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LENGTH-WEIGHT RELATIONSHIPS, CONVERSION FACTOR AND MONTHLY SIZE FREQUENCY DISTRIBUTION FOR SWORDFISH CAUGHT BY LONGLINERS IN THE MEDITERRANEAN SEA

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SUMMARY

The current study presents length-weight relationships and conversion factor related to size and weight of the Mediterranean swordfish caught by longliners in the Mediterranean Sea. Size to weight relationships and weight to weight conversion factor were obtained from 660 specimens collected during the months of May (n=88), June (n=227), July (n=53), August (n=164) and September (n=128) 2017 from longliners operating in the central area of the Mediterranean Sea. Moreover monthly frequency distribution of swordfish catches, related to the same fishing period and area, are also provided. Biomass comparison using different length-weight relationships and different conversion factors was also performed in order to identify possible differences between the ICCAT adopted equations, the equations proposed by different authors and the current equation. The authors highly recommend using the length-weight relationships and conversion factor proposed in this study for the central area of the Mediterranean swordfish. These results provide important information for stock assessment studies and management evaluations of this species.

KEYWORDS: *Xiphias gladius, length-weight relationship, RWT, GWT, LJFL, size, Mediterranean sea, longliners.*

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1. Introduction

Swordfish (*Xiphias gladius*) is a broad-based large pelagic species found in the tropical and temperate waters of all the oceans, between 45°N and 45°S. It is a commercially important migratory fish heavily exploited in the Atlantic Ocean and the Mediterranean Sea (Tserpes et al., 2003; Froese and Pauly, 2016; Lombardo et al., 2017).

According to ICCAT records (2003-2014), EU-Italy is the biggest producer of swordfish in the Mediterranean Sea followed by Morocco (14%), EU-Spain (13%), EU-Greece (10%) and Tunisia (8%). The main fishing gears used are: the drifting surface longlines (traditional fishing gear) and the American type gear which is set deeper than the traditional one and always employs fluorescent material to attract the fish (Tserpes et at. 2002).

Information on the estimates of the parameters of the standard allometric equation that is used to predict weight from length measurements, and *viceversa*, is essential for stock assessment studies and for management scenario evaluations. In the case of the Mediterranean swordfish, fish are landed and weighted in different condition as round weight (RWT), gilled-gutted weight (GWT) and dressed weight (DWT) and during the past decades many authors have proposed length-weight relationships that allow estimates of these different 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; Tserpes et al., 2003; Abid et. al., 2014, Lombardo et al., 2017).

In the past, ICCAT has adopted a quite dated (late 1980's) Mediterranean wide equation for the LJFL-GWT based on data from Italian fishery for the needs of the various assessment studies and management evaluations (De Metrio & Megalofonou, 1987). Recently, it has been proposed the use of a LJFL-RWT relationship that is based on data from the Spanish fisheries exploiting the western Mediterranean basin (Mejuto & de la Serna, 1993; Tserpes et al., 2016).

The main objective of the present study is to provide new length-weight relationships (LJFL-RWT and LJFL-GWT) and conversion factor (RWT-GWT) for Mediterranean swordfish based on data obtained from Italian longline fishery operating in the central part of the Mediterranean Sea. A biomass comparison using the dataset of the present study was performed in order to test possible differences of using different L-W relationships (ICCAT, Tserpes at al., 2016; Abid et al., 2013) and conversion factors (ICCAT).

2. Materials & Methods

Data have been collected in the frame national project funded by MiPAAF-Italy to the Department of Life and Environmental Sciences (DiSVA) - Università Politecnica delle Marche, Ancona (Italy) with the support of OCEANIS Srl (Italy). It included spatial and temporal information on catches and landings, biometric data collection and biological sampling throughout individual boat trips and landings monitoring. Scientific national observers monitored and covered the activities of the Italian fishing longline vessels exploiting different areas of the central Mediterranean Sea where fishing is mainly carried out all year round from April to September as it is prohibited by national law from October to November and from January to March.

A total of 684 biometric measurements (both sexes combined) were obtained from the catches of various Italian fleets operating in different areas of the central Mediterranean Sea. All observations (684) concerned LJFL (cm), RWT (kg) and GWT (kg) measurements. In this case, an initial visual inspection of the dataset identified 24 extreme outliers that were excluded from further analyses; hence a total of 660 observations were finally analysed. The size of fish was measured to the nearest centimeter from the tip of the lower jaw to the fork of the tail (LJFL) using a measuring tape and the whole body weight (RWT and GWT) was measured to the nearest g for each fish.

