Analysis of the length weight relationships for the western Atlantic bluefin tuna, *Thunnus thynnus* (L.)

José L. Cort[1], Vicente D. Estruch[2]

ABSTRACT

The recently adopted model by ICCAT Standing Committee on Research and Statistics (SCRS) for the western Atlantic bluefin tuna (ABFT), *Thunnus thynnus* (L.) (RW= 0.0000159137 $SFL^{3.020584}$; *WEST*), together with the model used to date (RW= 0.0000152 $SFL^{3.0531}$; *Ec 1*) are analyzed in using a bi-variant sample (*SFL* (cm), *RW* (kg)) of 698 pairs of data (K= 2.02 ± 0.23 *SD*) with the aim of validating them and establishing which model best fit the reality represented by the sample and, therefore, will have the greatest descriptive and predictive power. The result of the analysis indicates that the adopted model *WEST* clearly underestimates the weight of spawning ABFT being model *Ec 1* that best explains the data of the sample. The result of the classical statistical analysis is confirmed by means of the quantile regression technique, selecting the quantiles 5%, 25%, 50%, 75% and 95%. Other biological and fisheries indicators also conclude that the model *WEST* gradually underestimates the weight of ABFT spawners (of 2–3 m) by 11–13%, does not meet the criterion that for RW= 725 kg (W_{max}), SFL= 319.93 ± 11.3 cm (L_{max}), and the average value of K (1.77) obtained for a wide range of size-weight values, using that model, represents ABFT in low fattening condition.

KEY WORDS

Atlantic bluefin tuna, *Thunnus thynnus*, length–weight relationships, quantile regression.

[1] Instituto Español de Oceanografía, C. O. de Santander, Spain (jose.cort@st.ieo.es)

[2] Instituto de Investigación para la Gestión Integrada de Zonas Costeras (IGIC), Universitat Politècnica de Valencia, Spain

1. INTRODUCTION

Stock assessments made by the SCRS of ICCAT for the ABFT follow the designation of two separate stocks and apply a different length–weight relationship to each (ICCAT, 2014); equation 1 (Parrack and Phares, 1979), for the western stock, and equation 2 (Arena, unpublished), in ICCAT (2010), for the eastern stock.

$RW = 0.0000152\ SFL^{3.0531}$ (1)
$RW = 0.000019607\ SFL^{3.0092}$ (2)

Equations 1 and 2 have been questioned in recent times, and so several new equations have been proposed to the SCRS (equation 3, called *WEST*, and equation 4, called *EAST*), which are adaptations of those published by Rodríguez–Marín et al. (2013, 2014) in Rodríguez–Marín and Ortiz (2014). Models *WEST* and *EAST* were finally adopted by SCRS in 2014 (ICCAT, 2014).

In a recent publication, Cort et al. (2015) demonstrated that equation *EAST* clearly underestimates the weight of spawning ABFT up to 12.5%.

In the present study equation 3 is analyzed since it deals with model to be applied in the ABFT databases of the western stock.

$RW = 0.0000159137\ SFL^{3.020584}$ (3)
$RW = 0.0000315551\ SFL^{2.898454}$ (4)

In view of the above considerations, the specific aims of the present study are:

i) To compare the values of the adopted model *WEST*, equation 3, with equation 1 to establish which model best represent the reality as represented by a sample of ABFT spawners ($K \geq 2$) and, therefore, have the greatest descriptive and predictive power,

ii) To check how the equation *WEST* adapt to the biology of ABFT by means of the growth curve, and other biological and fisheries indicators.

2. MATERIAL AND METHODS

2. 1. Sample used and models subject to analysis

The sample used is based on data of spawners from the Gulf of Mexico (Knapp et al., 2010) and from fisheries of Canada (Caddy et al., 1976; Butler et al., 1977; Smith et al., 2006; Corrigan et al., 2007; Fraser, 2008 and Database from Fisheries and Oceans Canada). The sample contains a few young ABFT obtained from Rivas (1954), Baglin (1976); Farber and Chewning (1980); Hurley and Iles (1982), and own data from transatlantic migrations (East to West), cited in Cort (1990).

The bi-variant sample used is the following:

- Longliners, Gulf of Mexico: *n*= 29; size range: 212–326 cm; sampling year: 2008 (March–May); *K*= 1.86 ± 0.24 *SD*.
- Canadian fisheries: *n*= 645; size range: 150-320 cm; sampling years: 1975, 1976, 1999–2011 (July–October); *K*= 2.03 ± 0.23 *SD*.

Data of young ABFT:

-Straits of Florida: *n*= 2; sizes: 25 and 45 cm; sampling years: 1951; 1953.
-USA Atlantic coast: *n*= 22; size range: 91-137 cm; sampling years: 1959, 1967, 1968, 1974, 1980, 1981 and 1982 (July–October).

Extreme data

The sample contains two pairs of extreme data: two young-of-the-year of 25 cm (0. 3 kg) and 45 cm (1.7 kg), sampled respectively in the Straits of Florida in November 1953 and January 1951 (Rivas, 1954); and two large spawners: one of 326 cm (655 kg) sampled in the Gulf of Mexico in 2008 (Knapp et al., 2010) and another 320 cm (679 kg), which is the ABFT sport fishing world record since 1979 (Fraser, 2008).

The set of the database (*n*=698) will hereinafter be referred to as *GMX+CANADA* (**Table 1** and **Figure 1**). The overall *K*= 2.02 ± 0.*23 SD*

Models (equations) subject to analysis:

- Equation *West* ABFT of E. Rodríguez–Marín et al. (2013; 2014) and Rodríguez–Marín and Ortiz (2014) (hereafter, ***WEST***):

$$RW = 0.0000159137\ SFL^{3.020584} \text{ (hereafter, } \textbf{\textit{WEST}})$$
$$n = 51{,}204$$

The model *WEST* is the last adaptation made by the two authors to the models published by Rodríguez–Marín et al. (2013; 2014).

