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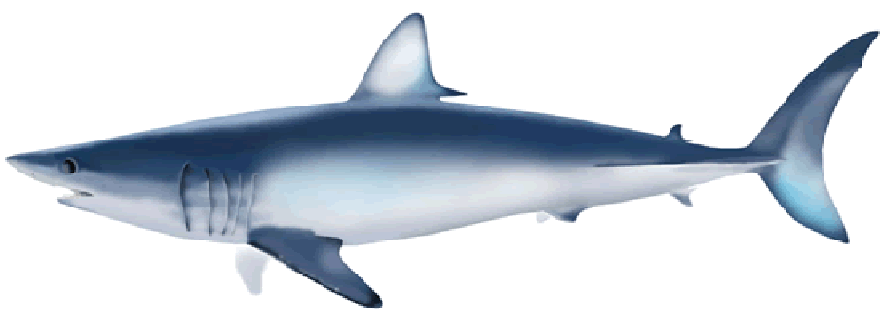
Size and Sex of the Shortfin Mako caught by the Mexican Longline Industrial Fleets Recorded by on board Observers in the Pacific 2006-2016

José Leonardo Castillo-Geniz[1], Carlos Javier Godínez-Padilla[2],
Luis Vicente González-Ania[3], Horacio Haro-Avalos[4] and
José Ignacio Fernández-Mendez[5]
.

Instituto Nacional de Pesca y Acuacultura
(National Fisheries and Aquaculture Institute of Mexico)
[1,2,4]Centro Regional de Investigación Pesquera de
Ensenada, Baja California
Carr. Tijuana-Ensenada, km 97.5, El Sauzal de Rodriguez,
C.P. 22760, Ensenada, Baja California, México
Email:[1]leonardo.castillo@inapesca.gob.mx; [2]javier.godinez@inapesca.gob.mx;
[4]horacio.haro@inapesca.gob.mx

[3,5]Oficinas Centrales
Pitágoras 1320, Col. Santa Cruz Atoyac
C.P. 03310, México, D.F., México
Email: [3]lgonzalez_inp@yahoo.com.mx; [5]wecsg20@yahoo.com.mx



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Abstract

Shorfin mako spatial and explicit size and sex data (2280 females and 1720 males) obtained by observers on board of the Mexican industrial longline fleets during 2006-2016 were used to conduct a first approximation to describe the geographical and seasonal size structure of *Isurus oxyrinchus* in Mexican Pacific waters. To determine the mature and immature condition of the measured sharks was used the 50% maturity size estimated for both sexes by Semba *et al.* 2011. Ninety nine percent of the females and 92% of the males measured were immature. Results of a GML to assess size differences by sex, zone and year quarter indicated no significant differences in sexes probably because most sharks analyzed are juveniles or immature. The west coast of the Baja California Peninsula could represent a nursery and growth zone for this species in the eastern Pacific.

Introduction

The shortfin mako, *Isurus oxyrinchus* is the second shark in importance in terms of numerical catches of the Ensenada longline shark and swordfish fishery which operate along the west coast of Baja California Peninsula (BCP) (Godinez-Padilla, et al. 2016; Castillo-Geniz et al. 2014). It is a high valuable shark species because its meat is exported to the seafood markets off California, USA. The shortfin mako is a cosmopolitan species that is found throughout temperate and tropical waters from 50°N to 50°S. It is a common offshore littoral and epipelagic species that occurs in waters below 16°C but its range of water temperatures is from 17 to 22°C. In the eastern Pacific is found from California southward to the tropics (Compagno, 2001; Stevens, 2008; Castro 2011).

The Mexican Shark Observer Program (SOP) since 2006 has been collecting fishery and biological data (size and sex, and occasionally maturity data) from large pelagic fishes, including sharks and swordfish on board of medium-size longline commercial fishery vessels from port-base fleets of Ensenada and Mazatlan. The fishery grounds of the Mexican industrial longline fleets cover practically the entire northern and central Mexico´s EEZ (Fig. 1a). Shortfin mako is also fished along the BCP by several artisanal small boats with surface longlines and bottom gillnets (Cartamil *et al*., 2011; Ramírez-Amaro, *et al*., 2013). Historically the Mexican industrial longline fleets have been operating in two broad fishing areas principally 1) North (> 27° LN) a common fishery ground for the Ensenada port-based fleet and 2) South (≤ 27° LN), that is the traditional fishing area of the Mazatlan port-based fleet that include the entrance of the Gulf of California and the central Pacific. Recently both fleets has been expanding their fishery grounds, the Ensenada port-based fleet is fishing further south reaching the tip of the BCP and the Mazatlan port-based fleet extended its operations to more oceanic waters and covering almost the southern part of the BCP (Fig. 1b).

Although *I. oxyrinchus* is a common shark species observed in catches and landings from coastal and pelagic fisheries limited information has been collected and published on its life history from Mexican pacific waters. The available data is mostly originated from studies from coastal artisanal fisheries. Conde-Moreno and Galvan-Magaña (2006) examined the reproductive condition of 153 females and 148 males of shortfin mako caught and landed by the artisanal fleet of Baja California Sur (BCS), in the fishery camps of Punta Lobos, Punta Belcher and Las

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Barrancas, during 2000-2004. The size range for combined sexes was 69-290 cm TL and the sex ratio 1.03/1 (F/M). Those authors determined the maturity size of 180 cm TL in males, but the lack of mature females in the samples hampered the estimation of maturity size. Cartamil *et al*. (2011) and Ramírez-Amaro *et al.* (2013) reported size structure of the artisanal commercial catches (longlines and bottom gillnets) of shortfin mako along the west coast of the BCP. The contribution of shortfin makos to the total elasmobranch numerical annual catch sampled were 28.3% in Baja California (BC) and 22.74% in BCS. The sizes ranges reported by those authors are very similar, 70-200cm TL and 70-190 cm TL, respectively. Shortfin mako longline catch data and nominal CPUE values from medium-size commercial vessels from port-based fleets of Ensenada and Mazatlan in the Mexican Pacific was recently reported by Castillo-Geniz *et al*. (2014). Semba and Yokawa (2014) and Clarke *et al.* (2015) provided a complete summary on the existing knowledge on the life history traits of shortfin mako from Pacific waters. Although exist a good number of studies on *I. oxyrinchus* from different regions in the world, the calculation of the age and growth parameters and the length of the reproductive cycle continue being difficult to determine with consistency. Such parameters are essential for any stock assessment.

