DEVELOPMENT OF LENGTH AND WEIGHT REGRESSION PARAMETERS FOR ATLANTIC SWORDFISH (Xiphias gladius)

D. W. Lee, G. P. Scott
NMFS-Southeast Fisheries Center, 75 Virginia Beach Drive, Miami, Florida 33149, U.S.A.

SUMMARY

Availability of a common unit of measurement, such as lower jaw fork length (LJFL), is often used for partitioning the catch into age groups for age-based stock assessments. In the U.S. fleet, swordfish (*Xiphias gladius*) are processed for the commercial market at sea. The processing used involves the removal of the head, viscera, gills, and caudal fin of the carcasses. In addition, whole weights cannot be measured on landed fish. Because the recent ICCAT agreement for a minimum size swordfish of 25 kg, whole weight, predictive relationships between the commonly available measurements for the U.S. landings were needed. For these reasons, length-weight and length-length relationships were derived from data collected by at-sea observers and volunteer crew members aboard cooperating swordfish vessels to allow conversion from carcass length (CK) to LJFL and CK to dressed (DWT) and whole weights.

RESUME

Le fait de disposer d'une unité commune de mesure, telle que la longueur maxillaire-fourche, est souvent utilisé pour répartir la prise en groupes d'âge pour les évaluations de stock basées sur l'âge. Pour la flottille américaine, les espadons *(Xiphias gladius)* sont traités en mer en vue du marché commercial. Le processus implique le retrait de la tête, des viscères, des branchies et de la fourche caudale des carcasses. De plus, il est impossible de relever le poids vif de poissons au débarquement. Du fait de l'accord récent de l'ICCAT sur une taille minimum de 25 kg de poids vif pour l'espadon, il fallait disposer de mensurations sur les débarquements américains. Des rapports longueur-poids et longueur-longueur ont donc été établis à partir de données relevées en mer par des observateurs et des membres volontaires de l'équipage de bateaux pêchant l'espadon qui ont collaboré, afin de permettre la conversion de la taille de la carcasse (CK) en longueur maxillaire-fourche et de CK en poids manipulé (DWT) et poids vif.

RESUMEN

Con frecuencia, para clasificar la captura por grupos de edad en las evaluaciones del stock basadas en la edad, se empleó una unidad de medida común, tal como la de mandíbula inferior-longitud horquilla (LJFL). En la flota norteamericana, el pez espada *(Xiphias gladius)* se prepara en la mar para su envío al mercado. Se les quita la cabeza, vísceras, agallas y la aleta caudal. Además, los peces que se desembarcan como peso vivo no pueden medirse. Debido al reciente acuerdo de ICCAT que establece la talla mínima del pez espada en 25 kg, peso vivo, era necesario saber cuáles eran las relaciones de predicción entre las medidas que se suelen obtener en los desembarques de la flota norteamericana. En consecuencia, se derivaron relaciones talla-peso y talla-talla, partiendo de datos recogidos en la mar por observadores y voluntarios de las tripulaciones de barcos que pescan pez espada, para convertirlos de talla de carcasas (CK) en LJFL y CK y en peso eviscerado (DWT) y peso vivo.

INTRODUCTION

Size frequency information of the U.S. commercial catch of Atlantic swordfish (Xiphias gladius) is required for stock assessments of this species. Because of the nature of the commercial swordfish market, this species is routinely dressed by the U.S. fleet (head along with the viscera, and all external fins removed) while the fishing vessel is at sea and away from port. Thus, the only definable reference features remaining on the swordfish carcass for mensuration purposes are the cleithrum and caudal keel structures. When in port and during unloading of the catch, only the dressed weight of the carcass can be recorded by fish dealers or fishery port agents.

In 1990, the National Marine Fisheries Service's (NMFS) Miami Laboratory began collecting sex ratio at size data from cooperating captains and owners of 5 U.S. longline vessels. Various morphometric data, including a special length measurement related to the available dressed carcass, and biological samples for sex identification were collected. In conjunction with these data collection activities on U.S. longline vessels, observer agents, under NMFS contract, were also placed onboard U.S. gillnet vessels to gather similar morphometric data. Utilizing the length and weight measurements from these two sources, regression equations were computed for male and female swordfish. The purpose of this paper was to report on these relationships for converting the non standard measurements into common units of measurement.