- Western Atlantic of Parrack and Phares (1979):

$$RW = 0.0000152\ SFL^{3.0531} \text{ (hereafter, } \textbf{\textit{Ec 1}})$$
$$n = 644$$

2. 2. Comparative validation study. Goodness of the fit, positional indicators and analysis of residuals

The two models were compared considering a bi-variant sample (*SFL* (cm), *RW* (kg)) of 698 pairs of data (*GMX+CANADA*) to validate them and, therefore, establish which model best approximates the reality represented by the sample and to establish which one provides greater descriptive and predictive power.

For the validation of the models we used the sample *GMX+CANADA*, upon which the calculation of several indicators and statistical estimators has been made, establishing in all cases that a 95% confidence level was required.

Firstly, descriptive indicators were calculated: Coefficient of determination (R^2), mean absolute error, standard error of the absolute error, mean relative error and standard error of the relative error. In addition, the 95% confidence intervals have been calculated for the mean absolute error and for the mean relative error, which are robust estimates for the statistics described. The equi-distribution property was evaluated by calculating for each equation the percentages of real data that are above and below the curve and through the 95% confidence intervals for these proportions. Lastly, an analysis of the residuals was made for each model.

Mean of the absolute errors ($Eam = \frac{\sum |RW_i - Estimated\ RW_i|}{N}$ kg), Standard error of the absolute errors, (Standard deviation of the absolute errors/ $\sqrt{N}$),
Mean of the relative errors ($Erm = \frac{\sum \frac{|RW_i - Estimated\ RW_i|}{Estimated\ RW_i}}{N} \cdot$ 100%) and Standard Error of the relative error (Standard deviation of relative error / $\sqrt{N}$).

2.3. Quantile regression

With the aim of obtaining a more complete and robust analysis of the relationship between the variables length and weight and an approximate idea of the evolution of the distribution of weight as the ABFT grow in size, we resorted to the use of quantile regression (Koenker and Basset, 1978; Koenker, 2005), considering the data of the sample (*GMX+CANADA*).

Taking into account the model $RW = a*SFL^b$, the different curves corresponding to the selection of the quantiles 5%, 25%, 50%, 75% and 95% were obtained.

2. 4. The fit of the equations to the growth equation of the western stock and to the weight of GMX+CANADA. Estimation of K

The over or underestimation that may occur in the models studied was performed using the growth equation of the western ABFT stock $Lt = 314.90\ [1 - e^{-0.089\ (t\ +1.13)}]$ from Restrepo et al. (2010), in weight.

According to Gulland (1971), if the weight was proportional to the *n* power of the length, then the growth equation would be:

$$W_t = W_\infty\ [1 - e^{-k\,(t - t_0)}]^n$$

where:

W_t = Size (Weight, in kg) of the animal at time t (years)
W_∞ = Maximum mean asymptotic size (weight)
k = Growth rate (year^{-1})
t_0 = Theoretical age (years) moment at which W= 0

Using the growth equation, length (in cm) of a group of ages (5, 10, 15, 20, 25 and 30 years) was estimated and their corresponding value in weight (kg) applying the models studied.

The over or underestimation that may occur in models *WEST* and *Ec 1* was calculated from the residual analysis when comparing the different models. The study is based on the total weight of *GMX+CANADA*.

To verify the fattening condition obtained when applying one or the other model (*WEST* and *Ec 1*), the condition factor (*K*; Ricker, 1975) has been calculated for the same values of size and weight/age, as in the previous case, and also for a wide range of length-weight values.

3. RESULTS

3.1. Study of comparative validation. Goodness of the fit, positional indicators and analysis of residuals

The model given by *Ec 1* have an overall fit to the data, significantly better than the model given by *WEST* if we consider the values of R^2, the mean absolute error and the mean relative error (**Table 2**). Observe how the upper ends of the 95% confidence intervals for absolute and relative errors corresponding to the equation *Ec 1* remain below the lower ends of the respective intervals corresponding to the model *WEST* (**Table 3,** and **Figures 2** and **3**). Taking into account the goodness indicators of the fit described, the model given by *Ec 1* fit the data better and, in principle, will have greater predictive power than the equation *WEST*.

On the other hand, the results shown in **Table 4** indicates that model *Ec 1* satisfies equi-distribution property (95% confidence level). The models *WEST* violate the property of equi-distribution underestimating weight. In the case of the model *WEST*, 84.24% of the real values are higher than the estimated values, which indicate that this model clearly underestimates weight. The model given by *Ec 1* overestimates the weight but only slightly.

From the results of the analysis of the residuals (**Table 5**), the difference between the mean and median values point to an important asymmetry of the residuals for the model *WEST i*n comparison with model *Ec 1*, which can be checked visually in **Figures 4** and **5 a)**, **b)**. Only model *Ec 1* strictly fulfills the requisite that the 95% confidence interval for the mean of the residuals contains the value 0. The 95% confidence interval for the residuals of *Ec 1* is the most accurate since, in addition to containing 0, it presents lower width, which means that it is a good predictive model with relatively low uncertainty. The mean values of the residuals are clearly lower, considering the absolute values, for model *Ec 1*. The positive and negative values of the mean (as well as the confidence intervals) for *WEST* and *Ec 1* confirm the tendency of these models to under and overestimate weight, respectively, although the magnitude of these values would indicate that the predictive power of model *Ec 1* is greater than that of *WEST* (*Ec 1* overestimates weight but does so more slightly when compared with *WEST*, which underestimates it).

In view of all this, it can be concluded that the predictive model that would clearly (and plausibly) best explain the data of the sample is *Ec 1*. On the other hand, the model *WEST* would be evidently the least appropriate to explain the behaviour of the sample data.

