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RESEARCH NOTE

Size structure and length-length relationships for two shark species (Chondrichthyes: Carcharhiniformes) from an artisanal fishery in the Gulf of Tehuantepec, Southern Mexico

Estructura de tallas y relaciones longitud-longitud para dos especies de tiburones (Chondrichthyes: Carcharhiniformes) de una pesquería artesanal en el Golfo de Tehuantepec, sureste de México

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Abstract.- This paper presents size structure by sex and length-length relationships for *Carcharhinus falciformis* and *Sphyrna lewini* caught by an artisanal fishery in the Gulf of Tehuantepec, Mexico. According to a local processing practice in this fishery, when sharks are landed, their jaws are removed but not their heads. The orbit-fork length was evaluated as a basis for estimating total length. A good fit ($r^2 > 0.9$) of linear regression models for length-length relationships was calculated for both species. Overall data showed that this area is an important habitat for juvenile sharks, and standardizing measurements is proposed to better characterize the catch structure.

Key words: *Carcharhinus falciformis*, *Sphyrna lewini*, Tropical Eastern Pacific, orbit-fork length

INTRODUCTION

Sharks represent a group of benthopelagic fishes, which are highly threatened globally by fishing pressure, pollution, and damage to their habitat (Field *et al.* 2009, Dulvy *et al.* 2014). Due to sharks' ecological and biological characteristics, specifically, those of commercial interest, the main challenges are their conservation and sustainable fishing. The analysis of morphometric relationships allows gathering useful individual biological information (*e.g.*, size, weight, age, and growth). Some of the sharks' processing practices after landing (*e.g.*, evisceration and beheading) do not always include estimating the specimens' total length (Walker 2005). Therefore, new relationships between length measurements have been estimated [*e.g.*, interdorsal and carcass lengths as a basis for evaluating total length (Santana-Hernández *et al.* 2014, Domingues *et al.* 2016)] to characterize size structure from specimens caught by commercial fisheries.

Shark fishing in Mexican Pacific waters operates according to the seasonal abundances of approximately 40 species of commercial importance, mainly from the families Carcharhinidae, Sphyrnidae, Triakidae, and Alopiidae (Castillo-Geniz *et al.* 2008). The Gulf of Tehuantepec is considered one of the leading regions for fishing (small and large-scale) of the Mexican Pacific. Fourteen species of sharks are caught in this region; however, the main fishing targets are *Carcharhinus falciformis* (Müller & Henle, 1839) and *Sphyrna lewini* (Griffith & Smith, 1834) (Castillo-Geniz *et al.* 2008). Although some studies suggest that the Gulf of Tehuantepec is an important habitat for juveniles of both species (Castillo-Geniz *et al.* 2008, Bejarano-Álvarez *et al.* 2011, Alejo-Plata *et al.* 2016), the biological information available for proposing an adequate management plan (*e.g.*, size and sex structure, age, and growth, reproductive and demographic parameters) is still insufficient for the current fishing regulations in Mexico (*e.g.*, SAGARPA-INAPESCA 2015[1]).

[1]SAGARPA-INAPESCA. 2015. PROYECTO de Modificación a la Norma Oficial Mexicana NOM-029-PESC-2006, Pesca responsable de tiburones y rayas. Especificaciones para su aprovechamiento. Diario Oficial de la Federación, 11 de febrero de 2015. Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación, Ciudad de México. <https://www.dof.gob.mx/nota_detalle.php?codigo=5381585&fecha=11/02/2015#gsc.tab=0>

Therefore, this study's goals were: 1) to characterize the size structure by sex for two shark species (*C. falciformis* and *S. lewini*) caught in the Gulf of Tehuantepec; and 2) to propose the orbit-fork length as a basis for estimating the total length in both species, which will allow analyzing the size of sharks caught with their jaws removed, a common case in this fishery. Estimation total length from orbit-fork length may be particularly useful for measurements far from landing sites where jawless are handled, for example at marketplaces or shark trade sites. Besides, it is not always possible to obtain complete specimens at fisheries.

Materials and methods

Sex ratio and length data from two shark species (*C. falciformis*, N= 117; *S. lewini*, N= 200) were obtained during the landing of a small-scale fishery in the northeastern Gulf of Tehuantepec (Tropical Eastern Pacific; 16°03′N-93°52′W, Paredón, Chiapas, Mexico) between April-November 2013 and February-April 2014. Specimens were captured using surface longlines (500-600 eagle-claw hooks, size number 13-16) and bottom longlines (300-400 Norwegian hooks, size number 9), deployed in coastal and oceanic waters up to a distance of 50 nautical miles from the shoreline. Each specimen was identified and sexed *in situ* and measured for total length (TL) with the tail in its natural position, fork length (FL) (Alejo-Plata *et al*. 2006, Cruz *et al*. 2011), and orbit-fork length (OFL) to the nearest centimeter (Fig. 1). All length measurements were recorded before the jaws were removed from the specimens, after obtaining permission from local fishermen.