MATERIALS AND METHODS

Beginning in 1990, efforts were made by personnel at the NMFS Miami Laboratory to work with the Bluewater Fisherman's Association, an association of U.S. pelagic fisherman, to gain the cooperation of various captains and owners of longline vessels to collect sex ratio at size data on Atlantic swordfish. The captains and their crews that volunteered in these efforts were provided a sampling manual for guidance concerning the data requirements and sampling procedures (Lee 1991). Morphometric data collected included (1) the measurement from the tip of the lower jaw to the fork of the tail (LJFL, inches), (2) the measurement from the cleithrum where demarkation of the body pigment is apparent to the anterior rise of the caudal keel (CK, inches), and, (3) at the time of the off-loading of the catch, the carcass dressed weight (head, external fins, and viscera removed; lb converted to kg). Crew members measured the two lengths following the contour of the body (curved) with a measuring tape (inches were converted to cm). In addition, date of capture and location were recorded. Gonad samples were also collected from each of the specimens so that NMFS Miami Laboratory personnel could confirm the sex. Initially, a total of 1,223 swordfish samples where LJFL and CK (curved) measurements and sex identification were collected from the longline fishery during 1990 through January of 1991. These data also included 1,058 samples on which both CK and DWT were recorded. The CK and LJFL and CK and DWT data were graphically displayed for each sex. Studentized residuals were examined and likely outliers were identified and deleted from further analysis. Based on these results, 1,187 observations (N=327 males, N=860 females) with CK-LJFL (curved) and 1,030 observations (N=285 males, N=745 females) with CK (curved)-DWT measurements were used for regression analysis.

In 1990, additional data were collected by NMFS contracted observer agents placed onboard U.S. gillnet vessels operating in the northwestern Atlantic Ocean. The observers were provided training associated with the morphometric measures (LJFL, CK, and DWT) and sex identification requirements. Measurements were recorded on observer forms as straight length (caliper, cm) and dressed weight (lbs converted to kg), along with date of capture and location. The observers also sampled swordfish in predefined size categories during each trip for gonad tissue in addition to morphometric data. All other swordfish were measured and the sex determinations made by the observers were recorded. For samples were sex was recorded but no gonad collected, the observer's sex determination was accepted if there was good agreement with those samples where the observer's sex determination was confirmed by the gonadal tissue collected. Through the efforts of the observer program, data were obtained from 486 swordfish with paired dressed weight and CK (caliper) length observations. From that data collection, 428 paired length observations of LJFL and CK (caliper) were also available. These data were also graphically displayed and likely outliers were identified and excluded from subsequent analysis as previously described. The data used in analysis included 415 swordfish samples (N=106 males, N=309 females) with CK-LJFL (caliper) measurements and 477 samples (N=126 males, N=351 females) with CK (caliper)-DWT measurements.

Linear and non-linear regression techniques (Snedecor and Cochran 1980) were used to determine the relationships between CK measurements (both curved and caliper) and DWT and between the measurements of CK and LJFL (both curved and caliper) obtained from the U.S. longline and gillnet fisheries. In addition, regression analysis was also utilized to develop a relationship that would allow direct translation of the length measures (CK, mixed units i.e., measurements in inches) into the International Commission for the Conservation of Atlantic Tunas (ICCAT) minimum size goal of 25 kg whole weight. For this part of the analysis, only observations in measurements with CK ranging from 24-34 inches (60.9 cm to 86.4 cm) were examined and associated DWT weights (lbs converted to whole weight kg, (DWT(lbs)/0.75))/2.204) were used.

RESULTS AND DISCUSSION

Linear regressions of curved and caliper measured CK (cm) and

LJFL (cm) obtained from the two commercial fishery sources (longline and gillnet, respectively) and the curvilinear regressions of CK (cm, curved and caliper) and DWT (kg) were computed separately for the males and females. The regression relationships are presented Figures 1 through 7.

