

FURTHER DEVELOPMENT OF LENGTH AND WEIGHT REGRESSION PARAMETERS FOR ATLANTIC BLUE MARLIN,
WHITE MARLIN, AND SAILFISH

D. W. Lee, E. D. Prince
NMFS, Southeast Fisheries Center, 75 Virginia Beach Drive, Miami, Florida, U.S.A.

SUMMARY

Length and weight regressions for Atlantic blue marlin, Makaira nigricans, white marlin, Tetrapterus albidus, and sailfish, Istiophorus platypterus, were developed so that estimates of lower jaw fork length (LJFL) and round weight (RWT) could be estimated from total length (TL). Recent development of regressions for Istiophoridae (Prince and Lee 1989) did not include an evaluation of TL measurements. However, regressions for predicting length and weight from TL are important because TL has been used historically by taxidermy facilities to archive measurements for their billfish replicas. In addition, measurements of TL are often used in newspaper articles and by anglers and captains who find it easier to report tag released or recaptured billfish in this manner.

The range in coefficients of determination (R^2) for the regressions between TL and LJFL for all species and sex categories were 0.81 to 0.97 and for the regressions TL and RWT were 0.83 to 0.99. The range in R^2 's for regressions LJFL and RWT for each sex and species was more variable ($R^2 = 0.65$ to 0.93). The proportion of total variation explained by regression relationships was generally lowest for white marlin, particularly females where R^2 's were usually less than 0.90 (0.93 to 0.65). Acquisition of more samples (>100) over a more comprehensive size range for each sex of white marlin might improve regression results. However, the proportion of total variation of the regression relationships for blue marlin and sailfish were sufficiently high that increased sample sizes are not likely to improve the predicting power of these regressions.

RESUME

Les régressions de taille et de poids du makaire bleu de l'Atlantique, Makaira nigricans, du makaire blanc, Tetrapterus albidus, et du voilier, Istiophorus platypterus, ont été effectuées de façon à obtenir, à partir de la taille totale (TL), des estimations de la taille maxillaire-fourche (LJFL) et du poids vif (RWT). Les derniers travaux de régression sur les istiophoridés (Prince & Lee 1989) ne comprenaient pas d'évaluation des mensurations de TL. Cependant, des régressions permettant de prédire la taille et le poids à partir de la TL sont importantes, du fait que cette mesure a été utilisée traditionnellement par les taxidermistes pour classer les dimensions de leurs exemplaires d'istiophoridés. En outre, les mensurations de TL sont fréquemment mentionnées dans la presse, et par les pêcheurs sportifs et les capitaines qui préfèrent signaler de cette façon les recaptures effectuées ou les marques récupérées.

La gamme des coefficients de détermination (R^2), pour toutes les espèces et toutes les catégories de taille, se situe entre 0.81 et 0.97 pour la régression TL-LJFL, et entre 0.83 et 0.99 pour la régression TL-RWT. La gamme des R^2 pour les régressions LJFL et RWT pour chaque sexe et chaque espèce était plus variable ($R^2 = 0.65$ à 0.93). Le pourcentage de la variation totale indiquée par le rapport de régression était en général moins important pour le makaire blanc, en particulier pour les femelles dont le R^2 était normalement inférieur à 0.90 (0.93 à 0.65). L'acquisition d'un plus grand nombre d'échantillons de makaire blanc (> 100) sur une gamme plus exhaustive de tailles pour les deux sexes pourrait améliorer les résultats de la régression. Néanmoins, le pourcentage de variation totale des rapports de régression pour le makaire bleu et le voilier était suffisamment élevé, ce qui rend peu probable une amélioration de la capacité prédictive par suite d'un accroissement de la taille de l'échantillon.

RESUMEN

Se obtuvieron regresiones de talla y peso para la aguja azul del Atlántico (*Makaria nigricans*), aguja blanca (*Tetrapturus albidus*) y pez vela (*Istiophorus platypterus*), con el fin de estimar la longitud mandíbula inferior-horquilla (LJFL) y peso vivo (RWT) en base a la longitud total (TL). Las regresiones para los istioforideos recientemente obtenidas (Prince y Lee, 1989) no incluían una evaluación de las mediciones de longitud total. Sin embargo, las regresiones que predicen la longitud y el peso a partir de la TL son importantes ya que esta TL ha sido siempre aplicada en la taxidermia para archivar estas mediciones con vistas a fabricar réplicas de marlines. Por otra parte, las mediciones de TL se citan a menudo en artículos periodísticos y también por parte de los pescadores y patronos que encuentran más sencilla esta forma de informar acerca del marcado o recaptura de marcas en marlines.

