

LENGTH AND WEIGHT CONVERSION EQUATIONS FOR BLUE MARLIN, WHITE MARLIN, AND SAILFISH FROM THE NORTH ATLANTIC

Michael H. Prager¹, Dennis W. Lee¹, Eric D. Prince¹

SUMMARY

This paper presents empirical estimators (equations) for converting among measures of size (length or weight) for blue marlin Makaira nigricans, white marlin Tetrapturus albidus, and sailfish Istiophorus platypterus from the north Atlantic Ocean. These equations allow conversion from six length measures to lower jaw-fork length and conversion between lower jaw-fork length and round weight. Changes from earlier studies include use of additional data, incorporation of bias corrections into the length-weight and weight-length models, the use of robust regressions for the length conversions, and the development of estimates based on data from specimens regardless of sex (i.e., from combined sexes).

RESUME

Le présent document fait état d'éléments empiriques d'estimation (équations) pour la conversion entre mesures de taille (longueur ou poids) pour le makaira bleu Makaira nigricans, le makaira blanc Tetrapturus albidus et le voilier Istiophorus platypterus de l'Atlantique nord. Ces équations permettent la conversion de six mesures de longueur en longueur maxillaire et celle de la longueur maxillaire en poids vif. Les changements par rapport aux études antérieures comprennent l'emploi de données supplémentaires, l'incorporation de corrections des biais dans les modèles longueur-poids et poids-longueur, l'emploi de régressions robustes pour les conversions de longueur, et l'élaboration d'estimations à partir de données sur des individus, quel que soit leur sexe (c'est-à-dire tous sexes combinés).

RESUMEN

El documento presenta estimadores empíricos (ecuaciones) para hacer conversiones entre medidas de tamaño (talla o peso) para la aguja azul (Makaira nigricans) aguja blanca (Tetrapturus albidus) y pez vela (Istiophorus platypterus) del Atlántico norte. Estas ecuaciones permiten hacer la conversión de seis medidas de talla en mandíbula inferior-longitud a la horquilla, y la conversión entre mandíbula inferior-longitud a la horquilla y peso vivo. Los cambios con respecto a estudios anteriores incluyen el uso de datos adicionales, la incorporación de correcciones a los sesgos en los modelos de talla-peso y peso-talla, el uso de regresiones sólidas para las conversiones de talla y la obtención de estimaciones basadas en datos de peces, sin tener en cuenta el sexo (es decir, sexos combinados).

¹ U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southeast Fisheries Center, 75 Virginia Beach Drive, Miami, Florida, 33149, U.S.A.

1. INTRODUCTION

Because the billfishes (Istiophoridae) are dressed in many different ways (Prince and Miyake 1990) and measurements of size (length and weight) are usually not obtained before processing, there is a need for empirical equations for conversion among different measures of dressed or undressed length (Table 1). Because some fish are either measured or weighed, but not both, there is also a need for conversions between length and weight. Equations for these purposes have been presented by several authors. Prince and Lee (1989) gave empirical conversion equations for estimating lower jaw-fork length (LJFL) from four other length measures: eye orbit-fork length (EOFL), pectoral-second dorsal length (PDL), dorsal-fork length (DFL), and pectoral-fork length (PFL). Lee and Prince (1990) presented empirical equations for converting LJFL to total length (TL) and TL to LJFL. (Their Table 2, containing conversions between LJFL and TL, had several typographical errors.) They also gave conversions between TL and round weight and between LJFL and round weight. In those two papers, results were given for each sex separately, but no equations were given for use on specimens of unknown sex.

Prager et al. (1992) reanalyzed the data of Lee and Prince (1990) to arrive at slightly revised equations for the length-weight and weight-length conversions. The revisions included, first, a minor correction of the equations for the bias due to log transformation and, second, the development of equations derived from data on both sexes and intended for use when the sex of a fish is not known. Prager et al. used only LJFL for length measurements because it is the most common measure and because equations have been presented for converting many other length measures to LJFL. In preparing the present paper, we had three objectives: (1) to add new equations for estimating LJFL from two additional measures, pectoral-anus length (PAL) and pectoral-fork length; (2) to recompute some of the existing equations with additional data that have become available; and (3) to collect as many of the estimation equations as possible in one reference source. In addition, we felt that the use of robust regression, a statistical technique relatively new to fishery science, would be of value in this area.

2. DATA AND MODELS

Data were obtained from the files of the National Marine Fisheries Service, Southeast Fisheries Science Center, Miami Laboratory. These data include observations made during billfish-survey field sampling by NMFS personnel (Farber and Browder 1992) and data obtained through the ICCAT Enhanced Research Program for Billfish, particularly in the western Atlantic Ocean (Carter 1992).