3. 2. Quantile regression

Table 6 shows the results for the parameters provided by quantile regression for the quantiles selected, calculated from the sample *GMX+CANADA*. As it can be seen in **Figure 6** the curve corresponding to *Ec 1* is slightly above the curve corresponding to the central quantile (50%) or median quantile. Model *WEST* is below the curve corresponding to quantile 25 and close to the one corresponding to quantile 5.

3.3. The fit of the equations to the growth equation of the western stock and to the weight of GMX+CANADA. Estimation of K

Table 7 shows the result of the same exercise but applying the growth equation (Restrepo et al., 2010). Firstly, the values of W_∞ that is obtained on applying the equation *WEST* (559 kg) are unreal values very far from the actual world record (679 kg; Fraser, 2008), or from the official value of W_{max} (726 kg; in ICCAT, 2010b). The W_∞ obtained by applying *Ec 1* (644 kg) are much more realistic. When comparing the results of the two models, the model *WEST* underestimates weight as ABFT ages increase. Thus, at age 5 the underestimation is 11.1%, whereas for 30 it is 13.1%.

With the total sample weight of *GMX+CANADA* being 207,940 kg, the residuals obtained through the application of the *WEST* and *Ec 1* models have been as follows:

Weight of the sample applying *WEST* model: 183,193 kg (-12%)

Weight of the sample applying *Ec 1* model: 209,420 kg (1%)

The obtained result is the same as that of the previous exercise, applying the growth equation. In the last column of **Table 7** it is verified that the values of *K* obtained by applying the *WEST* model represent fish in low fattening condition ($K < 1.8$), while those obtained applying the *Ec 1* model are clearly fish in high fattening condition ($K \geq 2$).

The results in **Table 8** are also very conclusive, verifying that for a wide range of size-weight values, the average value of *K* obtained using the *WEST* model (K=1.77) represents fish in low fattening condition, while when applying the *Ec 1* model, the value of K =1.99 is for fish in high fattening condition.

DISCUSSION

The results obtained from the various analyzes performed, allows us to confirm that the model predictive that would clearly best explain the data of the sample (*GMX+CANADA*), from a statistical point of view, is *Ec 1*, whereas model *WEST* would not be appropriate to explain the behaviour of the data.

If a sample (*SFL*, *RW*) is homogeneous and representative, except in exceptional cases, it will present a high degree of symmetry, which will be manifested in the curve corresponding to quantile 50, C50, which corresponds to the evolution of the median, appearing quite centered when compared, on one hand with C25 and C75, and also if compared with C5 and C95 (**Figure 6**). In this case the curve obtained by simple least squares regression can be expected, which best explains the evolution of the mean, to appear close to C50, which is clearly observed for *Ec 1* (**Figure 6**). In the case of the curve *WEST*, the separation with respect to the median confirms what was concluded in the previous statistical analysis, which is that *Ec 1* slightly overestimates the representative central value of the weight and *WEST* clearly underestimates it. It can be said that, based on the sample considered, *WEST* would only be representative of the length-weight relationship for tunas below the 25 % percentile of weight for one size.

Moreover, in view of the results of W_∞ obtained on fitting the growth equation to the models *WEST and Ec 1*, it is concluded that *Ec 1* represents the biology of ABFT growth much better, and it can therefore be applied perfectly well to ABFT juveniles and spawning adults. Moreover, and as conclusive proof of its authenticity, model *Ec 1* satisfies the criterion that for *RW*= 725 kg (W_{max}), *SFL*= 319.93 ± 11.3 cm (L_{max}), in accordance with Cort et al. (2013; 2014); this is not true for the model *WEST*.

The important disagreements found when applying the *WEST* and *Ec 1* models regarding the real weight of the sample *GMX+CANADA* confirm, through different methodologies, that the *WEST* model significantly underestimates the real weight of ABFT up to 13%.

According to Rodríguez-Roda (1964); Santos et al. (2004); Aguado and García (2005); Chapman et al. (2011), values of *K* between 1.4–1.7 are values for wild ABFT in a low fattening condition, far from what spawning ABFT have ($K \geq 2$), as has been demonstrated by: Rodríguez-Roda (1964); Percin and Akyol (2009; 2010); Golet and Lutcavage, unpublished data cited by Chapman et al. (2011); Deguara et al. (2011) and Galaz in Cort et al. (2013). The results of **Table 7** (*K* column) using values of size and average weight/age are sufficiently important to confirm that the *WEST* model represents fish in low fattening condition, while *Ec 1* model represents fish in high fattening condition. The same result is obtained when applying both models to a wide range of size-weight values (**Table 8**).

The results obtained in the present study statistically prove that there are significant differences between the model adopted by the SCRS over three decades ago, representing the spawning population of ABFT which adapts to the growth parameters of this species (*Ec 1*), and another one that does not adapt and which represents the population of ABFT in low fattening condition (*WEST*). Therefore, it should be noted that the utilization of the length weight model adopted by the SCRS in 2014 for the western stock, which underestimates the true weight of the ABFT (between 2-3 m) by up to 13% (*WEST*), can greatly impact results in future ABFT stock assessments.

ACKNOWLEGMENTS

To John Neilson for the data from Fisheries and Oceans Canada, St. Andrews, N.B., Canada, provided for a previous publication and which have also been utilized in the present study.

REFERENCES

Abid, N., S. Benchoucha, S. El Arraf, C. El Fanichi, and S.A. Baibbat. Updated length weight relationship of bluefin tuna (*Thunnus thynnus*) caught in Moroccan waters. ICCAT, SCRS/2014/42, 8 p. (2014).

Aguado, F., and B. García. Changes in some morphometric relationships in Atlantic bluefin tuna (*Thunnus thynnus* Linnaeus, 1758) as a result of fattening process. *Aquaculture*, **249**: 303–309 (2005).