La gama en coeficientes de determinación (R^2) para las regresiones entre TL y LJFL para todas las especies y categorías de sexo era de 0.81 a 0.97 y en el caso de las regresiones TL y RWT de 0.83 a 0.99. La gama de R^2 para regresiones LJFL y RWT para cada sexo y especie era más variable ($R^2 = 0.65$ a 0.93). La proporción más baja de la variación total, aclarada por las relaciones de regresión, era en general la correspondiente a la aguja blanca, sobre todo en el caso de las hembras, donde R^2 resultaba inferior a 0.90 (0.93 a 0.65). Se podrían mejorar los resultados de regresión obteniendo un mayor número de muestras (>100) de una gama de tallas más amplia de cada sexo dentro de la especie aguja blanca. Sin embargo, la proporción de la variación total de las relaciones de regresión en el caso de la aguja azul y el pez vela eran suficientes, por lo que no es probable que un mayor número de muestras de talla mejore la facultad predictiva de estas regresiones.

INTRODUCTION

The lack of detailed information on landing statistics, particularly size frequency data, has often been cited as hindering ICCAT assessment of istiophoridae in the Atlantic Ocean and adjacent seas (Prince, Brown, Diouf, and Miyake 1989). The statistical and biological data presently available have been collected over a number of years and by a variety of nations. Unfortunately, there is also great variability in the way these measurements are compiled. Since the establishment of the ICCAT Enhanced Research Program for billfish (Prince et al. 1989) in 1986, some progress has been made in this area. For example, from a survey of ICCAT reporting nations, at least 10 different methods of dressing (cleaning) istiophorids for commercial markets have been identified (Prince and Miyake 1989). Recently, Prince and Lee (1989) provided regression parameters for converting a variety of length measurements to lower jaw fork length (LJFL). These regression equations provide the means for estimating LJFL (the preferred measure of length for istiophoridae) when only the dressed carcass is available during offloading of the commercial catch in various transshipment ports.

In addition to size frequency data from the commercial catch, a large source of information exists from the recreational fishery, particularly from the taxidermy industry in the United States. In order for these data to be useful however, regressions need to be developed for converting taxidermy length measurements, which have historically been taken in total length (TL), into LJFL. In addition, measurements of total length or whole weight are generally reported to the Southeast Fisheries Center's (SEFC) Cooperative Gamefish Tagging Program. Therefore, in order to take advantage of these sources of size data for Atlantic blue marlin (*Makaria nigricans*), white marlin (*Tetrapturus albidus*), and sailfish (*Istiophorus platypterus*), the objective of this paper was to develop regression parameters for converting these data into a common unit of measurement (LJFL). Specifically, regression equations were developed between lower jaw fork length, round weight, and total length.

MATERIALS AND METHODS

Linear regression techniques were used to determine the relationships between various length and round weight measurements. Length measurements were obtained from blue marlin, white marlin, and sailfish caught in the western Atlantic Ocean and adjacent seas. Capture of the longbill spearfish (*Tetrapterus pfluegeri*) in the western Atlantic Ocean are rare and data on this species could not be collected in sufficient quantity to be included in this analysis.

