Estimation of the total, fork and precaudal lengths for the silky shark, *Carcharhinus falciformis* (Carcharhiniformes: Carcharhinidae), from the interdorsal length

Estimación de las longitudes total, furcal y precaudal del tiburón sedoso, *Carcharhinus falciformis* (Carcharhiniformes: Carcharhinidae), a partir de la longitud interdorsal

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Santana-Hernández H., J. Tovar-Ávila and J. J. Valdéz-Flores.2014. Estimation of the total, fork and precaudal lengths for the silky shark, *Carcharhinus falciformis* (Carcharhiniformes: Carcharhinidae), from the interdorsal length. *Hidrobiológica* 24 (2): 159-162.

ABSTRACT

The suitability of using the interdorsal length (IL) to estimate total (TL), fork (FL) and precaudal (PL) lengths of *Carcharhinus falciformis* in the Central Mexican Pacific (CMP) was analyzed. A linear model described adequately the relationships (TL = 3.974IL + 8.277, FL = 3.297IL + 6.561 and PL = 3.016IL + 4.814, r = 0.99 and $p < 0.001$ in all cases, n = 1196, 1162 and 1164 respectively). No significant differences between sexes were found for all the relationships (ANCOVA, $p > 0.05$ for all cases), but significant differences were found with both TL and PL estimated from IL with equations previously reported for the species in the South Eastern Pacific Ocean (t = -161.58, d.f. = 1199, $p < 0.001$ and t = -228.522, d.f. = 1168, $p < 0.001$ respectively). Such differences could be related to the short dimensions of IL, as discrepancies appeared to be larger in small organisms. Thus, measuring IL with the highest possible accuracy is recommended. IL is an alternative easy-to-take measure that allows estimation of shark's size when landed as carcass. The use of the present equations for *C. falciformis* from the CMP is recommended to standardize measurement methods, thereby allowing more reliable population comparisons based on shark size.

Key words: Central Mexican Pacific, linear model, morphometric relationships, size, standardization.

RESUMEN

La conveniencia de usar la longitud interdorsal (IL) para estimar las longitudes total (TL), furcal (FL) y precaudal (PL) de *Carcharhinus falciformis* en el Pacífico central mexicano (CMP) fue analizada. Las relaciones fueron descritas adecuadamente por un modelo lineal (TL = 3.974IL + 8.277, FL = 3.297IL + 6.561 y PL = 3.016IL + 4.814, r = 0.99 y $p < 0.001$ en todos los casos, n = 1196, 1162 and 1164 respectivamente). No se encontraron diferencias significativas entre sexos para ninguna de las relaciones (ANCOVA, $p > 0.05$ para todos los casos), pero sí se encontraron diferencias significativas tanto con la TL como con la PL estimadas a partir de la IL con ecuaciones reportadas previamente para la especie en el sur del Pacífico oriental (t = -161.58, g.l. = 1199, $p < 0.001$ y t = -228.522, g.l. = 1168, $p < 0.001$ respectivamente). Tales diferencias podrían estar relacionadas con la corta dimensión de la IL, ya que las discrepancias parecieron ser mayores en los organismos pequeños, por lo que se recomienda medir la IL con el mayor grado de exactitud posible. La IL es una medida alternativa fácil de obtener que permite la estimación de la talla de tiburones desembarcados sin cabeza y aletas. Se recomienda el uso de las ecuaciones presentadas aquí para *C. falciformis* del CMP a fin de lograr una estandarización de métodos de medición, que permitan comparaciones poblacionales confiables basadas en la talla de los tiburones.

Palabras clave: Estandarización, modelo lineal, relaciones morfométricas, talla, Pacífico central mexicano.

The silky shark, *Carcharhinus falciformis* (Bibron, 1839), is the main species caught by the semi-industrial shark long-line fishery

in the Central Mexican Pacific (CMP) (Cruz *et al*., 2011). It is also one of the main pelagic shark species caught as bycatch by several fisheries around the world (Oshitani *et al*., 2003).