This working paper provided a first insight on the spatial and temporal size and sex distribution of the shortfin mako caught by the Mexican industrial longline fleets in the Pacific. The size structure of those catches should be an important input for the next stock assessment of the shortfin mako in the northern Pacific conducted by the ISC. Apparently the Mexican longline fleet is the only recent source of fishery depended data of this species in the northeastern Pacific.

Material and Methods

Shortfin mako spatial explicit size and sex data were available from 2258 observed sets (39.6% of the total effort observed) during 2006-2016 from the Mexican longline fishery shark fleet. Data on length and sex were documented on board by observers trained by the National Fisheries and Aquaculture Institute of Mexico (INAPESCA). The morphometric measurements (Total length TL, Furcal length FL and Pre-caudal Length PCL) were obtained following Compagno (1984). In agree with the ISC's SHARKWG, PCL was used as standard measurement to determine the size of the sharks in the present study. Unfortunately maturity condition of the sharks measured was not determined except only in the case of pregnancy, because of the ability to observe the presence of embryos during the evisceration process on the ship's deck.

A statistical analysis was performed to assess shortfin mako pre-caudal length (PCL) differences by sex (S), zone (North: fishing zone of longline fleets based in Ensenada and San Carlos, west coast of BCP; South: fishing zone of longline fleet based in Mazatlan, southward from Baja California Peninsula) and year quarter (1 – 4). The analysis was made using a Generalized Linear Model (GLM) in the programming language and environment *R* version 3.4.0 (*R* Core Team, 2017), on a validated random sample of 4000 mako shark PCLs (2006 – 2016).

For the spatial and temporal distribution of shortfin mako catches maps were built using the software ArgGIS® 10.3 (ESRI, 2014). Length and sex data were agglutinated in 1x1° (LON x LAT) spatial bins because this resolution fits better to the spatial scale of the fishery grounds of the longline industrial fleet. The estimated length at 50% (156 cm PCL males and 256 cm PCL

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females; Semba *et al.* 2011) for each sex was used to separate immature from mature measured shortfin makos. Only seven gravid females were documented during this period, five identified on board by the presence of embryos in their uteri and two that were donated by the industry and examined in laboratory (1 complete female and the second, was only available the uteri with embryos).

Finally with the size spatial explicit data a Kernel density spatial analysis was performed with ArcGis 10.3, to estimate the magnitude per unit area of the number of shortfin mako sharks caught in the fishing sets made during 2006-2016.

Results

Spatially explicit size and sex data were available through the SOP operating on board of the Ensenada and Mazatlan fleets. In general terms the SOP has observed 5328 longline sets from the Mexican longline fishery industry fleet during 2006-2016, which represented 9.1% of the total effort (58759 sets)(Table 1). From the total of longlines sets observed by SOP (5724 sets) during a decade, shortfin mako was captured in 39.5% (positive sets). Separating the data by fleets, Ensenada and Mazatlan, proportions change. Individuals of *I. oxyrinchus* were caught in 54.8% of the sets observed from the Ensenada fleet and from 29.8% of the sets reported by observers in fishery boats of Mazatlan (Table 2). A total of 5721 shortfin makos were measured by observers during 2006-2016 but 69.9% of those measurements included pre-caudal lengths (PCL). Those sharks with PCL measurements were 2280 females (57%) and 1720 males (43%). Females had a range of 43-341 cm PCL (average= 119.4 ± 0.6 cm PCL) and males 51-270 cm PCL (average= 120.1 ± 0.7 cm PCL) (Fig. 2a). No significance difference was found between mean sizes of both sexes, although the sex ratio was unequally 1: 0.75 (female/male) ($X^2_{(1)(n=4000)}$ = 788.4, p=0.05).

The GLM applied to assess shortfin mako shark PCL size differences by sex (S), zone and quarter was structure as follow:

glm(PCL ~ S + Quarter + Zone + S:Quarter + S:Zone + Quarter:Zone + S:Quarter:Zone, family = Gaussian (link = "identity"))

where “:” denotes interaction (conditioning) terms.

Table 3 show descriptive statistics of observed shortfin mako shark PCL used in the statistical analysis, by zone, quarter and marginal totals. As shown in Table 4, there was no statistical difference (α = 0.01) in PCL by sex (p = 0.42), even conditioned by quarter (S: Quarter, p = 0.16), zone (S: Zone, p = 0.67) or quarter and zone (S: Quarter: Zone, p > 0.01), probably because most sharks analyzed are juvenile or immature according with Semba *et al.* (2011). However, significant differences in PCL were found by zone (p<2.2e-16), quarter (p = 1.12e-05) and zone conditioned by quarter (p = 4.77e-04), pointing to a geographical and seasonal size structure of mako shark in Mexican waters.

The comparison of shortfin mako mean sizes of sexes combined through quarters along the two

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zones, it was observed that the lowest means in both areas were reported during the third quarter (Jul-Sep) (Table 5). Larger pre-caudal mean lengths was observed in the north during the first quarter of the year meanwhile was the second quarter during was estimated the largest average in the south area. Although there is not statistical significance between sizes by sex between both fishing areas (fleets), larger shortfin makos were caught in the south (Fig. 3).