Three sources of data were used: (1) the SEFC recreational

billfish survey; (2) the ICCAT Enhanced Research Program for billfish; and (3) age and growth samples from the SEFC. Field personnel, participating in the SEFC recreational billfish survey, have collected catch statistics (LJFL, round weight, sex, catch and environmental data) since 1971 at billfish tournaments along the U. S. Atlantic and U. S. Gulf of Mexico and at various island ports in the Caribbean Sea. Only data records with complete length (cm), round weight (kg), and sex were used for these analyses (Table 1). Since whole fish are traditionally landed from the recreational fishery, many of the SEFC survey personnel took additional length measurements from billfish to fulfill ICCAT needs identified by Prince and Lee (1989) during 1988-89. The ICCAT Enhanced Research Program for billfish has conducted shore-based and at-sea billfish sampling at major Caribbean ports and aboard their longline vessels from 1987-89. Billfish measurements as reported by Prince and Lee (1989) were taken from whole fish prior to being processed for commercial markets (Table 1). Furthermore, many extremely small and large billfish obtained from SEFC's age and growth research, through a special SAVE IT FOR SCIENCE program, were incorporated into this study (Prince 1984). The length measurements used in this analysis follow those described by Rivas (1956) and are defined as follows: (1) LJFL--distance from tip of lower jaw to fork of tail; (2) TL--distance from tip of bill to the midpoint between the dorsal and ventral tips of the longest caudal fin rays. For consistency, all billfish measurements were taken along the lateral line contour (curved body length). Round weight (RWT) and the length measurements were converted to kilograms and centimeters when necessary.

Three extremely small specimens of unknown sex, for each billfish species, were included in the data analysis for males and females to anchor the origin of the regression lines. These were: (1) a blue marlin measuring 23.0 cm (LJFL), 25.5 cm (TL), and 0.06 kg (round weight); (2) a sailfish measuring 27.1 cm (LJFL), 37.8 cm (TL), and 0.04 kg (round weight); and (3) a white marlin measuring 105.5 cm (LJFL), 142.6 cm (TL), and 4.5 kg (round weight). Prince et al. (in press) report that length-weight regressions for all sex categories of blue marlin less than 140 cm (LJFL) were not significantly different from each other (covariance analysis). Therefore, we felt justified in using the smallest blue marlin sample (23.0 cm LJFL; 25.5 cm TL; and 0.06 kg RWT) where sex was unknown, in both male and female length-weight data to anchor these regression lines. In addition, we also assumed that this relationship (i.e., no difference in the length-weight relationships for the small size category) would apply to white marlin and sailfish.

In order to achieve more complete coverage of the entire size range for each billfish species, we incorporated a size selected sub-sample of larger fish for each sex in all regressions when possible. For example, three male blue marlin greater than 160

kg (352 lb) and seven females over 454.5 kg (1000 lb) were included in the analysis. The largest male and female white marlin were 41.3 kg (91 lb) and 67.1 kg (148 lb), respectively, and the largest male sailfish was 30.1 kg (66 lb) whereas the largest female was 52.7 kg (116 lb).

RESULTS AND DISCUSSION

Linear regressions of LJFL (cm) and TL (cm) and the log transformation of the two length measurements and round weight (kg) were computed separately by sex for each of the three species since sexual dimorphic growth has been reported for most istiophorids (Yoe 1978, Baglin 1979, Wilson 1984, and Prince et al. in press). In addition, the regression figures 1 through 5 are presented for convenience in the arithmetic scale. Thus, the LJFL and RWT and TL and RWT relationships are curvilinear. The lines presented in these figures are unsmoothed approximations.

The coefficient of determination (R^2), defined as the proportion of the sum of squares of the dependent variable that can be attributed to the independent variable, is useful in assessing the reliability of the regressions (Steel and Torrie 1960). The range of R^2 's for all male and female blue marlin regressions were 0.91 to 0.99 and 0.93 to 0.98, respectively; 0.65 to 0.93 and 0.71 to 0.83 for male and female white marlin, respectively; and 0.90 to 0.95 and 0.86 to 0.96 for male and female sailfish, respectively (Tables 2 and 3; Figs. 1-5).

The relationships between TL and LJFL (Table 2; Figs. 1A and B; 2A and B; and 3A and B) were strongly related for males and females of all three billfish species ($R^2 = 81$ to 0.97). Even though sample sizes were generally low (i.e., ranging from $N = 26$ to 74), the R^2 values were all above 0.80 and increasing sample size for each analysis category would probably not improve these relationships significantly. Prince and Lee (1989) concluded that R^2 values exceeding 0.80 for length-weight regressions of istiophoridae provided acceptable estimates of length.