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). In addition, regression analysis by other authors on fish species of similar body design (i.e., Istiophorids) have suggested that R^2 values exceeding 0.80 are acceptable for the estimation of length and weight measurements (Prince and Lee 1989). The R^2's computed in these analyses of the curved and caliper measurements were high indicating strong relationships with the range for male swordfish from 0.90 to 0.97, while R^2's from the female swordfish regressions ranged from 0.92 to 0.97 (Tables 1 and 2).

The curvilinear relationships between CK (cm, curved) and DWT (kg) measurements (Table 1; Figs. 1 and 2A) collected from the longline fishery were strongly related for both males and females (R^2=0.90 and 0.93, respectively). Likewise, the curvilinear relationships of CK (cm, caliper) and DWT (kg) collected from the gillnet fishery (Table 2; Figs. 3 and 4A) also showed strong relationships (males: R^2=0.94; females: R^2=0.92). Covariance analysis comparing the CK(curved)-DWT relationship derived from longline caught male swordfish to the longline caught female swordfish, as well as for male and female CK(caliper)-DWT relationships derived from gillnet caught swordfish, indicated that the model parameter estimates between sexes of each fishery were not significantly different (α=0.05; longline: F=0.51, p=0.481, df=1, 1026; gillnet: F=0.67, p=0.413, df=1, 473). However, the level of the male and female regression relationships were found to be different (gillnet only; F=13.10). Along these same lines, covariance analysis was used in comparing the longline regression relationship of CK(curved)-DWT to the relationship derived from the gillnet CK(caliper)-DWT data by examining the swordfish males separately from the females. Results indicated no significant differences in the model parameter estimates for either the males (α=0.05; F=0.05 p=0.827 df=1, 407) or females (F=3.00 p=0.079 df=1, 1092). The levels of the relationship lines, however, were different only for the female swordfish (F=40.19).

Linear regression relationships of CK (cm, curved) and LJFL (cm, curved) derived for male and female swordfish sampled aboard longline vessels (Table 2) were found to be strongly related (males: R^2=0.95; females: R^2=0.97). Similarly, R^2's of the relationships of CK (caliper) and LJFL (caliper) for males and females sampled aboard the gillnet vessels (Table 2) were strongly related (R^2=0.97 for both sexes). The regression relationships were compared using covariance analysis between male (Fig. 1B) and female (Fig. 2B) swordfish where CK and LJFL were collected as curved measurements from the longline fishery, as well as the relationships derived for male (Fig. 3B) and female (Fig. 4B) swordfish measured as caliper from the gillnet fishery. Results indicated that no significant differences (α=0.05) were found between the model slope parameter estimates (longline: F=3.14, p=0.073, df=1,1183; gillnet: F=0.001, p=0.978, df=1,411), as well as no significant differences in the level of the relationship lines (longline: F=0.32; gillnet: F=2.25). In addition, the relationships of CK-LJFL (curved vs. caliper) for male swordfish were compared using covariance analysis separately from the CK-LJFL (curved vs. caliper) relationships derived for the female swordfish. Subsequently, no significant differences (α=0.05) were found between slope parameter estimates of the CK-LJFL relationships for the males (F=0.68, p=0.411, df=1,429) or for the females (F=0.43, p=0.521, df=1,1165), as well as no significant differences with levels of the relationships (males: F=1.09; females: F=0.54). These results indicate that the curved CK measurements collected from the longline fishery and the caliper CK measurements collected from the gillnet fishery were not statistically different and could be pooled to derive regression relationship for swordfish males and for swordfish females (Table 2; Figs. 5A and B). In fact, with no significant differences between sexes all data were combined to derive a single, overall equation regardless of sex (Table 2; Fig. 6A).

For most assessment purposes, being able to estimate a dressed weight (DWT) of a carcass or LJFL with knowledge of the sex of the fish is preferred. However, sex is generally unknown by those collecting size frequency data for the U.S. swordfish landings, thus estimates need also be derived from single equations. Although covariance analysis indicated statistically that CK and DWT measurements among males and females swordfish or between gear types should be kept separate, a relationship combining all sexes and gears was also derived (Table 1; Fig. 6B).

