LENGTH-WEIGHT RELATIONSHIPS FOR THE MEDITERRANEAN SWORDFISH

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SUMMARY

The present paper presents different length-weight relationships for Mediterranean swordfish based on extended series of data obtained from various fisheries operating in different parts of the Mediterranean Sea. The performance of the developed length-weight models has been tested against those previously used in ICCAT/SCRS and the adoption of new equations relating Lower Jaw Fork Length (LJFL) to Gilled-Gutted (GG) and Gutted (GW) weights is suggested.

RÉSUMÉ

Ce document présente différentes relations taille-poids concernant l'espadon de la Méditerranée sur la base d'une longue série de données provenant de plusieurs pêcheries opérant dans différentes parties de la mer Méditerranée. Les performances des modèles taille-poids développés ont été testées par rapport à celles précédemment utilisées par le SCRS et l'adoption de nouvelles équations reliant la longueur maxillaire inférieur-fourche (LJFL) au poids éviscéré et sans branchies (GG) et au poids éviscéré (GW) est suggérée.

RESUMEN

Este documento presenta las diferentes relaciones talla-peso para el pez espada del Mediterráneo basadas en una larga serie temporal de datos procedentes de varias pesquerías que operan en diferentes zonas del Mediterráneo. Se ha probado el rendimiento de los modelos talla-peso respecto a los utilizados anteriormente en el SCRS/ICCAT y se sugiere la adopción de nuevas ecuaciones para la longitud mandíbula inferior a la horquilla (LJFL) respecto a los pesos eviscerado y sin agallas (GG) y eviscerado (GW).

KEYWORDS

Length-weight relationships, Swordfish, Mediterranean

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1 Introduction

Information on the estimates of the parameters of the standard allometric equation that is used to predict weight from length measurements is essential for stock assessment studies and for various management scenario evaluations. In the case of the Mediterranean swordfish, the various fisheries are landing their catches in different condition (round, gilled and gutted, etc) and several past authors have proposed length-weight relationships that allow estimates of various weight forms from lower jaw-fork length (LJFL) measurements (e.g. De Metrio & Megalofonou 1987; Tsimenides and Tserpes 1989; Mejuto and de la Serna 1993; De la Serna *et al.* 1995; Hattour 1996; Orsi-Relini *et al*. 1999; Alicli and Oray 2001; Tserpes et al. 2003; Abid et. al. 2014).

For the needs of the various assessment studies, ICCAT has adopted a Mediterranean-wide equation for the LJFL – gilled and gutted weight (GG) that is dated back to the late 1980's and it is based on data from a rather local Italian fishery (De Metrio & Megalofonou 1987). Recently, it has been proposed the use of a LJFL – live weight (RW) relationship that is based on data from the Spanish fisheries exploiting the western Mediterranean basin (Mejuto & de la Serna 1993). The main objective of the present work is to provide updated information regarding Mediterranean-wide length-weight relationships through the analysis of extended data series from various fisheries operating in different parts of the Mediterranean Sea.

2 Materials and Methods

Various swordfish Length (cm) - Weight (kg) measurements were available from the catches of different national fisheries, operating in the Mediterranean in the period 1987-2014. Specifically: (a) a total of 41202 LJFL - Gutted weight (GW) measurements were obtained from Italian, Spanish and Moroccan fisheries mainly exploiting the western part of the Mediterranean basin, (b) 32949 LJFL - Gilled Gutted weight (GG) measurements were available from Italian and Greek fisheries exploiting the central and eastern parts of the basin and (c) 1408 LJFL - Round Weight (RW) measurements were available from the Turkish fisheries mainly exploiting the eastern part of the Aegean Sea.

Before proceeding with the analysis of the three data sets, a visual inspection of the data was performed in order to identify highly suspicious values that were automatically removed by drawing ellipse-like confidence regions of extremely high (0.999999) probability (Fox and Weisberg 2011). In this way 63 LJFL-GW, 181 LJFL-GG and seven LJFL-RW observations were removed.

