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RESEARCH NOTE

Estimation of the length-to-length relationship of commercially important sharks in the Mexican Pacific Northwest

Estimación de la relación longitud a longitud de tiburones de importancia comercial en el noroeste del Pacífico mexicano

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Abstract.- Most shark records are reported using different measurements; thus, length-to-length conversion parameters are needed to standardize and compare the available data as a function of different size measures. Shark biological information collected in the Mexican Pacific Northwest between 2006 and 2019 was used to estimate total fork length/precaudal length relationships for nine shark species. A total of 95,814 specimens were analyzed for length estimates, and a simple linear regression described all relationships correctly with a strong positive relationship (R^2 > 0.75). The present equations will allow more reliable population comparisons based on shark size.

Key words: Eastern North Pacific, linear model, morphometric relationships, sharks

INTRODUCTION

The lack of biological information necessary for evaluating populations hinders the establishment of conservation and management policies for various species worldwide (Mas *et al*. 2014). For example, data about the minimum and maximum sizes of landed sharks are often unavailable, leading to a scarcity of information about most species' age, weight, and length-length relationships. These morphometric relationships enable the better use of data and knowledge required for their management and conservation (Sánchez-de Ita *et al*. 2011, Hall *et al*. 2012)

One of the most valuable fisheries in the Mexican Pacific is the multi-specific shark fishery. Of the 211 shark species distributed in this Pacific section, 39 are frequently caught by two main fleets (medium-pelagic industrial fleet and small coastal artisanal fleet); however, only 12 species are considered numerically abundant, representing an essential component of the catch biomass. These 12 shark species belong to the families: Alopiidae, Carcharhinidae, Squatinidae, Sphyrnidae, and Triakidae (Del Moral-Flores & Pérez-Ponce de León 2013).

Shark lengths are generally reported using a variety of different measures: total length (TL, distance from the tip of the snout to the tip of the upper caudal lobe in its natural position), fork length (FL, from the tip of the snout to the caudal fork), and precaudal length (PCL, from the tip of the snout to the precaudal peduncle) (Compagno 1984). When it is available, as an alternative to length, the distance between the origin of the first dorsal fin and the caudal fin is used (Semba *et al*. 2011).

The problems associated with shark fisheries are that, in some places, only the trunks of caught specimens are usually landed (Gallegos-Camacho & Tovar-Ávila 2011), and different measurements are used to report their sizes (Francis 2006). Consequently, a lack of length-length conversion factors often precludes direct comparisons among other studies. Researchers are forced to use length data gathered elsewhere, which most likely come from different shark populations and may not accurately describe the length-length relationship of the population under study (Mas *et al*. 2014). This study estimated the length-length relationship for the nine most frequently landed shark species in the northwestern Mexican Pacific's longline fishing fleet. These linear regression parameters helped standardize size data.

Materials and methods

The Mexican shark observer program of FIDEMAR (Research Trust for the Development of the National Tuna Harvesting Program and Protection of Dolphins and Others around Protected Aquatic Species) collected size and sex data between 2006 and 2019 from shark specimens of the Blue shark, *Prionace glauca*; Shortfin mako, *Isurus oxyrinchus*; Pelagic thresher, *Alopias pelagicus*; Bigeye thresher, *A. superciliosus*; Thresher, *A. vulpinus*; Oceanic whitetip shark, *Carcharhinus longimanus*; Silky shark, *C. falciformis*; Smooth hammerhead, *Sphyrna zygaena*; and Scalloped hammerhead, *S. lewini*. The study area was defined based on the distribution of fishing longline sets conducted by the fishing trips made by the industrial fleets of Ensenada (Baja California); Puerto Peñasco (Sonora); and Mazatlán (Sinaloa) (Fig. 1). Each specimen was identified and measured (TL, FL, and PCL) on-board to the nearest centimeter in a straight line along the body axis by FIDEMAR trained observers (Gallegos-Camacho & Tovar-Ávila 2011, Polo-Silva *et al*. 2017).