The nonlinear fit of a power function (Table 3, Fig. 7A) to the truncated data set of swordfish CK measurements of 24-34 inches (N=870 resulted in a model that predicts a whole weight of 25 kg (the ICCAT minimum size) at slightly below 29 inches. The results of this analysis suggests that, given the available data, on average a swordfish with a CK length of at least 29 inches will have a whole weight 25 kg or more. These results do not imply that all swordfish with CK lengths of >29 inches will have a dressed weight of at least 25 kg. Based on the model fit, assuming a normal error distribution about the prediction of whole weight by CK, there is approximately a 40% chance that a swordfish with a CK length of 29 inches would have a whole weight less than 25 kg. Given the model and associated assumptions, the probabilities of encountering swordfish with whole weight less that 25 kg for CK lengths of 30, 31, and 32 inches, are approximately 22%, 9%, and 3% respectively (Fig. 7B).

In summary, regression analysis was conducted on the morphometric data collected by captains and crews onboard longline vessels (curved measurements) and observer agents monitoring the gillnet fishing activities (caliper measurements). Regression relationships for estimating LJFL from CK measurements (both curved and caliper) and DWT from CK measurements (both curved and caliper) for male and female swordfish were found to be strongly related (R^2's $\geq$ 0.90). Covariance analysis conducted on the curved and caliper relationships of CK-LJFL indicated no significant differences for the male swordfish data combined nor for the females combined. Regression relationships of CK-LJFL were also determined for the male swordfish (combining curved and caliper measurements), as well as for the females (Fig. 5). In addition, a single, overall equation was developed (Fig. 6A). Because covariance analysis indicated some sex-specific differences for CK-DWT relationships, separate relationships for estimating DWT from CK measurements for males and females should be applied. However, for practical reasons this may not be possible and a single relationship was developed (Fig. 6B).

LITERATURE CITATION

Lee, D.W., 1991. Tabulation of recent Data on swordfish sex ratio at size collected from the U.S. fishery. Int. Comm. Conserv. Atl. Tunas, Coll. Vol. Sci. Pap., Madrid, 35(2):405-414.

Snedecor, G.W. and W.G. Cochran, 1980. Statistical methods. (7th edition), The Iowa State University Press, Ames, Iowa: 507p.

Steel, G.D. and J.H. Torrie, 1960. Principles and procedures of statistics. McGraw-Hill Book Company, Inc., NY: 481p.

Prince E.D. and D.W. Lee, 1989. Development of length regressions for Atlantic istiophoridae. Int. Comm. Conserv. Atl. Tunas, Coll. Vol. Sci. Pap., Madrid, 30(2):364-374.

Table 1: Gear type, sex, Y-variable, curvilinear regression equation, sample size (N), and coefficient of determination (R^2) for Atlantic swordfish. The length variable was the distance measured from the cleithrum to anterior rise of the caudal keel (CK, cm). The CK measurement collected onboard U.S. longline vessels followed the contour of the body while observers onboard U.S. gillnet vessels collected caliper lengths. Dressed weights (DWT, kg) were collected during unloading of the catch. The equations for converting DWT to a CK measurement were derived algebraically from the curvilinear relationships and are provided for convenience.

Gear Type	Sex	Y-variable	Regression Equation	Sample Size (N)	R^2
Gillnet					
	Male	DWT	$0.000118(CK)^{2.8037}$	126	0.94
		CK	$25.1795(DWT)^{0.3567}$		
	Female	DWT	$0.000215(CK)^{2.6875}$	351	0.92
		CK	$23.1566(DWT)^{0.3721}$		
Longline					
	Male	DWT	$0.000063(CK)^{2.9344}$	285	0.90
		CK	$27.0099(DWT)^{0.3408}$		
	Female	DWT	$0.000154(CK)^{2.7462}$	745	0.93
		CK	$24.4498(DWT)^{0.3641}$		
Pooled data (all sex and gear combined)					
		DWT	$0.000152(CK)^{2.7517}$	1,507	0.93

Table 2: Gear type, sex, Y-variable, linear regression equation, sample size (N), and coefficient of determination (R^2) for Atlantic swordfish. The length variables are the distance measured from the cleithrum to anterior rise of the caudal keel (CK, cm) and the distance measured from the tip of lower jaw to fork of tail JFL, cm). The CK and LJFL measurements collected onboard U.S. longline vessels followed the contour of the body while observers onboard U.S. gillnet vessels collected caliper lengths. Dressed weights (DWT, kg) were collected during unloading of the catch. The equations for converting LJFL to a CK measurement were derived algebraically from the linear relationships and are provided for convenience.

