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SEX RATIO AND SIZE STRUCTURE OF Carcharhinus longimanus*,* Galeocerdo cuvier*, AND* Alopias superciliosus *INCIDENTALLY CAUGHT IN A LONGLINE FISHERY FROM THE CENTRAL MEXICAN PACIFIC*

Proporção sexual e estrutura de comprimento e peso de *Carcharhinus longimanus*, *Galeocerdo cuvier* e *Alopias superciliosus* capturados incidentalmente em uma pescaria de espinhel do Pacífico central mexicano

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ABSTRACT

Knowledge of life history and fish reproduction is essential to understand the population dynamics of exploited shark populations. We provide information regarding the length, weight, and sex ratio of *Carcharhinus longimanus* (oceanic whitetip shark), *Galeocerdo cuvier* (tiger sharks) and *Alopias superciliosus* (bigeye thresher sharks) from longline boats based on Manzanillo (39-45 m longline vessels), Colima, Mexico, from 1986 to 2001. We analyzed a total of 264 oceanic whitetip sharks with 107 females (86-186 cm FL) and 157 males (68-184 cm FL); 67 tiger sharks with 36 females (105-193 cm FL) and 31 males (103-207 cm FL) and 67 bigeye thresher sharks with 22 females (131-209 cm FL) and 45 males (138-204 cm FL). The sex ratio for the whole sample differed significantly from the expected 1:1 in the oceanic whitetip shark and bigeye thresher shark, probably due to the mobility nature of the species. The length-frequency distribution of the bigeyethresher shark revealed a high frequency of individuals of large size in the catches. This shark is, on average, larger and heavier than the oceanic whitetip shark and the tiger

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shark. Factors affecting the catch susceptibility of this particular group of species and their lengths (or ages) are discussed.

Keywords: length-frequency, life history, Mexican Pacific, pelagic sharks.

RESUMO

O conhecimento da história de vida e reprodução dos peixes é essencial para entender a dinâmica populacional das populações de tubarões exploradas. Foram fornecidas informações sobre o comprimento, o peso e a proporção sexual de Carcharhinus longimanus *(tubarão-galha-branca-oceânico),* Galeocerdo cuvier *(tubarões-tigre) e* Alopias superciliosus *(tubarões-raposa) de barcos deespinhel (39-45 m de comprimento) baseados em Manzanillo, Colima, México, de 1986 a 2001. Analisou-se um total de 264 tubarões-galha-branca-oceânico, sendo 107 fêmeas (86-186 cm de comprimento furcal – CF) e 157 machos (68-184 cm CF); 67 tubarões- tigre, sendo 36 fêmeas (105-193 cm CF) e 31 machos (103-207 cm CF); e 67 tubarões-raposa, sendo 22 fêmeas (131-209 cm CF) e 45 machos (138-204 cm CF). A proporção sexual para toda a amostra diferiu significativamente do esperado – 1:1 – para o tubarão-galha-branca-oceânico e para o tubarão-raposa, provavelmente devido à natureza de mobilidade dessas espécies. A distribuição de frequência de comprimento do tubarão-raposa revelou uma alta frequência de indivíduos de grande porte nas capturas. Esse tubarão é, em média, maior e mais pesado que o tubarão-galha-branca-oceânico e o tubarão-tigre. Fatores que afetam a suscetibilidade à captura desse grupo particular de espécies e seus comprimentos (ou idades) são discutidos.*

Palavras-chave*: frequência de comprimento, história de vida, Pacífico mexicano, tubarões pelágicos.*

INTRODUCTION

Mexico is a leading nation in shark production. In 2017, it reached a historical peak of 42,704 t. The Pacific coast contributes 80% of the total shark catches of Mexico, and the remaining 20% comes from the Gulf of Mexico and Caribbean (SAGARPA, 2008). However, in Mexico, scientific data on sharks is still limited to carrying out any stock assessment for which long time series of catch/effort data and biological information (e.g., size structure and sex ratio) is required (Pilling *et al*., 2008).

