obtained when using the linear fit parameters. Furthermore, a comparison of the results obtained with both types of fit as opposed to the equation obtained by another author (Parks *et al*. 1981), considered as a reference for this stock-species (Anon. in press) suggests that the average weight of this sample as a whole would increase from 4.1% to 4.3% in the event of using the parameters obtained by linear and non-linear fit, respectively, in terms of the average weight obtained using the reference equation.

Size-weight relationships based on the linearization of the size and weight data are often criticized. But however, in this type of biometric relationship, linearization is a frequently proposed alternative as a good approximation when the samples available are truly representative of the sizes present in the catch. The results obtained in this study indicate that the fitting methods applied in this case had a marginal impact on the predicted mean individual weight from size data and also on the average weight of this whole size-sample considered. Furthermore, the predicted individual mean weights are also very similar to those obtained using the equation considered as reference for this species (Parks *et al*. 1981, Anon. in press). A slightly above mean weight (+4%) of the whole sample size-distribution is obtained when the new equations obtained are used.

The ICCAT bigeye Working Group has recently noted the importance of this type of length-weight contributions. The relationships provided in this paper cover an extended portion of the regularly reported full size spectrum of the bigeye tuna for gears combined. At the same time, nonlinear and linear fits of the length-weight relationships have been tested and compared with the relationship more regularly used for the assessment.

Additionally, a review of literature on size-weight relationships in this species was conducted (**Tables 5** and **6**). This review highlighted a considerable diversity of results between authors, which may be due to diverse factors. Among these, we underline the different quality of the raw data, the inclusion or exclusion of "outliers" values in the respective fits, the size-weight range used in each study, etc. In some of the studies, there is no clear definition – the definition is confusing – of the type of weight used in the fits, and in some cases there may be a confusion regarding the equations obtained from the total or round weight, gutted weight, gutted and gilled weight, dressed weight, etc. When such confusion is conveyed from one work to another, this has occasionally led to some inappropriate comparisons or to presenting comparative summaries without considering the type of weight used in each case. The different types of processing catches –when units other than live weight are used– may be an element that contributes to the diversity of relationships between authors. The different proportion of genders in the samples used - when there are tested significant differences between genders- may be another source of diversity in results. The range of sizes included in each study, particularly when fitting methods based on minimum squares are used, may be another source of discrepancy. Subsequent studies should incorporate more detailed descriptions of the type of size and weight used in each case and, in the event of using weights other than live weight, more detailed descriptions should be made on the preparation of the fish-product.

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Table 1. Number of observations, minimum, maximum and average values, standard and median error in the size observations (FL cm) obtained by year and for all the years combined.

Year	#Obs.	Min.	Max.	Mean	Std. Error	Median
2007	107	81	168	117	1.602	115
2008	24	71	178	107	5.179	104
2009	29	69	151	98	3.774	93
2010	47	87	165	119	2.236	121
2011	589	64	181	111	0.966	114
2012	8	61	108	91	5.925	93
2013	250	72	194	113	1.125	113
2014	447	65	179	121	0.971	120
Total	**1501**	**61**	**194**	**114**	**0.556**	**116**

Table 2. Number of observations, minimum, maximum and average values, standard and median error in the observations on live weight (RW kg) obtained by year and for all the years combined.

Year	#Obs.	Min.	Max.	Mean	Std. Error	Median
2007	107	11	109	37	1.480	33
2008	24	9	103	31	4.236	26
2009	29	8	68	24	2.534	20
2010	47	17	90	39	2.062	39
2011	589	6	131	36	0.857	34
2012	8	5	32	19	3.414	18
2013	250	8	140	35	1.104	34
2014	447	6	128	42	0.976	38
Total	**1501**	**5**	**140**	**37**	**0.512**	**35**

Table 3. Solution of the linear fit between pairs of values (logarithmized) size (FL cm) and weight (RW kg), variance analysis and estimation of the parameters obtained: $RW=5.29919E^{-05} * FL^{2.8211264}$.