To describe the length structure for both species, the smallest length value was subtracted from the highest value and divided between 20 classes, with each value adjusted according to Espino-Barr *et al.* (2008). Body length groups are also distinguished between males and females. Deviation from an expected 1:1 sex ratio by length group was analyzed through a Chi-square test (χ^2). Length-length relationships (FL *vs.* TL; OFL *vs.* TL; OFL *vs.* FL) were performed by linear regressions fitted by a least-squares method (Chen & Jackson 2000). An Analysis of Covariance (ANCOVA) was conducted in order to test significant differences (α= 0.05) in length-length relationships among sexes. All data were analyzed using STATISTICA 8.0 (StatSoft 2007) and PAST 4.2 packages (Hammer *et al.* 2001).

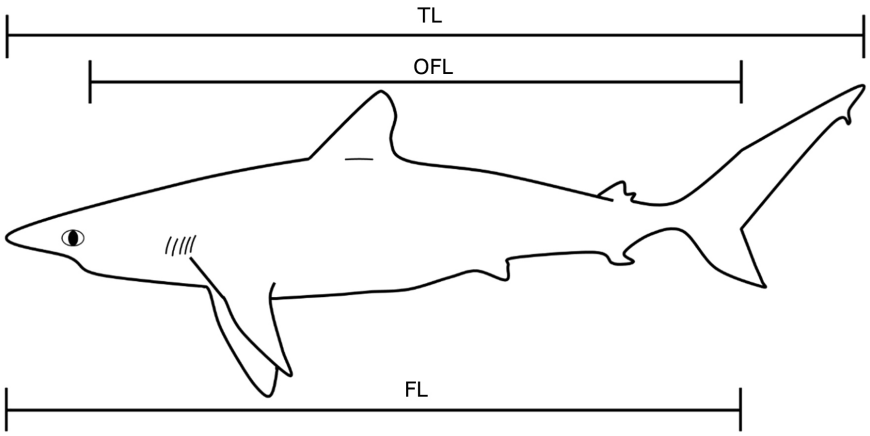

Figure 1. Measurements taken to sharks specimen: TL (total length), OFL (orbit-fork length) and FL (fork length) / Medidas tomadas a los ejemplares de tiburones: LT (longitud total), LOF (longitud orbito-furcal) y LF (longitud furcal)

Results and discussion

The distribution of frequencies in the estimated TL intervals for *C. falciformis* and *S. lewini* is shown in the Figure 2. For *C. falciformis*, 50 males with a size range of 61 to 200 cm TL (Mean= 139.71, SD= 32.83) and 67 females with a size range of 61 to 246 cm TL (Mean= 137.22, SD= 38.89) were recorded. The 76% of the sample for this species correspond to individuals that can be considered juveniles (<160 cm TL), according to Torres-Huerta *et al.* (2008) and Alejo-Plata *et al.* (2016), and only a small percentage of adults. The TL histograms for all individuals and males allowed the identification of two modes for juveniles, meanwhile, for females, three modes were identified (Fig. 2A-C). The catch structure found for *C. falciformis* in this study is similar to that reported by Cruz-Jiménez *et al*. (2014) (50-157 cm TL), Galván-Tirado *et al.* (2015) (69-229 cm TL), and Alejo-Plata *et al.* (2006, 2016) (59-320 cm TL; 49-265 cm TL) in the Mexican South Pacific. The size structure found in our study also matches with those published for *C. falciformis* in the Mexican States of Nayarit (Mondragón-Sánchez 2011), Colima, Jalisco, and Michoacán (Cruz *et al*. 2011). The most contrasting information about the catch structure for this species is found in northernmost latitudes (Baja California Sur state), where adult sizes tend to be caught more frequently than juveniles (more than 85% of species captured were reported in the range of 165 to 220 cm TL; Sánchez-de Ita *et al.* 2011), although the effects of the sampling method need to be considered. On the other hand, the Gulf of Tehuantepec is an area with high productivity and optimal sea surface temperature, which favors the development of a feeding zone for juvenile sharks (Cruz *et al*. 2011, Morales *et al.* 2016).

