

**PRELIMINARY RELATIONSHIP BETWEEN STRAIGHT  
AND CURVED LOWER JAW FORK LENGTH FOR  
SWORDFISH (*XIPHIAS GLADIUS*) IN THE NORTH ATLANTIC**

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SUMMARY

*This document present preliminary information with regards to conversion factors between Straight Lower Jaw Fork Length (S-LJFL) and Curved Lower Jaw Fork Length (C-LJFL) for swordfish (*Xiphias gladius* Linnaeus, 1758) in the North Atlantic. This is part of an ongoing work, and the current sample is composed of 15,139 specimens sampled for both size types. A linear model was used to predict S-LJFL from C-LJFL, with Sex, Area and Month tested as covariates. Preliminary estimates for the equation parameters are provided. The covariates Sex and Month had the larger effects, while Area was not significant. An example of predictions is provided, showing that the differences between C-LJFL and S-LJFL increase as specimens grow to larger sizes, and that the differences are larger for females than for males.*

RÉSUMÉ

*Ce document présente des informations préliminaires concernant les facteurs de conversion entre la longueur droite fourche-maxillaire inférieur (S-LJFL) et la longueur courbée fourche-maxillaire inférieur (C-LJFL) pour l'espadon (*Xiphias gladius* Linnaeus, 1758) dans l'Atlantique Nord. Ceci fait partie d'un travail en cours et l'échantillon actuel est composé de 15.139 spécimens échantillonnés pour les deux types de taille. Un modèle linéaire a été utilisé pour prédire la S-LJFL à partir de la C-LJFL, avec le sexe, la zone et le mois testés comme covariables. Les estimations préliminaires des paramètres de l'équation sont fournies. Les covariables « sexe » et « mois » ont les effets les plus importants, tandis que la « zone » n'est pas significative. Un exemple de prédictions est fourni, montrant que les différences entre C-LJFL et S-LJFL augmentent lorsque les spécimens atteignent des tailles plus importantes, et que les différences sont plus grandes pour les femelles que pour les mâles.*

RESUMEN

*Este documento presenta información preliminar con respecto a los factores de conversión entre la longitud recta mandíbula inferior a horquilla (S-LJFL) y la longitud curva mandíbula inferior a horquilla (C-LJFL) para el pez espada (*Xiphias gladius* Linnaeus, 1758) en el Atlántico norte. Esto forma parte de un trabajo en curso, y la muestra actual está compuesta por 15.139 ejemplares muestreados para ambos tipos de tallas. Se utilizó un modelo lineal para predecir la S-LJFL a partir de la C-LJFL, con el sexo, el área y el mes como covariables. Se ofrecen estimaciones preliminares de los parámetros de la ecuación. Las covariables «sexo» y «mes» tuvieron los mayores efectos, mientras que el «área» no tuvo un efecto significativo. Se proporciona un ejemplo de predicciones, que muestra que las diferencias entre C-LJFL y S-LJFL aumentan a medida que los ejemplares crecen hasta alcanzar tallas mayores, y que las diferencias son mayores para las hembras que para los machos.*

KEYWORDS

*Morphometric relationships, Swordfish, North Atlantic*

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## 1. Introduction

Recently, Di Natale and Garibaldi (2021) raised the issue of introducing bias in size sampling in billfishes when not clearly specifying if the measurements (usually Lower Jaw Fork Length – LJFL) are taken in a straight line or over the curvature of the body. These authors further noted that currently there are no relationships in the ICCAT manual (ICCAT, 2006-2016) to convert between those two measurements for swordfish, which hinders size conversion when the two types of different measurements are taken and reported to ICCAT.

The objective of this paper is to provide preliminary Straight versus Curved LJFL conversion parameters for swordfish. At this stage we present preliminary relationships from data collected by Canada and EU.Portugal that can be used to convert between the two types of measurements. However, the work is ongoing to increase the sample size, cover a wider geographical area (especially in the NE Atlantic) and various time periods, and eventually compare relationships between males and females and over a range of condition factors.

## 2. Methods

### 2.1 Data collection and onboard sampling

Data for this work was collected by the Portuguese and Canadian pelagic longline fleets. The Canadian fleet operates in the NW Atlantic, while the Portuguese fleet operates mainly in the NE Atlantic. Data from the Canadian fleet was available from 178 trips for the years 2003 thru 2021; while data from the Portuguese fleet is at this stage only available from one fishing trip in the fall of 2021 (**Figure 1 and Figure 2**).