The strongest relationships for length-weight regressions were achieved with TL, where R^2 's were ≥ 0.83 (Table 3; Figs. 1C and D; 2C and D; and 3C and D). In fact, with the exception of female white marlin ($R^2 = 0.83$), all of the relationships involving TL appear to be very reliable for estimating weight since R^2 's ranged from 0.93 to 0.99. Factors contributing to the comparatively low R^2 for the female white marlin regression may be related to the small sample size ($N=38$) and the low number of samples in the extremely small or large size categories.

The predictive power of regressions of LJFL and RWT was quite variable for the three species, with R^2 's ranging from 0.65 to 0.93 (Table 3; Figs. 4 and 5). Both the male and female white

marlin relationships (Figs 4B and 5B) had the lowest values ($R^2 = 0.65$ and 0.71 , respectively). Since the measurement of LJFL has been the target length measurement for all three species collected by personnel in the SEFC recreational billfish survey since 1971, the coefficient of determination would probably not show any significant improvement by increasing sample sizes which are already large (N ranged from 907 to 3,267). The poor relationship between LJFL and RWT for white marlin regressions is not clearly understood except that growth in length or weight appears to be much more variable for this species. Baglin (1979) examined a smaller white marlin data set (female $N = 875$; male $N = 518$) from the same source (SEFC recreational billfish survey) used in this analysis. He computed similar R^2 values, although he separated the data for the Gulf of Mexico and Atlantic Ocean (Gulf: $R^2 = 0.64$ females and 0.43 males; Atlantic: $R^2 = 0.68$ females and 0.64 males). Wilson (1984) also obtained similar R^2 values for white marlin regressions of LJFL and RWT ($R^2 = 0.47$ females and 0.38 males) from a much smaller sample size (female $N = 131$, male $N = 76$) caught in the northwest Atlantic and adjacent seas.

Increasing the sample size (> 100) and size range coverage of the TL measurement for female white marlin is probably warranted to improve regressions. However, Prince and Lee (1989) also found similar R^2 values ($R^2 = 0.64$ to 0.90) in their analysis of female white marlin for the relationships between LJFL and four ICCAT measurements. It seems apparent from these results that compared to other billfishes, white marlin (both sexes) show a great deal of variability in their growth (both length and weight). These results also indicate that length and weight regressions for blue marlin and sailfish are sufficiently strong that further samples are probably not necessary for reliable LJFL or weight conversions.

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TABLE 1: Species, sex, length variable, length range (cm), round weight range (kg), sample size (N), and data source used in regressions developed for Atlantic istiophoridae. Length variables are defined as lower jaw forklength (LJFL) and total length (TL). Data sources are defined as (1) SEFC Recreational Billfish Survey, (2) ICCAT Enhanced Research Program, and (3) SEFC age and growth research.

Species Sex	Length Variable	Length Range (cm)	Weight Range (kg)	Sample Size (N)	Data Source
<u>Blue Marlin</u>					
Males	LJFL	23.0-277.0	0.06-178.0	1978	1,3
	TL	25.5-320.0	0.06-129.1	26	1,2,3
	LJFL ¹	23.0-246.0	0.06-129.1	26	1,2,3
Females	LJFL	23.0-378.5	0.06-540.9	3267	1,3
	TL	25.5-480.1	0.06-540.9	59	1,2,3
	LJFL ¹	23.0-378.5	0.06-540.9	59	1,2,3
<u>White marlin</u>					
Males	LJFL	96.0-195.5	3.6-41.3	1719	1,3
	TL	131.0-223.0	3.6-25.5	37	1,2,3
	LJFL ¹	96.0-168.0	3.6-25.5	43	1,2,3
Females	LJFL	91.4-205.0	2.7-67.1	3149	1,3
	TL	142.6-259.0	4.5-63.2	35	1,2,3
	LJFL ¹	105.5-199.0	4.5-63.2	38	1,2,3
<u>Sailfish</u>					
Males	LJFL	27.1-188.0	0.04-30.1	907	1,3
	TL	37.8-243.8	0.04-24.1	51	1,2,3
	LJFL ¹	27.1-177.8	0.04-24.1	51	1,2,3
Females	LJFL	27.1-204.5	0.04-52.7	1280	1,3
	TL	37.8-259.0	0.04-52.7	74	1,2,3
	LJFL ¹	27.1-204.5	0.04-52.7	74	1,2,3

1 Used in the TL / LJFL regressions.

TABLE 2: Length regression equations, y-variables, sample size (N), coefficient of determination (R^2), and sex for three species of Atlantic istiophoridae. Length measurements include lower jaw fork length (LJFL) and total length (TL).