Transformed Fit Log to Log

Ln (RW) = -9.845371 + 2.8211264*Ln (FL)

Summary of Fit	
RSquare	0.98193
RSquare Adj.	0.981918
Root Mean Square Error	0.073343
Mean of Response	3.479596
Observations	1501

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	438.17343	438.173	81456.13
Error	1499	8.06351	0.005379	**Prob > F**
C. Total	1500	446.23694		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-9.845371	0.046726	-210.7	<.0001*
Ln (FL)	2.8211264	0.009885	285.41	<.0001*
a=	**$5.29919E^{-05}$**			
b=	**2.8211264**			

Table 4. Solution of the non-linear fit between the pairs of values size (FL cm) and weight (RW kg), estimated parameters, confidence interval (95%) of the estimated parameters and correlation of the estimates: $RW=6.0568E^{-05} * FL^{2.793790}$

Non-linear solution

SSE	DFE	MSE	RMSE
15127.38139	1499	10.091649	3.1767355

Parameter	Estimate	Approx StdErr	Lower CL95%	Upper CL95%
a=	**$6.0568E^{-05}$**	$3.55E^{-06}$	$5.40E^{-05}$	$6.79E^{-05}$
b=	**2.79379045**	0.01196395	2.77034027	2.81727013

Solved by: Analytic Gauss-Newton

Correlation of Estimates

	a	b
a=	1	-0.9994
b=	-0.9994	1

Table 5. Compilation of some length-weight relationships in bigeye tuna (*Thunnus obesus*) for the Atlantic Ocean, observed in several studies. **RW**: live weight (**RW_f** : RW females, **RW_m**: RW males). **DW:** processed weight. **GW:** gilled and gutted weight. **?W:** type of weight not specified in the reference source (**$?W_f$** : ?W females, **$?W_m$**: ?W males). **DW(?):** carcass weight whose unit of weight is not specified in the reference source. **FL:** length from the tip of the snout to the fork of the tail. **OCKL:** (Operculum-Caudal Keel Length) from the distal edge of the operculum to the tip of the caudal keel. **?L:** type of length not specified in the reference source. N.B.: in Zu *et al*., 2009, there is an inconsistency in the range of total sizes and the range of size by gender that is not explained by the author.