For the Portuguese data, measurements were collected by onboard observers from IPMA (*Portuguese Institute for the Ocean and Atmosphere, I.P.*), while collecting data and samples within the Portuguese Program for Biological Sampling (PNAB), carried out within the EU Data Collection Framework (EU-DCF). Measurements in the Canadian fleet were taken by on-board observers as part of the Government of Canada’s at-sea observer program.

Swordfish specimens in both programs were measured for Straight lower jaw fork length (S-LJFL) and Curve lower jaw fork length (C-LJFL). Additional information that is regularly collected by the onboard observers was also taken, namely location, date, sex, and other fisheries and biological parameters.

For the Portuguese fleet, the C-LJFL was taken with a flexible measuring tape placed over the body curvature from the tip of the lower jaw to the fork of the caudal fin. The S-LJFL was taken as a straight line with a long flexible ictiometer (model iK2R from Aquatic BioTechnology) placed on the boat deck and measuring also from the tip of the lower jaw to the fork of the caudal fin. All measurement were taken by the onboard observer immediately after capture and when the fish was placed in the deck, before any fish evisceration or processing took place.

The measurement protocol for C-LJFL in the Canadian fleet was similar to the one used in the Portuguese fleet. The C-LJFL was taken with a flexible measuring tape placed over the body curvature from the tip of the lower jaw to the fork of the caudal fin. The S-LJFL was measured by placing the same flexible measuring tape flat on the boat deck and measuring from the tip of the lower jaw to the fork of the caudal fin. All measurement were taken by the onboard observer immediately after capture and when the fish was placed in the deck, before any fish evisceration or processing took place.

### 2.2 Data QA/QC

In the Canadian data-set, a small subset of values were recorded using a combination of inches and centimetres rather than strictly centimetres. These observations showed linear patterns that strongly diverged from the rest of the data set. To identify these outliers, we applied a filter for values that diverged by more than 25% from their expected position on the regression line. Observation missing month and location were also removed from the dataset.

### 2.3 Data analysis

The model used to convert the size types was a linear model, represented as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_n X_n + \epsilon$$

Where Y represents the response variable (in this case S-LJFL) and X represents the predictors, specifically X<sub>1</sub> (C-LJFL, continuous variable), X<sub>2</sub> (Sex, categorical variable), X<sub>2</sub> (Areas – that correspond to NE and NW Atl where each fleet operates, categorical variable) and X<sub>3</sub> (Months, categorical variable). The  $\beta$  are the parameters to be estimated, noting that sex, fleet and month are used as dummy variables. The interactions were tested but were in general non-significant and therefore not considered at this stage. The error ( $\epsilon$ ) was assumed to be normally distributed and with constant variance. Goodness-of-fit was assessed with the coefficient of determination ( $R^2$ ).

The equations estimated were used to calculate predictions of S-LJFL for several examples of input C-LJFL, with the respective 95% confidence intervals. These predictions were made for each sex and area separately, to compare the sexes over a range of different sizes in each of the North Atlantic Areas.

All analysis was carried out in R language for statistical computing version 4.0.5 (R Core Team, 2021). Maps and plots were created with package “ggplot2” (Wickham, 2016).

## 3. Results

### 3.1 Sample characteristics

A total of 15,139 specimens were measured for both straight and curved LJFL measurements for this preliminary work, with the majority from the NW Atlantic (14,868 from the NW Atlantic collected by the Canadian fleet, and 271 from the NE Atlantic collected by the Portuguese fleet). This included 10,009 females and 5,130 males. The overall sample ranged in size between 69 and 370 cm S-LJFL, with the males ranging between 76 and 264 cm S-LJFL and the females between 69 and 370 cm S-LJFL.

### 3.2 Morphometric relationships

The estimated parameters of the relationship between straight and curved LJFL, with Sex, Area and Month as covariates, is provided in **Table 1**. The analysis of variance table for the regression is provided in **Table 2**, and indicates that the Sex and Month are highly significant, while the Area is not significant. The estimated  $R^2$  for the model is very high (0.991). The linear models by Sex and Month are shown in **Figure 3**.

Given that using the various variables as indicated in **Table 2** produces multiple coefficients and therefore multiple equations, simpler models were also run, namely one without any covariate and another using only Sex. These simpler models, even though preliminary, can be considered for conversion between curve and straight LJFL.