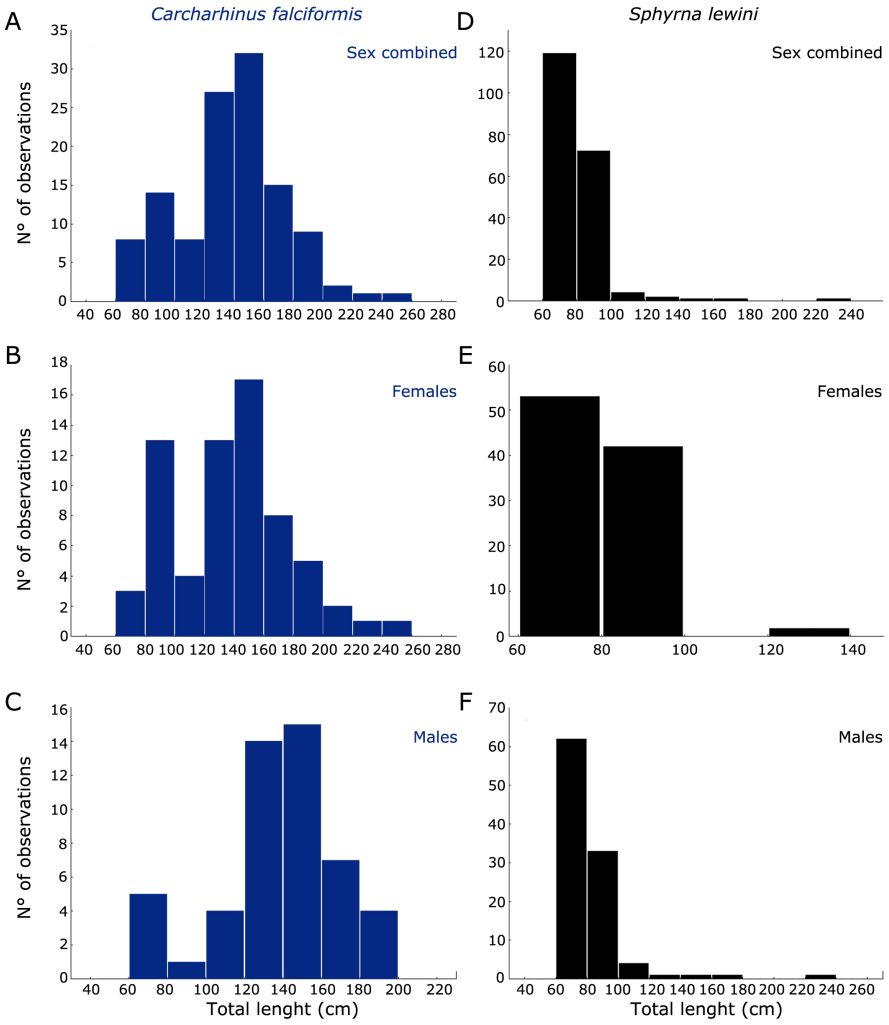

Figure 2. Size structure in total length (TL, cm). *Carcharhinus falciformis*. A) sex combined, B) females, C) males. *Sphyrna lewini*, D) sex combined, E) females, F) males; in the Gulf of Tehuantepec, Mexican Pacific / Estructura de tallas en longitud total (LT, cm). *Carcharhinus falciformis*. A) sexos combinados, B) hembras, C) machos. *Sphyrna lewini*, D) sexos combinados, E) hembras, F) machos; en el Golfo de Tehuantepec, Pacífico mexicano

In *S. lewini*, 102 males with a size range of 61 to 231 cm TL (Mean= 83, SD= 21.3) and 98 females with a size range of 62 to 133 cm TL (Mean= 80, SD= 9.4) were recorded. 98.5% of the individuals measured for both sexes were considered juveniles (<140 cm TL) (Torres-Huerta *et al.* 2008). In this case, unimodal histograms (left-skewed) in the length-frequency distribution are observed (Fig. 2D-F). Although in other studies in the Mexican Pacific, the length frequencies exhibit a bimodal behavior (Alejo-Plata *et al.* 2006, Bejarano-Álvarez *et al.* 2011, Coiraton *et al.* 2017), most of the individuals sampled in the current study have not reached a first maturity size (170-207 cm TL) (Torres-Huerta *et al.* 2008). However, it is necessary to consider the sampling method of each referenced study.

For *C. falciformis*, a significant difference in sex ratio (χ^2= 17.05, $P < 0.05$) was found for individuals with sizes between 60 and 260 cm TL, where a more significant number of females were observed with respect to males. Cruz *et al.* (2011) also found differences in sex ratio in the Mexican central Pacific, but these authors recorded an inverse proportion. In the case of another tropical shark fishery in the Southern Mexican Pacific, Alejo-Plata *et al.* (2006, 2016) found no differences in this particular species' sex ratio. However, it was determined that the rate varies on a monthly scale. On the other hand, although more males than females of *S. lewini* were captured in our study, their distribution among length classes was not significant (χ^2= 3.85, $P > 0.05$); therefore, a sex ratio of 1:1 was assumed. This sex ratio coincides with that reported by Alejo-Plata *et al.* (2006, 2007) and Coiraton *et al.* (2017) for this species in the Mexican Pacific.