Large (39-45 m) longline vessels based on Manzanillo, Colima, started in 1983 with four vessels with large autonomy and storage capacity. In addition, smaller longlines (6-10 m) were also established in the locality using fishing ground offshore areas from Manzanillo. These fleets targeted billfish, tuna, sharks, and large pelagic species. Detailed information and characteristics of the fleets are reported by Santana-Hernández, Macías-Zamora and Valdez-Flores (1998), Santana-Hernández (2001), Santana-Hernández *et al.* (2008) and Santana-Hernández and Valdez-Flores (2014). The shark species such as the oceanic whitetip shark (*Carcharhinus longimanus*), tiger shark (*Galeocerdo cuvier*), and bigeye thresher shark (*Alopias superciliosus*) historically had a low incidence representing numerically < 3% in the longline fishery from the Mexican Central Pacific.

Consequently, information available on their life history in the region is lacking. The International Union for Conservation of Nature's Red List of Threatened Species classified the oceanic whitetip shark as critically endangered (CR), the bigeye thresher shark as vulnerable (VU), and the tiger shark as near threatened (NT). This status highlights the importance of contributing information about the life history and the fisheries in which they are caught in other regions.

The size structure is one of the most commonly used fishery indicators. The size structure of a fish population at any point in time can be considered a snapshot that reflects the interactions of the dynamic rates of recruitment, growth, and mortality; thus, length-frequency data provide valuable insight into the fish population dynamics (Neumann & Allen, 2007). The proper interpretation of length-frequency distribution of sharks caught by longline vessels requires considering the influence of the season, fishing strategy, horizontal and vertical distribution of the species, and other technological items of the gear such as the type and size of the hook and bait (Lokkeborg & Bjordal,1992).

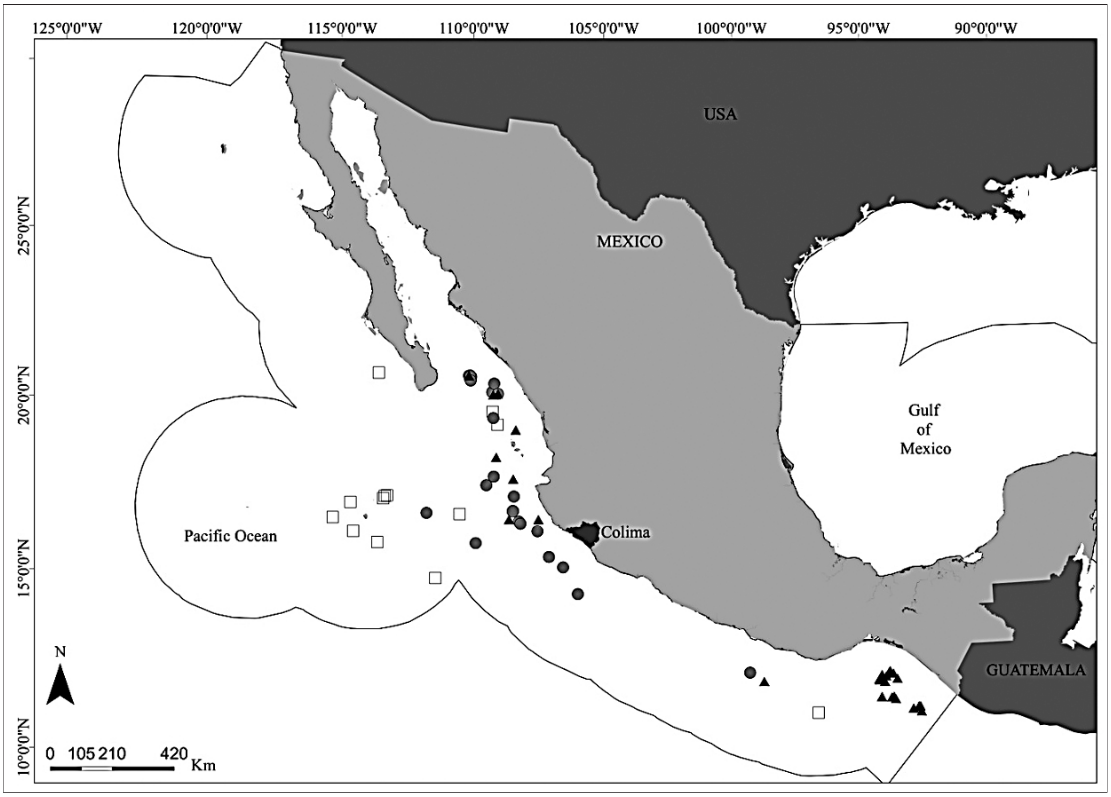
We recognize that the sex ratio estimations of the shark populations should ideally use data of embryos because they are unbiased. However, we consider that understanding the sex ratio of free-swimming sharks in a given time and space may suggest the closenessof both sexes for reproductive purposes (mating). Therefore, ignoring the sex structure has consequences when conducting a stock assessment, leading to bias management advice (Walker, 2011). Equally important is knowing the length structure that is susceptible to capture in this fishery. Finally, the fraction of the stock removed by a fishery has important implications for stock assessment, particularly when compared with current versus historical average sizes. Due to the incidence of vulnerable shark species in the longline fishery, we consider it necessary to report the information available on these low- incidence species to complement their natural history in other regions. Therefore, the present study reports the seasonal sex ratio and the size structure of three sharks with low incidence in the Mexican Central Pacific longline fishery compiled by Instituto Nacional de Pesca (INAPESCA).