Arena, P. Rilevazini e studi sulle affluenze del tonno nel Tirreno e sull'andamento della pesca da parte delle "tonnare volanti" nel quadriennio 1984–1988. E.S.P.I. Ente Siciliano per la Promozione Industriale-Palermo Unit`a Operativa No. **5**, 66 p. (1988).

Baglin, R. Jr. A preliminary study of the gonadal development and fecundity of the western Atlantic bluefin tuna. *Col. Vol. Sci. Pap. ICCAT*, **5** (2): 279–289 (1976).

Butler, M., Caddy, J., Dickson, C., Hunt, J. and Burnett, C. Apparent age and growth, based on otolith analysis, of giant bluefin tuna (*Thunnus thynnus*) in the 1975–1976 Canadian catch. *Col. Vol. Sci. Pap, ICCAT*, **6** (2): 31/8–330 (1977).

Caddy, J., C. A, Dickson, and J. A. Butler. Age and growth of giant bluefin tuna (, *Thunnus thynnus thynnus*) taken in Canadian waters in 1975. Fisheries Research Canada. Manuscript Report Series, 1395, 17p. (1976).

Chapman, E. W., C. Jørgensen, and M. E. Lutcavage. Atlantic bluefin tuna (*Thunnus thynnus*): A state-dependent energy allocation model for growth, maturation, and reproductive investment. *Can. J. Fish. Aquat. Sci*., **68**: 1934–1951 (2011).

Coan, A. Length weight conversion tables for Atlantic tunas. *Col. Vol. Sci. Pap. ICCAT*, **5**: 64–66 (1976).

Corrigan, S., Neilson, J. and Stacey, P. 2006 summary of ongoing Canadian bluefin tuna sampling activities supported by the ICCAT bluefin tuna year program. *Col. Vol. Sci. Pap. ICCAT*, **60** (4): 1345–1348 (2007).

Cort, J. L. Biología y pesca del atún rojo, *Thunnus thynnus*, del mar Cantábrico. Publicaciones Especiales IEO, **4**; 272 p. (1990).

Cort, J. L., S. Deguara, T. Galaz, B. Mèlich, I. Artetxe, I. Arregi, J. Neilson, I. Andrushchenko, A. Hanke, M. N. Dos Santos, V. Estruch, M. Lutcavage, J. Knapp, G. Compeán-Jiménez, R. Solana-Sansores, A. Belmonte, D. Martínez, C. Piccinetti, A. Kimoto, P. Addis, M. Velasco, J. M. De la Serna, D. Godoy, T. Ceyhan, I. Oray, S. Karakulak, L. Nøttestad, A. López, O. Ribalta, N. Abid, and M. Idrissi. Determination of L_{max} for Atlantic Bluefin Tuna, *Thunnus thynnus* (L.), from Meta-Analysis of Published and Available Biometric Data, *Reviews in Fisheries Science*, **21: 2**, 181–212 (2013).

Cort, J. L., I. Arregui, V. Estruch, and S. Deguara. Validation of the growth equation applicable to the eastern Atlantic bluefin tuna, *Thunnus thynnus* (L.), using L_{max}, tag-recapture and first dorsal spine analysis. *Reviews in Fisheries Science & Aquaculture*, **22**: **3**, 239–255 (2014).

Cort, J. L., V. D. Estruch, M. N. Santos, A. Di Natale, N. Abid, J. M. de la Serna. On the variability of the length-weight relationship for Atlantic bluefin tuna, *Thunnus thynnus* (L.). *Reviews in Fisheries Science & Aquaculture* **23**:1, 23–38 (2015).

Deguara, S., M. Gatt, S. Caruana, and C. Agius. Changes in length–weight relationships of Atlantic bluefin tuna, *Thunnus thynnus*, caught by Maltese longliners during the years 2008–2011. *Col. Vol. Sci. Pap. ICCAT* SCRS/2011/170, 7 p. (2011).

Farber, M. I., and T. W. Chewning. An update of U.S. bluefin tuna tagging. *Col. Vol. Sci. Pap. ICCAT*, **9** (2): 463-469 (1980).

Fraser, K. *Possessed. World Record Holder for Bluefin Tuna*. Kingstown, Nova Scotia: T & S Office Essentials and printing, 243 pp. (2008).

Gulland, J. A. Manual de métodos para la evaluación de las poblaciones de peces. Editorial Acribia. Royo, 23 Zaragoza, 164 pp. (1971).

Hurley, P. C. F. and T. D. Iles. An unusual bluefin tuna tag return. *Col. Vol. Sci. Pap. ICCAT*, **17** (2): 295–298 (1982).

ICCAT. Length-weight relationships adopted by the SCRS for major species. http://www.iccat.int/Documents/SCRS/Manual/Appendices/Appendix%204%20III%20Length-weight.pdf (2006).

ICCAT. ICCAT Manual. Description of species. Chapter 2; 2.1.5 Atlantic Bluefin Tuna, 99: 93–111. Madrid, ICCAT (2010).

ICCAT. Report of the 2010 Atlantic bluefin tuna stock assessment session. Madrid, Spain, September 6–12, 2010. Available from: http:// www.iccat.int /Documents/Meetings /Docs /2010 BFT ASSESS REP ENG.pdf (2010).

ICCAT. Report of the Standing Committee on Research and Statistics (SCRS), 348 p. http://www.iccat.int/Documents/Meetings/Docs/2014-SCRS-REP_ENG.pdf (2014).

Knapp, J., Heinisch, G. and Lutcavage, M. Preliminary results on the reproductive status of Atlantic bluefin tuna sampled in the Gulf of Mexico during spawning season, 2007-2008. *Col. Vol. Sci. Pap. ICCAT*, **65** (3): 822–827 (2010).

Koenker, R., and G. Basset. *Regression Quantiles*. Econometrica: *J. Econometric Soc*., **46** (1), 33-50 (1978).

Koenker, R. (2005): *Quantile Regression*. Cambridge U. Press. (2005).