From these data, equations were developed to estimate LJFL from any of the six alternative measures of length (Table 1). Before we used the data for estimation, we screened for gross outliers, which were removed. To increase robustness to other possible outliers or data errors, the equations were fit with a robust-regression method, least-absolute-values (LAV) regression. In the LAV technique, the quantity minimized is not the sum of the squares of the residuals, as in ordinary-least-squares (OLS) regression, but instead the sum of the absolute values of the residuals (Berk 1990, Krasker 1988). When the data contain no outliers, estimates from LAV regression are nearly identical to those from OLS regression. However, the OLS parameter estimates can be influenced quite strongly by relatively few outliers, especially if they occur near the extremes of the observations on the predictor variable. In contrast, the parameter estimates from LAV regression are much less influenced by outliers; hence the term "robust regression." Equations derived from LAV are applied in the same way as those derived from OLS.

We estimated the predictive equations with the NONLIN procedure of Systat (Wilkinson 1990). Estimation of LAV regressions can be accomplished with most commercially available nonlinear estimation software; however the NLIN procedure of SAS for Personal Computers (Version 6.04; SAS 1988) contains a program error (bug) that makes its use for LAV regression unreliable.

To meet our third objective (a relatively complete compilation of estimators), we have reprinted here the conversions between weight and LJFL presented by Prager et al (1992). In computing those regressions, bias correction factors (Whittaker and Marks 1975; Sprugel 1983) were applied to correct the bias associated with logarithmic transformation. Because sample sizes were quite large and residual errors were small, the correction factors were within 1% of unity. The weight-length conversion equations were estimated with the REG procedure of the Statistical Analysis System (SAS 1988).

3. RESULTS

Results are presented in tabular form. Coefficients of the conversion equations between length and weight for all three species are given in Table 2. Conversions among length measures are given in Table 3, Table 4, and Table 5.

4. COMMENTS

4.1 Statistical Comments

The equations in Tables 3 through 5 are predictive equations; i.e., when estimating them, the errors in the estimated quantity (LJFL) were minimized. This procedure is optimal when the equations are to be used for prediction or estimation, but does not provide an unbiased parameter estimate in the presence of error in the explanatory (predictor) variable. For this reason, the predictive equations should not be inverted and used to estimate other length measures from LJFL. If necessary, equations for estimating LJFL from other measures can be derived from the same data, but these would not be equivalent to the inverses of the equations given.

The bias correction used in the weight-length conversion equations is simple to compute when estimating such conversions. In the present case, model fits were good and sample sizes were large, and therefore the corrections were nominal. However, the correction can be more important under other realistic circumstances. For that reason, and because it seems logical to correct for a known bias, we urge that this correction be incorporated routinely in the computation of conversions between length and weight.

Robust regression is a useful statistical technique with a large literature. It was motivated by the fact that OLS can be quite inefficient when the errors in the data have heavier tails than under a normal distribution (Krasker 1988), and this may be the case for many fisheries data, especially when quality control is not perfect. Data sets should always be screened for obvious outliers, but in many practical cases questionable points will remain after this is done. Then the investigator is faced with a difficult choice—whether to discard a few potentially influential (in the statistical sense) observations because they *may* be wrong. The use of robust regression is not a replacement for quality control nor a panacea for all problems, yet it provides a practical solution to the type of difficulties mentioned, as it allows questionable data to be retained while reducing their influence on the final estimates.

4.2 Biological Comments

Most Atlantic billfish landings are from commercial longline fisheries directed at tuna and swordfish; the billfishes are caught only incidentally (Prince and Brown 1991). These incidental landings are usually dressed at sea, with heads, spines, fins, viscera, and occasionally tails removed. Data on whole specimens of non-targeted species are taken only occasionally and inconsistently, depending on the fishing nation and year. The carcasses are usually frozen for three to nine months before being transshipped. This situation confounds identification of species and prevents acquisition of size-frequency and sex ratio data. A further complication is that ICCAT member nations dress billfishes in at least ten different ways (compared with two or three for tuna), which makes it more complex to develop regression relationships for converting size measurements to some standard measure (Prince and Miyake 1989).

The most reliable measure of length for the Istiophoridae is lower jaw-fork length (Rivas 1956), but this measurement is seldom taken on billfishes caught in the offshore longline fisheries, for the reasons given above. The present report provides regression relationships for most of the anticipated conversions of billfish length and weight categories, particularly those obtained from offshore longline fisheries. This information should allow most ICCAT size-frequency data to be converted into a standard unit of measurement (LJFL).

Most of the length data used in this study were taken by placing measuring tapes over the curve of the body (curved body measurements). Because many of the length measurements available from the offshore longline fleets are straight measurements (i.e., taken by fixing a ruler to the deck and not including the body curvature), the differences between straight and curved body measurements should be evaluated. Billfishes are elongated species, so these differences are likely to be minimal. Nonetheless, at present they are unknown.