*Preliminary equations to convert from Straight to Curve LJFL*

- Equation for both sexes combined (for both areas and all months)

$$C-LJFL = 0.625703 + S-LJFL * 1.017407$$

- Sex-specific equations (for both areas and all months)

- Equation for females

$$C-LJFL = 1.411777 + S-LJFL * 1.014032$$

- Equation for males

$$C-LJFL = 0.805786 + S-LJFL * 1.014032$$

*Preliminary equations to convert from Curve to Straight LJFL*

- Equation for both sexes combined (for both areas and all months)

$$S-LJFL = 0.97016 + C-LJFL * 0.97387$$

- Sex-specific equation (for both areas and all months)

- Equation for females

$$S-LJFL = 0.52211 + C-LJFL * 0.97576$$

- Equation for males

$$S-LJFL = 0.86347 + C-LJFL * 0.97576$$

For illustrative purposes, the sex specific predictions of S-LJFL over a range of input C-LJFL are provided in **Table 3**, with both the point estimates and the 95% confidence intervals. It is noteworthy that for the smaller sizes the differences between males and females are minimal, possibly even smaller than the measurement errors that might happen when collecting data in the field during regular biological sampling operations. However, those differences increase for the larger sizes, and tend to be larger for females compared to males. Note that the size predictions are carried out over a range wider than the observer collected data and are therefore provided here mainly for illustrative purposes to highlight sex related differences as specimens grow to larger sizes.

#### **4. Final remarks**

The current work is preliminary, and more size measurements will be taken during 2022 to further increase the sample size and complete the analysis, especially for the NE Atlantic area. Still, and even though it is not final, the current equations provided can be used in a preliminary way to convert between curved to straight LJFL for swordfish (males and females separately, or for sexes combined) as needed.

#### **Acknowledgments**

Sampling for the Portuguese data was carried out by onboard observers on Portuguese pelagic longline vessels, funded by the *Programa Nacional de Amostragem Biologica* (PNAB) within the scope of the EU Data Collection Framework (DCF). Measurements in the Canadian fleet were taken by on-board observers as part of the Government of Canada's at-sea observer program.

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**Table 1.** Coefficients of the linear model between curved and straight LJFL, with the sex, area and months included as covariates.

```

Coefficients:
      Estimate Std. Error  t value Pr(>|t|)
(Intercept) -0.0535779  0.3369810   -0.159  0.87368
C.LJFL       0.9749273  0.0008483 1149.283 < 2e-16 ***
SexM        0.3307470  0.0544605   6.073 1.28e-09 ***
AreaNW At1  1.5160125  0.2665408   5.688 1.31e-08 ***
Month6      -0.1941804  0.2095350   -0.927  0.35409
Month7      -1.2203535  0.1824071  -6.690 2.31e-11 ***
Month8      -0.7253211  0.1786846  -4.059 4.95e-05 ***
Month9      -0.9992318  0.1791082  -5.579 2.46e-08 ***
Month10     -0.4046606  0.1852676  -2.184  0.02896 *
Month11     0.6844259  0.2593322   2.639  0.00832 **
Month12     1.2680419  1.7229855   0.736  0.46177
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 2.934 on 15128 degrees of freedom
Multiple R-squared:  0.991,    Adjusted R-squared:  0.991
F-statistic: 1.661e+05 on 10 and 15128 DF,  p-value: < 2.2e-16