Species and Sex	Y-variable	Regression Equation	Sample Size (N)	R^2
<u>Blue Marlin</u>				
Male	LJFL	$-4.9914 + 1.3313(TL)$	26	0.97
	TL	$9.5182 + 0.7385(LJFL)$	26	0.97
Female	LJFL	$8.8446 + 1.2662(TL)$	59	0.97
	TL	$0.5785 + 0.7666(LJFL)$	59	0.97
<u>White Marlin</u>				
Male	LJFL	$-2.0297 + 0.7669(TL)$	43	0.92
	TL	$17.8484 + 1.2054(LJFL)$	43	0.92
Female	LJFL	$26.3682 + 1.1448(TL)$	38	0.81
	TL	$12.1394 + 0.7113(LJFL)$	38	0.81
<u>Sailfish</u>				
Male	LJFL	$5.5778 + 1.2709(TL)$	51	0.93
	TL	$6.4744 + 0.7313(LJFL)$	51	0.93
Female	LJFL	$15.0996 + 1.2120(TL)$	74	0.90
	TL	$4.4791 + 0.7464(LJFL)$	74	0.90

Figure 1

Regressions involving total length for Atlantic blue marlin. (A) total length and lower jaw fork length for males, (B) total length and lower jaw fork length for females, (C) total length and round weight for males, and (D) total length and round weight for females. Coefficient of determination (R^2) and sample size (N) are given for each relationship. Data points occurring on the X axis are encircled.