ATLANTIC OCEAN

Length-Weight relationship	n	Size FL(cm)	Sampling area	Research-Source
$RW(kg) = 2.396 \times 10^{-5} \times FL(cm)^{2.9774}$	3,186	37-210	Eastern Atlantic (30ºN20ºS/30ºWCosta)	[2]Parks *et al.* 1982 (pooled-deleted)
$RW(kg) = 2.6472 \times 10^{-5} \times FL(cm)^{2.9400}$	253	-	Central Atlantic(high sea area) (12º50´N04º11´S/41º22´W15º30´W)	[1]Song Liming *et al.* 2005
$RW_f(kg) = 2.2590 \times 10^{-5} \times FL(cm)^{2.9724}$	81	92-196	Central Atlantic(high sea area) (12º50´N04º11´S/41º22´W15º30´W)	[1]Song Liming *et al.* 2005
$RW_m(kg) = 2.8164 \times 10^{-5} \times FL(cm)^{2.9275}$	172	93-199	Central Atlantic(high sea area) (12º50´N04º11´S/41º22´W15º30´W)	[1]Song Liming *et al.* 2005
$DW(?) = 4 \times 10^{-4} \times OCKL(cm)^{2.6205}$ $FL(cm) = (1.541 \times OCKL(cm)) + 8.2069$	1,760 270	73-179	North East Brazil (5º00´N5º44´S/27º01´W36º40´W)	[1]Lins-Oliveira *et al.* 2005
$RW(kg) = 3.376 \times 10^{-5} \times FL(cm)^{2.8813}$	1,772	50-206	Central Atlantic (1°18'N12º24'N/18º30'W41°12'W)	[1]Zhu *et al.* 2009
$RW_f(kg) = 2.601 \times 10^{-5} \times FL(cm)^{2.9362}$	741	90-189	Central Atlantic (1°18'N12º24'N/18º30'W41°12'W)	[1]Zhu *et al.* 2009
$RW_m(kg) = 3.926 \times 10^{-5} \times FL(cm)^{2.8495}$	1031	85-206	Central Atlantic (1°18'N12º24'N/18º30'W41°12'W)	[1]Zhu *et al.* 2009
$?W(kg) = 2.2606 \times 10^{-5} \times FL(cm)^{2.9885}$	489	98-147	Tropical Atlantic (7-11ºN/36-38ºW)	[1]Chur and Krasovskaya 1980
$?W(kg) = 1.8117 \times 10^{-5} \times FL(cm)^{3.0386}$	729	93-162	Tropical Atlantic (3ºN-2ºS/6-13ºW)	[1]Chur and Krasovskaya 1980
$?W(kg) = 1.8786 \times 10^{-5} \times FL(cm)^{2.9912}$	132	148-182	Tropical Atlantic (2-7ºS/2-10ºW)	[1]Chur and Krasovskaya 1980
$?W(kg) = 1.6029 \times 10^{-5} \times FL(cm)^{3.0242}$	413	133-167	Tropical Atlantic (0-4ºS/4-9ºW)	[1]Chur and Krasovskaya 1980
$RW\ kg = 1.2494 \times 10^{-5} \times FL(cm)^{3.12082}$	190	41-132	Eastern Atlantic	[1]Lenarz 1974
$DW(kg) = 2.5506 \times 10^{-5} \times FL(cm)^{2.8997}$	804	79-206	Western Central Atlantic (05º46'S09º35'N/18º30'W39º12'W)	[1]Xu et al. 2006
$GW(kg) = 1.766 \times 10^{-5} \times FL(cm)^{2.985}$	8,919	60-220	Tropical Atlantic	[1]Chang *et al*. 2008
$GW(kg) = 2.373 \times 10^{-5} \times FL(cm)^{2.932}$	54,173	60-220	Tropical Atlantic	[1]Chang *et al.* 2008
$?W_f(kg) = 5.8106 \times 10^{-5} \times ?L(cm)^{2.79}$			South Africa	[3]de Jaeger 1963
$?W_m(kg) = 8.24277 \times 10^{-5} \times ?L(cm)^{2.72}$			South Africa	[2] de Jaeger 1963
$?W(kg) = 4.454 \times 10^{-6} \times ?L(cm)^{3.31768}$		86.2-179.2	Eastern Atlantic (off Ivory Cost) (02ºN/07ºW near Abidjan)	[1]Choo 1976
$?W(kg) = 2.50577 \times 10^{-5} \times L??(cm)^{2.973242}$		50.2-175.5	Atlantic	[2]Morita 1973
$RW(kg)= 5.29919 \times 10^{-5} \times FL(cm)^{2.8211264}$	1,501	61-194	North East Atlantic	Present work Linear fit
$RW(kg)= 6.0568 \times 10^{-5} \times FL(cm)^{2.79379045}$	1,501	61-194	North East Atlantic	Present work Non-linear fit

Table 6. Compilation of some length-weight relationships in bigeye tuna (*Thunnus obesus*) for the Pacific and Indian oceans in several studies. **RW**: live weight (**RW_f** : RW females, **RW_m** : RW males). **?W:** type of weight not specified in the reference source. **FL:** length from the tip of the snout to the fork of the tail.