Medina, A., F. J. Abascal, C. Megina, and A. García. Stereological assessment of the reproductive status of female Atlantic northern bluefin tuna during *migrations to Mediterranean spawning grounds through the Strait of Gibraltar*. *Journal of Fish Biology*, **60**: 203-217. doi: 10.1111/j.1095-8649.2002.tb02398.x (2002).

Parrack, M., and P. Phares. Aspects of the growth of Atlantic bluefin tuna determined from marck-recapture data. *Col. Vol. Sci. Pap. ICCAT*, **8**: 356–366 (1979).

Percin, F., and O. Akyol. Length–weight and length–length relationships of bluefin tuna, *Thunnus thynnus*, in the Turkish part of the eastern Mediterranean sea. *J. Appl. Ichthyol*., **25**: 782–784 (2009).

Percin, F., and O. Akyol. Some morphometric relationships in fattened bluefin tuna, *Thunnus thynnus* from Turkish Aegean Sea. *J. Animal Vet. Adv*., **9:** 1684–1688 (2010).

Restrepo, V. R., Díaz, G. A., Walter, J. F., Neilson, J., Campana, S. E., Secor, D. and Wingate, R. L. Updated estimate of the growth curve of western Atlantic bluefin tuna. *Aquat. Living Resour*., **23**, 335–342 (2010).

Ricker, W. E. Computation and interpretation of biological statistics of fish populations. *Bull. Fish. Board Canada*, **191:** 1–382 (1975).

Rivas, L. R. A preliminary report on the spawning of the western North Atlantic bluefin tuna (*Thunnus thynnus*) in the Straits of Florida. *Bull. Mar. Sci. Gulf. Caribb*., **4** (4): 302–322 (1954).

Rodríguez-Marín, E., J. M. Ortiz de Urbina, P. Quelle, M. N. dos Santos, N. Abid, E. Alot, S. Deguara, J. M. de la Serna, M. J. Gómez, S. Karakulak, N. Labidi, D. Macias, P. Rioja, M. Ruiz and S. Saber. Biometric relationships and condition of Atlantic bluefin tuna (*Thunnus thynnus*) from the North-East Atlantic and Mediterranean Sea. ICCAT, SCRS/2013/079, 16 p. (2013).

Rodríguez-Marín, E., and M. Ortiz. Further analysis results of biometric relationships of Atlantic bluefin tuna, attending to the recommendation of ICCAT bluefin tuna Group (2014 ICCAT Bluefin Data Preparatory Meeting). SCRS/2014/053 Rev, 17 p. (2014).

Rodríguez-Marín, E., J. M. Ortiz de Urbina, N. Abid, E. Alot, I. Andrushchenko, S. Deguara, A. Di Natale, M. Gatt, W. Golet, S. Karakulak, A. Kimoto, D. Macias, P. Quelle, S. Saber, M. N. Santos, J. Walter and R. Zarrad. Length weight relationships for Atlantic bluefin tuna (*Thunnus thynnus*). ICCAT, SCRS/2014/053, 19 p. (2014).

Rodríguez-Roda, J. Biología del atún, *Thunnus thynnus* (L.), de la costa sudatlántica española. *Inv. Pesq*., **25**: 33–146 (1964).

Santos, M. N., A. García, P. Gil Lino, and M. Hirofumi. Length–weight relationships and weight conversion factors for bluefin tuna (*Thunnus thynnus*) from Algarve: Prior to and after fattening. *Col. Doc. Sci. Pap. ICCAT*, **56**: 1089–1095 (2004).

Smith, S., Neilson, J. and Stacey, P. Summary of ongoing Canadian bluefin tuna sampling activities reported by the ICCAT bluefin tuna year program. *Col. Vol. Sci. Pap. ICCAT*, **59** (3): 824–828 (2006).

Table 1. Summary statistics of the sample *GMX+CANADA*

	SFL (cm)	*RW* (kg)
Count	698.0	698.0
Mean	240.1	297.9
Median	247.0	299.5
Standard deviation	37.2	110.5
Minimum	25.0	0.3
Maximum	326.0	679.0
Range	301.0	678.7
Lower cuartile	229.0	232.0
Upper quartile	264.0	377.0

Table 2. Descriptive indicators of the goodness of fit of the equations to the data (n=698)

	R^2 (%)	MAE (kg)	St. err. MAE	MRE	St. err. MRE
WEST	**86.2**	39.32	1.2501	15.0034	0.421234
Ec 1	**90.0**	27.68	0.8085	9.3275	0.240824

Table 3. 95% confidence intervals for the mean of the absolute errors (MAE) and for the mean of the relative errors (MRE)

	CI (95%) MAE	CI (95%) MRE
WEST	39.3195 +/- 2.4502 [36.8693; 41.7697]	15.0034 +/- 0.8256 [14.1778; 15.829]
Ec 1	27.6818 +/- 1.5847 [26.0971; 29.2665]	9.3275 +/- 0.4720 [8.85546; 9.79947]

Table 4. Positional indicators to assess whether the models provide estimated values of the weight higher or lower than the actual values

	Percentage of actual values lower than estimates values (%) estimated values (Percentage of actual values higher than estimated values (%))	95% confidence intervals for the percentage of actual values lower than estimated values. (95% confidence intervals for the percentage of actual values higher than the estimated values.)
WEST	15.76 (84. 24)	[13.1347; 18.6785] ([81.3215; 86.8653])
Ec 1	53.72 (46. 28)	[49.9403; 57.4682] ([42.5318; 50.0597])

Table 5. Summary statistics for the residuals corresponding to the different models analyzed, with respect to the global data and confidence intervals (95%) for the average of the residuals

	WEST	*Ec 1*
Count	698	698
Mean	35.4744	-2.0999
Standard deviation	37.1325	34.9182
Median	28.619	-2.9779
95% confidence interval for the mean	35.4744 +/- 2.7547 [32.7197; 38.2291]	-2.09994 +/- 2.59044 [-4.69038; 0.490505]