Spatial distribution of individuals by sex and maturity of shortfin mako observed during 2006-2016 is presented in Fig. 4a. From the total number of females and males PCL sizes reported, 99.7% and 82% were immature, respectively. Females were more numerically abundant during the observed sets but apparently both sexes were equally caught in the northern region of the west coast of the BCP. Only on the southern limit of the fishery grounds were observed larger proportions of males. High proportion of the numerical catches of this species was composed by juvenile and immature individuals of both sexes (Fig. 4b). Most of the females measured by the observers were immature in the geographical region where operate the Mexican longline industrial fleet in the Pacific. Only a small number of mature females was fished in waters in front of Sebastian Vizcaino Bay located in middle of the Peninsula (between 27°LN and 30°LN) (Fig. 5a). Although immature shortfin mako males also were larger in number, mature individuals were observed more frequently in waters more distant of the coast, especially in central Pacific where were caught near the border limit of the Mexico´s EEZ.

Figures 6 and 7 showed the seasonality in the presence of mature individuals by sex and by quarters in the eastern coast of the Mexican Pacific. The reduced number of mature females observed were reported during the first (Jan-Mar), second (April-Jun) and four (Oct-Dec) quarters principally (Fig. 6). Mature and immature male shortfin makos were observed seasonality distributed along all the year. Larger size males (mature) were reported more frequently during the first and four quarters (Fig. 7). During Oct-Dec mature male were caught in significant far areas of the coast in the central Pacific.

Finally Fig. 8 corresponded to the Kernel density spatial analysis of the numerical catches of the shortfin mako reported by observers during the study period. The shorfin mako fishery grounds in Mexican waters almost cover the entire north and central Pacific of the EEZ. High proportion of the positive sets and numerical catches were distributed along coastal and oceanic waters of the west coast of the BCP, but northern region (Fig. 8). The area with largest concentration (density) of numerical catches was located in a coastal region north of Sebastian Vizcaino Bay (29.03° LN – 115.14° LW, 28.82° LN – 114.60° LW, 28.42° LN – 114.75° LW and 28.62° LN – 115.16° LW) (Fig. 8).

In spite of the observers didn’t reported the maturity condition in detail of the shortfin makos caught, it was possible documented the presence of very few gravid females with uteri with embryos in development. The size and number of embryos were reported. During 2006-2016 it has reported data from seven gravid females of *I. oxyrinchus*, caught by longline commercial vessels. All except two were reported on board. One gravid female complete was examined in the laboratory (with 9 embryos in its uteri) and the other, just the uteri complete with embryos was delivery to the INAPESCA by a commercial vessel crew from Ensenada. Fig. 9 showed the geographical location where those females were caught. The group of gravid females was caught

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along the BCP during 2015-2016 but four of them in the oceanic vicinity of Sebastian Vizcaino Bay. Inside this bay it reported the caught of several shortfin mako neonates and juveniles by the artisanal fishery fleet (Castillo-Geniz unpublished data).

Revising the pre-caudal lengths of the seven females it was considerate that two PCL measurements were suspicious because they were < 200 cm PCL, a significant smaller size from Semba *et al.* (2011) maturity size of 256 cm PCL for females. Eliminating those females the average PCL for the rest pregnant females was 248.2 ± 8.8 cm PCL, a similar size to those reported by Semba *et al.* (2011). The scarce number of females with gravid condition reported by SOP and the lack of data on the average size of the embryos hampered to delineate a possible parturition season. All pregnant females, except two, were caught during the first semester of the year.

Discussion

The spatial and seasonally distribution of the positive fishery sets with catches of shortfin mako in the Mexican industrial longline fleet indicate this species is available in a year-round basis in northern and central Pacific regions of Mexico. Size and sex data collected by observers during 2006-2016 indicated the fishery is sustained principally juveniles of both sexes where females dominated the catches in a sex ratio 2:1.

The GLM conducted to assess possible size differences between sexes resulted negative but found significant size differences by quarter and zone. The lack of differences between sexes is probably because of the dominance of juveniles and immature individuals of shortfin makos caught in both fishery grounds (north and south). Significant differences in PCL were found by zone, quarter and zone conditioned by quarter, that could suggest a spatial and seasonal segregation of mako sharks in Mexican Pacific waters. Sharks caught by the Ensenada port-based fleet presented small sizes than those were fished by the Mazatlan port-based fleet. Because of this pattern of small sizes this broad region (BCP) can be considerate as a nursery and growth area for shortfin mako in the southern California bight in the northeastern Pacific coast. This region of the high productive California Current can provide the optimal habitat for the rapid growth of this species. This zone can be describe as a transitional region between subtropical intermediate latitudes and the tropic in the margin of the northeastern Pacific that is characterized by its cooling and warming throughout the year, derived from the intensity and displacement of the California Current (Sverdrup et al. 1942, Lynn and Simpson 1987 cited by Funes-Rodriguez *et al.,* 2010).

The dominance of immature females in the catches and the presence of few mature females including seven gravid sharks could be reasonable elements that can sustain the hypothesis that this region it is in fact a nursery area for *I. oxyrinchus*. The generalized lack of mature females > 200 cm PCL in the SOP reports of the study period (2006-2016) could be explained as a selectivity matter because of the mandatory use of Mustad 39965 tuna circle hooks 0/16 in both fleets and the common use of nylon monofilament branchlines (snoods) in both fleets is possible that the longline gear could not retain larger sharks.

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With so few mature females in the observed samples (0.3% of the total number) is very difficult to delineate the length of reproductive cycle, including the mating and parturition seasons of shortfin mako in Mexican waters. The presence of few gravid females all except two, caught during February-May period could suggest an important reproductive activity during spring. This observation coincided with the results of Semba *et al*. (2011).

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Table 1. Number of commercial fishery trips and sets observed by the Mexican shark observer program (SOP) that operated onboard of the longline industrial fleets during 2006-2016, along the northern and central Mexican Pacific coast.