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Length-Weight relationship	*n*	*Size FL(cm)*	*Sampling area*	*Researcher-Source*
RW(kg) = 3.661x**10**$^{-5}$ x **FL(cm)**$^{2.90182}$	9,144	80-190	Central Pacific	[2]Nakamura y Uchiyama 1966
RW(kg) = **2.9537**x**10**$^{-5}$ x **FL(cm)**$^{2.9304}$			Central Pacific	[2]Iversen 1955
RW(kg) = 3.3263x**10**$^{-5}$ x **FL(cm)**$^{2.9180}$	1,832		Central Pacific	[2]Kume and Shiohama 1964
RW(kg) = 1.3504x**10**$^{-5}$ x **FL(cm)**$^{3.1056}$	4,121		Western North Pacific	[2]Kume and Shiohama 1964
RW(kg) = 1.7265x**10**$^{-5}$ x **FL(cm)**$^{3.0475}$	2,538		Western Equatorial Pacific	[2]Kume and Shiohama 1964
RW_m(kg) = 4.786x**10**$^{-5}$ x **FL(cm)**$^{2.94430}$	27	112-186	Philippines	[2]Ronquillo 1963
RW_f (kg) = 1.721x**10**$^{-5}$ x **FL(cm)**$^{2.74669}$	28	105-170	Philippines	[2]Ronquillo 1963
RW(kg) = **5.856**x**10**$^{-5}$ x **FL(cm)**$^{2.7884}$	428		Waters Taipei Chino	[1]Wang *et al.* 2002
?W (kg) = 3x**10**$^{-5}$ x **FL(cm)**$^{2.9278}$	856		Central Pacific	[1]Sun *et al.* 2001
RW(g) = 1.32x**10**$^{-2}$ x **FL(cm)**$^{3.043}$	1,436	60.0-202.0	Eastern Pacific	[1]Zhu *et al*. 2008
RW(kg) = 1.97308 x**10**$^{-5}$ x **FL(cm)**$^{3.024669}$	481	45.5-163.8	Western North Pacific	[2]Morita 1973
RW(kg) = 1.9793 x**10**$^{-5}$ x **FL(cm)**$^{3.0216}$	15	65.5-173.0	Eastern and Central Pacific	[2]Morita 1973
?W (kg) = 4.92194 x**10**$^{-5}$ x **FL(cm)**$^{2.832860}$		73.5-166.5	Indian Ocean	[2]Morita 1973
RW(kg) = 2.1681x**10**$^{-5}$ x **FL(cm)**$^{2.9968}$	2,707		Eastern Indian Ocean	[1]Chantawong *et al.* 1999
RW(g) = 2.47x**10**$^{-2}$ x **FL(cm)**$^{2.926}$	1,052	54.8-201.0	Indian Ocean	[1]Zhu *et al.* 2008
?W(kg) = 2.74x**10**$^{-5}$ x **FL(cm)**$^{2.951}$ FL *< 80 cm*			Indian Ocean	[2]Poreeyanond 1994
?W(kg) = 2.7x**10**$^{-5}$ x **FL(cm)**$^{2.9278}$ FL *< 80 cm*			Indian Ocean	[2]Cort 1986
RW(kg) = **2.77562**x**10**$^{-5}$ x **FL(cm)**$^{2.93652}$	62	48.4-166.1	Hawaii area	[1]Uchiyama and Kazama 2003

[1] Reference taken directly from the author's document.
[2] Reference taken from the document by another author.