MATERIAL AND METHODS

Surveys

The data used in this study were obtained during commercial fishing cruises conducted from 1986 to 2001. Data were collected by observer's onboard longline vessels based in Manzanillo, Colima, Mexico. Each specimen was identified following Fischer *et al*. (1995), sexed, and measured in fork length (FL) and total length (TL). The longline vessels were 44.7 m long with a storage capacity of 120 t. The mainline size ranged from 25,200- 75,600 m, depending on the number of hooks (No. 3.8: 65 mm in length, 30 mm in width,and 4 mm in diameter) used per set (500 to 1500). Given the autonomy of the vessels > 30 days per trip, the fleet operated in a wide range of the Economic Exclusive Zone of the Mexican Pacific (Figure 1).

Figure 1 – Map showing the catch coordinates of *Carcharhinus longimanus* (●), *Galeocerdo cuvier* (▲), and *Alopias superciliosus* (□) in the central Pacific of Mexico between 1987-2001 by the longline vessels based in Manzanillo, Colima. The black lines indicate the exclusive economic zone



Data analysis

A chi-square test was used to compare the observed sex ratio of the entire sample and by bimester against the expected value of 1:1. In addition, the median length (FL) between sexes and bimesters was statistically analyzed using a 2-group Mann-Whitney U Test and Kruskal-Wallis Test due to the non-normality of the residuals, respectively. For the statistical treatment, bimester was considered as follows: I (January-February), II (March-April), III (May-June), IV (July-August), V (September-October), and VI (November-December).

Length-frequency histograms were constructed to know the structure of each species in the study period. In addition, relationships between FL and TL were determined using simple linear regressions. Finally, the available length and weight data were plotted for comparative purposes. The visualization and ordering of data were carried out in Microsoft Excel 2013, and all statistical analyses were performed using R studio, vers. 4.0.3 (R Core Team, 2019).

RESULTS

Oceanic whitetip shark (*C. longimanus*)

A total of 264 oceanic whitetip sharks (107 females and 157males) were measured. The sex ratio differed significantly from the expected 1:1 for the whole sample (X^2 = 9.81, df = 1, P < 0.01) and by bimester (Table I). The size range of females and males was 86-186 cm FL and 68-184 cm FL, respectively. The median length for females was 143 cm FL and for males was 145 cm FL. The differences between medians and the sex were not significant ($W = 7972$, $P = 0.483$). However, the FL was statistically different between bimesters ($X^2 = 15.56$, $df = 5$, $P < 0.01$). The length-frequency distribution was unimodal with the mode in the length interval 140-150 cm FL and few catches of small individuals in size range 60-80 cm FL (Figure 2a). The mean weight was 23.61 kg (SD = 9.9) with a range of 9-45 kg (Figure 3).

