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ESTIMATION OF CONVERSION FACTOR FROM CURVED FORK LENGTH TO STRAIGHT FORK LENGTH FOR FARMED EASTERN BLUEFIN TUNA (*THUNNUS THYNNUS*)

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SUMMARY

*The aim of this investigation was to identify a curved fork length to straight fork length (CFL-SFL) conversion applicable to farmed eastern bluefin tuna (*Thunnus thynnus*). Fattened bluefin tuna are expected to increase in girth to a greater degree than wild specimens, and therefore curved fork length to straight fork length (CFL-SFL) conversion methods based on data collected from wild-caught specimens may not be applicable in this context. Measurements of CFL and SFL were collected from 436 individual fish at harvesting operations on Maltese farms between 2011 and 2013. Simple linear regression analysis was used to obtain an equation of the relationship between the two variables considered, which was compared to that of existing (CFL-SFL) conversion factors. The results obtained indicate that the current (CFL-SFL) conversion factor adopted by ICCAT overestimates SFL of farmed bluefin tuna to a statistically significant degree. This effect is magnified for larger specimens, as these have been fattened to a greater extent than smaller individuals. The conversion factor proposed here provides a suitable alternative applicable to farmed eastern bluefin tuna.*

RÉSUMÉ

*Le but de cette étude consistait à identifier une conversion de « longueur courbée à la fourche » en « longueur droite à la fourche » (CFL-SFL) applicable au thon rouge de l'Est d'élevage (*Thunnus thynnus*). On s'attend à ce que la circonférence du thon rouge engraissé augmente davantage que celle des spécimens sauvages et, par conséquent, les méthodes de conversion de longueur courbée à la fourche en longueur droite à la fourche (CFL-SFL), reposant sur des données concernant des spécimens sauvages, peuvent ne pas être applicable dans ce contexte. Les longueurs CFL et SFL de 436 poissons ont été mesurées lors d'opérations de mise à mort dans des fermes maltaises entre 2011 et 2013. Une analyse de régression linéaire simple a été utilisée pour obtenir une équation de la relation entre les deux variables considérées, qui a été comparée à celle des facteurs de conversion existants (CFL-SFL). Les résultats obtenus indiquent que le facteur de conversion actuel (CFL-SFL) adopté par l'ICCAT surestime la SFL du thon rouge engraissé de façon statistiquement significative. Cet effet est amplifié pour les spécimens plus gros, car ceux-ci ont été engraissés dans une plus grande mesure que les spécimens plus petits. Le facteur de conversion proposé ici fournit une alternative applicable au thon rouge de l'Est engraissé.*

RESUMEN

*El objetivo de esta investigación fue identificar una conversión de longitud curva a la horquilla a longitud recta a la horquilla (CFL-SFL) aplicable al atún rojo del este de granja (*Thunnus thynnus*). Se espera que el perímetro del aún rojo de granja se incremente en mayor medida que el de los ejemplares salvajes, y por tanto los métodos de conversión de longitud a la horquilla a longitud curva a la horquilla (CFL-SFL) basados en datos obtenidos de especímenes capturados en estado salvaje podría no ser aplicable en este contexto. Se recopilaron datos de mediciones de CFL y SFL de 436 ejemplares en operaciones de sacrifico en granjas maltesas entre 2011 y 2013. Se utilizó un análisis de regresión lineal simple para obtener una ecuación de la relación entre las dos variables consideradas, que fue comparada con la de los factores de conversión (CFL-SFL) existentes. Los resultados obtenidos indican que el factor de conversión (CFL-SFL) actual adoptado por ICCAT sobreestima la SFL del atún rojo de granja hasta un grado*

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estadísticamente significativo. Este efecto se magnifica en los ejemplares más grandes, ya que éstos han sido engordados en mayor medida que los ejemplares más pequeños. El factor de conversión propuesto aquí proporciona una alternativa adecuada aplicable al atún rojo de granja del este.

KEYWORDS

Atlantic bluefin tuna, Thunnus thynnus*, fattened bluefin tuna, fish conversion factors*

1. Introduction

Accurate stock assessments of Atlantic bluefin tuna (BFT), *Thunnus thynnus*, require the analysis of capture data from the entire spectrum of BFT-related fishing activities (Deguara *et al.* 2009). Presently, most of the purse seine catch of *Thunnus thynnus* in the Mediterranean is transferred live to floating cages for fattening. Thus, prior to the implementation of Stereoscopic Camera estimations at each caging the only way to collect representative catch at size statistics for *T. thynnus* from the purse seine fishery was by retrieving this information from caged fish at harvest time.