The use of alternative measurements to estimate sharks' size when landed without the head has been previously suggested, as it has become a common practice in recent years among Mexican fishermen to remove the head (Gallegos-Camacho & Tovar-Ávila, 2011). The distance between the origin of the first dorsal fin and the origin of the caudal fin (defined here as alternative length, AL) has been suggested as useful to estimate the total length (TL) (distance from the tip of the snout to the end of the caudal fin) of *C. falciformis* from two regions of the Mexican Pacific (TL = 2.29AL + 10.50, $r^2 = 0.95$, n = 391) (Ramírez-Santiago *et al*., 2006).

The relationship between the distance from the last gill slit to the origin of the caudal fin (defined here as carcass length, CL) and TL has been estimated for this species caught off the Oaxaca coast ($CL = 0.473TL^{1.084}$, $r^2 = 0.98$, n = 308) (Cruz-Jiménez, 2010). Similarly, the relationships of the distance between both dorsal fin bases (interdorsal length, IL) with TL (IL = 0.246TL-1.893, r^2 = 0.97, n = 3935 for combined sexes) and precaudal length (PL) (distance from the tip of the snout to the origin of the caudal fin) (IL = 0.326PL-0.996, $r^2 = 0.97$, n = 3935 for combined sexes) have been described for this species in the South Eastern (SE) Pacific Ocean (Martínez-Ortíz *et al*., 2011). Therefore, estimating TL from other measurements such as CL, IL and indirectly from PL is possible.

In the present study, the suitability of using IL to estimate other lengths commonly used to describe the size of *C. falciformis* in the CMP was analyzed. The morphometric relationships determined were also compared to those proposed for the species in the SE Pacific Ocean (Martínez-Ortíz *et al*., 2011).

All sharks were measured, while still intact and before being frozen, onboard semi-industrial vessels fishing in the CMP from February to December 2011. After determining the sex, TL, fork length (FL) (distance from the tip of the snout to the fork of the caudal fin), PL and IL were measured. All lengths were measured using the common field methodologies, with a fiberglass tape to the nearest cm, except for IL, which was measured to the nearest 0.5 cm. TL was measured with the shark lying on its side, with the caudal fin extended in natural position but not stretched (Compagno, 1984).

A linear model of the form $Y = \alpha X+\beta$, where Y = TL, FL or PL and X = IL, was used to describe each relationship. The Pearson correlation coefficient (r) and the Root Mean Square Error (RMSE), derived from the analysis of the residuals, were used to estimate the degree of correlation between the variables and how accurately is the variable Y predicted from X (Francis, 2006). The probability (p) of the model fitting the data and the Durbin-Watson statistic to detect the presence of autocorrelation between the variables were also estimated.

The existence of differences between sexes for each relationship was tested using covariance analysis (ANCOVA). TL and FL estimated in the present study were compared to those estimated with the equations for the species (combined sexes) in the SE Pacific Ocean (Martínez-Ortiz *et al*., 2011) with a paired t test. Homoscedasticity of all samples compared was proved with the Levene test ($p > 0.05$ in all cases). All statistical tests were undertaken with the IBM SPSS Statistics 19 (International Business Machines Corp.) and SYSTAT 12 Statistics-I (SYSTAT Software, Inc.) programs.

The linear model described in an adequate form all the morphometric relationships determined ($p < 0.001$ in all cases) and no autocorrelation between the variables was found (Durbin-Watson test >1 in all cases). Given the similarity of the correlation coefficients and RMSE, it is evident that IL is positively and strongly correlated with TL, FL and PL, and all these variables can be predicted from IL with similar accuracy (Table 1; Fig. 1).

No significant differences were found between sexes (ANCOVA, $p > 0.05$ for all cases) in the CMP, but significant differences were found for both TL and PL estimated from IL for *C. falciformis* in the CMP and those from the SE Pacific Ocean (t = -161.58, d.f. = 1199, $p < 0.001$ and t = -228.522, d.f. = 1168, $p < 0.001$ respectively).