The parameters *a* and *b* of the classical LJFL – weight (GW, GG, RW) relationship, $W = aL^b$ were determined by means of non-linear robust regression under the R language environment using the "nlrob" function of the "robustbase" package which employs an iterated re-weighted least squares algorithm (Maronna et al., 2006). The use of robust regression, instead of the ordinary one was preferred as it gives less weight in the more "distant" values; thus decreases the impact on the parameter estimates of outliers that cannot be visually identified and *a priori* removed. In order to evaluate the prediction accuracy of the estimated equations a certain number of observations was excluded from the analysis and was used as a "test set" for the prediction of weights from the given LJFL measurements. The test data sets were consisted of values randomly selected from the initial sets following the distribution of data in quartiles and included 1000 observations in the case of the LJFL-GW and LJFL-GG data sets. Due to the small size of the LJFL-RW data set, the test set included in this case only 100 observations.

For comparisons, predictions were also made based on the currently assumed equations in ICCAT. Predictions were related to the observed values through linear regressions forced to pass through the origin. The estimated values of R-squared and regression slopes (ideally should be 1) were used to evaluate the accuracy of the examined models.

As preliminary analysis (not shown here) demonstrated statistical differences among fisheries, the final data sets were balanced by including equal number of observations from the various fisheries in order to arrive in, as much as possible, representative equations for the whole Mediterranean.

All statistical inference was based on the 95% significance level.

3. Results

LJFL – GW
Summary statistics of both, the modeled and the test data sets are shown in **Table 1**. The estimated model parameters are shown on **Table 2**. The parameters of the linear model relating predicted GW rates of the "test dataset" with the observed ones suggested that the estimated model provides satisfactory accuracy levels (R-squared=0.98, slope=0.95). The test data points together with the corresponding model predictions are illustrated in **Figure 1**.

LJFL – GG
Summary statistics of both, the modeled and the test data sets are shown in **Table 3**, while the estimated model parameters are shown on **Table 4**. The parameters of the linear models relating predicted GG values of the "test dataset" with the observed ones suggested that the current model performs better than the currently assumed in ICCAT (**Table 5**). Generally, the existing ICCAT model (a=0.0000057, b=3.16) overestimates weight, and the total weight of the test data set is estimated to be about 11% higher than the actual one (30787, instead of 27808 kg). The test data points, together with the corresponding model predictions, are illustrated in **Figure 2**.

LJFL – RW
Summary statistics of both, the modeled and test datasets are shown on **Table 6**, while the estimated parameters are shown on **Table 7**. The median values indicate that the datasets are dominated by juveniles. The correlation coefficients and slopes of the linear models relating predicted RW values of the "test dataset" with the observed ones suggested that the current model fits far better to the test data than the ICCAT model (a=0.00000089, b=3.554738) (**Table 8**). Generally the ICCAT model tends to overestimate the RW of fish of the data set that are larger than 100cm (**Figure 3**).

For comparisons, **Table 9** shows the GG, GW, and RW model estimates for a range of lengths, together with the RW estimates obtained from the ICCAT equation and the existing conversion factors RW=1.12*GG and RW=1.14*GG, for the Mediterranean and the Atlantic respectively. Relevant plots are shown in **Figure 4**.

4. Discussion

In the past, several LJFL – weight relationships for the Mediterranean swordfish have been developed based on data collected from the landings of various fisheries (Hattour 1996; De Metrio & Megalofonou 1987; Tsimenides and Tserpes 1989; de la Serna *et al.* 1995). Although statistical comparisons among areas are limited, it has been suggested that length-weight conversions should be preferably based on models specifically developed for each fishery and fishing period, as fish are neither in the same physiological condition throughout the year, nor always dressed in the same way (Tserpes et al. 2003). This statement is also supported from the preliminary analysis carried out in the present study. However, the development of representative Mediterranean-wide length-weight equations is essential for the realization of stock assessment studies and management scenario evaluations. In addition such equations could be used for conversions when models based on local data are not available.