The size data were aggregated by 10 cm intervals in order to estimate the monthly size frequencies distribution and, regarding length-weight relationships and conversion factor, the correlation coefficients (R^2) was used to evaluate the accuracy of the examined equations.

Biomass comparison was performed using the entire period dataset of the present study to test possible differences of using different LJFL-RWT relationships (Current: $RWT=1{,}42E^{-06}LJFL^{3{,}456}$; ICCAT: RWT=8,9E-

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$^{07}LJFL^{3,5547}$, Tserpes: $RWT=5,94E^{-06}LJFL^{3,138}$), different LJFL-GWT relationships (Current: $GWT=2,06E^{-06}LJFL^{3,341}$; ICCAT: $5,7E^{-06}LJFL^{3,16}$; Tserpes: $GWT=7,83E^{-06}LJFL^{3,083}$; Abid: $GWT=2,00E^{-06}LJFL^{3,373}$) and different RWT-GWT conversion factors (Currrent: RWT=1,25GWT-0,6; ICCAT: RWT=1,12GWT). The comparisons were made to the total RWT and GWT of the current dataset data.

3.Results

The main fishing ground of the Italian longline fleet monitored for the current study is shown in Fig. 1.

A total of 660 biometric data records were analysed, which were collected during the fishing period May-September 2017 from onboard observations and landings in the main national harbors (Sicily and south Italy).

Table 1 summarizes the statistics of the number and the percentage of fish sampled by month and for the entire study period May-September 2017. Fish was sampled during the months of: May (13,3%), June (34,4%), July (8,0%), August (24,8%) and September (19,4%).

Considering the all dataset May-Sept with no monthly differences, fish size ranges from 83 to 225 cm LJFL and from 7 to 194 kg RWT. However, sizes between 100-140 cm LJFL represent 79,1% of the total catches and weights <40 kg represent 81,8% of the total catches. The monthly size frequency distributions of swordfish catches during the fishing period May-September is shown in Fig. 2 and, as percentage, in Fig. 3. It can be noted that the monthly percentages of the catches are small fish (100-140 cm LJFL): May (72,7%), June (74,9%), August (80,5%), September (94,5%) while slightly bigger fish (120-160 cm LJFL) were mainly caught on July (83,0%).

The estimated length-weight (LJFL-RWT) relationship parameters (a, b) of the linear transformation of the classical L–W relationship ($W=aL^b$), the number of fish sampled, the size range and the coefficient of determination (R^2) corresponding to the length-weight relationships by month and for the entire season are summarized in Table 2 and shown in Fig. 4.

The estimated length-weight (LJFL-GWT) relationship parameters (a, b) of the linear transformation of the classical L–W relationship ($W=aL^b$) the number of fish sampled, the size range and the coefficient of determination (R^2) corresponding to the length-weight relationships by month and for the entire season, are summarized in Table 3 and shown in Fig. 5.

The estimated weight-weight (RWT-GWT) relationship parameters (a, b) of the linear W_1–W_2 relationship ($W_1=aW_2+b$), the number of fish sampled, the size range and the coefficient of determination (R^2) corresponding to the weight-weight relationships by month and for the entire season, are summarized in Table 4 and shown in Fig. 6.

Biomass comparison results are shown in Table 5 and Fig.7. The biomass comparisons were performed using as reference (100%) the total RWT (18,54t) obtained during the current study and the results obtained using different equations: 18,42t (-0,7%), 18,78t (+1,3%), and 16,10t (-13,2%) if LJFL-RWT relationship of the current study, ICCAT and Tserpes relationships are respectively used and statistical analyses; 15,17t (-0,35%), 17,23t (+13,21%), 16,22t (+6,54%) and 17,25t (+13,31%) if LJFL-GWT relationship of the current study, ICCAT, Tserpes and Abid relationships are respectively used; 17,05t (-8%) and 18,63 (+0,5%) if RWT-GWT relationship of the current study and ICCAT equation are respectively used and compared. Statistical analyses, using Student's t-test showed significant differences ($p<0,05$) between the equations.

