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SHORT PAPERS AND NOTES

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LENGTH–LENGTH CONVERSIONS AND WEIGHT–LENGTH RELATIONSHIPS FOR GULF MENHADEN (*BREVOORTIA PATRONUS*) IN THE GULF OF MEXICO—The gulf menhaden (*Brevoortia patronus*) is a relatively small clupeid fish, generally measuring less than 25 cm fork length, weighing less than 250 g, and whose center of distribution is the northern Gulf of Mexico (Ahrenholz, 1991). They form dense, near-surface schools, which are the targets of a large industrial purse-seine fishery (Smith, 1991). In terms of volume, the gulf menhaden fishery is one of the largest in the United States—landings have averaged 466,000 metric tons annually in recent years (2007–2011). Currently, about 40 purse-seine vessels harvest gulf menhaden for industrial purposes, the catch being processed into fish meal, fish oil, and fish solubles at four shore-based factories in coastal Mississippi (one factory) and Louisiana (three factories). Over 90% of the catch is harvested in the coastal waters of Louisiana, with smaller quantities coming from Mississippi, Texas, and Alabama (Smith et al., 2002).

Often fishery biologists record length and weight measurements of fish specimens to determine size structure of a population and for use in stock assessment or bioenergetics models. Lengths that are commonly measured are total length, standard length, and fork length. Total length (TL) is the length measurement from the nose of the fish to the tip of the tail without pinching the tail lobes together (natural total length); standard length (SL) is the length measurement from the nose of the fish to the base of the caudal fin; and fork length (FL) is the length measurement from the nose of the fish to the fork in the caudal fin (e.g., Murphy and Willis, 1996; Smith et al., 2008). Whole weight, weight of the entire fish, is also often collected.

Conversions among standard length, fork length, and total length were needed to convert lengths to a common format for the gulf menhaden *Brevoortia patronus* stock assessment. During the data workshop portion of the stock assessment process in the southeastern United States, participants realized that states used standard and total length measurements for their fishery-independent surveys, while National Marine Fisheries Service used fork lengths in

their biostatistical database of the commercial reduction fishery. Therefore, the need for statistical regressions to transform between the different length measurements became evident.

Conversions between the different length measurements and weight-length relationships developed with fishery-independent data were unavailable in the literature. Therefore, archived length data were examined from Texas Parks and Wildlife Department (TPWD). Additionally, state biologists agreed to collect and measure lengths (fork length, standard length, and total length) and weight for several hundred juvenile and adult gulf menhaden in late March and early April 2011. The intent of these collections was to acquire a broad range of specimen sizes from a wide geographic location.

Methods and results.—Archived lengths of gulf menhaden from 1975 to 1978 were provided by TPWD; standard and total lengths were measured (N = 9,158; Classen et al., 1988). Specimens were collected during all months of the year. Sites were randomly selected from 100 fixed stations in Texas' bay systems.

In response to our request for contemporary length and weight data on gulf menhaden, biologists from individual gulf states acquired specimens during their routine monitoring surveys in March and April 2011. A total of 927 specimens were collected during this time period using a variety of gears, and all three lengths and weight were measured (Table 1; Table 2). The samples covered a broad range of sizes including juveniles and adults (Table 1; Table 2).

In spring 2011, TPWD used bay trawls, gulf trawls, and bag seines to collect 191 gulf menhaden. All sampling was done following protocols for their fishery-independent sampling. TPWD's fishery-independent data are collected as a stratified cluster sampling design; each bay system and gulf area serves as nonoverlapping strata with a fixed number of samples per month. Trawls were towed in open water for 10 min. Bay trawls were used in estuarine systems, while gulf trawls, identical to those used in the bays, were used in the Texas territorial sea <16.7 km from shore. Bag seine sample locations were randomly selected from grids that contained >15.2 m of shoreline. Bag seines were pulled parallel to the shoreline for 15.2 m.

Louisiana Wildlife and Fisheries Department (LWFD) used seines, gillnets, and trawls to sample 410 gulf menhaden in spring 2011. All

TABLE 1. Sample sizes used to estimate the length–length conversions by state and gear, and sample sizes of juvenile and adult gulf menhaden (juveniles were classified as specimens ≤ 100 mm FL). “Other” gear includes cast net, purse-seine, push net, rotenone, and trammel net.