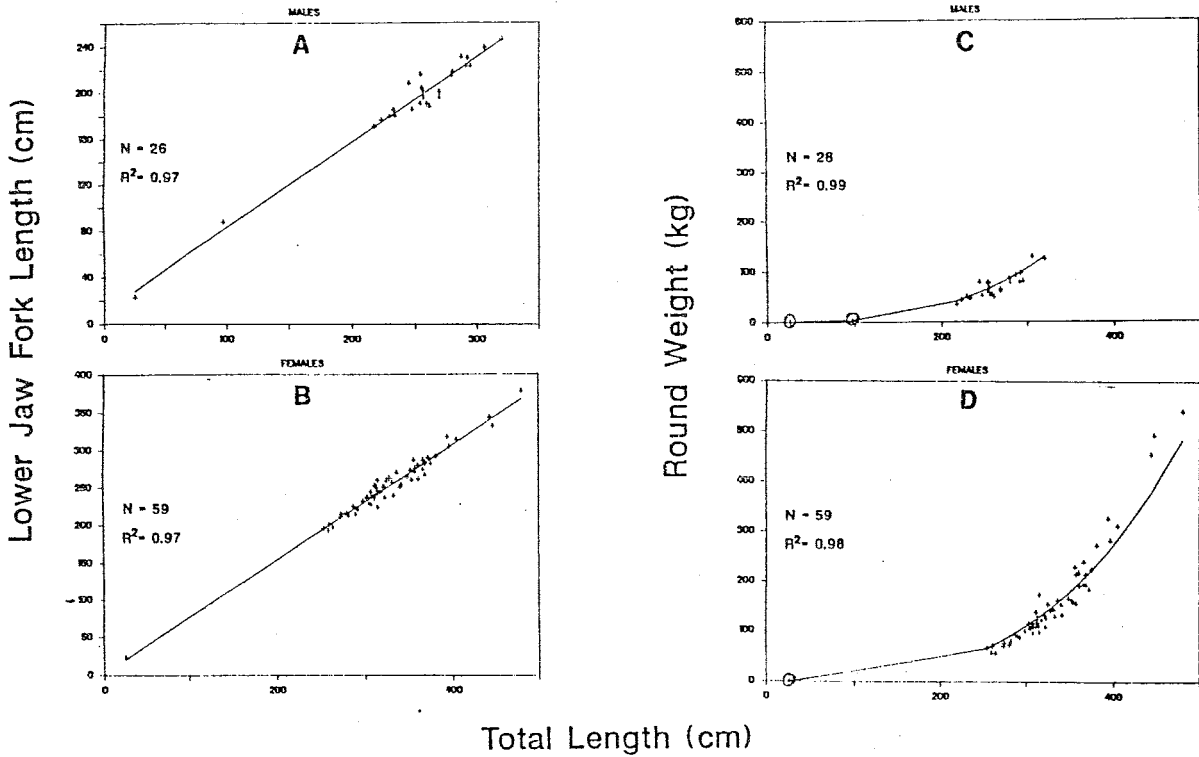
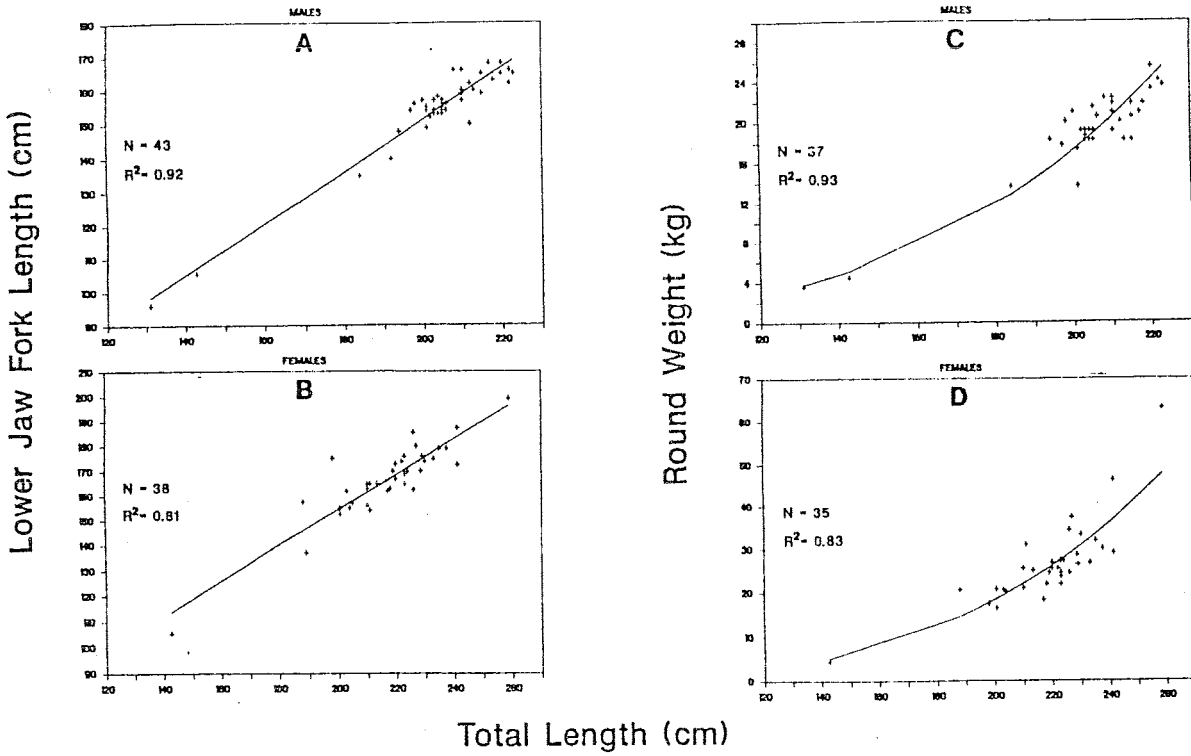


TABLE 3: Regression equations (LOG_{10}), Y-variable (LOG_{10}), sample size (N), coefficient of determination (R^2), and sex for three species of Atlantic istiophoridae. Measurement variables include lower jaw fork length (LJFL), total length (TL), and round weight (RWT).