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4. Discussion

In the past, several length–weight relationships for the Mediterranean swordfish have been developed based on data collected from the landings of various fisheries. Although statistical comparisons among areas are limited, it has been suggested that length-weight equations 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 processed in the same way (Tserpes et al., 2003). However, the development of specific Mediterranean length-weight equations is essential for stock assessment studies and management evaluations. In addition they could be used for length-weight and weight-weight conversions when complete biometric data are not available. The current estimated LJFL-RWT and LJFL-GWT equations are based on a large dataset (660) from the most important Mediterranean longliners and our results indicated a slightly better estimation of the total biomass caught during the studied period than that of the equations which have been previously used in various SCRS/ICCAT groups.

On the other hand, the estimated RWT-GWT conversion factor appears much more accurate than those of the corresponding ICCAT equation since the ICCAT equation tended to underestimate RWT probably due to the fact that such ICCAT equation does not take into account the geographic origin of the data. In that sense, neither the ICCAT equation for estimating RWT from GWT should be used on a Mediterranean-wide basis.

Regarding the monthly size and weight frequency distribution, our results showed a high percentage of small swordfish catches during May-September (100-140 cm LJFL and <40 kg RWT) which, on the basis of our new findings regarding the size at first maturity of this species (data not included), should be well considered for further management scenario evaluations as the advice for the minimum catch-at-size (at the moment set at 100 cm LJFL).

Moreover, in the following case of estimating the total biomass caught by Italian longliners from May to September 2017 using different LJFL-RWT relationships, 0,7% underestimation, 1,3% overestimation and 13,2% underestimation were found if using the current equation, the ICCAT equation and the equation proposed by Tserpes et al. 2016 respectively been the latest significant different ($p<0,05$). Using different LJFL-GWT relationships, 0,4%, underestimation was found if using the current equation while 13,2%, 6,5% and 13,3% significant overestimations ($p<0,05$) were found if using the ICCAT, Tserpese and Abid equations respectively. An overestimation of 0,5% was evidenced using the RWT-GWT conversion factor of the current study while a significant underestimation ($p<0,05$) of 8% was obtained if using the ICCAT conversion factor. Until further data are collected and analyzed, for swordfish stock assessment and management evaluation purposes, the authors recommend to adopt only for the central part of the Mediterranean swordfish catches the estimated LJFL-RWT and the LJFL-GWT relationships obtained in this study ($RWT=1,42E^{-06}LJFL^{3,456}$; $GWT=2,06E^{-6}LJFL^{3,341}$) as well as the conversion factor (RWT=1,25GWT-0,6) for estimating RWT from GWT.

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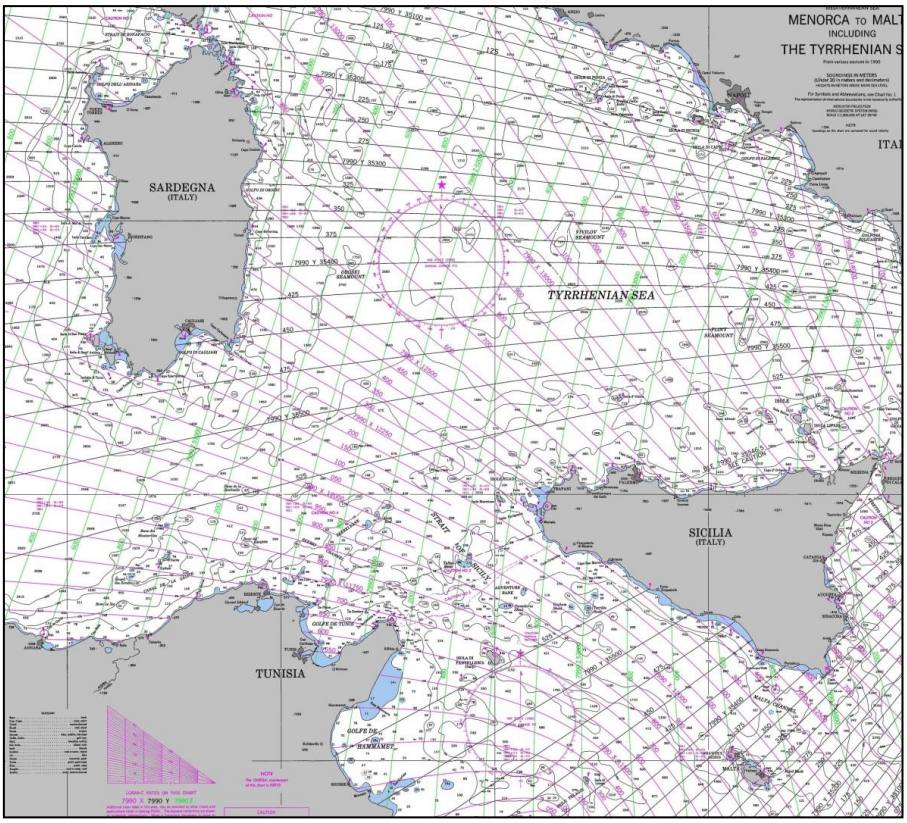