The currently estimated LJFL-GW and LJFL-GG relationships are based on large datasets from the most important Mediterranean fisheries and in the case of the LJFL-GG relationship our findings indicated that it performs better than the equation previously used in various SCRS/ICCAT groups. In addition, the non-linear modeling approach that has been followed in the present study allowed the unbiased estimates of confidence intervals for the equation parameters, which were not previously computed. Hence the proposed equation is statistically more robust and could be generalized. The same can be said for the LJFL-GW equation, which performs well on the test dataset. The parameters of both equations are summarized in **Table 10**.

On the contrary, the estimated LJFL-RW relationship was based on data coming from a rather confined area of the eastern Mediterranean and the sample was dominated by young individuals. The resulted RW estimates are in several cases incompatible with those obtained from the LJFL-GG and LJFL-GW relationships (**Table 9**) and are probably biased. Therefore, generalization of this equation is not advisable. Regarding the corresponding ICCAT equation, this underestimates the RW of young fish, while the RW of individuals >150 cm seems to be overestimated. In that sense, this equation is not also recommended for use on a Mediterranean-wide basis. Until further data are analyzed, it may be better to adopt for global use only the estimated LJFL-GW and LJFL-GG relationships and use conversion factors (multipliers) for estimating RW from GG. In this case, the 1.14 multiplier, adopted for the Atlantic swordfish (ICCAT 1993), probably performs better than the poorly documented 1.12 one, which is currently in use in the Mediterranean (**Figure 4**).

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Table 1. Summary LJFL statistics of the modeled and test data-sets used in the LJFL-GW analysis.

Dataset	Min	Median	Mean	Max	N
Modeled	57	123	126	255	17419
Test	65	113.8	117.7	215	1000

Table 2. Coefficients of the estimated LJFL-GW relationship *($GW=a\ LJFL^b$).*

Coefficient	Estimate	Std. Error
a	0.00000645	0.000000187
b	3.129	0.00575

Table 3. Summary LJFL statistics of the modeled and test data-sets used in the LJFL-GG analysis.

Dataset	Min	Median	Mean	Max	N
Modeled	52	130	133.5	290	23529
Test	50	125	129.7	220	1000

Table 4. Coefficients of the estimated LJFL-GG relationship *($GG=a\ LJFL^b$)*

Coefficient	Estimate	Std. Error
a	0.00000843	0.000000251
b	3.059	0.005871

Table 5. Parameters of the linear regression models fitted to the estimated – observed GG data of the "test dataset", based on the current and ICCAT models. The last column indicates the predicted total weight of the test data-set and its % difference (in parenthesis) from the actual one (27808 kg).

Model	R-squared	Slope	Total Weight
Current	0.968	0.967	27720(-0.31%)
ICCAT	0.967	1.089	30875(11.03%)

Table 6. Summary LJFL statistics of the modeled and test data-sets used in the LJFL-RW analysis.

Dataset	Min	Median	Mean	Max	N
Modeled	51	80	94.88	242	1143
Test	59	78.5	92.51	169	100

Table 7. Coefficients of the estimated LJFL-RW relationship *($RW=a\ LJFL^b$).*

Coefficient	Estimate	Std. Error
a	0.0000038	0.000000189
b	3.234	0.00999

Table 8. Parameters of the linear regression models fitted to the estimated – observed RW data of the "test dataset", based on the current and ICCAT models. The last column indicates the predicted total weight of the test data-set and its % difference (in parenthesis) from the actual one (1216 kg).

Model	R-squared	Slope	Total Weight
Current	0.982	0.980	1196(-1.68%)
ICCAT	0.975	1.127	1298(6.71%)

Table 9. Different weight at length estimates based on the currently estimated parameters (columns 2-4) and past formulas.