Year	No. Trips	No. Sets	No. Trips Obser	No. Sets Obser	% Sets Obser
2006	462	6316	27	331	5.2
2007	191	2138	80	1048	41.4
2008	445	6086	54	777	11.6
2009	271	3034	33	460	14.7
2010	401	5356	50	927	16.5
2011	428	5815	33	517	8.3
2012	419	5665	6	106	1.7
2013	422	5784	23	387	5.9
2014	444	5936	34	578	9.7
2015	535	7196	24	317	4.4
2016	433	5433	19	276	5.1

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Table 2. Number of commercial fishery trips and sets observed by the Mexican shark observer program documented by principal longline fleets during 2006-2016, including number and percentage of the positive sets with shortfin mako catches.

Año	Ensenada fleet			Mazatlan fleet		
	Total No. Sets	Total No. sets shortfin mako	% sets shortfin mako	Total No. Sets	Total No. sets shortfin mako	% sets shortfin mako
2006	116	88	75.9	215	59	27.4
2007	474	237	50.0	574	179	31.5
2008	320	100	31.3	457	144	31.7
2009	125	99	79.0	335	76	22.8
2010	149	99	66.4	778	172	23.0
2011	128	74	57.8	389	150	36.2
2012	34	27	79.4	72	23	35.4
2013	183	100	54.7	204	80	37.3
2014	276	169	61.2	302	121	40.1
2015	243	155	63.4	74	11	14.9
2016	182	75	41.8	94	25	26.6

Table 3. Descriptive statistics of observed shortfin mako shark PCL in Mexican waters (2006-2016), used in the statistical analysis.

ZONE		QUARTER				TOTAL
		1	2	3	4	
North	**Mean PCL**	**118.09**	**111.22**	**114.12**	**116.28**	**115.14**
	Std. dev.	27.01	29.28	31.80	30.86	30.53
	Sample size	389	350	952	1048	2739
South	**Mean PCL**	**126.53**	**131.92**	**128.49**	**132.16**	**129.56**
	Std. dev.	26.32	26.19	23.31	25.00	25.65
	Sample size	429	385	210	237	1261
TOTAL	**Mean PCL**	**122.52**	**122.06**	**116.72**	**119.21**	**119.69**
	Std. dev.	26.97	29.55	30.93	30.48	29.84
	Sample size	818	735	1162	1285	4000

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Table 4. Analysis of deviance of the GLM applied to assess shortfin mako shark PCL size differences by sex (S), zone and quarter.

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Analysis of Deviance Table

Model: gaussian, link: identity

Response: PCL

Terms added sequentially (first to last)


               Df Deviance Resid. Df Resid. Dev        F    Pr(>F)    
NULL                            3999    3560579                       
S               1      551      3998    3560027   0.6564 0.4178769    
Quarter         3    21623      3995    3538405   8.5835 1.118e-05 ***
Zone            1   163985      3994    3374419 195.2888 < 2.2e-16 ***
S:Quarter       3     4394      3991    3370025   1.7443 0.1557058    
S:Zone          1      153      3990    3369872   0.1826 0.6691819    
Quarter:Zone    3    15002      3987    3354869   5.9554 0.0004771 ***
S:Quarter:Zone  3     9477      3984    3345392   3.7621 0.0103430 *  
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
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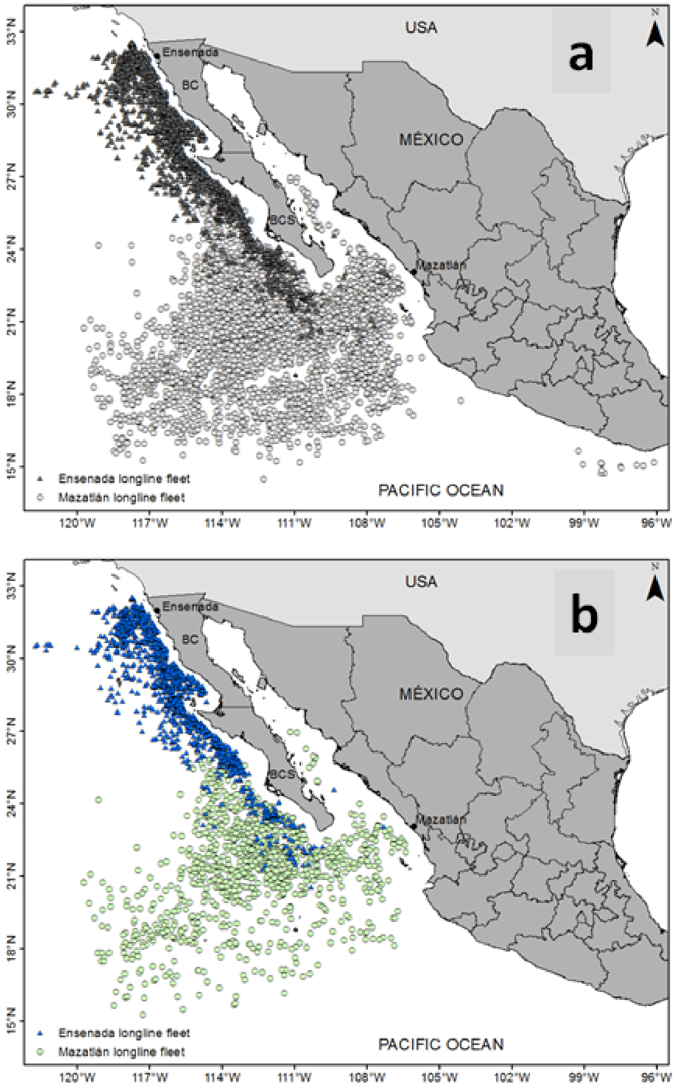

Figure 1. a) Fishing sets conducted by the industrial longline fleets in the Mexican Pacific registered by on board observers during 2006-2016; b) Sets with shortfin mako catches by fleet (Dark blue triangles representing Ensenada port-based fleet sets and green circles Mazatlan port-based fleet sets).