Relationships between FL, PCL, and TL were calculated using ordinary linear regressions ($y = \beta_1 + \beta_2 X_i$), fitted using the log-likelihood method. A normal error structure was assumed for each pair of data E (0, 1), σ_E (Wang & Liu 2006). Analysis of variance (ANOVA) was conducted to assess differences in length between each species' sex after performing normality and residual analysis for each species. All statistical tests were done on the R platform (R Core Team 2019).

Results and discussion

A total of 95,814 records from the program were analyzed. The linear regression model showed a strong uphill linear relationship between all measures. The sample size, parameters, and determination coefficient (R^2) are presented in Table 1, as well as length ranges for each species. The relationship of FL/PCL with TL differed significantly between sexes for the Blue, Pelagic thresher, Bigeye thresher, and Silky sharks. On the other hand, no significant differences were found between sexes for the Oceanic whitetip, Hammerhead, Smooth hammerhead, or Shortfin mako sharks. Globally, most shark species captured by a longline have large heterocercal caudal fins, as seen for Carcharhinidae and Sphyrnidae. In particular, Alopiids' long caudal fin hinders the TL in organisms measured on-board fishing trips or surveys. In general, PCL was the measurement with minor error as an estimator of TL. Previous studies also showed this (Mejuto *et al.* 2008, Mas *et al.* 2014, Santana-Hernández *et al.* 2014). Moreover, in addition to its high accuracy in estimating TL, PCL has been demonstrated to be easy to take on-board sampling, which leads to better quality in data collection and, thus, to more accurate statistics for better management and conservation.