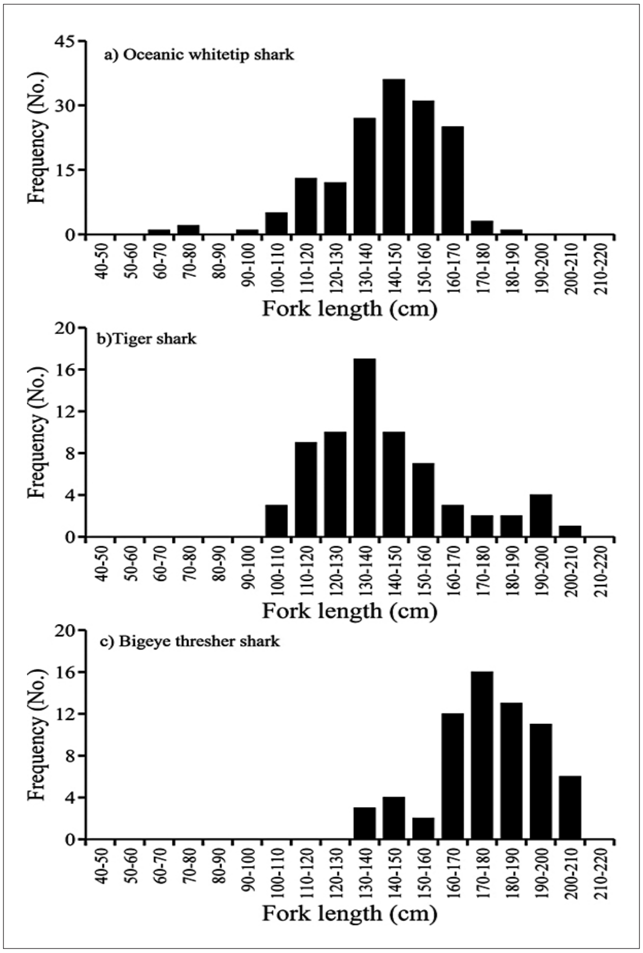


Figure 2 – Length-frequency distribution of captured sharks by the longline vessels based in Manzanillo, Colima, between 1987-2001 in the central Pacific of Mexico

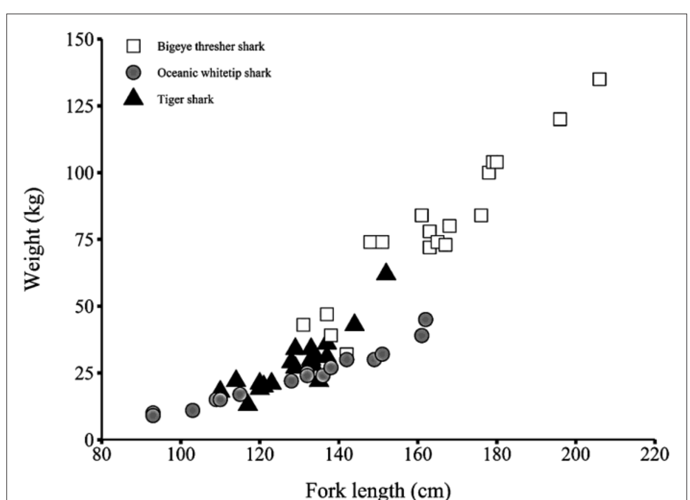


Figure 3 – Comparison of weight and length by species caught by the longline based in Manzanillo, Colima between 1987-2001 in the central Pacific of Mexico

Table I – Number of individuals by sex, sex ratio, and chi-square statistics by species caught by the longline vessels from central Pacific of Mexico. The number of female and male samples (n (F, M)), chi-square value (X^2), probability value (P), and sex ratio were observed