Gear Type	Sex	Y-variable	Regression Equation	Sample Size (N)	R^2
Gillnet					
	Male	LJFL	17.1589 + 1.5307(CK)	106	0.97
		CK	-11.2098 + 0.6533(LJFL)		
	Female	LJFL	18.0524 + 1.5298(CK)	309	0.97
		CK	-11.8005 + 0.6537(LJFL)		
Longline					
	Male	LJFL	20.2768 + 1.5000(CK)	327	0.95
		CK	-13.5179 + 0.6667(LJFL)		
	Female	LJFL	17.1627 + 1.5425(CK)	860	0.97
		CK	-11.1265 + 0.6483(LJFL)		
Pooled data from Longline and Gillnet					
	Male	LJFL	19.6233 + 1.5052(CK)	433	0.95
	Female	LJFL	17.4176 + 1.5384(CK)	1,169	0.97
Pooled data (all sex and gear combined)					
		LJFL	17.6414 + 1.5349(CK)	1,602	0.97

Figure 1. Male swordfish regression relationships derived from data collected from U.S. longline vessels fishing in the NW Atlantic Ocean and Gulf of Mexico during 1990 and January of 1991. (A) Relationship represents comparison of measurements of CK (cm, curved) and DWT (kg). (B) Linear relationship represents comparison of measurements CK (cm) and LJFL (cm, curved). Coefficient of determination (R^2) and sample size (N) are given for each relationship.

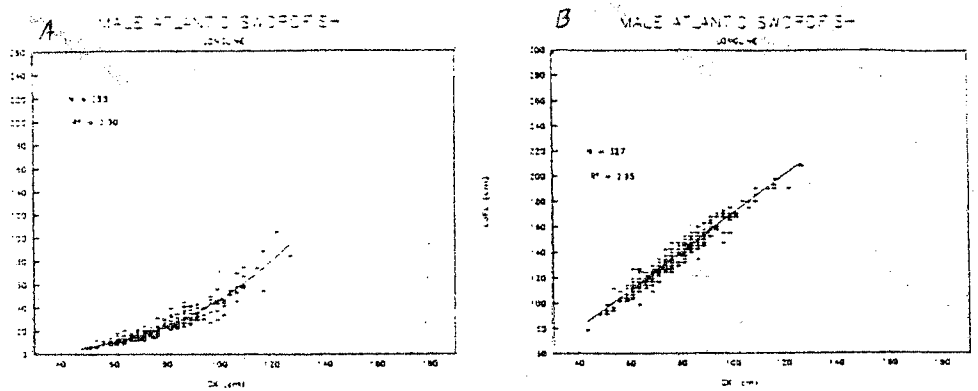

Figure 2. Female swordfish regression relationships derived from data collected from U.S. longline vessels fishing in the NW Atlantic Ocean and Gulf of Mexico during 1990 and January of 1991. (A) Relationship represents comparison of measurements of CK (cm, curved) and DWT (kg). (B) Linear relationship represents comparison of measurement CK (cm, curved) and LJFL (cm, curved). Coefficient of determination (R^2) and sample size (N) are given for each relationship.