Figure 1. Fishing grounds of the Italian longline fleet targeting swordfish in the Mediterranean Sea.

Table 1. Summary statistics of the number of fish sampled for size (cm) and weight (kg) by month and for the entire period May-September 2017.

Date	Month	n	Min LJFL	Median LJFL	Mean LJFL	Max LJFL	Min RWT	Median RWT	Mean RWT	Max RWT	%
3-31	May	88	92	127	130	225	8	25	36	194	13,3
1-19	Jun	227	83	122	126	202	7	25	31	105	34,4
11-24	Jul	53	106	128	136	198	15	31	39	119	8,0
10-28	Aug	164	90	116	121	182	7	20	25	95	24,8
4-8	Sept	128	88	108	111	172	8	14	16	59	19,4
Entire period		660	83	120	123	225	7	22	28	194	100

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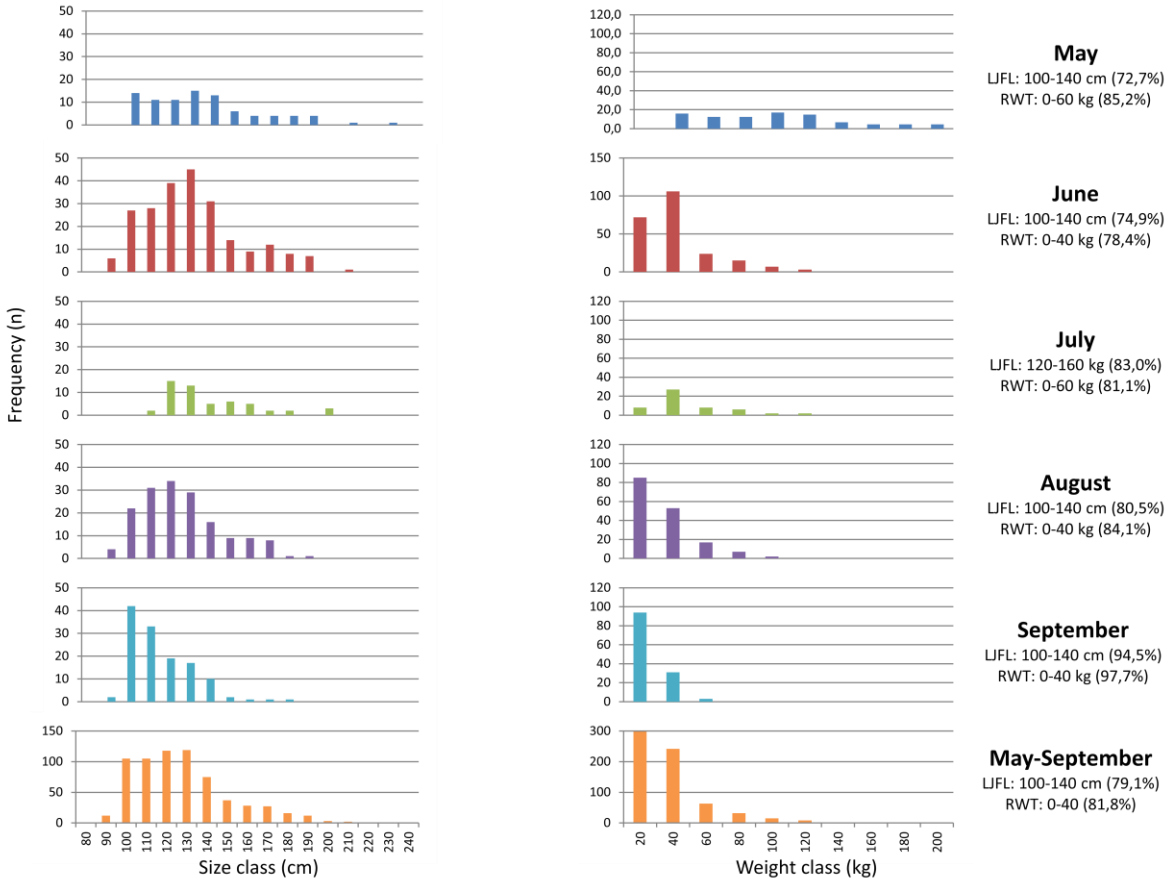