Table 6. Results for the parameters provided by the quantile regression for the selected quantiles calculated from the sample *GMX+CANADA* (in Figure 6)

Percentile curve	**a**	**b**
5%	1.7379E-05	2.993942
25%	2.0184E-05	2.993847
50% (median)	1.7913E-05	3.020156
75%	1.9340E-05	3.022508
95%	1.4997E-05	3.087066

Table 7. Comparison of the estimated size (*SFL*, cm), round weight (*RW*, kg) and *K* at age obtained from the models *WEST* and *Ec 1* applied to the growth equation of the western ABFT stock

A			***SFL* (cm)**	***RW* (kg)**	**Diference, A/B (%)**	***K***
	$Lt = 314.90\ [1 - e^{-0.089\ (t + 1.13)}]$					
$W = 0.0000159137\ L^{3.020584}$ (***WEST***)						
$Wt = 559\ [1 - e^{-0.089\ (t + 1.13)}]^{3.020584}$						
	Age 5		132	40	-11.1	1.74
	Age 10		198	137	-12.2	1.76
	Age 15		240	246	-12.4	1.78
	Age 20		267	340	-12.6	1.79
	Age 25		284	409	-13.0	1.79
	Age 30		295	459	-13.1	1.79
B			***SFL* (cm)**	***RW* (kg)**		
	$Lt = 314.90\ [1 - e^{-0.089\ (t + 1.13)}]$					
$W = 0.0000152\ L^{3.0531}$ (***Ec 1***)						
$Wt = 644\ [1 - e^{-0.089\ (t + 1.13)}]^{3.0531}$						
	Age 5		132	45	–	1.96
	Age 10		198	156	–	2.01
	Age 15		240	281	–	2.03
	Age 20		267	389	–	2.04
	Age 25		284	470	–	2.05
	Age 30		295	528	–	2.06

Table 8. Condition factor (*K*) calculated for a wide range of length-weight values, using models *WEST* and *Ec 1*

Model	***WEST***		***Ec 1***	
a	1.59137E-05		0.0000152	
b	3.020584		3.0531	
***SFL* (cm)**	***W* (kg)**	***K (WEST)***	***W* (kg)**	***K (Ec 1)***
40	1.10	1.72	1.18	1.85
60	3.74	1.73	4.08	1.89
80	8.92	1.74	9.82	1.92
100	17.50	1.75	19.41	1.94
120	30.35	1.76	33.87	1.96
140	48.34	1.76	54.22	1.98
160	72.36	1.77	81.52	1.99
180	103.28	1.77	116.79	2.00
200	141.98	1.77	161.11	2.01
220	189.35	1.78	215.52	2.02
240	246.26	1.78	281.10	2.03
260	313.62	1.78	358.92	2.04
280	392.30	1.79	450.05	2.05
300	483.20	1.79	555.57	2.06
320	587.20	1.79	676.58	2.06
Mean (*K*)		**1.77**	**Mean (*K*)**	**1.99**
SD		**± 0.02**	***SD***	**± 0.06**

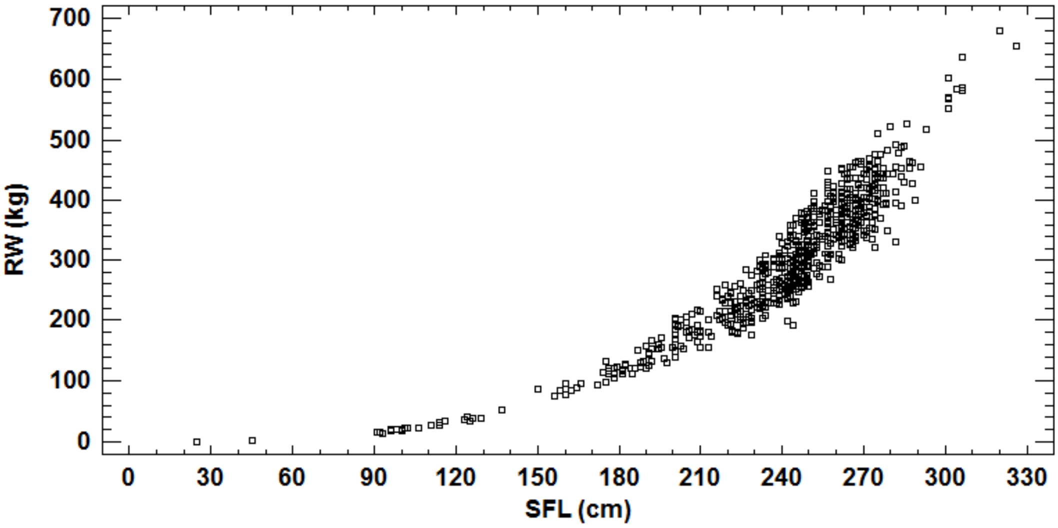


Figure 1. Plot of the used sample (*GMX+CANADA*)