Species and Sex	Y-variable (LOG_{10})	Regression Equation (LOG_{10})	Sample Size (N)	R^2
Blue Marlin Male	RWT	$-5.6106 + 3.2243 (\text{LJFL})$	1978	0.91
	LJFL	$1.7919 + 0.2814 (\text{RWT})$	1978	0.91
	RWT	$-5.4311 + 2.9976 (\text{TL})$	26	0.99
	TL	$1.8174 + 0.3301 (\text{RWT})$	26	0.99
Blue Marlin Female	RWT	$-5.7243 + 3.2840 (\text{LJFL})$	3267	0.93
	LJFL	$1.7901 + 0.2817 (\text{RWT})$	3267	0.93
	RWT	$-5.7197 + 3.1273 (\text{TL})$	59	0.98
	TL	$1.8391 + 0.3148 (\text{RWT})$	59	0.98
White Marlin Male	RWT	$-4.7114 + 2.7487 (\text{LJFL})$	1719	0.65
	LJFL	$1.8854 + 0.2356 (\text{RWT})$	1719	0.65
	RWT	$-7.0317 + 3.5928 (\text{TL})$	37	0.93
	TL	$1.9808 + 0.2595 (\text{RWT})$	37	0.93
White Marlin Female	RWT	$-5.4116 + 3.0694 (\text{LJFL})$	3149	0.71
	LJFL	$1.8854 + 0.2319 (\text{RWT})$	3149	0.71
	RWT	$-7.3415 + 3.7370 (\text{TL})$	37	0.83
	TL	$2.0267 + 0.2229 (\text{RWT})$	37	0.83
Sailfish Male	RWT	$-5.7747 + 3.1879 (\text{LJFL})$	907	0.90
	LJFL	$1.8504 + 0.2819 (\text{RWT})$	907	0.90
	RWT	$-6.7842 + 3.4674 (\text{TL})$	51	0.95
	TL	$1.9729 + 0.2738 (\text{RWT})$	51	0.95
Sailfish Female	RWT	$-5.9457 + 3.2683 (\text{LJFL})$	1280	0.86
	LJFL	$1.8725 + 0.2646 (\text{RWT})$	1280	0.86
	RWT	$-6.9823 + 3.5615 (\text{TL})$	74	0.96
	TL	$1.9736 + 0.2706 (\text{RWT})$	74	0.96

Figure 2

Total length regressions for Atlantic white marlin. (A) total length to lower jaw fork length for males, (B) total length to lower jaw fork length for females, (C) total length to round weight for males, and (D) total length to round weight for females. Coefficient of determination (R^2) and sample size (N) are given for each relationship.



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Figure 3

Total length regressions for Atlantic sailfish. (A) total length to lower jaw fork length for males, (B) total length to lower jaw fork length for females, (C) total length to round weight for males, and (D) total length to round weight for females. Coefficient of determination (R^2) and sample size (N) are given for each relationship. Data points occurring on the X axis are encircled.