```

**Table 2.** Analysis of variance table for the linear model between curved and straight LJFL, with the sex, areas and month included as covariates.

```

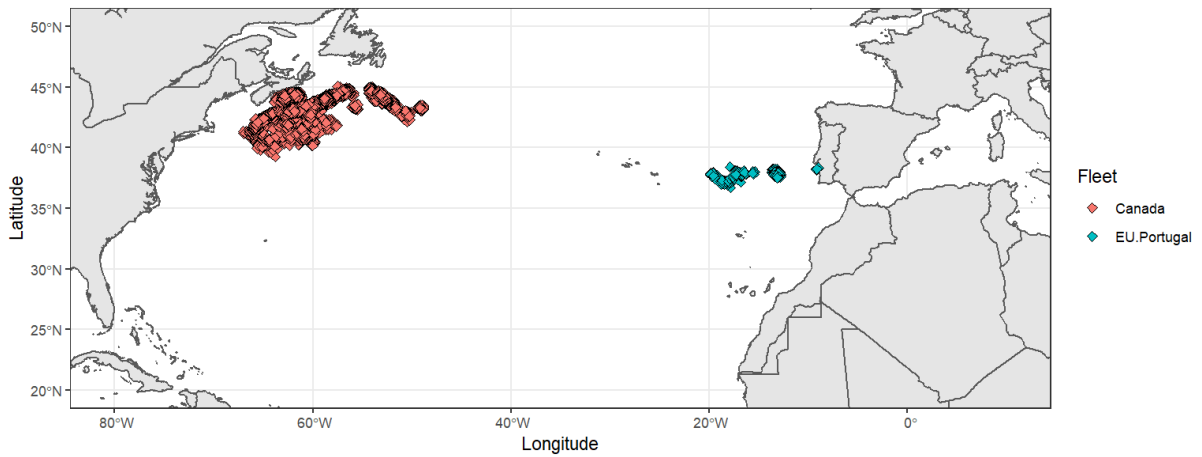
Analysis of Variance Table

Response: S.LJFL
      Df Sum Sq Mean Sq  F value    Pr(>F)
C.LJFL  1 14295686 14295686 1.6609e+06 < 2.2e-16 ***
Sex      1     341     341 3.9647e+01 3.127e-10 ***
Area     1         0         0 1.0000e-03  0.9744
Month    7     1903     272 3.1579e+01 < 2.2e-16 ***
Residuals 15128  130211         9
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

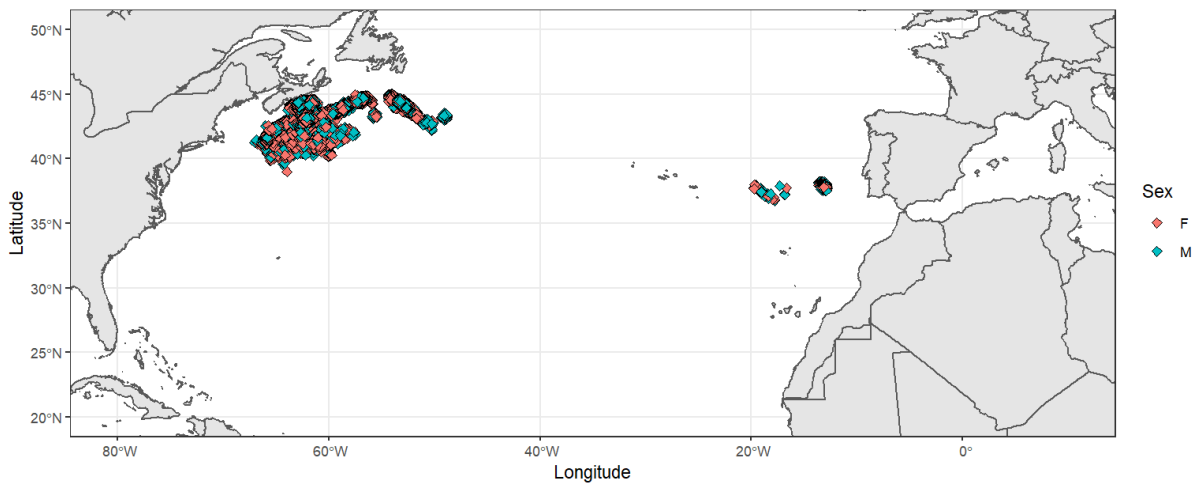
```

**Table 3.** Predictions of S-LJFL (by sex), for a range of input C-LJFL, used for illustrative purposes. Predictions are only shown for the model with the sexes as a covariate, but without Area or Month, as the purpose is to illustrate sex related differences over several sizes.