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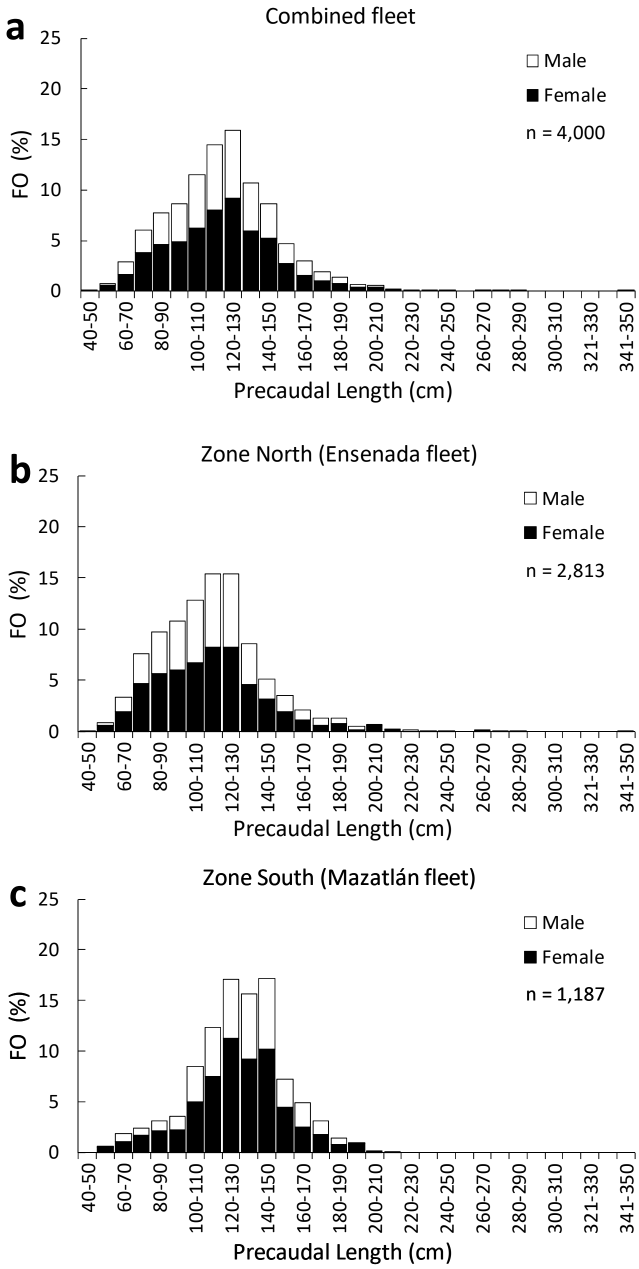

Figure 2. Sex-length frequency distributions of blue sharks caught in the Mexican Pacific; a) Fleets combined; b) Ensenada, BC port-based fleet; and c) Mazatlan, Sinaloa port-based fleet.

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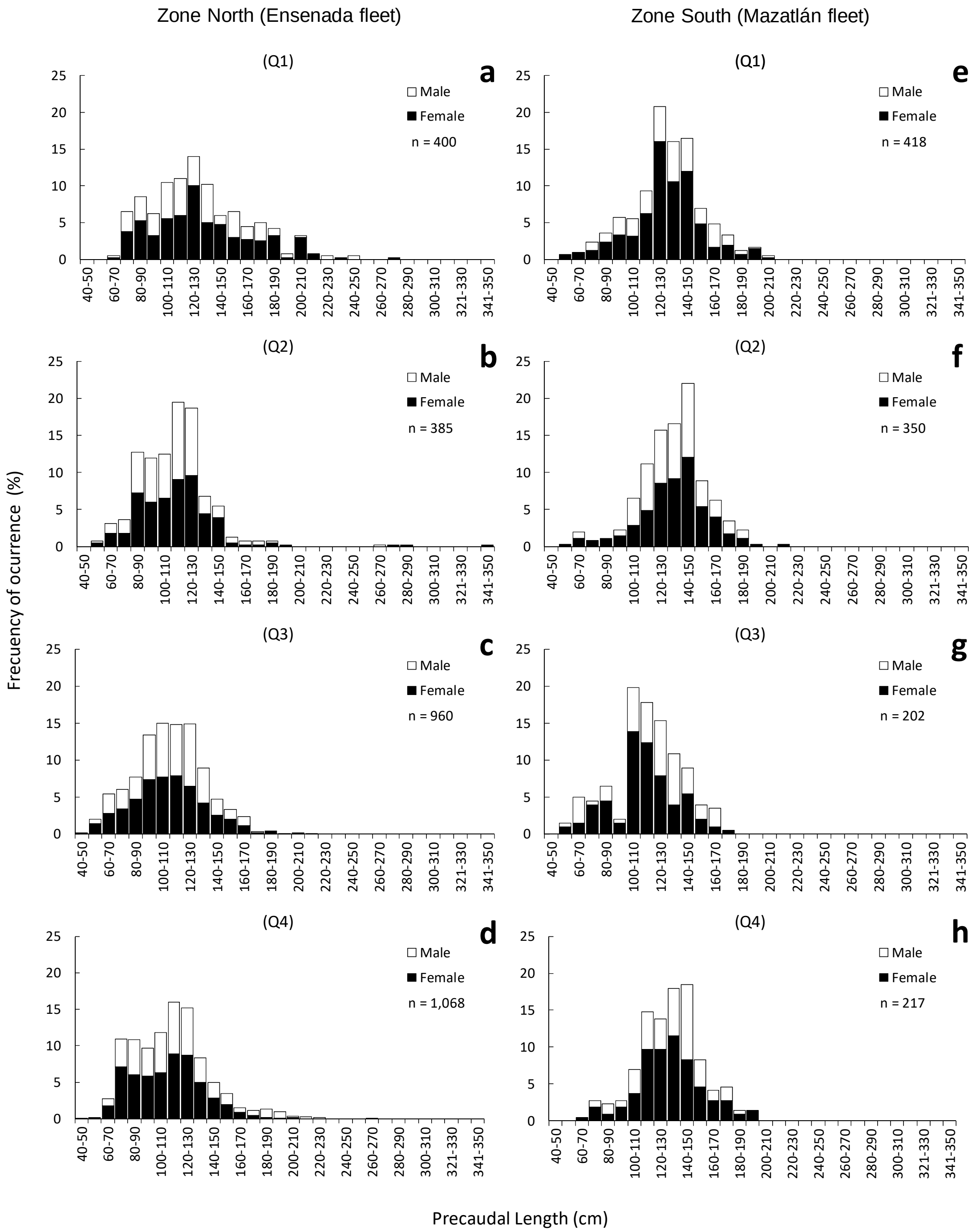