Bluefin Tuna length measurements may be collected in either format (CFL or SFL). Due to the fact that during harvesting operations it is easier to measure the length of larger tuna as CFL, most of the observers choose to collect this information as CFL. Most of the Bluefin tuna length data collected during harvest operations in previous years is thus available as CFL. It is therefore necessary to identify an accurate method of converting CFL measurements to values of SFL. Currently, in estimates for East Atlantic and Mediterranean BFT, the International Commission for the Conservation of Atlantic Bluefin Tuna (ICCAT) uses the equation from Rodriguez-Marin et al. (2015).

Since then, various other authors have proposed equations for the conversion of CFL to SFL (Rodriguez-Marin *et al.* 2015; Lombardo *et al.* 2016). However, it is important to note that all conversions proposed thus far, including that currently in use (Rodriguez-Marin *et al.* 2015)., are based on data collected from wild-caught Bluefin Tuna and not from farmed specimens. It has been shown that the fattening process results in variation in some morphometric relationships; specifically, fattened Bluefin Tuna become significantly heavier and increase more in weight for each unit increase in length than do wild specimens (Aguado-Giménez & García-García 2005). Therefore, it is expected that CFL-SFL conversions determined from wild-caught specimens would not be entirely applicable to farmed specimens.

The aim of this investigation was therefore to identify a CFL-SFL conversion suitable for use for farmed Eastern Bluefin Tuna, and to compare the farmed CFL-SFL conversion with that of conversions previously reported in the literature, including that currently in use by ICCAT.

2. Methods

Specimens of farmed *Thunnus thynnus* were representatively sampled during harvesting operations on Maltese Bluefin Tuna farming establishments between 2011 and 2013. For each individual fish included in the dataset, measurements of curved fork length (CFL) and straight fork length (SFL) were immediately taken to the lowest centimetre on-site after harvest. In the case of SFL, the fish was placed on a flat surface in a horizontal position and the length from the end of the upper jaw to the posterior of the shortest caudal ray was measured using a calliper (ICCAT, 2016) (**Figure 1**). In the case of CFL, a tape measure was used to measure the same length by an imaginary longitudinal line along the curvature of the fish (ICCAT, 2016) (**Figure 2**).

An equation for the conversion of curved fork length (CFL) to straight fork length (SFL) and vice-versa was obtained for the entire dataset in the form $y = mx + c$ through simple linear regression analysis. For comparison purposes, the CFL data collected was converted to SFL in three ways: (1) the conversion obtained in this report, (2) the conversion for wild *Thunnus thynnus* proposed by Rodriguez-Marin *et al*. (2015), (3) the conversion for wild *T. thynnus* proposed by Parrack *et al.* (1979), (4) the conversion for wild *Thunnus thynnus* proposed by Lombardo *et al.* (2016).

(1) $$SFL = (0.9103 * CFL) + 4.2131$$

(2) $$SFL = (0.9442 * CFL) + 2.9475$$

(3) $SFL = 0.955 * CFL$

(4) $SFL = (0.9766 * CFL) - 2.0621$

The differences in estimated SFL between (1) and (2), between (1) and (3), and between (1) and (4) were calculated and the average difference was calculated in each case. Paired t-tests were used to determine whether there is a significant difference in SFL as estimated by the conversion equation reported here, and as estimated by previously proposed conversion equations (Parrack *et al*. 1979; Rodriguez-Marin *et al.* 2015; Lombardo *et al*. 2016).

Subsequently, the size distribution of the specimens sampled for this study was investigated by constructing a histogram of frequencies for each size category. The dataset was split into size classes as indicated by said distribution and the average differences in estimated SFL between (1) and (2), between (1) and (3), and between (1) and (4) were calculated for each size class. Two-sample t-tests assuming unequal variance were used to determine whether the degree of difference varies significantly between size classes in the case of each comparison**.**

3. Results and Discussion

The graph given in **Figure 3** illustrates the results of simple linear regression analysis carried out on the dataset of curved fork length (CFL) and straight fork length (SFL) measurements taken for 436 individual fish harvested from Maltese Bluefin Tuna farming establishments. The regression equation obtained is in the form $y = mx + c$, where y represents SFL, x represents CFL, and m and c are constants. The R^2 value associated with this equation is approximately 0.99, indicating that the relationship between CFL and SFL is adequately explained by a linear model.