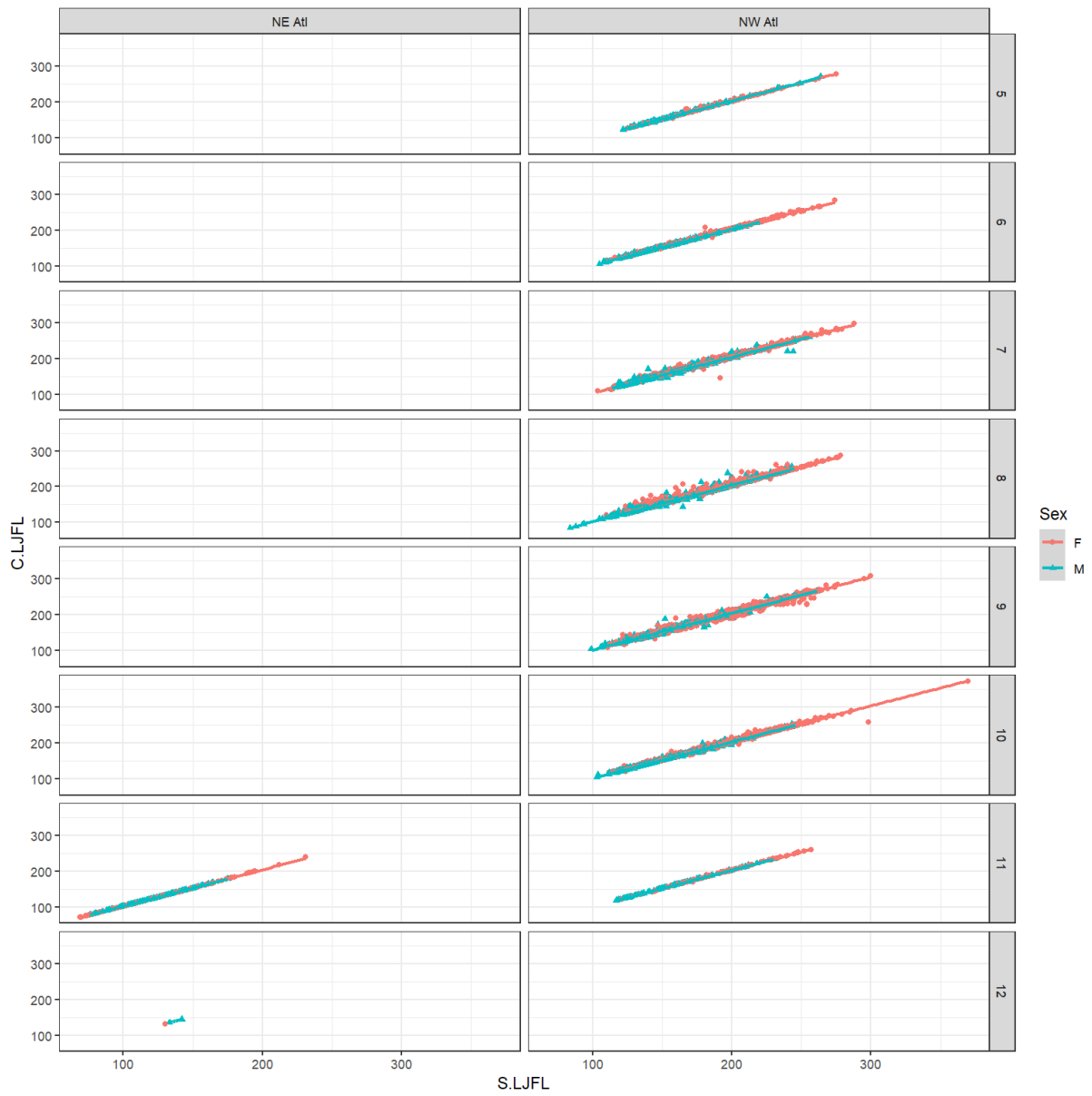
| Curved-LJFL (cm) |         | Estimated Straight-LJFL (cm) |             |              |
|------------------|---------|------------------------------|-------------|--------------|
|                  |         | Estimate                     | Lower 95%IC | Upper 95% CI |
| 50               | Females | 49.31                        | 49.09       | 49.53        |
|                  | Males   | 49.65                        | 49.46       | 49.84        |
| 100              | Females | 98.10                        | 97.95       | 98.24        |
|                  | Males   | 98.44                        | 98.31       | 98.56        |
| 150              | Females | 146.89                       | 146.81      | 146.97       |
|                  | Males   | 147.23                       | 147.15      | 147.31       |
| 200              | Females | 195.67                       | 195.61      | 195.74       |
|                  | Males   | 196.02                       | 195.91      | 196.12       |
| 250              | Females | 244.46                       | 244.34      | 244.58       |
|                  | Males   | 244.80                       | 244.64      | 244.97       |
| 300              | Females | 293.25                       | 293.06      | 293.44       |
|                  | Males   | 293.59                       | 293.35      | 293.83       |
| 350              | Females | 342.04                       | 341.77      | 342.31       |
|                  | Males   | 342.38                       | 342.06      | 342.70       |



**Figure 1.** Map with the location of the swordfish size samples (Canada and Portugal) used for this work and analysis. Note: points are jittered by 0.2 degrees latitude and longitude for illustration of point density only.



**Figure 2.** Map with the location of the swordfish size samples (Males and Females) used for this work and analysis. Note: points are jittered by 0.2 degrees latitude and longitude for illustration of point density only.



**Figure 3.** Preliminary relationships between the Straight and Curved LJFL for swordfish. Males and females are plotted separately, for each Area (NE and NW Atlantic) and each Month.