Figure 2. On the left panel, monthly size (LJFL) and on the right panel monthly weight (RWT) frequency distribution for Mediterranean swordfish caught by longliners in the Mediterranean Sea during the fishing period May-September 2017.

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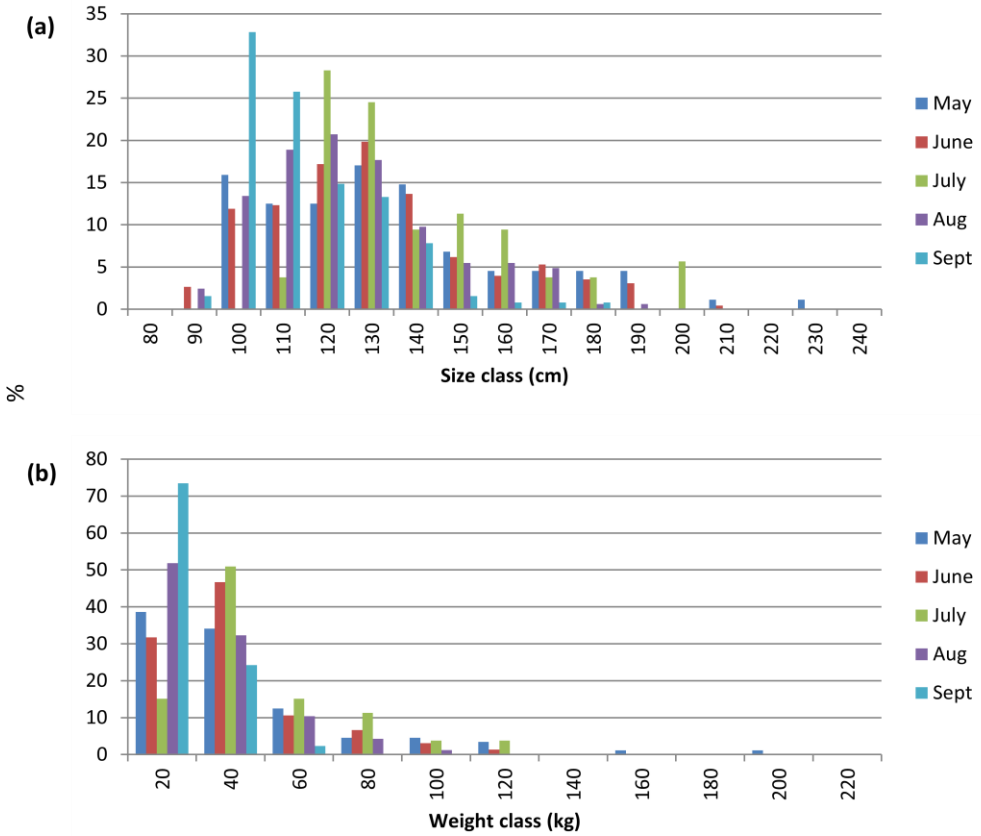

Figure 3. Percentage of the monthly size (a) and weight (b) frequency distribution for Mediterranean swordfish caught by longliners in the Mediterranean Sea.

Table 2. Length-weight relationship (LJFL-RWT) parameters (a and b), number of samples, size range and coefficient of determination (R^2) by month and for the entire period May-September 2017.