5. REFERENCES CITED

- BERK, R.A. 1990. A primer on robust regression. Chapter 7 (pp. 292-324) In J. Fox and J.S. Long (eds.), modern methods of data analysis. Sage Publications, Inc., Newbury Park, California. 442 pp.
- CARTER, R.L. 1992. A summary of shore-based and at-sea sampling in the western Atlantic Ocean 1987-1992: ICCAT Enhanced Research Program for Billfish. ICCAT Working Document SCRS/92/59.
- FARBER, M.I., J.A. BROWDER, AND J.P. CONTILLO. 1992. Standardization of recreational fishing success for marlin in the western north Atlantic Ocean, 1973-1991, using generalized linear model techniques. ICCAT Working Document SCRS/92/62.
- KRASKER, W.S. 1988. Robust regression. Pages 166-169 In S. Kotz and N.L. Johnson (eds.), Encyclopedia of statistical sciences, vol 8. John Wiley & Sons, New York. 870 pp.
- LEE, D.W., AND E. D. PRINCE. 1990. Further development of length and weight regression parameters for Atlantic blue marlin, white marlin, and sailfish. Int. Comm. Conserv. Atl. Tunas (Madrid), Coll. Vol. Sci. Pap. 32(1): 418-425 (ICCAT Working Document SCRS/89/70).
- PRAGER, M.H., D.W. LEE, AND E.D. PRINCE. 1992. Bias-corrected length-weight relationships for Atlantic blue marlin, white marlin, and sailfish. Int. Comm. Conserv. Atl. Tunas (Madrid), Coll. Vol. Sci. Pap. 34(3): 656-658. (ICCAT Working Document SCRS/91/93.).
- PRINCE, E.D., AND B.E. BROWN. 1991. Coordination of the ICCAT Enhanced Research Program for Billfish. Am. Fish. Soc. Symp. 12: 13-18.
- PRINCE, E.D., AND D.W. LEE. 1989. Development of length regressions for Atlantic Istiophoridae. Int. Comm. Conserv. Atl. Tunas (Madrid), Coll. Vol. Sci. Pap. 30(2): 364-374. (ICCAT Working Document SCRS/88/43.)
- PRINCE, E.D., AND P.M. MIYAKE. 1989. Methods of dressing Atlantic billfishes (Istiophoridae) by ICCAT reporting countries. Int. Comm. Conserv. Atl. Tunas (Madrid), Coll. Vol. Sci. Pap. 30(2):xxx-xxx. (ICCAT Working Document SCRS/88/44.)
- RIVAS, L.R. 1956. Definitions and methods of measuring and counting in the billfishes (Istiophoridae, Xiphiidae). Bull. Mar. Sci. 6: xxx-xxx.
- SAS (SAS Institute, Inc.). 1988. SAS/STAT user's guide, release 6.03 edition. SAS Institute, Inc., Cary, N.C. 1028 pp.
- SPRUGEL, D. G. 1983. Correcting for bias in log-transformed allometric equations. Ecology 64: 209-210.
- WHITTAKER, R. H., AND P. L. MARKS. 1975. Methods of assessing primary productivity. Chapter 4 in H. Leigh and R. H. Whittaker (eds.). Primary productivity of the biosphere. Springer-Verlag, New York.
- WILKINSON, L. 1990. SYSTAT: the system for statistics. Statistics. Systat, Inc., Evanston, Illinois. 676 pp.

Table 1. Length measures used in this study, with mnemonic codes used in text and tables. For description of length measures, see Carter (1992).

Mnemonic code	Length measure
LJFL	Lower jaw-fork length
PAL	Pectoral-anus length
PFL	Pectoral-fork length
PDL	Pectoral-second dorsal length
TL	Total length
EOFL	Eye orbit-fork length
DFL	Dorsal-fork length

Table 2. Coefficients of bias-corrected equations for predicting round weight (kg) from lower-jaw fork length (cm) using the equation $W = a \cdot l^b$ or predicting lower-jaw fork length from round weight using the equation $l = c \cdot W^d$. Bias-correction factors have been incorporated into parameters a and c so that no further correction is necessary. For explanation, see text.