Figure 3. Sex-length frequency distribution of shortfin makos caught during each quarter of 2006-2015 by the Ensenada port-based fleet in the north region (a-d) and the Mazatlan port-based fleet in the southern region (e-h).

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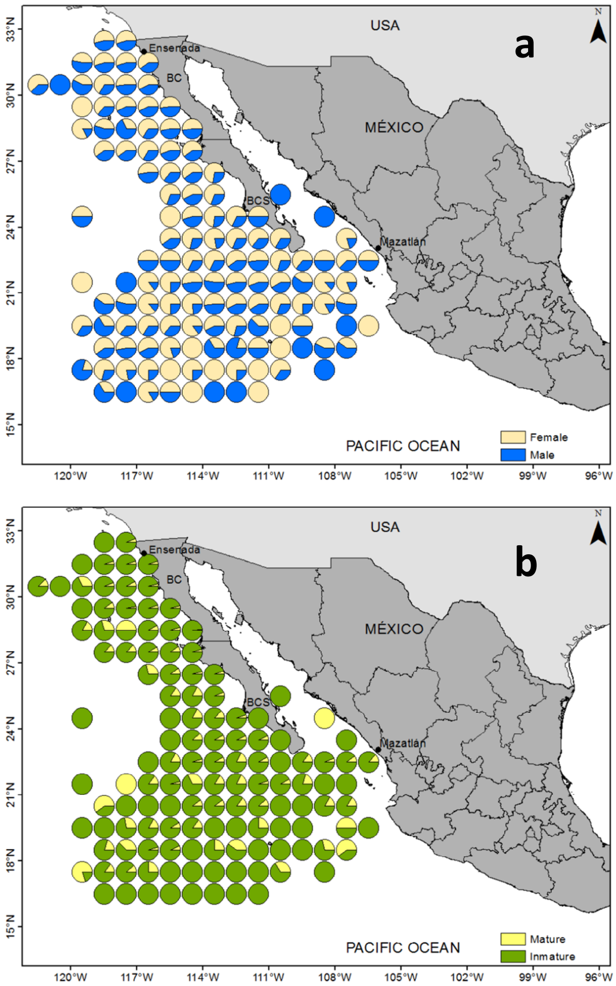

Figure 4. Spatial distribution of the shortfin makos caught by the Mexican industrial longline fleet documented by the observers during 2006-2016; a) Spatial distribution proportion by sex; b) Spatial distribution of mature and immature sharks.

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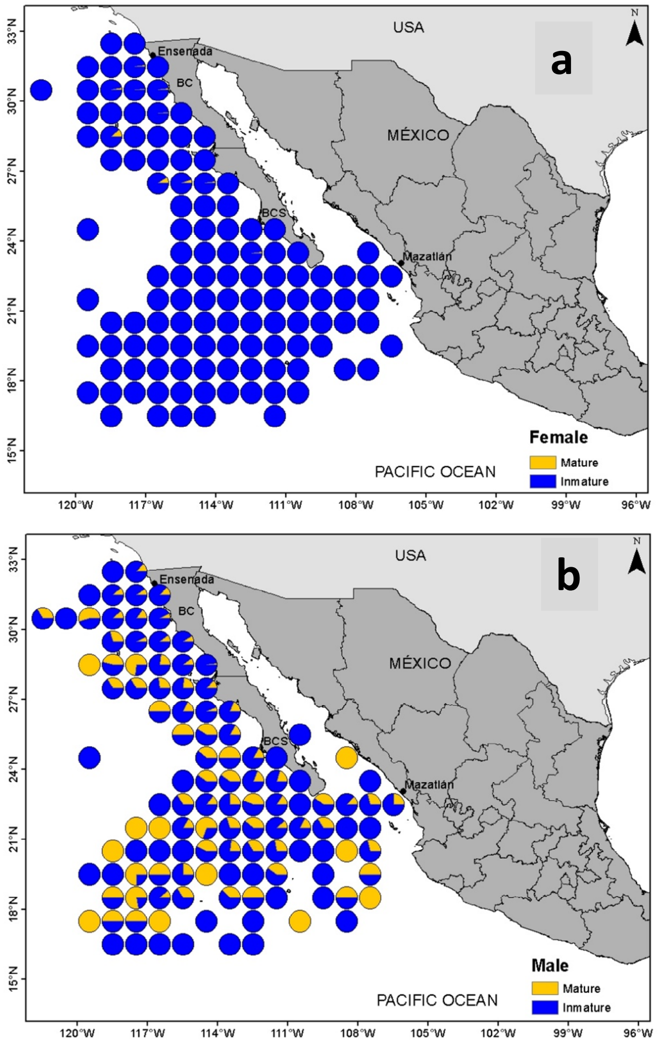

Figure 5. Spatial pattern of sexual condition (mature and immature) of shortfin makos caught by the Mexican industrial longline fleet documented by the observers during 2006-2016; a) Females; b) Males.