LJFL	GG	GW	RW	ICCAT-RW	RW=1.12*GG	RW=1.14*GG
80	5.59	5.81	5.42	5.19	6.26	6.37
85	6.73	7.03	6.60	6.43	7.54	7.67
90	8.01	8.40	7.94	7.88	8.97	9.13
95	9.46	9.95	9.46	9.55	10.60	10.78
100	11.06	11.68	11.16	11.47	12.39	12.61
105	12.84	13.61	13.07	13.64	14.38	14.64
110	14.81	15.74	15.19	16.09	16.59	16.88
115	16.96	18.09	17.54	18.84	19.00	19.33
120	19.32	20.67	20.13	21.92	21.64	22.02
125	21.89	23.49	22.97	25.35	24.52	24.95
130	24.68	26.55	26.08	29.14	27.64	28.14
135	27.70	29.88	29.46	33.32	31.02	31.58
140	30.96	33.48	33.14	37.92	34.68	35.29
145	34.47	37.37	37.12	42.96	38.61	39.30
150	38.24	41.55	41.43	48.46	42.83	43.59
155	42.27	46.04	46.06	54.45	47.34	48.19
160	46.58	50.85	51.04	60.96	52.17	53.10
165	51.18	55.98	56.38	68.01	57.32	58.35
170	56.08	61.47	62.09	75.62	62.81	63.93
175	61.27	67.30	68.20	83.83	68.62	69.85
180	66.79	73.50	74.70	92.66	74.80	76.14
185	72.63	80.08	81.62	102.14	81.35	82.80
190	78.80	87.05	88.98	112.29	88.26	89.83
195	85.32	94.42	96.77	123.16	95.56	97.26
200	92.19	102.21	105.03	134.76	103.25	105.10

Table 10. Coefficients of the estimated LJFL-GG and LJFL-GW relationships

Coefficient	GG	GW
a	8.43E-06	6.45E-06
b	3.059	3.129

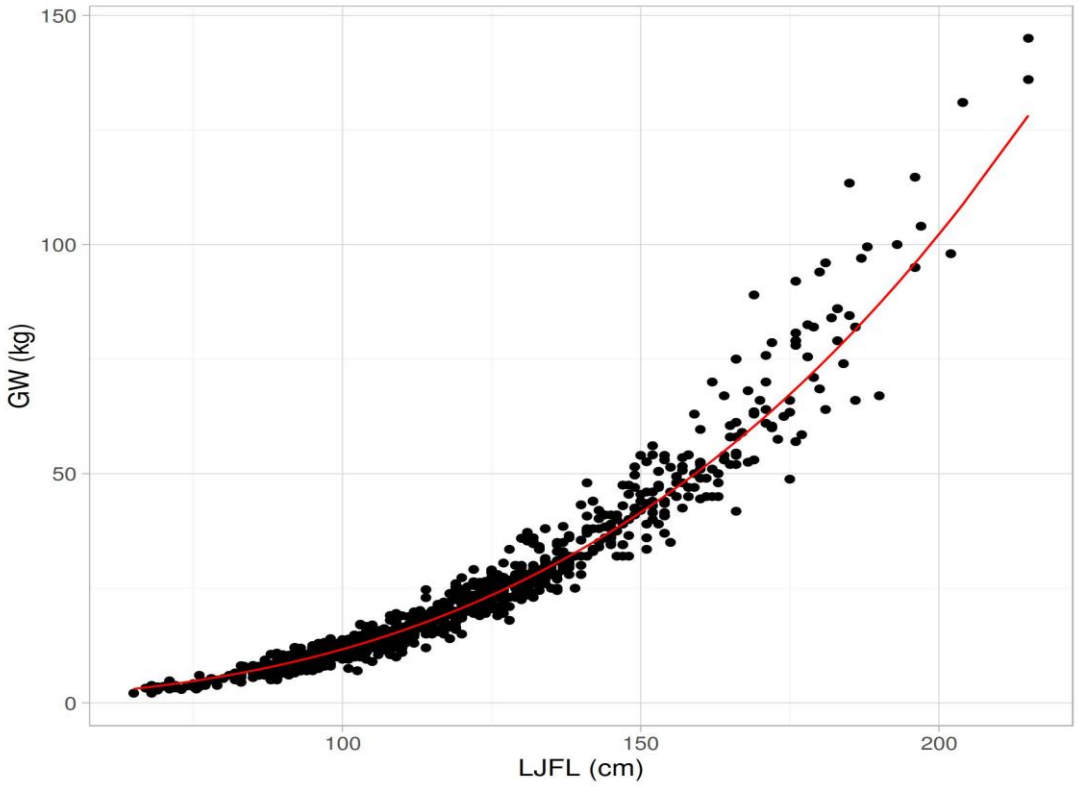

Figure 1. LJFL-GW data of the "test dataset". Red line corresponds to model estimates.