State	N	N _{adults}	N _{juveniles}	BPL	Trawl	Gillnet	Seine	Other
Alabama	90	37	53	6	47	37	—	—
Mississippi	236	151	85	14	19	103	—	100
Texas (2011)	191	79	112	—	183	—	8	—
Louisiana	410	64	346	—	329	50	31	—
Texas (historical)	8,967	8,234	733	—	184	7,122	284	1,377
Omega	195	195	—	—	—	—	—	195

TABLE 2. Sample sizes used to estimate the weight–length relationships by state and gear, and sample sizes of juvenile and adult gulf menhaden (juveniles were classified as specimens ≤ 100 mm FL). “Other” gear includes cast net, purse-seine, push net, rotenone, and trammel net.

State	N	N _{adults}	N _{juveniles}	BPL	Trawl	Gillnet	Seine	Other
Alabama	89	37	52	6	46	37	—	—
Mississippi	224	151	73	14	19	91	—	100
Texas (2011)	172	79	93	—	164	—	8	—
Louisiana	409	64	345	—	328	50	31	—
Omega	195	195	—	—	—	—	—	195

sampling followed state protocols. The sampling design for LWFD data consists of fixed stations selected by coastal study areas. Seines were anchored to the shoreline, fully extended perpendicular to shore, and then hauled to shore. Experimental gill nets were composed of five panels of different mesh sizes and were set parallel to the shoreline or reef or in a crescent shape. A skiff was run around both the inside and outside of the net, and the net was then retrieved. Trawls were towed for 10 min at a constant speed and in a weaving or circular track

to allow the prop wash to pass on either side of the trawl.

During March and April 2011, Alabama Department of Conservation and Natural Resources (ADCNR) used trawls, beam plankton and larvae (BPL) nets, and gillnets to collect 90 gulf menhaden. All sampling followed state protocols. Trawls were towed at fixed stations for 10 min. Beam plankton and larvae nets were towed at fixed stations and were towed perpendicular to shore for 130 m. Gillnet sampling stations were selected using stratified random

TABLE 3. Relationship fit, data source, years of data availability, sample size, and fitted relationship with associated R^2 value for each of the length–length relationships fitted for gulf menhaden in the Gulf of Mexico.

Relationship	Source	Years	N	R^2	Intercept	Slope
TL = f(SL)	AL	2011	90	0.9994	−3.270	1.299
	LA	2011	410	0.9962	−1.389	1.298
	MS	2011	235	0.9983	1.049	1.237
	TX	1975–1978, 2011	9,158	0.9903	2.993	1.261
	Overall	1975–1978, 2011	9,892	0.9927	1.739	1.267
FL = f(SL)	AL	2011	90	0.9996	−0.956	1.109
	LA	2011	409	0.9964	0.378	1.088
	MS	2011	235	0.9984	3.547	1.046
	Omega Protein	2010	195	0.9657	1.768	1.107
	TX	2011	191	0.9987	1.814	1.045
Overall	2010–2011	1,120	0.9968	0.110	1.094	
FL = f(TL)	AL	2011	90	0.9996	1.869	0.854
	LA	2011	410	0.9974	1.571	0.838
	MS	2011	236	0.9990	2.710	0.846
	TX	2011	191	0.9986	1.506	0.840
	Overall	2010–2011	927	0.9987	1.191	0.850