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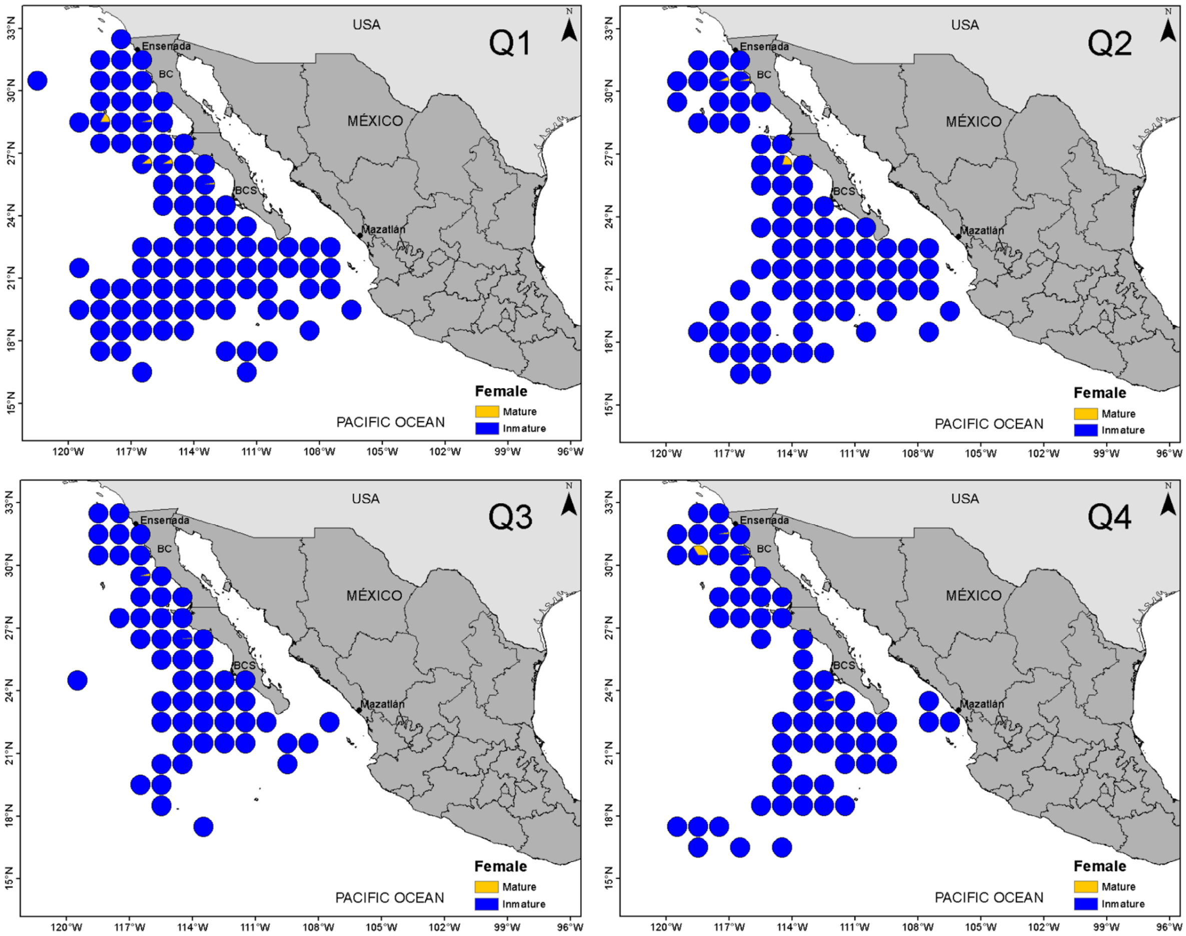

Figure 6. Spatial distribution of sexual condition of shortfin mako females caught by quarter during 2006-2016.

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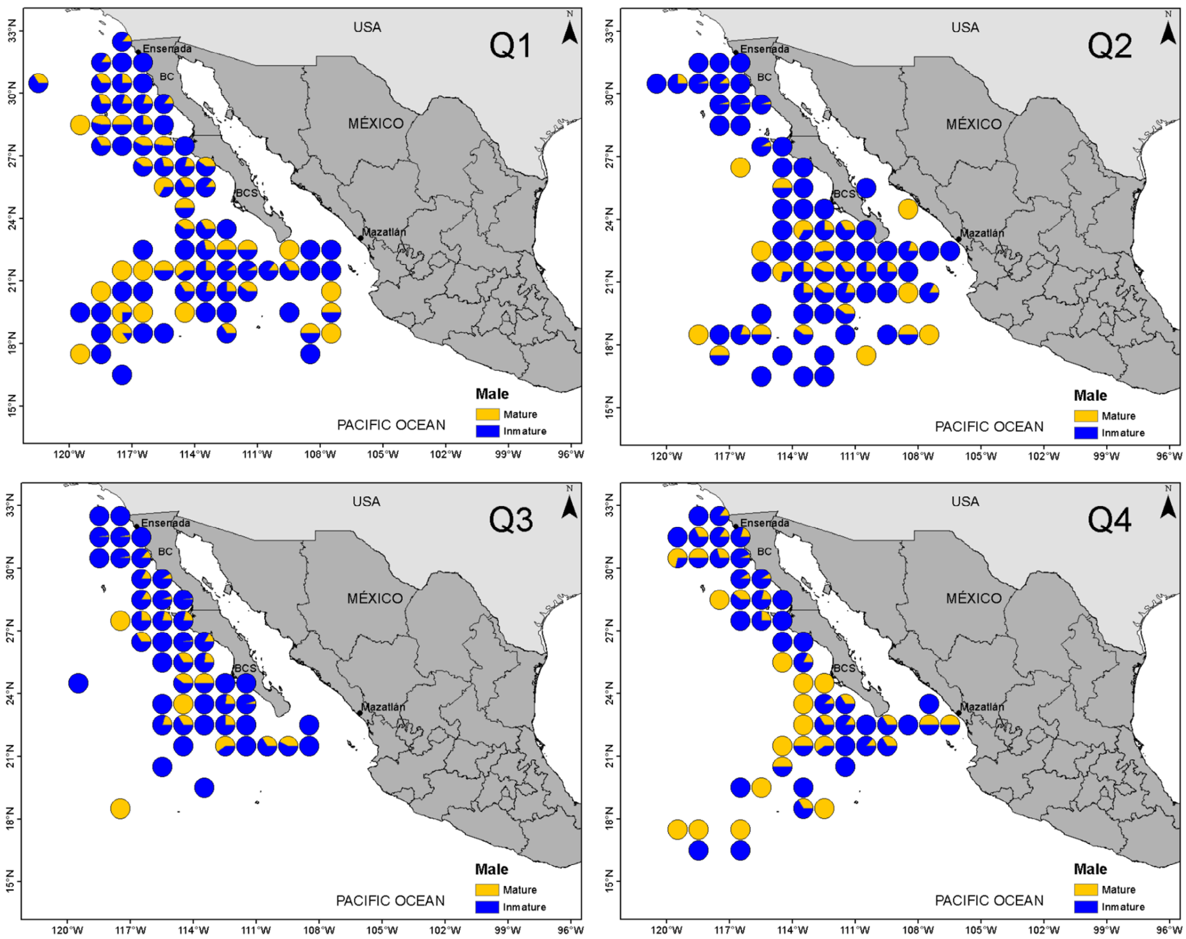