The simultaneous use of several alternative measurements to estimate sharks' size has been recommended (Francis, 2006). However, this is not always possible in the CMP semi-industrial fishery, since landed shark carcasses do not include the gill slits as these tissues can affect the quality of meat and fins (mainly the first dorsal and caudal fin) are not always cut at the same point, limiting the use of AL and CL. Therefore IL becomes in such case the single and most plausible measure to estimate the size of sharks.

The regional differences found among IL-TL and IL-PL relationships do not necessarily imply the existence of different populations, since the same effect can be attributed to methodological inconsistencies. It has been stated that measuring TL with the shark tail in a supposed natural position (Compagno, 1984) may result in high variability and error, due to the difficulty of determining a "natural" position (Francis, 2006), and this could account for the regional differences found in the IL-TL relationship. In contrast, the differences found in the PL-IL relationships are unaffected by the position of the tail. However, no significant differences in the relationship between AL and TL have been found for other shark species, such as *Sphyrna lewini* from different regions of the Mexican Pacific measured with both methods (natural or extended in the body axis as recommended by Compagno, 2001), amounting to the apparently insignificant effect of such error in this morphometric relationship (Gallegos-Camacho & Tovar-Ávila, 2011).

Another possible explanation for regional differences in both relationships could be related to the short dimensions of IL, partic-

Table 1. Parameters of the relationship ($Y = \alpha X + \beta$) between total (TL), fork (FL) and precaudal lengths (PL) and interdorsal length (IL) for *C. falciformis* (combined sexes) in the Central Mexican Pacific.

Y	X	α		s.e.	β		s.e.	n	r	*RMSE*
TL	IL	8.249	6.978-9.521	0.648	3.976	3.938-4.014	0.019	1200	0.97	4.568
FL	IL	6.421	5.366-7.475	0.537	3.303	3.271-3.334	0.016	1169	0.97	3.650
PL	IL	4.524	3.582-5.466	0.480	3.026	2.998-3.054	0.014	1169	0.97	3.306

s.e. = standard error, n = sample size, r = correlation coefficient, RSME = Root Mean Square Error.

ularly in small organisms, as the differences appear to be related to shark size and the effect of such error could increase inversely with the shark size (Fig. 2). Measuring IL to a higher resolution level than TL, FL or PL is therefore recommended to avoid such an error. Unfortunately, measuring resolution is seldom described in other studies. It is necessary to determine in the future whether regional differences exist for other morphometric relationships.

The IL is an alternative measurement that is easy to take onboard fishing vessels, reducing sampling time when catches are abundant, and it is also useful to estimate shark size from their carcasses at landing sites. We recommend using the relationships introduced in the present study for sharks from the CMP when sharks are landed in such conditions, to achieve standardization of measurement methods that allow reliable comparisons of population parameters related to shark size (e.g. length-at-age, length-at-maturity or catch length composition).