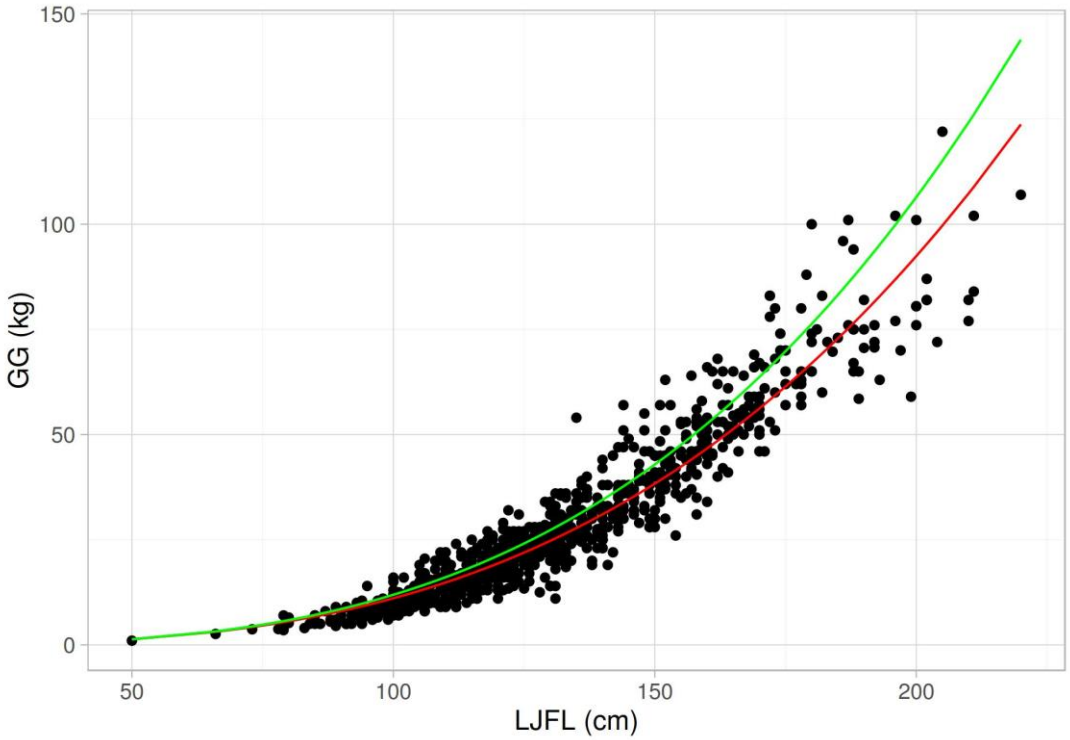

Figure 2. LJFL-GG data of the "test dataset". Lines correspond to the estimates of the current (red) and ICCAT (green) models.