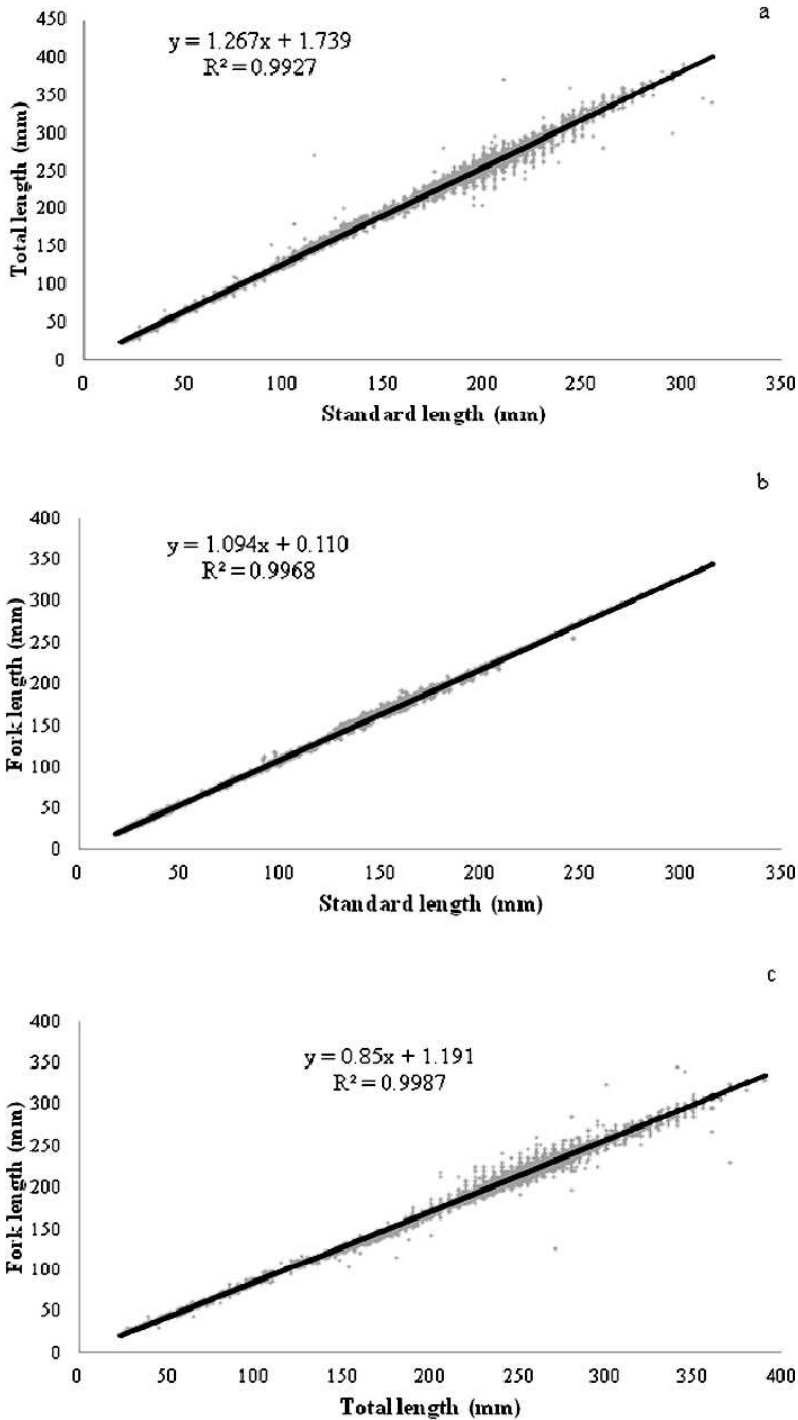


Fig. 1. Fitted relationships for (a) TL with SL, (b) FL with SL, and (c) FL with TL for gulf menhaden.

design with sampling sites allocated based on variation in samples. Experimental gillnets were used for sampling and were composed of five panels of graduated mesh sizes. Gillnets were soaked for a period of 1 hr.

Also in spring 2011, the Mississippi Department of Marine Resources (MDMR) and the Gulf Coast Research Laboratory used trawls, cast nets, BPL nets, and gillnets to collect 236 gulf menhaden. All sampling followed state protocols. Trawl, BPL,

TABLE 4. Relationship fit, data source, years of data availability, sample size, and fitted relationship with associated R^2 value for each of the weight-length relationships fitted for gulf menhaden in the Gulf of Mexico.

Relationship	Source	Years	N	R^2	Intercept	Slope	MSE
ln w = f(ln FL)	AL	2011	89	0.9962	-12.207	3.248	0.026
	LA	2011	409	0.9817	-12.197	3.271	0.045
	MS	2011	224	0.9923	-11.667	3.145	0.027
	Omega protein	2010	195	0.6209	-11.460	3.118	0.060
	TX	2011	172	0.9931	-12.808	3.414	0.019
	Overall	2010-2011	1,089	0.9904	-12.088	3.241	0.041
ln w = f(ln TL)	AL	2011	89	0.9969	-12.264	3.169	0.022
	LA	2011	409	0.9850	-12.362	3.196	0.037
	MS	2011	224	0.9933	-11.497	3.020	0.024
	TX	2011	172	0.9945	-12.839	3.307	0.015
	Overall	2011	894	0.9918	-12.230	3.168	0.031
	Overall	2011	89	0.9967	-12.015	3.272	0.023
ln w = f(ln SL)	AL	2011	89	0.9967	-12.015	3.272	0.023
	LA	2011	408	0.9834	-11.823	3.252	0.040
	MS	2011	223	0.9933	-10.868	3.029	0.023
	Omega protein	2010	195	0.6122	-11.195	3.136	0.061
	TX	2011	172	0.9933	-12.089	3.305	0.019
	Overall	2010-2011	1,087	0.9903	-11.732	3.227	0.041