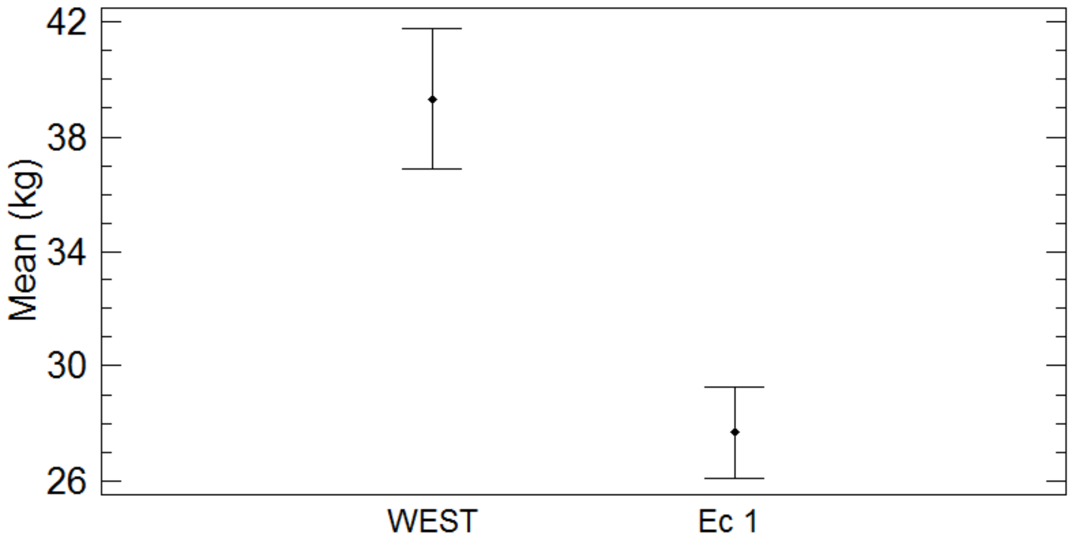


Figure 2. Means and 95% confidence intervals for the absolute errors

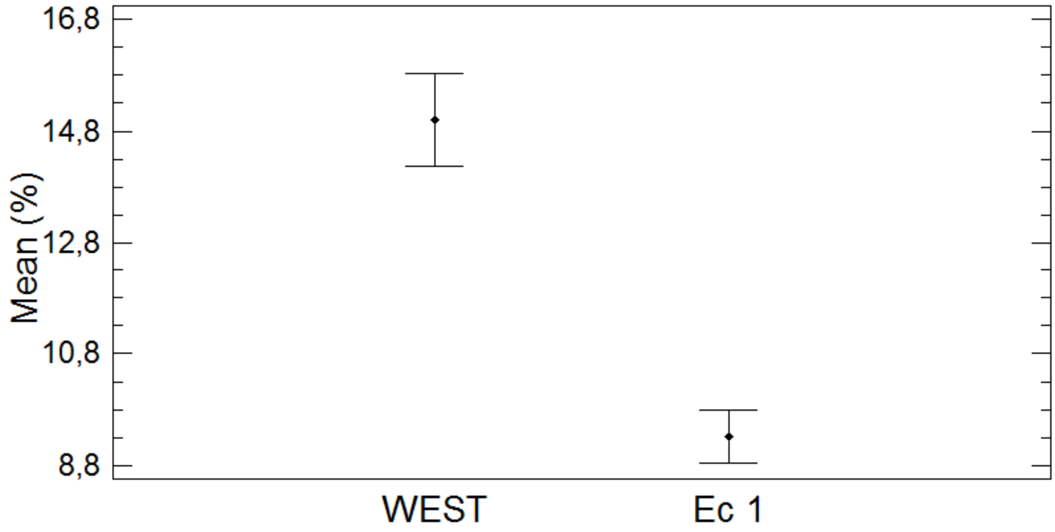


Figure 3. Means and 95% confidence intervals for the relative errors

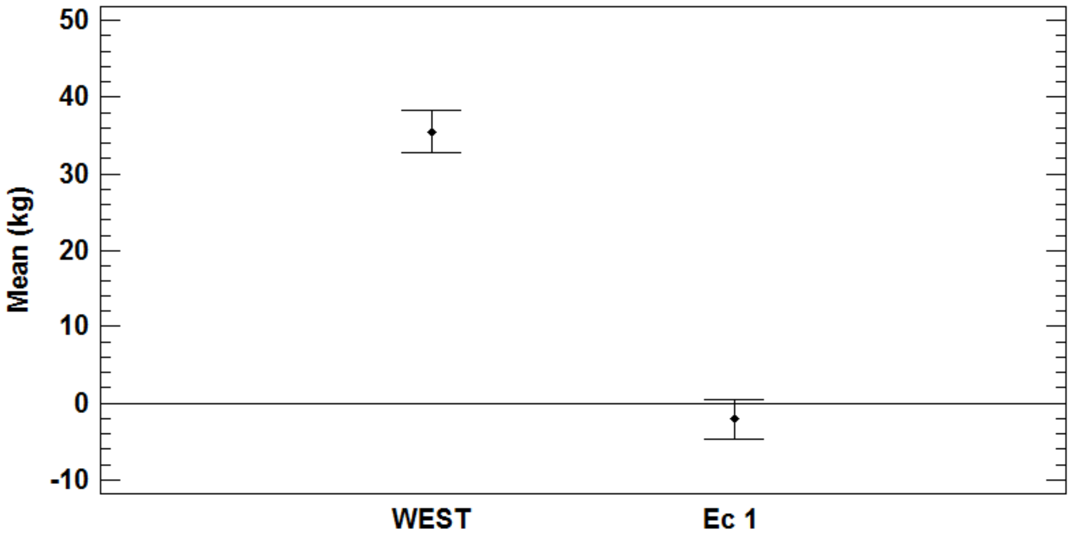
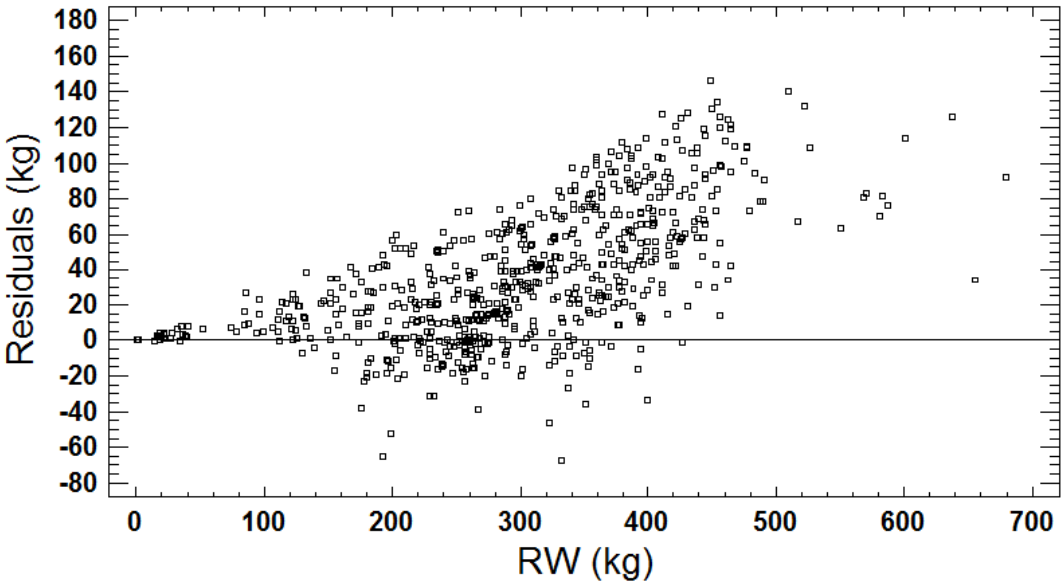