Table 1 summarizes the results of comparisons carried out as specified in the Methods section. A statistically significant difference in calculated SFL values is reported in all cases ($p < 0.05$). In general, equations (2), (3) and (4) appear to overestimate SFL for farmed *Thunnus thynnus* when converting from CFL measurements. This is not unexpected; farmed bluefin tuna are intentionally fattened and increase in girth to a greater degree than they would in the wild (Aguado-Giménez & García-García 2005). As equations (2), (3) and (4) are based on measurements taken from wild-caught bluefin tuna, the resultant relationships fail to take into account the effect of fattening.

This conclusion is further supported by the results obtained after splitting the dataset used here into size classes according to measured SFL. **Figure 4** is a histogram showing the size distribution of the specimens sampled during this investigation. The distribution appears to be bimodal, with a frequency peak at approximately 140 cm and a second, lesser peak at approximately 220 cm. The dataset was therefore split into two size classes:

- Class 1: 100 cm $\geq x >$ 200 cm
- Class 2: 200 cm $\geq x >$ 300 cm

Table 2 compares the four conversion methods considered here in terms of mean SFL calculated for each size class. There is less of a difference in calculated SFL for Class 1 fish in all cases. Furthermore, this discrepancy between size classes is statistically significant ($p < 0.05$) in all cases. This suggests that conversion methods based on datasets obtained from wild-caught fish are more accurate in estimating the SFL of smaller farmed bluefin tuna than that of larger individuals. In general, as farmed bluefin tuna increase in size, they also increase in girth to a greater extent than wild individuals. Therefore, the biometric relationships of smaller individuals would be more comparable to those of wild specimens than is the case for larger individuals (Aguado-Giménez & García-García 2005).

In conclusion, the conversions currently available for converting curved fork length (CFL) measurements to straight fork length (SFL) should not be applied for farmed fish, as these conversions are based on wild specimens that have not been exposed to fattening procedures. Therefore, these CFL-SFL conversions based on wild specimens overestimate SFL to a statistically significant degree, particularly for larger fish. The equation proposed here provides an alternative to be directly applied to farmed Bluefin tuna.

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Table 1. Summary of comparisons between the conversion method obtained in this investigation and previous conversions reported in the literature (Parrack *et al.* 1979; Rodriguez-Marin *et al.* 2015; Lombardo *et al.* 2016). Equations as specified in Methods section.

	Eqn. (1) vs Eqn. (2)	Eqn. (1) vs Eqn. (3)	Eqn. (1) vs Eqn. (4)
***p*-value**	< 0.05	< 0.05	< 0.05
t critical value	1.96	1.96	1.96
Mean difference in SFL (cm)	-4.96	-3.99	-5.40
Standard deviation (cm)	1.47	1.93	2.87

Table 2. Differences in calculated straight fork length (SFL) for each size class between the conversion method obtained in this investigation and previous conversions reported in the literature (Parrack *et al.* 1979; Rodriguez-Marin *et al.* 2015; Lombardo *et al.* 2016). Equations as specified in the Methods section.

	Eqn. (1) vs. Eqn. (2)	
	Class 1	**Class 2**
Mean difference in SFL calculated (cm)	-4.03	-6.91
Standard deviation (cm)	0.57	0.60
	Eqn. (1) vs. Eqn. (3)	
	Class 1	**Class 2**
Mean difference in SFL calculated (cm)	-2.77	-6.57
Standard deviation (cm)	0.75	0.79
	Eqn. (1) vs. Eqn. (4)	
	Class 1	**Class 2**
Mean difference in SFL calculated (cm)	-4.08	-9.72
Standard deviation (cm)	1.11	1.17

Figure 1. Measurement of straight fork length (SFL).

Figure 2. Measurement of curved fork length (CFL).