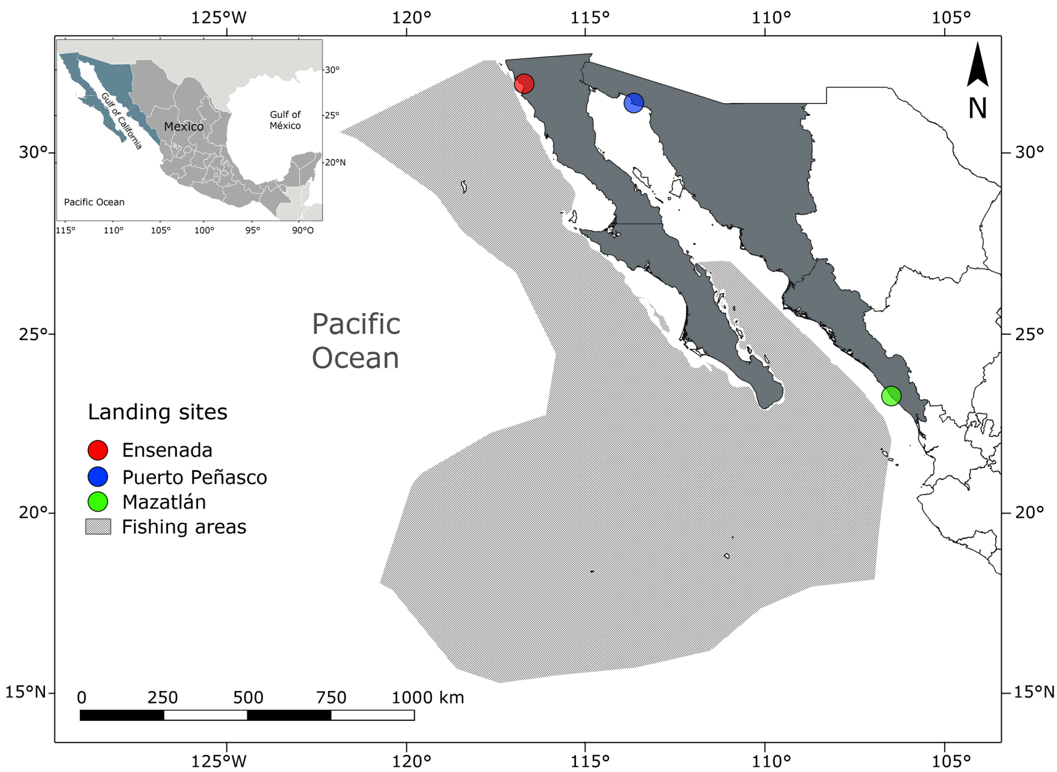

Figure 1. Study region (fishing areas), including primary sampling locations in the Northwest Mexican Pacific / Región de estudio (zona de pesca), incluyendo sitios de desembarque en el noroeste del Pacífico mexicano

Table 1. Parameters of the relationship Y= $\beta_1 + \beta_2 X_i$ between total (TL), fork (FL), and precaudal length (PCL) for shark species caught by an industrial fishery in the northwestern Mexican Pacific / Parámetros de la relación Y= $\beta_1 + \beta_2 X_i$ entre la longitud total, furcal y precaudal de las especies capturadas por la flota industrial en el noroeste del Pacífico mexicano

Species	Sex	FL (cm) Min-Max	TL~FL						
			β_1	CI	β_2	CI	R^2	*n*	ANOVA test
Prionace glauca	F	50-304	8.41	7.97-8.86	1.16	1.15-1.16	0.96	22,807	$F_{(1,77672)}$= 485.40, $P < 0.05$
	M	45-357	6.52	6.22-6.82	1.17	1.16-1.18	0.96	54,867	
Isurus oxyrinchus	BS	32-375	0.16	0.0-0.96	1.11	1.10-1.12	0.96	4,453	$F_{(1,4451)}$= 1.58, $P > 0.05$
Alopias pelagicus	F	76-203	28.34	24.41-31.98	1.52	1.49-1.54	0.85	2,763	$F_{(1,5692)}$= 47.88, $P < 0.05$
	M	90-193	22.97	19.88-26.06	1.55	1.53-1.57	0.88	2,931	
Alopias superciliosus	F	89-218	20.81	14.72-26.90	1.59	1.55-1.63	0.88	715	$F_{(1,1419)}$= 19.37, $P < 0.05$
	M	89-205	27.11	21.96-32.26	1.52	1.49-1.55	0.90	706	
Alopias vulpinus	BS	94-267	39.02	(28.41-49.64)	1.96	1.90-2.03	0.83	328	$F_{(1, 326)}$= 9.43, $P > 0.05$
Carcharhinus falciformis	F	51-312	13.22	11.61-14.82	1.13	1.12-1.14	0.96	1,615	$F_{(1,3335)}$= 8.44, $P < 0.05$
	M	70-223	8.75	6.89-10.61	1.16	1.14-1.17	0.94	1,722	
Carcharhinus longimanus	BS	71-243	6.30	0.0-13.37	1.20	1.14-1.25	0.94	90	$F_{(1, 88)}$= 0.55, $P > 0.05$
Sphyrna zygaena	BS	66-252	14.65	12.61-16.69	1.17	1.16-1.19	0.96	1,101	$F_{(1,1099)}$= 2.14, $P > 0.05$
Sphyrna lewini	BS	101-273	6.36	3.74-8.98	1.23	1.21-1.25	0.96	726	$F_{(1, 724)}$= 3.27, $P > 0.05$
		PCL (cm)	TL~PCL						
Prionace glauca	F	43-340	10.69	10.25-11.13	1.24	1.24-1.25	0.96	23,123	$F_{(1,78903)}$= 249.40, $P < 0.05$
	M	40-358	12.36	10.02-12.69	1.24	1.24-1.25	0.96	55,746	
Isurus oxyrinchus	BS	21-341	3.23	2.32-4.14	1.20	1.20-1.21	0.96	4,453	$F_{(1,4441)}$= 1.66, $P > 0.05$
Alopias pelagicus	F	68-179	21.19	17.52-24.62	1.73	1.70-1.75	0.86	2,707	$F_{(1,5616)}$= 57.20, $P < 0.05$
	M	87-177	12.36	12.02-12.69	1.24	1.24-1.25	0.86	2,911	
Alopias superciliosus	F	80-198	18.01	12.73-23.30	1.77	1.73-1.81	0.92	715	$F_{(1,598)}$= 125.40, $P < 0.05$
	M	82-193	32.55	27.55-37.56	1.64	1.61-1.68	0.90	577	
Alopias vulpinus	BS	30-230	38.58	26.30-50.85	2.18	2.09-2.26	0.77	328	$F_{(1, 326)}$= 8.50, $P > 0.05$
Carcharhinus falciformis	F	46-300	15.01	12.73-17.28	1.24	1.22-1.26	0.92	1,615	$F_{(1,3335)}$= 7.36, $P < 0.05$
	M	63-197	19.53	17.69-21.37	1.20	1.18-1.22	0.94	1,722	
Carcharhinus longimanus	BS	70-208	4.32	3.04-11.69	1.35	1.23-1.42	0.94	90	$F_{(1, 88)}$= 0.51, $P > 0.05$
Sphyrna zygaena	BS	55-252	19.10	16.89-21.32	1.26	1.25-1.28	0.94	1,101	$F_{(1, 1099)}$= 1.99, $P > 0.05$
Sphyrna lewini	BS	92-250	12.08	9.23-14.94	1.32	1.30-1.34	0.94	726	$F_{(1, 724)}$= 2.42, $P > 0.05$