Temporal Strata	n	LJFL (cm)	RWT (kg)	a	b	R^2
May	88	92-225	8-194	$6,67x10^{-7}$	3,607	0,97
Jun	227	83-202	7-105	$3,50x10^{-6}$	3,278	0,95
Jul	53	106-198	15-119	$5,24x10^{-6}$	3,199	0,95
Aug	164	90-182	7-95	$1,29x10^{-6}$	3,475	0,96
Sept	128	88-172	8-59	$2,60x10^{-6}$	3,311	0,94
Entire period	660	83-225	7-194	$1,42x10^{-6}$	3,456	0,96

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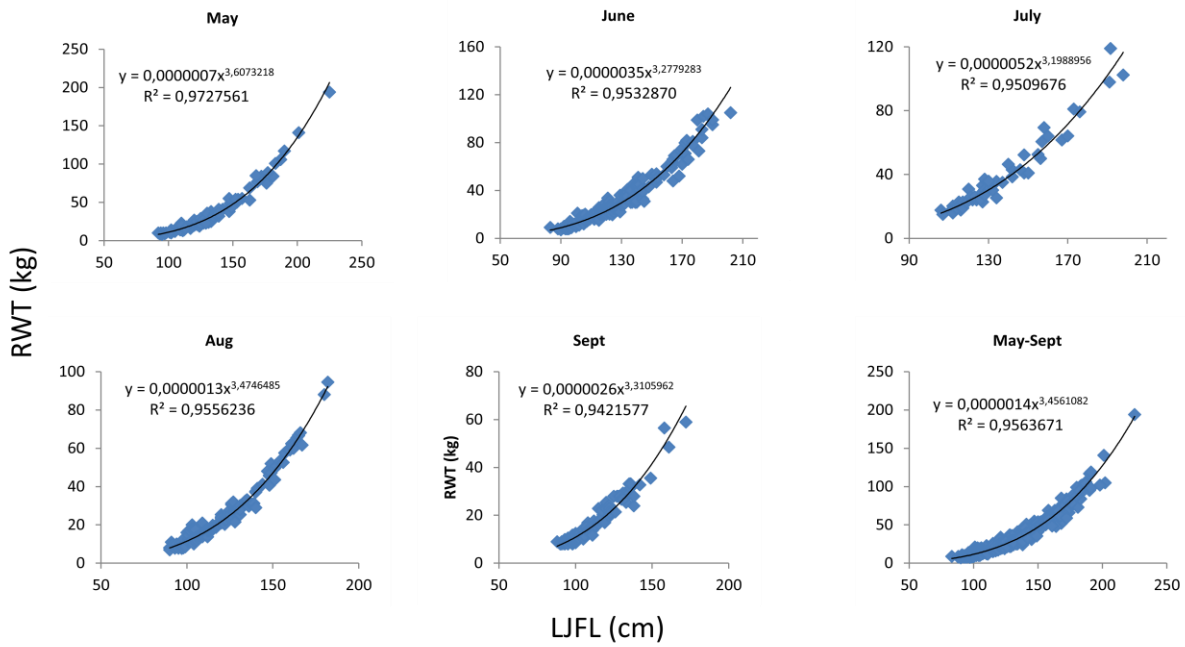

Figure 4. Length-weight (LJFL-RWT) relationships by month and for the entire period May-September 2017 for Mediterranean swordfish caught by longliners in the Mediterranean Sea.

Table 3. Length-weight relationship (LJFL-GWT) parameters (a and b), number of samples, size range and coefficient of determination (R^2) by month and for the entire period May-September 2017.

Temporal Strata	n	LJFL (cm)	GWT (kg)	a	b	R^2
May	88	92-225	7-151	$1{,}52\times10^{-6}$	3,403	0,97
Jun	227	83-202	5-98	$3{,}01\times10^{-6}$	3,267	0,96
Jul	53	106-198	14-94	$8{,}62\times10^{-6}$	3,056	0,95
Aug	164	90-182	6-74	$2{,}24\times10^{-7}$	3,321	0,97
Sept	128	88-172	6-53	$2{,}76\times10^{-8}$	3,268	0,95
Entire period	660	83-225	5-151	$2{,}06\times10^{-6}$	3,341	0,97