Bimester:	1	2	3	4	5	6
Oceanic whitetip shark						
n (F, M)	(23,28)	(11,26)	(29,50)	(4,4)	(23,31)	(17,25)
X^2	0.49	6.08	5.58	0	1.18	1.52
P	0.483	0.013	0.018	1	0.276	0.217
Sex ratio (F, M)	1:1.1	1:2.3	1:1.7	1:1	1:1.3	1:1.5
Tiger shark						
n (F, M)	(1,0)	(2,1)	(30,29)	(1,0)	(1,0)	(1,1)
X^2		16.66	0.016			0
P		<<0.05	0.896			1
Sex ratio (F, M)		1:0.5	1:1.0			1:1
Bigeye thresher shark						
n (F, M)	(1,13)	(9,15)	(2,4)	(0,1)	(3,2)	(10,12)
X^2	10.28	1.5	1.33		0.052	0.181
P	0.0013	0.22	0.248		0.818	0.669
Sex ratio (F, M)	1:13	1:1.7	1:2		1:0.7	1:1.2

Tiger shark (*G. cuvier*)

We analyzed 67 tiger sharks, 36 females and 31 males. The overall sex ratio of tiger sharks did not differ significantly from the expected 1:1 (X^2 = 0.529, df = 1, P = 0.529). For bimesters, males only were present in three (Table I). The size range of females and males was 105-193 cm FL and 103-207cm FL, respectively. The median length for females was 136 cm FL and for males was 140 cm FL. The overall length-frequency distribution is right-skewed with a size range of 103-207 cm FL showing a mode in the length interval 130-140 cm FL and a smaller mode at 190-200 cm FL (Figure 2b). There were no statistical differences between median FL by sexes ($W = 482$, P = 0.342) and among bimesters ($X^2 = 7.11$, $df = 5$ P = 0.212). The mean weight was 28.76 kg (SD 10.5) with a range of 13-62 kg (Figure 3).

Bigeye thresher shark (*A. superciliosus*)

From the 67 bigeye thresher sharks examined, 45 were males, and 22 were females. The overall sex ratio did vary significantly from the expected 1:1 (X^2 = 6.72, df = 1, P < 0.001). However, by bimester, only the first one was significantly different (Table I). The size range of males and females was 138-204 cm FL and 131-209 cm FL, respectively, with a mode in the length-class 170-180 cm FL (Figure 2c). The median size of females was 174.5 cm FL and 179 cm FL for males. There were no statistical differences between FL and sexes ($W = 440.5$, P = 0.470), but differences were significant among bimesters (X^2 = 23.29, df = 5, P < 0.001). The mean weight was 78.68 kg (SD 26.7) with a range of 32-135 kg (Figure 3).

Analyses of biometrics with the available FL and TL for the three species are presented in Table II. All the relationships were explained by the model [coefficient of determination (r^2 > 0.85)] and were statistically significant.

Table II – Summary of the regression between fork length (FL) and total length (TL) (equation=TL=a+b*FL) for the three species caught by the longline from the central Pacific of Mexico. The number of samples (n), females (F), Males (M), the intercept (a), slope (b),95% confidence interval (CI), determination coefficient (r^2), and probability value (*P*)

Species	n	Sex	a	CI	b	CI	r^2	*P*
Oceanic whitetip shark	107	F	7.07	1.83–13.58	1.16	1.12–1.20	0.97	$P<0.05$
	157	M	6.20	0.34–12.07	1.18	1.13–1.22	0.95	$P<0.05$
Tiger shark	36	F	-33.03	-52.84–-13.22	1.40	1.25–1.54	0.91	$P<0.05$
	31	M	-19.92	-36.64–-3.20	1.30	1.18–1.41	0.94	$P<0.05$
Bigeye thresher shark	22	F	90.44	62.93–117.97	1.15	0.99–1.30	0.92	$P<0.05$
	45	M	104.42	76.33–132.52	1.05	0.90–1.21	0.81	$P<0.05$