Figure 7. Spatial distribution of sexual condition of shortfin mako males caught by quarter during 2006-2016.

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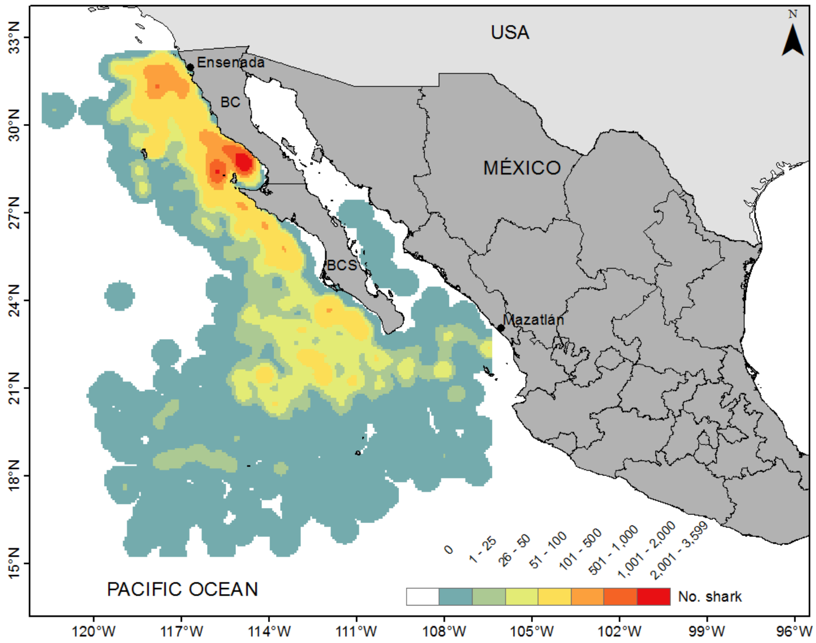

Figure 8. Kernel density spatial analysis of the number of shortfin mako sharks caught by the Mexican industrial fleet and reported by observers during 2006-2016.

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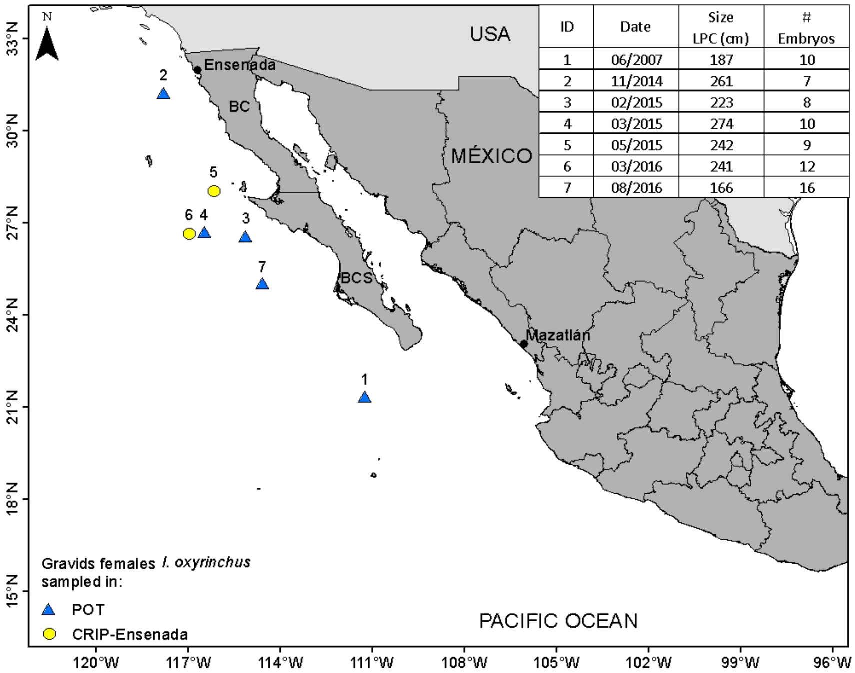

ID	Date	Size LPC (cm)	# Embryos
1	06/2007	187	10
2	11/2014	261	7
3	02/2015	223	8
4	03/2015	274	10
5	05/2015	242	9
6	03/2016	241	12
7	08/2016	166	16

Figure 9. Location of the shortfin mako gravid females caught by the Mexican industrial longline fishery fleet during 2006-2016 and reported by observers. Inside table provide date, size and number of embryos observed.

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