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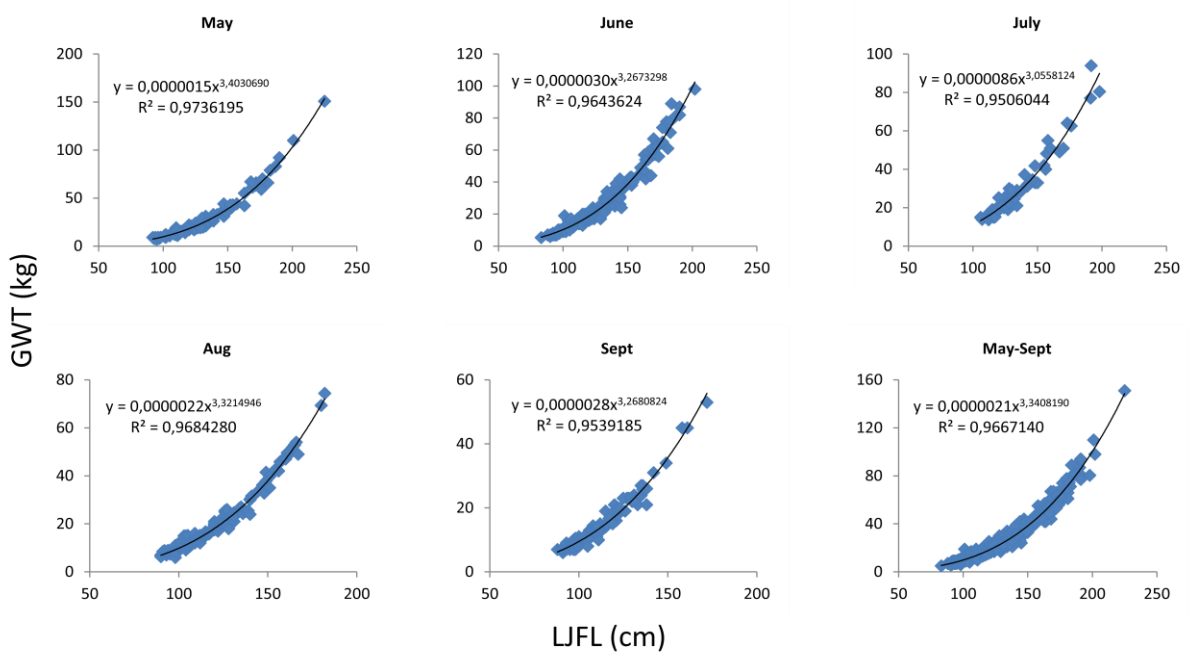

Figure 5. Length-weight (LJFL-GWT) relationships by month and for the entire period May-September 2017 for Mediterranean swordfish caught by longliners in the Mediterranean Sea.

Table 4. Weight-weight relationship (RWT-GWT) parameters (a and b), number of samples, size range and coefficient of determination (R^2) by month and for the entire period May-September 2017.

Temporal Strata	n	RWT (kg)	GWT (kg)	a	b	R^2
May	88	8-194	7-151	1,2966	-1,8173	0,9998
Jun	227	7-105	5-98	1,1762	+1,1348	0,9848
Jul	53	15-119	14-94	0,7748	+1,2082	0,9994
Aug	164	7-95	6-74	0,7796	+1,0112	0,9974
Sept	128	8-59	6-53	1,5059	+5,1422	0,9801
Entire period	660	7-194	5-151	1,2455	-0,6345	0,9919