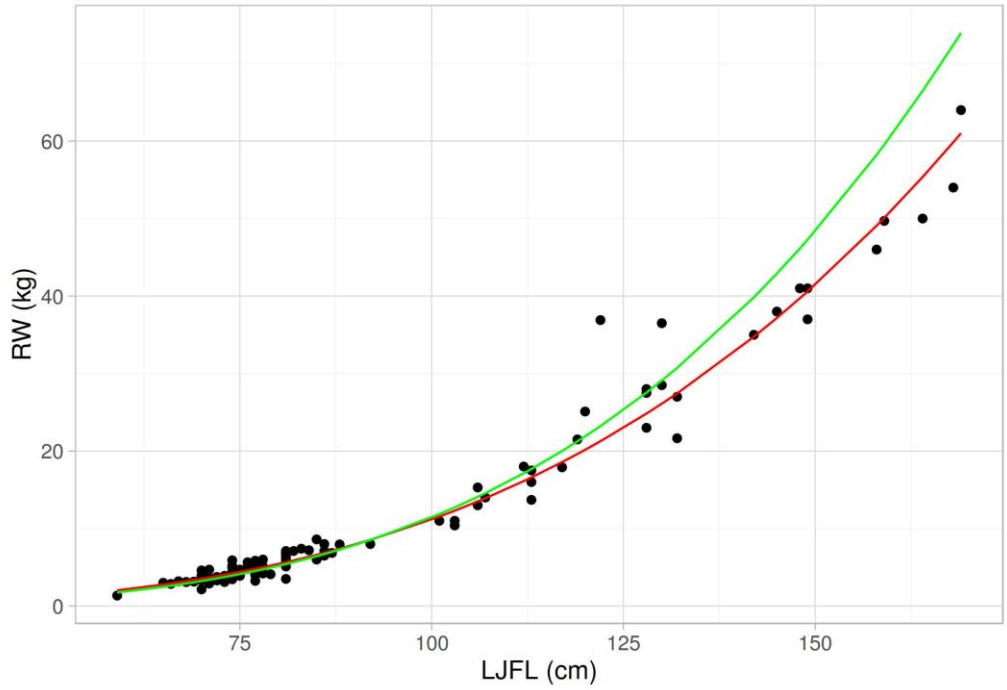

Figure 3. LJFL-RW data of the "test dataset". Lines correspond to the estimates of the current (red) and ICCAT (green) models.

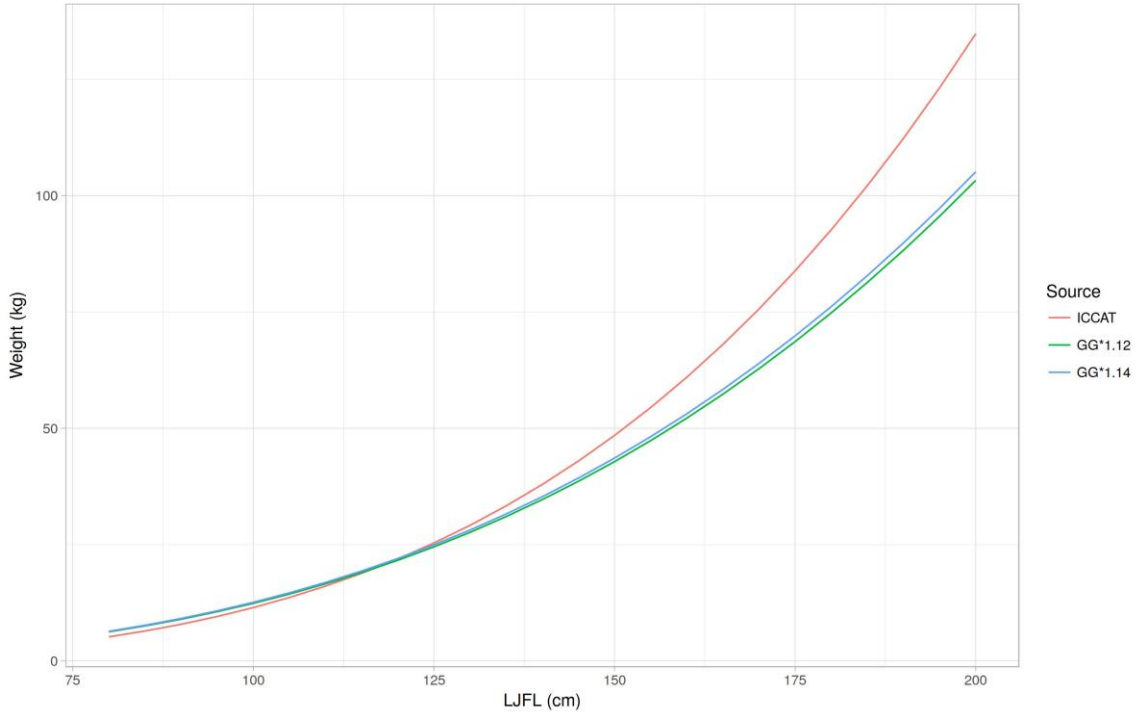

Figure 4. Plots of different LJFL-RW relationships including the one currently used in ICCAT and those based on GG conversion factors.