DISCUSSION

This study provides improved information on the length composition and sex ratio of the catch of oceanic whitetip, tiger, and bigeye thresher shark in the central Mexican Pacific longline fishery. The previous analysis in Mexican waters focus on artisanal shark fisheries (Pérez-Jiménez *et al.,* 2005) and data from other parts of the world; therefore, the present study provides information on this species with low incidence in the longline fishery from the Mexican Pacific. The sex ratio is essential for stock assessment and demographic modeling in fishery biology. Significant differences in sex ratio can be found in the same species in all the distribution range. The sex ratio may be influencedby their habitat, seasonality, food availability, gear selectivity, and other factors specificto the species, including size segregation, migration, and reproductive behavior (Oliveira *et al.,* 2012).

The oceanic whitetip shark did not show a 1:1 sex ratio. Males dominated all bimesters except bimester IV (July-August). We found similar proportions in the bimesters I, IV, and V. These values differed from those reported in other studies, where the females dominated the samples in the Atlantic Ocean (García-Cortéz & Mejuto, 2002; Asano-Filho *et al*., 2004; Coelho *et al*., 2009; Travassos-Tolotti *et al*., 2013; Ruiz-Abierno *et al*., 2021b). This sex ratio is reported in the Mexican Central Pacific for the first time. Bimester IV, where we found a 1:1 sex ratio, coincides with the mating period in the North Pacific Ocean (June-July) (Seki *et al*., 1998). However, the average size of 162.5 cm TL (131.8 cm FL) in this bimester wasnot within the range of sexual maturity (168-196 cm TL for males and from 175-189 cm TL for females) reported for the species (Bonfíl; Clarke & Nakano, 2008).

The most common size range reported for oceanic whitetip sharks is about 150-250 cm TL (121-202 cm FL) (Castro, 2011). However, some records document females up to 350 cm TL (283 cm FL) (Bigelow & Schroeder, 1948). In the present study, even though the samples come from several discontinuous years, the size distribution showed a prominent mode in length-class 140-150 cm FL (170-180 cm TL). This mode coincides with the size interval of males (168-196 cm TL), and females (175-189 cm TL) reported from the Northwest Pacific Ocean (Seki *et al*., 1998). Recently, Ruiz-Abierno *et al*. (2021a) reported the catch of the oceanic whitetip taken in the longline fishery from northern Cuba with a size range of75-265 cm TL (sex combined) and a mode for males and females in length-class 180-200 cm TL and 120-140 cm TL, respectively.

This difference in sex ratio could be explained by the study region and the smaller sample size. Previous studies indicated that geographical segregation by sex might occur for oceanic whitetip sharks (Strasburg, 1958). In the present study, the catch distribution was concentrated from about 15° N to 20° N and from 113° W to 109° W (Figure 1). The spatial distribution of the sampling also varied throughout the period. Even though the oceanic whitetip shark is one of the most abundant oceanic sharks, it does not generally aggregate. However, aggregations can be found around food sources (Nakano; Okazaki & Okamoto, 1997). Santana-Hernández, Espino-Barr and Valdez-Flores (2013) confirm that the longline fishery from Manzanillo does not target oceanic whitetip shark. Neither has been an essential component in most small-scale pelagic fisheries that operate along the Mexican Pacific coast, as reported in other regions. For example, Domingo *et al*. (2007) reported a CPUE of 0.491 individuals per 1000 hooks for the longline fishery from the Equatorial and South Atlantic Ocean.

Tiger shark (*G. cuvier*)

The sex ratio of tiger sharks from the central Mexican Pacific showed no temporal or spatial segregation by sex. Nevertheless, these results are not conclusive for the reduced number of recorded specimens. This null variation in sex ratio has been previously reported for adult individuals > 300 cm TL (Lowe *et al*., 1996). However, the size range found in this study includes only immature individuals (< 300 cm TL), which differs from those reported by Heithaus (2001) for Shark Bay, Australia. This intraspecific selectivity factor of the longline fishery is common for the rest of the shark species. Furthermore, due to the technical characteristics of this fishing gear, fishing strategy (depth of the hooks, diurnal/nocturnal sets) affect the catch susceptibility of a particular group of species and their lengths (or ages). Also, these results suggest no spatial segregation of the size classes or maturity stages (Heithaus, 2001).