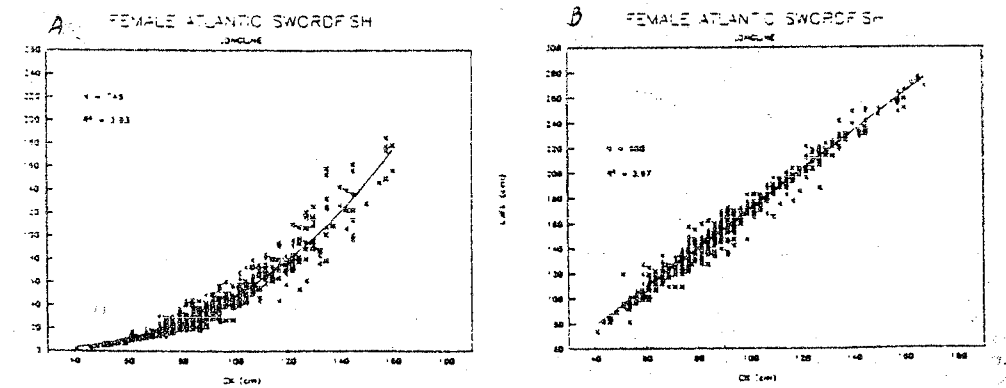

Figure 3. Male swordfish regression relationships derived from data collected from U.S. gillnet vessels fishing in the NW Atlantic Ocean during 1990. (A) Relationship represents comparison of measurements of CK (cm, caliper) and DWT (kg). (B) Linear relationship represents comparison of measurements CK (cm, caliper) and LJFL (cm, caliper). Coefficient of determination (R^2) and sample size (N) are given for each relationship.

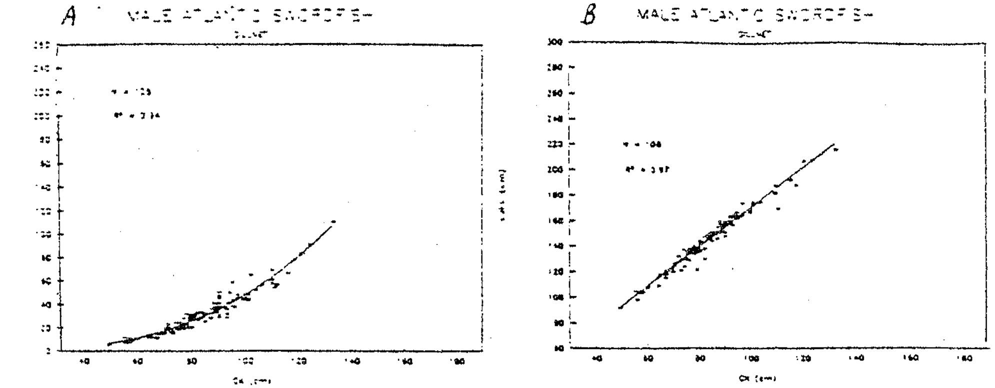

Figure 4. Female swordfish regression relationships derived from data collected from U.S. gillnet vessels fishing in the NW Atlantic Ocean during 1990. (A) Relationship represents comparison of measurements of CK (cm, caliper) and DWT (kg). (B) Linear relationship represents comparison of measurements CK (cm, caliper) and LJFL (cm, caliper). Coefficient of determination (R^2) and sample size (N) are given for each relationship.

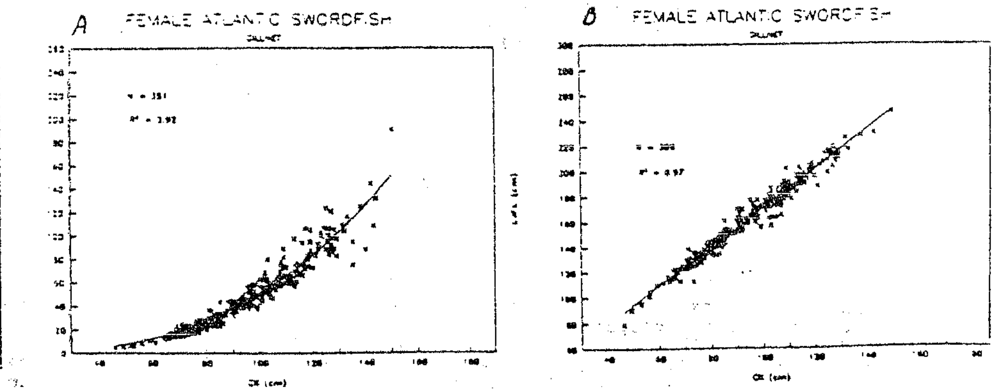

Figure 5. Swordfish regression relationships derived from data collected from U.S. longline vessels (curved length) and gillnet vessels (caliper length) fishing in the NW Atlantic Ocean and Gulf of Mexico during 1990 and 1991. Linear relationships represents comparison of combined measurements (curved and caliper) of CK (cm), and LJFL (cm) for (A) male and (B) female swordfish. Coefficient of determination (R^2) and sample size (N) are given for each relationship.