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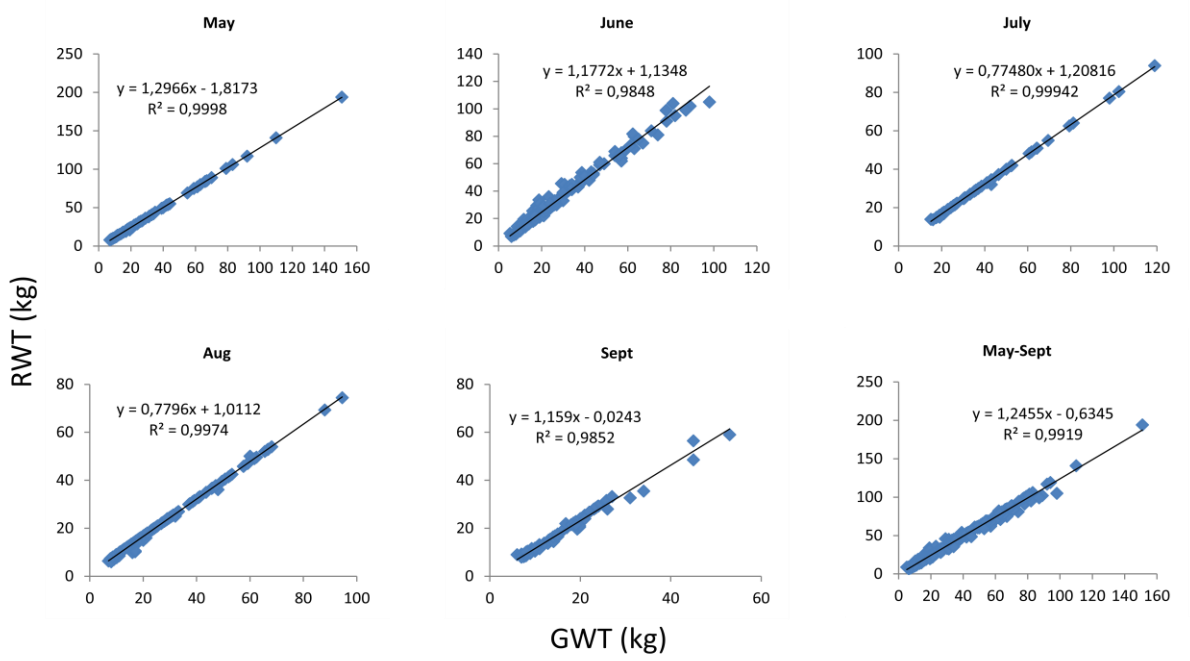

Figure 6. Weight-weight (RWT-GWT) relationships by month and for the entire period May-September 2017 for Mediterranean swordfish caught by longliners in the Mediterranean Sea.

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(a)

LJFL-RWT

Equation	a	b	Biomass (kg)	Diff. (%)
Real			18536,13	
Current	1,42E-06	3,456	18418,14	-0,7
ICCAT	8,90E-07	3,554738	18779,86	+1,3
Tserpes	5,94E-06	3,138	16101,86	-13,2

(b)

LJFL-GWT

Equation	a	b	Biomass (kg)	Diff. (%)
Real			15220	
Current	2,06E-06	3,341	15166,5844	+0,4
ICCAT	5,70E-06	3,16	17229,8995	-13,2
Tserpes	7,83E-06	3,083	16215,4354	-6,5
Abid	2,00E-06	3,3731	17245,4931	-13,3

(c)

RWT-GWT

Equation	a	b	Biomass (kg)	Diff. (%)
Real			18536,13	
Current	1,25	-0,6	18627,53	+0,5
ICCAT	1,12		17045,08	-8,0

Table 5. Length-weight (a and b) and weight-weight (c) relationships comparisons using the dataset May-September 2017 showing different estimated biomass (as total kg and percentage) of the total swordfish caches.

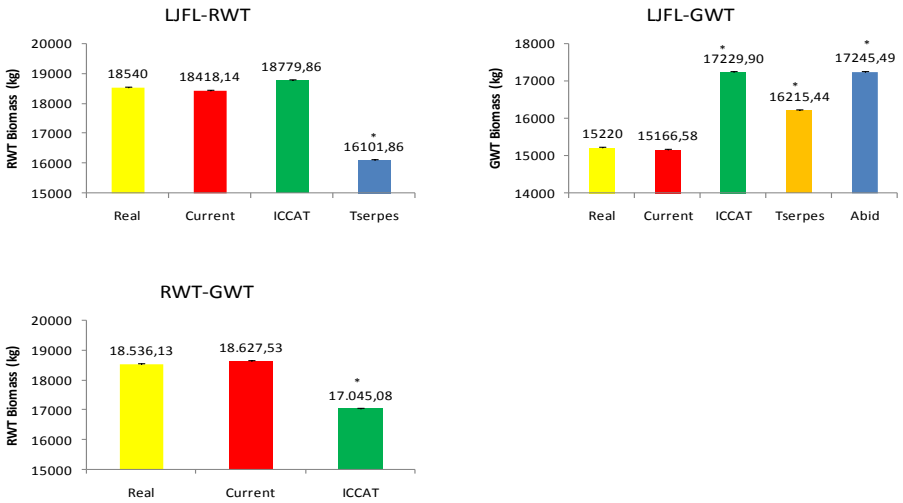

Figure 7. Biomass comparisons using different length-weight relationships and conversion factors for Mediterranean swordfish. Astericks denote significant differences between groups ($p<0,05$) analysed by Student's t-test. (See text for details).

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