The fishing gears' characteristics determining that juveniles are the most susceptible individuals are the hooks' size, the bait's type, bait's size, the hooks' depth, and the wire in the gangions (Santana-Hernández *et al*., 2008; Santana-Hernández; Espino-Barr & Valdez-Flores, 2013). Lowe *et al*. (1996) have previously suggested that there is segregation based on the size of the tiger shark; however, this segregation could be sexually biased. There are records of cannibalism among the species (Compagno, 1984), and such segregation could be a function of small sharks avoiding large ones to minimize the risk of predation.

Although the tiger shark is one of the largest shark species (300-450 cm TL) (Castro, 2011), in this study, the size range was 40% smaller than reported in the literature (Simpfendorfer, 1992; Natanson *et al*., 1999; Heithaus, 2001; Simpfendorfer; Goodreid & McAuley, 2001; Whitney & Crow, 2007). In any case, individuals as large, as the one reported by Whitney and Crow (2007) of a 447 cm TL female would be unlikely to catch for the fisheries, as a 426 cm TL female could reach weigh up to 809 kg (Castro, 2011), breaking the line of the longline.

The distance to the coast and the time of day where the fishing gear is deployedcould be a factor to explain the low presence of tiger sharks in the catches. Sexually mature individuals of this species can be found in more oceanic waters (Whitney & Crow, 2007). Unlike many other sharks that show a clear diel cycle, approaching land at night and retreating to deeper waters during the day, tiger sharks can be found in coastal areas, shallow beaches in between the day (Simpfendorfer, 1992).

Bigeye thresher shark (*A. superciliosus*)

The commercial shark fishing logbooks for larger vessels of the Ensenada longline fleet reported 131 bigeye thresher sharks in the 2011-2015 period, representing 0.02% of the total shark catch (Godínez-Padilla *et al*., 2016). Corro-Espinoza *et al*. (2014) documented the specific composition of the shark catches of the Mazatlán longline fleet. They reported that the bigeye thresher shark was the third species numerically for the 2009-2012 period, representing 9.3% with 14,036 individuals.

Even though the bigeye thresher is a large shark with a maximum length recorded for a female of 460.7 cm TL (Nakamura, 1935) in Taiwanese waters and 425 cm, TL reported by Castro (2011), the largest individual analyzed in this study was a female with a smaller size (343 cm TL). This maximum size is the first time reported for the central Mexican Pacific waters. Fitch and Craig (1964) mentioned a 375 cm TL male caught in a net at the bottom of a canyon off San Clemente, California. Holts (1988) stated that in the California thresher shark fishery of the 1980s, the common thresher was the principal target, but bigeye threshers were also landed (Castro, 2011). Recently, Del Moral-Flores *et al*. (2021) reported a 370 cm TL female incidentally captured in waters of the Gulf of Mexico. Furthermore, the size range of the present study (246-343 cm TL) suggests that 55% of the total sample is represented by mature individuals (290-350 cm TL) (Chen; Liu & Chang, 1997). This species has no economic importance in the North Pacific Ocean because of its meat and fins (Castro, 2011); nevertheless, there is evidence that bigeye thresher sharks are vulnerable to overexploitation and need close monitoring starting with this essential biological data.

FINAL REMARKS

Shark capture in Mexico is regulated by the Official Mexican Standard (NOM-029), which includes some provisions and technical restrictions to improve the use of sharks as a fishing resource. However, it is not easy to implement specific species measures in multispecies fisheries. Therefore, it is more convenient to find a way to mitigate the capture susceptibility by a group of species in the fisheries. Although the data presented in this study are old, we consider it very valid and valuable that they are published to be taken into consideration for comparative purposes in areas and years.

Except for the tiger shark, the other two species analyzed in this study are in some risk category by the IUCN, also cataloged in appendix II of CITES. We consider that the results of this study are useful to complement and update the evaluation of conservation categories.

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