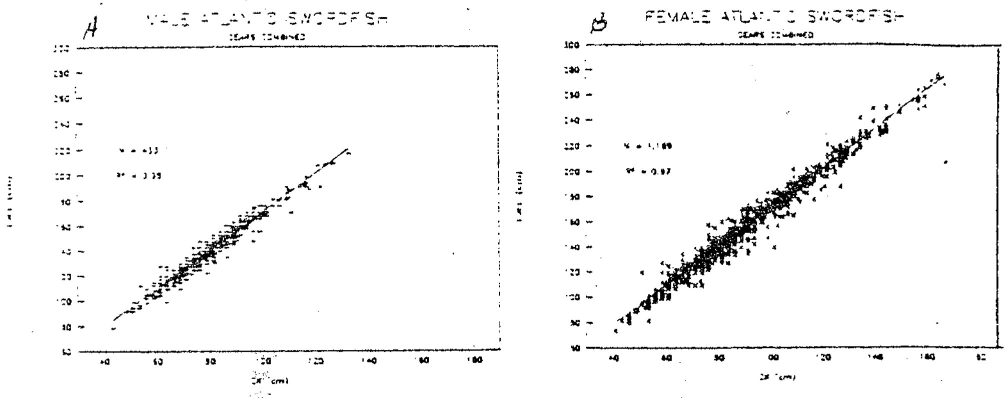

Figure 6. Swordfish regression relationships combining data for both sexes collected from U.S. longline vessels (curved length) and gillnet vessels (caliper length) fishing in the NW Atlantic Ocean and Gulf of Mexico during 1990 and 1991. (A) Linear relationship represents comparison of combined measurements (curved and caliper) of CK (cm) and LJFL (cm). (B) Length-weight relationship of CK (cm) and dressed weight (kg). Coefficient of determination (R^2) and sample size (N) are given for each relationship.

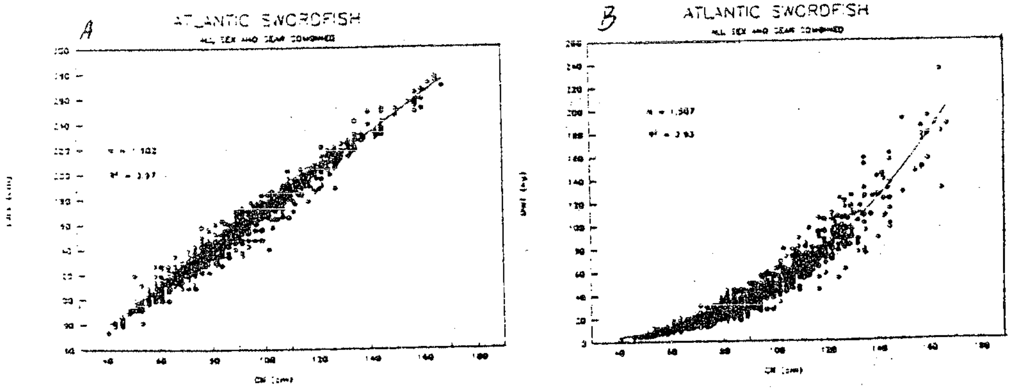

Figure 7. Swordfish regression relationship combining data for both sexes collected from U.S. longline vessels (curved length) and gillnet vessels (caliper length) fishing in the NW Atlantic Ocean and Gulf of Mexico during 1990 and 1991. (A) Power function (a) fitted to truncated data (N=870) which included those samples with CK length between 24 and 34 inches (cm converted to whole inch) and whole weight (kg; DWT/0.75). Solid lines (b) represents 95% confidence interval on the prediction of whole weight given CK. (B) The model (see Figure 7A) prediction probability of a swordfish with a CK length (inches) indicated having a whole weight less than or equal to the ICCAT minimum size target of 25 kg.