Linear models adequately described significant relationships ($P < 0.001$) in all cases. The number of individuals for both species' minimum and maximum lengths measured by sex are presented in Table 1, as well as the length-length relationship parameters (*a* and *b*) and the coefficient of determination (r^2). The r^2 values were high for all the estimated models, varying from 0.91 (*S. lewini*; female; OFL *vs.* TL, OFL *vs.* FL) to 0.99 (*C. falciformis*; sex combined, female; OFL *vs.* FL). The sex differences in the length-length regression models were not significant (ANCOVA, $P > 0.05$) for both species; however, for *S. lewini*, the covariate had a considerable effect (ANCOVA, $P \leq 0.04$) on OFL *vs.* TL and OFL *vs.* FL, so homogeneity of regression slopes is not assumed (Table 2).

Table 1. Relationships among length measurements for *Carcharhinus falciformis* and *Sphyrna lewini* in the Gulf of Tehuantepec, Mexican Pacific
/ Relaciones entre medidas de longitud para *Carcharhinus falciformis* y *Sphyrna lewini* en el Golfo de Tehuantepec, Pacífico mexicano

Species / Sex	N	TL range (cm)	FL range (cm)	OFL range (cm)	TL= *a*+(*b**FL)			TL= *a*+(*b**OFL)			FL= *a*+(*b**OFL)		
					a	*b*	r^2	*a*	*b*	r^2	*a*	*b*	r^2
Carcharhinus falciformis													
Sex combined	117	61-246	47-205	41-185	4.48	1.18	0.95	6.59	1.30	0.95	2.30	1.10	0.99
Male	50	65-200	53-175	46-144	2.10	1.19	0.97	3.03	1.33	0.96	1.72	1.11	0.98
Female	67	61-246	47-205	41-185	5.71	1.17	0.94	8.34	1.28	0.94	2.55	1.09	0.99
Sphyrna lewini													
Sex combined	200	61-231	49-175	44-154	-2.84	1.32	0.97	-2.51	1.45	0.96	0.57	1.09	0.97
Male	102	61-231	50-175	48-154	-3.24	1.33	0.98	-4.29	1.47	0.96	-0.92	1.11	0.98
Female	98	62-133	49-94	44-85	-0.74	1.29	0.92	3.28	1.35	0.91	5.66	1.01	0.91

TL: Total length, FL: Fork length, OFL: Orbit-fork length, N: Number of individuals, a: Intercept, b: Slope, r^2: Coefficient of determination

Table 2. Results of the Analysis of Covariance to compare regression lines between sexes of the length-length relationships estimated for *Carcharhinus falciformis* and *Sphyrna lewini* in the Gulf of Tehuantepec, Mexican Pacific / Resultados del Análisis de Covarianza para comparar líneas de regresión entre sexos de relaciones longitud-longitud estimadas para *Carcharhinus falciformis* y *Sphyrna lewini* en el Golfo de Tehuantepec, Pacífico mexicano

Species / Relationship	Treatment / Interaction	*F*	*P*-value
Carcharhinus falciformis			
FL *vs*. TL	Sex	0.173	0.69
	Sex*Covariate	0.230	0.63
OFL *vs*. TL	Sex	0.001	0.97
	Sex*Covariate	0.741	0.39
OFL *vs*. FL	Sex	1.000	0.32
	Sex*Covariate	0.357	0.55
Sphyrna lewini			
FL *vs*. TL	Sex	0.001	0.98
	Sex*Covariate	0.852	0.36
OFL *vs*. TL	Sex	2.030	0.16
	Sex*Covariate	4.178	**0.04**
OFL *vs*. FL	Sex	3.000	0.08
	Sex*Covariate	9.340	**0.01**

TL: Total length, FL: Fork length, OFL: Orbit-fork length
Sex was assumed as treatment and Sex*Covariate was used to verify homogeneity of slopes
Significant *P*-values ($P < 0.05$) are in bold

The value of the coefficient of determination (FL *vs*. TL) estimates for *C. falciformis* and *S. lewini* can vary depending on sex, length structure, and sample size (Gallegos-Camacho *et al*. 2008, Cruz *et al*. 2011). In our study, the coefficient of determination values was high ($r^2 \geq 0.91$), indicating a useful predictive model for TL. The use of OFL is usually a standard measure for bony fishes, but it is rarely considered for elasmobranchs. In the particular case of the Paredón shark fishery, the jaws are removed from the carcass without beheading the specimen. Therefore, TL's estimation from OFL (the ocular orbit usually remains intact in the trunk) will allow obtaining total length for specimens with this type of processing. It is advisable to explore new length relationships between different measures, considering that sharks are processed differently by local fisheries before landings (Santana-Hernández *et al.* 2014, Domingues *et al.* 2016).

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