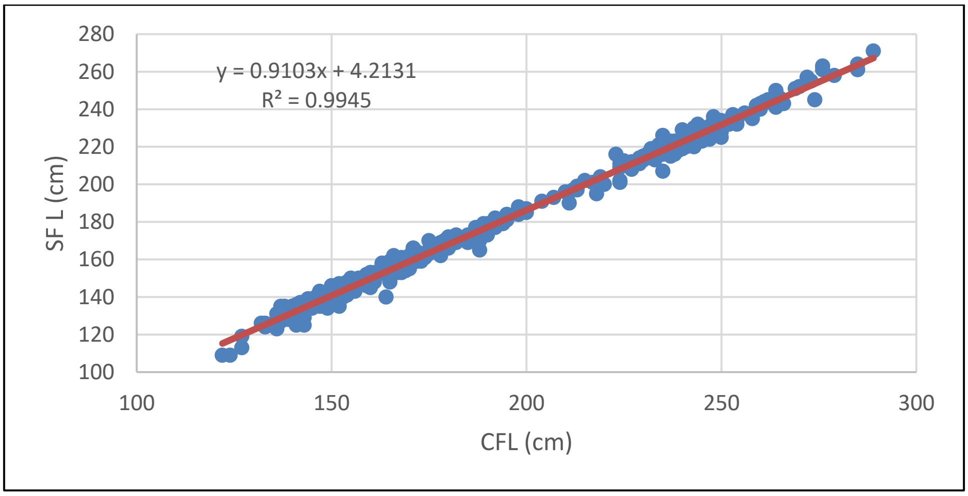

Figure 3. Simple linear regression plot showing the relationship between curved fork length (CFL) and straight fork length (SFL). Also given are the equation of the plot and the R^2 value.

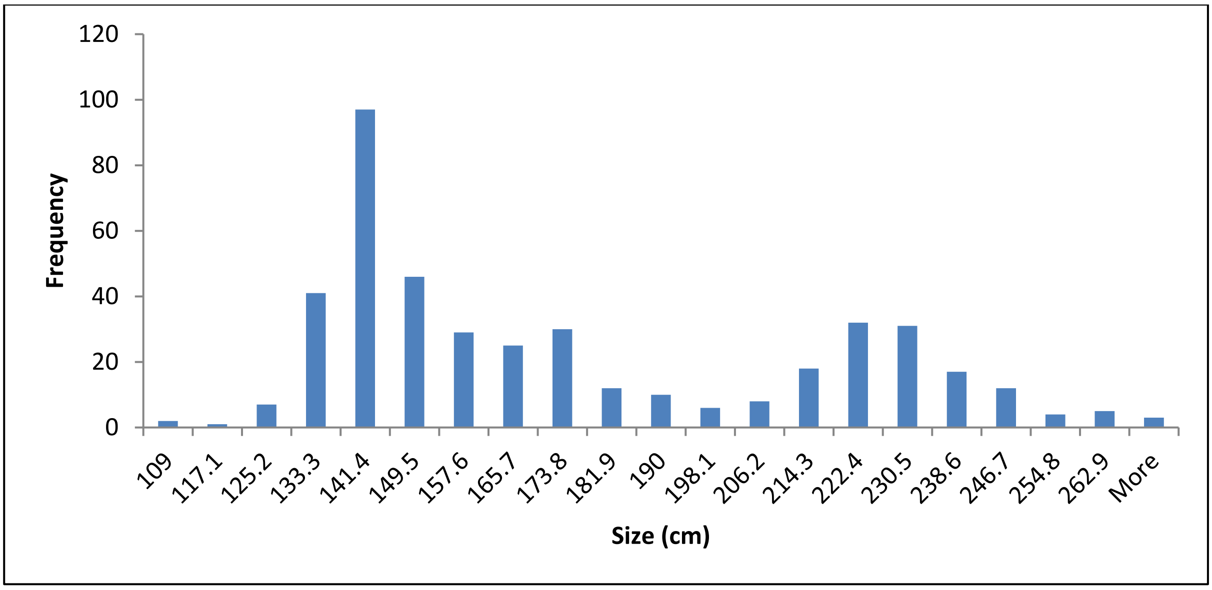

Figure 4. Histogram showing the size frequency distribution of the *Thunnus thynnus* individuals included in the dataset. Distribution appears to be bimodal.