and gillnet sampling all occur at fixed stations. Trawls were towed 10 min at each station. Cast nets were 8 foot nets with 3/4 inch stretch mesh. The BPL net was pulled by hand for 50 m parallel to the shoreline, then turned around and pulled outside the previous track to the starting point. Experimental gillnets consisted of five panels with graduated mesh sizes. Gillnets were deployed from the shoreline angling out then turning parallel to the shoreline and had a soak time of 1 hr.

Lastly, a total of 195 gulf menhaden were collected by the menhaden industry (Omega Protein, Inc.) in fall 2010 related to the BP Deep Water Horizon oil disaster, and specimens were processed for FL, SL, and weight (EcoFish Consulting, 2010).

The relationships between the different length measurements were fitted using linear regressions. Separate regressions were completed relating TL with SL, FL with SL, and FL with TL. Overall relationships, including all available data, were fit, as well as relationships by state and using only data from Omega Protein, Inc.

Individuals sampled ranged from 22 to 255 mm FL, 18 to 315 mm SL, and 23 to 390 mm TL. Each relationship covered a wide and inclusive range of gulf menhaden. Sample sizes were adequate for each relationship with $N = 9,892$ for the TL:SL relationship, $N = 1,120$ for the FL:SL relationship, and $N = 927$ for the FL:TL relationship (Table 3).

The linear relationship developed from the TL with SL relationship was

$$TL = 1.739 + 1.267 SL$$

$$(R^2 = 0.9927; \text{ Fig. 1a; Table 3}).$$

The linear relationship developed from the FL with SL relationship was

$$FL = 0.110 + 1.094 SL$$

$$(R^2 = 0.9968; \text{ Fig. 1b; Table 3}).$$

The linear relationship developed from the FL with TL relationship was

$$FL = 1.191 + 0.850 TL$$

$$(R^2 = 0.9987; \text{ Fig. 1c; Table 3}).$$

Relationships developed for the individual states were similar to the overall relationships (Table 3). Slopes estimated for each of the individual state relationships were similar to the overall slope, but the intercepts were more variable (Table 3).

The relationships between weight and the three different length measurements were fitted using linear regressions. Separate regressions were completed relating weight with FL, weight with TL, and weight with SL. Overall relationships, including all available data, were fit, as well as relationships by state and using only data from Omega Protein, Inc.

Individuals sampled ranged from 0.1 to 288 g. Each relationship covered a wide and inclusive range of gulf menhaden. Sample sizes were adequate for each relationship with $N = 1,089$