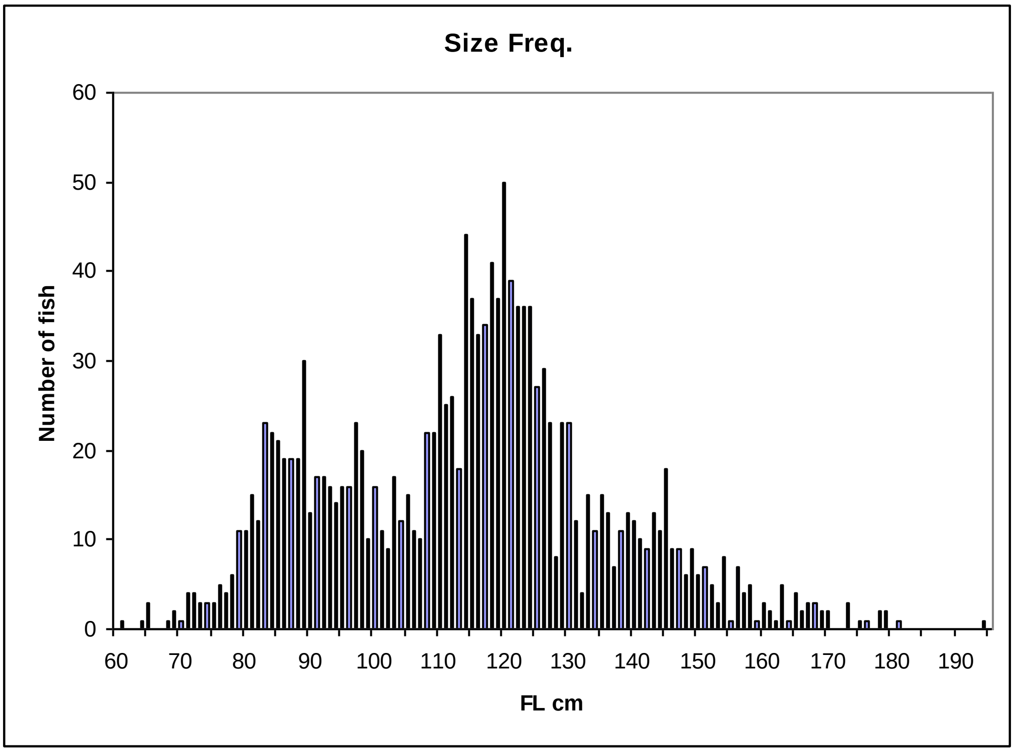

Figure 1. Size-frequency data used to obtain the length (FL cm) to round weight (RW kg) relationships of the Atlantic bigeye tuna.

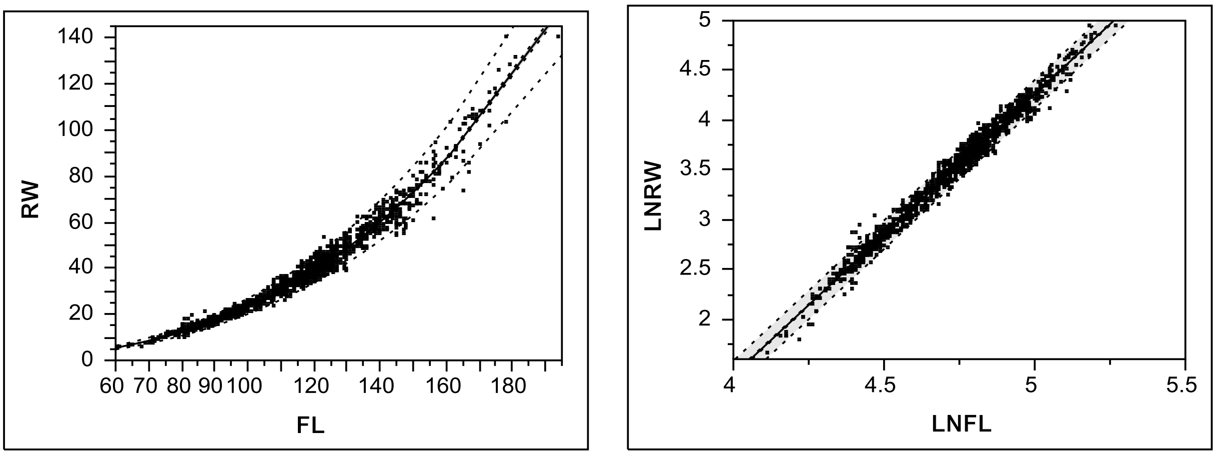

Figure 2. Bivariate lineal fit of the round weight (RW kg) by size (FL cm) –left panel- and bivariate fit of the Ln (RW) by Ln (FL) –right panel-, and 95% confidence intervals of the observations.

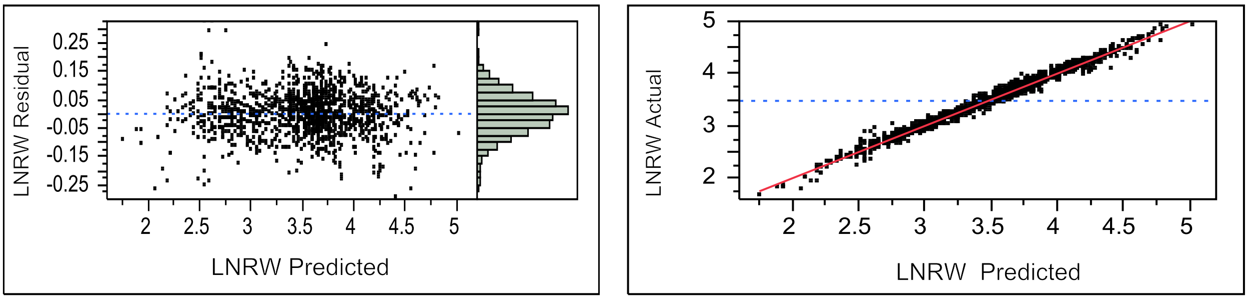

Figure 3. Residuals by predicted plot of Ln (RW) –left panel- and actual by predicted plot of Ln (RW) – right panel.