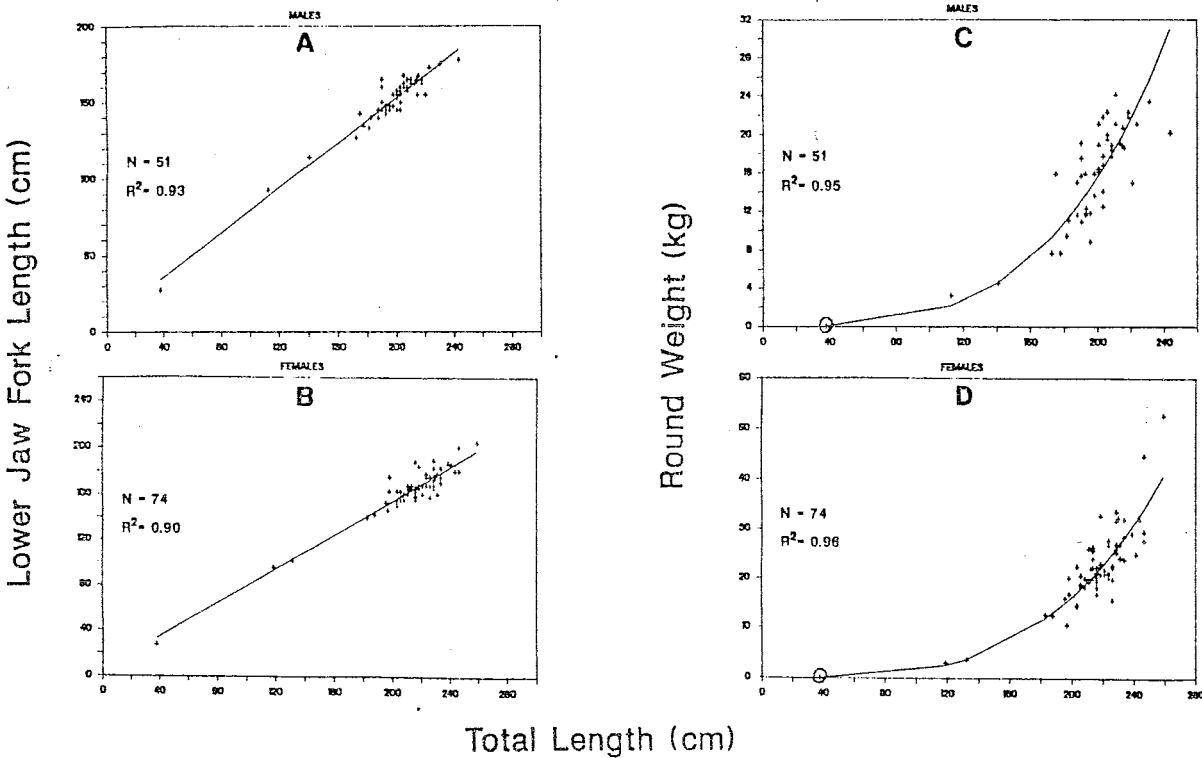


Figure 4
 Lower jaw fork length to round weight regressions for male (A) blue marlin, (B) white marlin, and (C) sailfish caught in the North Atlantic and adjacent seas. Coefficient of determination (R^2) and sample size (N) are given for each relationship. Data points occurring on the X axis are encircled.

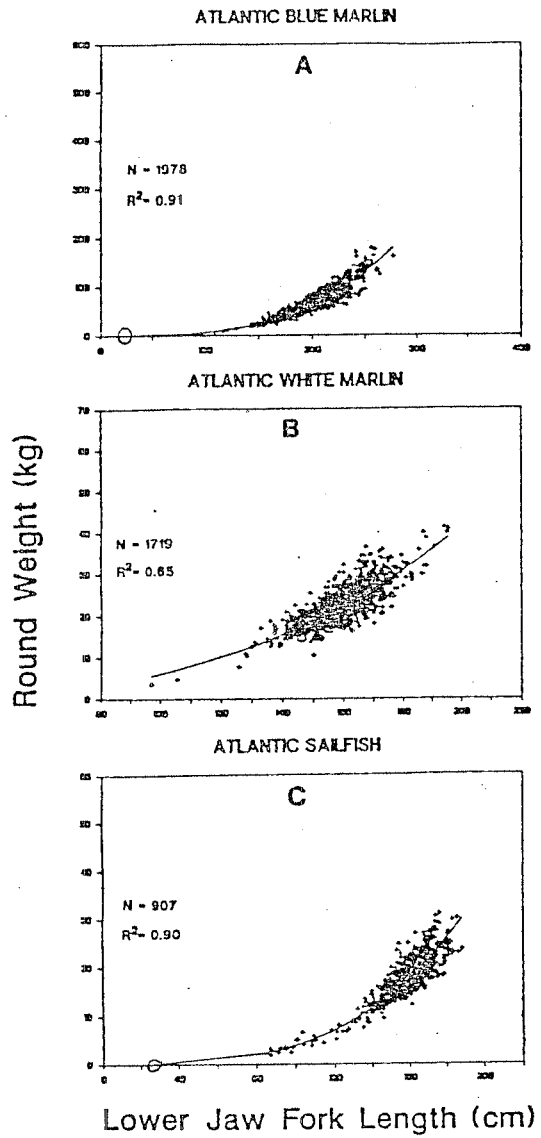


Figure 5
 Lower jaw fork length to round weight regressions for female (A) blue marlin, (B) white marlin, and (C) sailfish caught in the North Atlantic and adjacent seas. Coefficient of determination (R^2) and sample size (N) are given for each relationship. Data points occurring on the X axis are encircled.