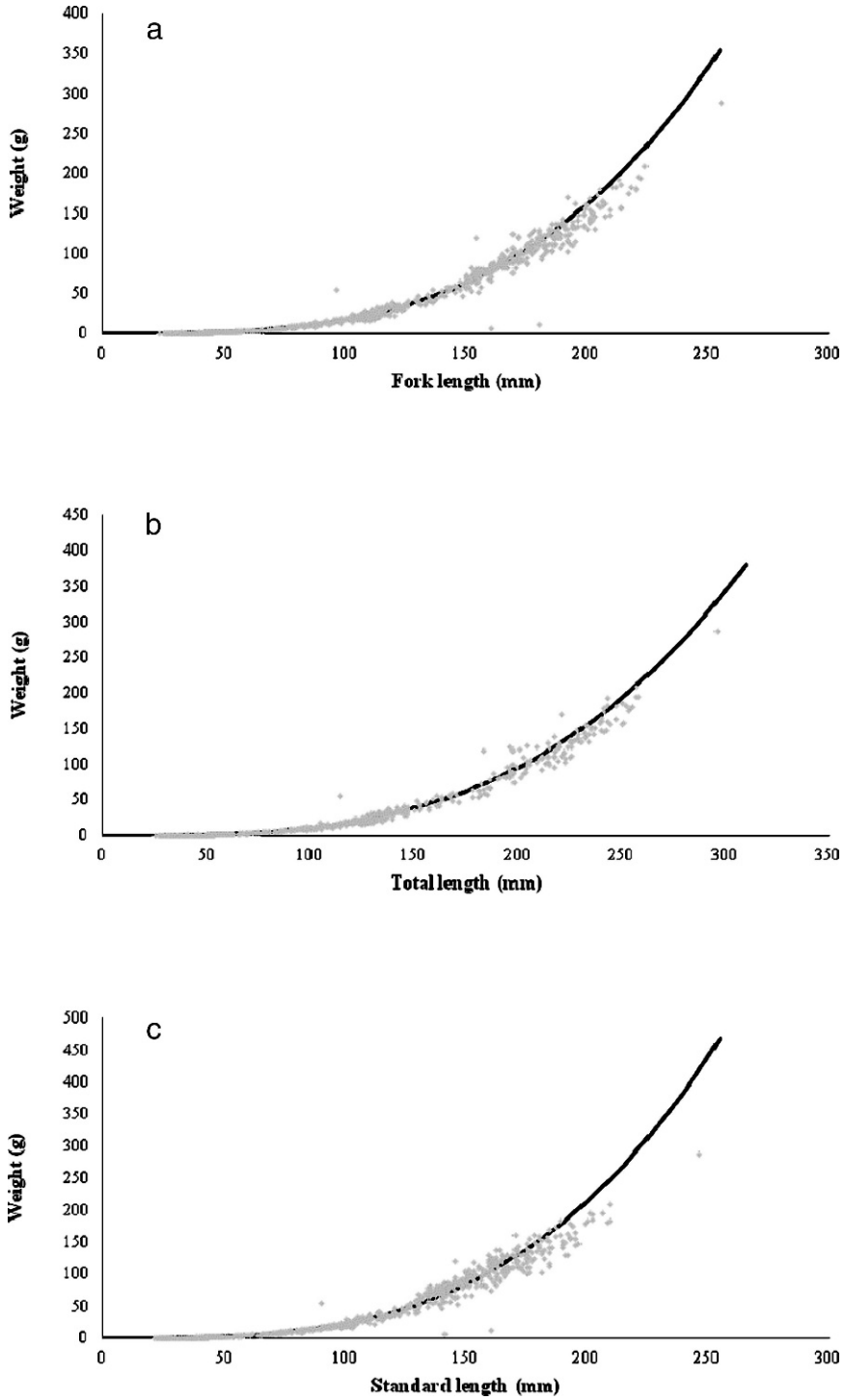


Fig. 2. Fitted relationships for (a) weight-FL, (b) weight-TL, and (c) weight-SL for gulf menhaden.

for the weight–FL relationship, $N = 894$ for the weight–TL relationship, and $N = 1,087$ for the weight–SL relationship (Table 4).

The linear relationship developed from weight (W) with FL was

$$\ln W = 3.241 - 12.088 \ln FL$$

($R^2 = 0.9904$; Fig. 2a; Table 4).

The linear relationship developed from weight with TL was

$$\ln W = 3.168 - 12.230 \ln TL$$

($R^2 = 0.9918$; Fig. 2b; Table 4).

The linear relationship developed from weight with SL was

$$\ln W = 3.227 - 11.732 \ln SL$$

($R^2 = 0.9903$; Fig. 2c; Table 4).

Relationships developed for the individual states were fairly similar to the overall relationships (Table 4), with the biggest difference being seen for data collected in Mississippi and by Omega Protein, Inc. Slopes estimated for each of the individual state relationships were similar to the overall slope, but the intercepts were more variable (Table 4).

Discussion.—Inevitably when perusing through fisheries literature and data sets for fish size-at-age information, researchers are confronted by studies that have employed different standards for fish measurement. The length–length conversions developed herein will allow for the comparison of gulf menhaden length data across state fisheries agencies in the Gulf of Mexico and will also be applicable to port samples from the commercial gulf menhaden fishery. The weight–length relationships developed herein are similar to yearly relationships developed for a past gulf menhaden stock assessment (Vaughan et al., 2000) and could thus be applicable to port samples from the commercial gulf menhaden fishery. The length–length and weight–length relationships developed herein for gulf menhaden will be useful for future stock assessments and bioenergetics models that require input from diverse, fishery-independent and fishery-dependent data sets collected by various entities.

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