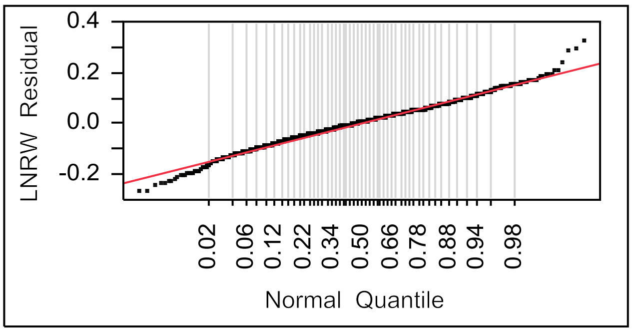

Figure 4. Residual normal quantile plot of Ln (RW).

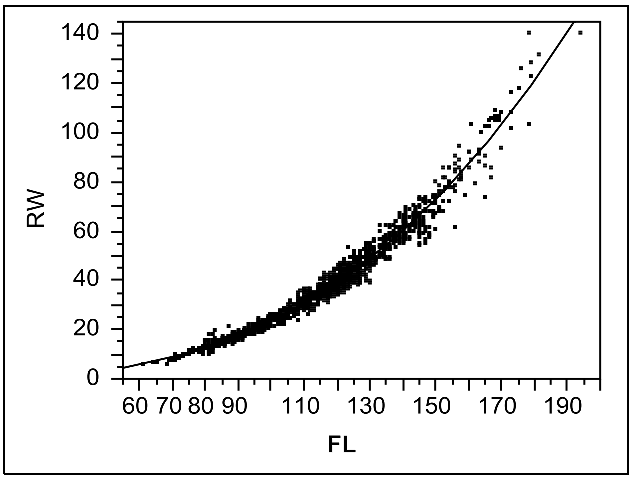

Figure 5. Plot of the non-lineal fit between the round weight (RW kg) by size (FL cm) -see table 3 for additional information-: RW= $6.0568E^{-05}$ * FL $^{2.793790}$.

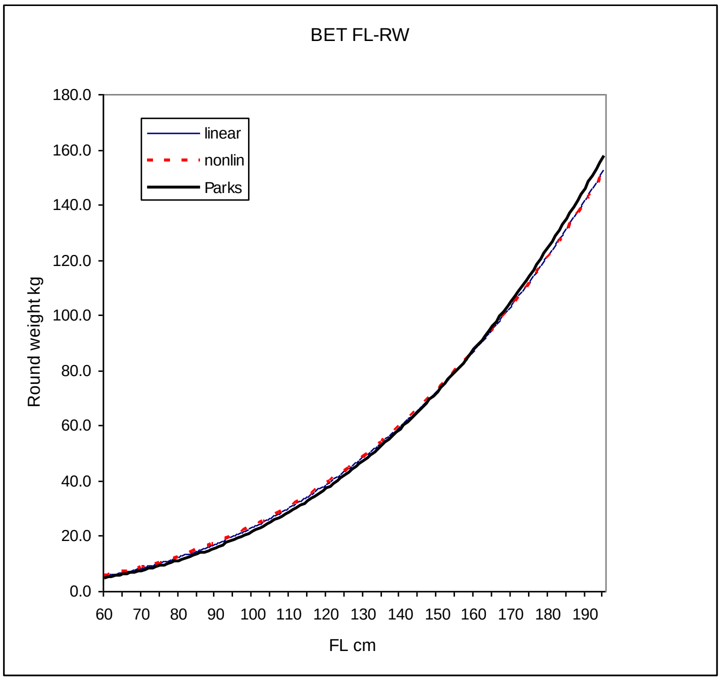

Figure 6. Comparison of several FL-RW equations available: linear and non-linear fit obtained in this document vs. the fit obtained by Parks *et al*. 1981.