Figure 4. Means and 95% confidence intervals for the residuals



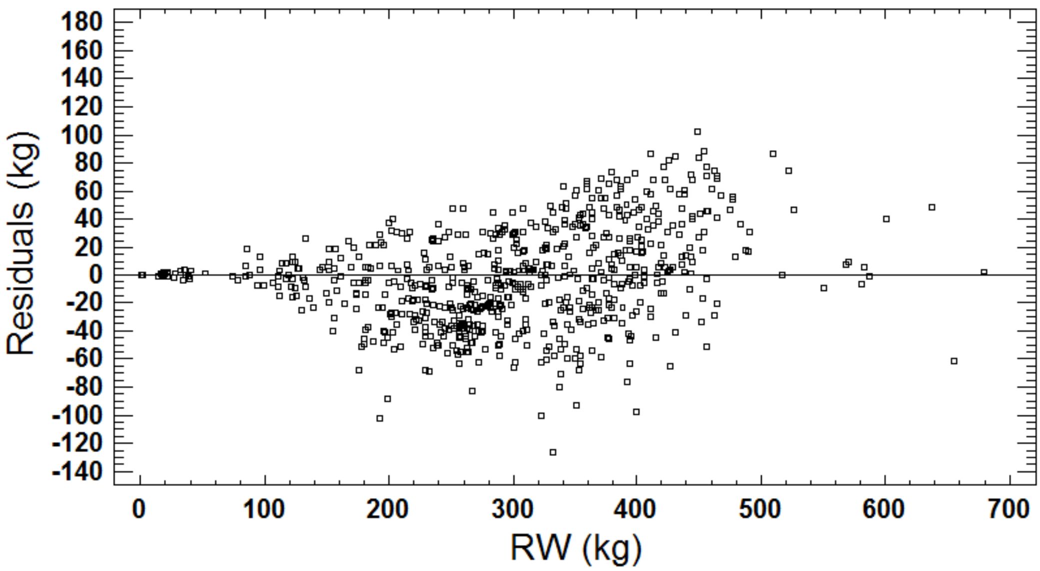


Figure 5. Residual plots. The figures a) and b) correspond to the model linked to the equations *WEST* and *Ec 1*, respectively

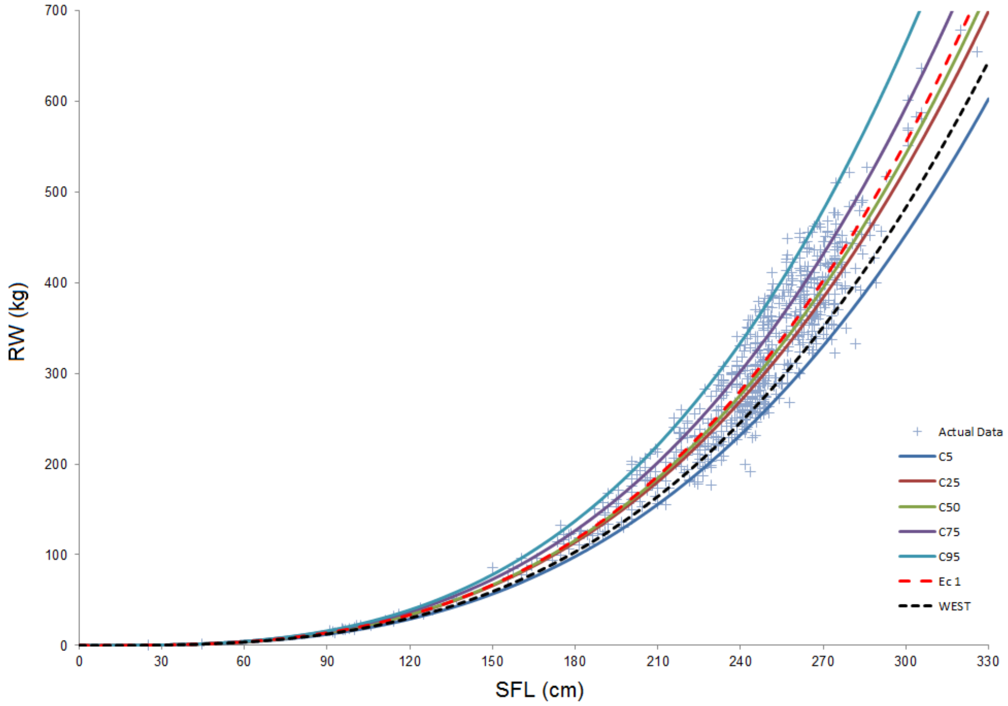


Figure 6. Graphs corresponding to the selected quantile curves (5%, 25%, 50%, 75% and 95%; solid lines) and to the analyzed models *WEST* and *Ec 1* (dashed lines)