Sex	Sample size (n)	Weight range, kg	Length range, cm	Coefficients			
				a	b	c	d
Blue Marlin							
F	3267	0.06-540.9	23.0-378.5	1.9034×10^{-6}	3.2842	61.731	0.28180
M	1978	0.06-178.0	23.0-277.0	2.4682×10^{-6}	3.2243	61.961	0.28137
F+M	5245	0.06-540.9	23.0-378.5	1.1955×10^{-6}	3.3663	62.010	0.28065
White marlin							
F	3149	2.7-67.1	91.4-205.0	3.9045×10^{-6}	3.0694	78.423	0.23191
M	1719	3.6-41.3	96.0-195.5	1.9556×10^{-5}	2.7487	76.847	0.23548
F+M	4868	2.7-67.1	91.4-205.0	5.2068×10^{-6}	3.0120	76.460	0.23888
Sailfish							
F	1280	0.04-52.7	27.1-204.5	1.1441×10^{-6}	3.2683	74.614	0.26460
M	907	0.04-30.1	27.1-188.0	1.6922×10^{-6}	3.1879	70.907	0.28191
F+M	2187	0.04-52.7	27.1-204.5	1.2869×10^{-6}	3.2439	72.962	0.27201

Table 3. Blue marlin from the north Atlantic. Coefficients of robust-regression equations for predicting lower jaw-fork length λ_0 (cm) from another measure of length λ_1 (cm) using the equation $\lambda_0 = a + b \lambda_1$. "Approx. length range" refers to the predictor variable in the equation. A question mark in column 2 indicates that the sex of some specimens was not known.

Predictor variable λ_1	Sex(es)	Sample size (n)	Approx. length range (cm)	Intercept a	Slope b
PAL	F	123	34-120	32.063	2.504
	M	249	35-90	86.874	1.660
	F+M+?	453	30-120	72.161	1.920
PFL	F	243	80-270	10.388	1.246
	M	387	100-220	16.183	1.197
	F+M+?	732	65-280	9.486	1.248
PDL	F	140	85-190	23.533	1.681
	M	276	66-150	49.441	1.354
	F+M+?	482	60-190	12.626	1.738
TL	F	69	250-490	-1.331	0.773
	M	153	200-330	26.458	0.663
	F+M+?	258	30-500	8.886	0.738
EOFL	F	113	130-300	10.737	1.090
	M	104	135-210	13.682	1.068
	F+M+?	250	120-300	10.127	1.092
DFL	F	115	125-280	10.134	1.200
	M	125	115-200	8.985	1.197
	F+M+?	271	100-280	8.303	1.206

Table 4. White marlin from the north Atlantic. Coefficients of robust-regression equations for predicting lower jaw-fork length λ_0 (cm) from another measure of length λ_1 (cm) using the equation $\lambda_0 = a + b \lambda_1$. "Approx. length range" refers to the predictor variable in the equation. A question mark in column 2 indicates that the sex of some specimens was not known.

Predictor variable λ_1	Sex(es)	Sample size (n)	Approx. length range (cm)	Intercept a	Slope b
PAL	F	105	40-66	81.559	1.545
	M	123	40-85	80.254	1.538
	F+M+?	272	35-85	88.904	1.375
PFL	F	188	92-145	13.667	1.241
	M	172	80-180	31.623	1.083
	F+M+?	424	80-180	25.291	1.139
PDL	F	127	72-115	40.686	1.366
	M	121	68-110	66.208	1.060
	F+M+?	294	65-115	42.753	1.333
TL	F	51	190-245	32.069	0.615
	M	65	130-235	9.944	0.710
	F+M+?	127	130-280	15.886	0.685
EOFL	F	65	128-165	18.372	1.037
	M	30	115-160	6.897	1.112
	F+M+?	102	115-165	13.742	1.068
DFL	F	75	115-150	35.783	1.000
	M	47	105-150	17.482	1.131
	F+M+?	129	105-150	21.965	1.102

Table 5. Sailfish from the north Atlantic. Coefficients of robust-regression equations for predicting lower jaw-fork length λ_0 (cm) from another measure of length λ_1 (cm) using the equation $\lambda_0 = a + b \lambda_1$. "Approx. length range" refers to the predictor variable in the equation. A question mark in column 2 indicates that the sex of some specimens was not known.

Predictor variable λ_1	Sex(es)	Sample size (n)	Approx. length range (cm)	Intercept a	Slope b
PAL	F	652	30-90	120.170	0.798
	M	455	35-80	111.175	0.907
	F+M+?	1553	30-100	107.196	0.999
PFL	F	728	75-175	36.766	1.025
	M	484	90-150	34.211	1.043
	F+M+?	1810	75-180	29.441	1.083
PDL	F	113	55-120	44.370	1.268
	M	42	75-110	19.074	1.526
	F+M+?	330	55-120	38.322	1.332
TL	F	83	120-260	32.188	0.623
	M	52	110-245	21.961	0.657
	F+M+?	142	40-270	18.171	0.686
EOFL	F	58	85-175	18.235	1.015
	M	27	105-155	21.707	0.987
	F+M+?	251	85-175	11.240	1.076
DFL	F	59	75-165	39.104	0.951
	M	21	110-145	1.555	1.221
	F+M+?	252	75-165	38.438	0.958