β_1: intercept, β_2: slope, CI: 95% confidence interval, *n*: sample size, R^2: determination coefficient, F: female, M: male, BS: both sexes, Min-Max: minimum and maximum values, TL: total length, FL: fork length, PCL: precaudal length, *P*: Probability value

The Blue shark (*P. glauca*) was the most represented species in this study, and it has sustained industrial shark fisheries from the Mexican Pacific for years (Sosa-Nishizaki *et al*. 2008, Godínez-Padilla *et al.* 2016). Determination coefficients in this study did not differ from those previously reported by Mas *et al*. (2014), which showed a strong fit ($R^2 >$ 0.95) between TL, PCL, and FL, making them good predictors of each other (Santana-Hernández *et al.* 2014).

For the Silky shark (*C. falciformis*), the distance between the origin of the first dorsal fin and caudal fin (alternative length, AL) helped estimate TL for two regions in the Mexican Pacific (Martínez-Ortíz *et al*. 2011). Interdorsal length (the distance between the two dorsal fins) has also been used to estimate other sizes and is commonly used in Pacific Ocean species (Santana-Hernández *et al.* 2014). However, estimates obtained here for the Scalloped hammerhead (*S. lewini*) differed from those previously reported by Gallegos-Camacho and Tovar-Ávila (2011) for central Pacific Mexican waters. These differences can be attributed to methodological differences between the two studies rather than regional differences between populations. For example, Santana-Hernández *et al*. (2014) mentioned that measuring TL with the caudal fin in a natural position may result in high variability and error and account for the regional differences between studies rather than natural morphometric variability. Moreover, Mejuto *et al*. (2008) recommended estimating conversion factors for each fleet. The fleets must validate these factors before a generally recommended value can be applied to each species.

In contrast to the present study, Mas *et al*. (2014) did not perform statistical tests to detect significant differences between length and sex, reporting linear coefficients for separate sexes in all analyzed species. Statistical differences among sexes weren't found in the length-length relationship for Mako and Smooth hammerhead sharks. The slope could be the same or different between the sexes. By the principle of parsimony, it was convenient to define whether the sex factor could cause a significant difference before adjusting the model to the data.

This study provides information on length-length relationships of nine shark species of the Mexican Pacific that can be used to standardize measurement methods, allowing for direct comparisons of population parameters from disparate regions.

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