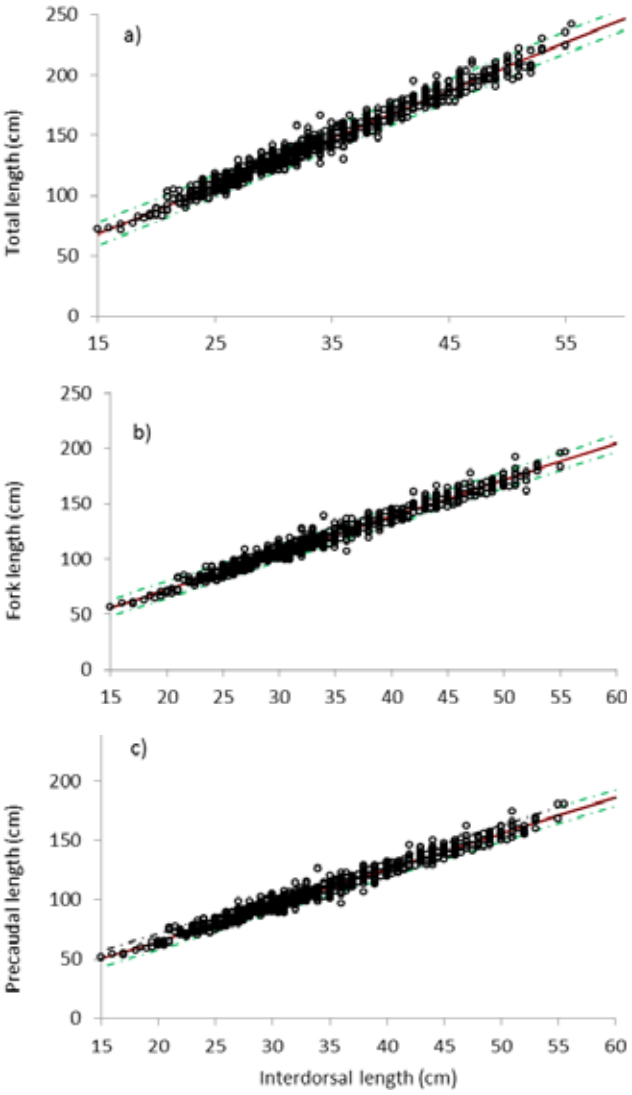

Figure 1. Relationship between total (a), fork (b) and precaudal (c) lengths with interdorsal length for *C. falciformis* (combined sexes) in the Central Mexican Pacific. The 95% confidence (- - -) and prediction (- — -) intervals are presented.

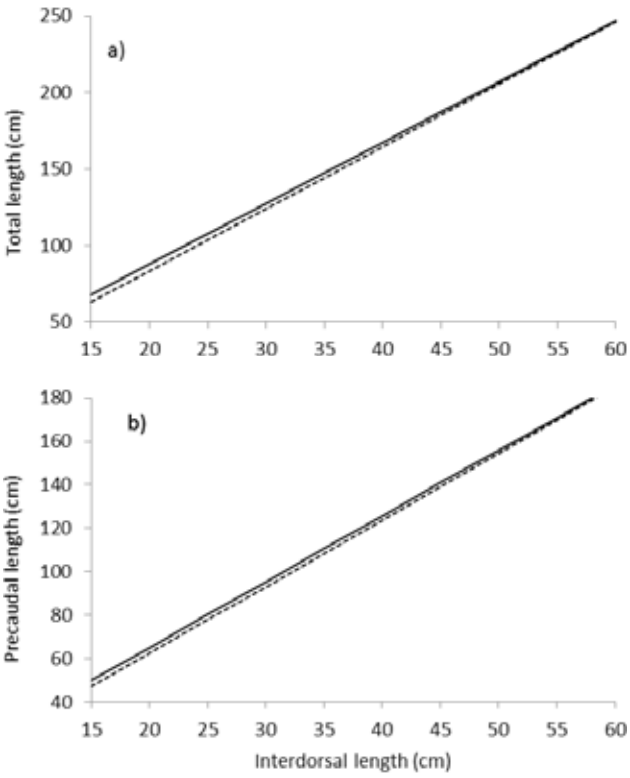

Figure 2. Comparison of the relationships between total (a) and precaudal (b) lengths with interdorsal length for *C. falciformis* (combined sexes) in the Central Mexican Pacific (CMP) (——) and the South Eastern Pacific Ocean (- -).

ACKNOWLEDGMENTS

We thank the fishermen and vessel owners that kindly allowed on-board observers obtaining the data. The corrections of Luis Vicente González-Ania, an anonymous referee, J Francisco Barba T. statistical advice and the review of the English by Warren Hair and Willem Brakel are also appreciated.

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Recibido: 23 de julio del 2012.

Aceptado: 19 de agosto del 2013.