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Distribution and size of the shortfin mako (*Isurus oxyrinchus*) in the Mexican Pacific Ocean

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Abstract. The shortfin mako, *Isurus oxyrinchus*, is a highly migratory species with wide distribution. It is caught directly both as target and bycatch in pelagic fisheries. Detailed knowledge of the biology and nursery grounds of shortfin mako in Eastern Pacific Ocean is limited. Hence, insights on this issue will help understand the structure of the population for further assessment. In the present study we analyze the catch and biological data collected by scientific observers aboard longline vessels during fishing periods from 1986 to 2003. The examined sharks ranged from 55 to 264 cm in fork length (FL) (63-276 cm total length, TL) and from 7 to 72 kg in weight. No sex-specific differences were observed between the weight-length relationship. Shortfin makos are caught in Northwest Mexico, especially along the southwest Baja California Peninsula, in the vicinity of the Marias and Revillagigedo Islands. In the same area, young makos of 55 to 88 cm FL (63-100 cm TL) were found from January to August. Presumably, these juveniles inhabit the corridor from the Southern California Bight to an oceanic polygon that includes the Marias and Revillagigedo Islands, suggesting a nursery for this species.

Key words: Elasmobranchs, Lamniformes, Nursery area, bycatch, longline pelagic fishery

Resumen. Distribución y tamaño del tiburón mako (*Isurus oxyrinchus*) en el Océano Pacífico Mexicano. El Tiburón mako, *Isurus oxyrinchus*, es una especie altamente migratoria de amplia distribución. Es una especie valiosa capturada directa e incidentalmente en pesquerías pelágicas. El conocimiento detallado de su biología y áreas de crianza del mako en el Océano Pacífico Oriental es limitado. Contribuciones al respecto permitirán entender la estructura de la población para evaluaciones a futuro. En el presente estudio, se analizaron la captura y datos biológicos colectados por observadores científicos abordo de embarcaciones palangreras durante los periodos de pesca de 1986 a 2003. Los tiburones examinados oscilaron de 55 a 264 cm de longitud furcal (LF) (63-276 cm longitud total, LT) y de 7 a 72 kg de peso entero. No se observaron diferencias significativas en la relación peso-longitud entre sexos. Los makos son capturados en el noroeste de México, especialmente a lo largo de la costa suroeste de la Península de Baja California, en la vecindad de las Islas Marías e Islas Revillagigedo. En la misma área, se encontraron los juveniles de 55 a 88 cm LF (63-100 cm TL) de enero a agosto ocupando el área que va del sur de la Bahía de California a un polígono oceánico que incluye las Islas Marías e I. Revillagigedo sugiriendo esta área de crianza.

Palabras clave: Elasmobranquios, Lamniformes, Área de crianza, captura incidental, pesquería pelágica palangrera.

Introduction.

The shortfin mako *Isurus oxyrinchus* (Rafinesque 1810) is one of the two shark species of the genus *Isurus* and is circumglobal distributed in temperate and tropical waters. Shortfin mako is common in epipelagic zone vertically ranging from 0 to 500 m depth. The preferred water temperature ranges from 17 to 22ºC (Compagno 2001). In the eastern Pacific Ocean shortfin mako occurs in almost all coastal areas North and South America from 50º N to 40ºS (Strasburg 1958).

The characteristic mobility of this species renders the study of its life history rather difficult. The biology of makos in the eastern Pacific Ocean is still poorly understood. Previous reports are mainly based on individuals of large size captured in US waters (Strasburg 1958, Cailliet *et al*. 1983; Cailliet & Bedford 1983, Hanan *et al*. 1993). Mollet *et al*. (2000) gathered worldwide information on the mako shark and provided an overview of the reproductive biology focusing on the size at maturity. These authors concluded that size at maturity of the shortfin mako is 270 cm to 300 cm TL for females and 200 to 220 cm TL for males; fecundity is 4 to 25 embryos that feed on uterine capsules. Shortfin makos are born with 70 cm TL and their gestation period lasts 15 to18 months (Mollet *et al*. 2000). The diet consists of a variety of demersal and pelagic species of teleost fishes, cephalopods and elasmobranchs (Compagno 2001). Except for an age and growth study from specimens captured in the northwest of Mexican Pacific (Ribot−Carballal *et al*. 2005) data on distribution, abundance, catch composition and fishery biology of the shortfin mako occurring in Economic Exclusive Zone (EEZ) of Mexico are limited.

Longline fishing industry along the Economic Exclusive Zone (EEZ) of Mexico includes both domestic and joint venture Japanese vessels, the later targeting highly valuable sailfish (*Istiophorus platypterus*), striped marlin (*Tetrapturus audax*), swordfish (*Xhiphias gladius*) and tunas (*Tunnus albacares*) (Squire & Au 1990). The operation of such fleets generated invaluable research data sets for targeted species (Squire & Suzuki 1990) whereas information brought about for pelagic sharks captured by Japanese longliners was rather limited (Sosa–Nishizaki 1998).

Analyzed data in the present study come from longline fleet based in Manzanillo, Colima, operating in the EEZ of the Mexican Pacific Ocean since the 1980's targeting billfishes and sharks. Billfishes and sharks were proportionally equivalent in the catches of these vessels. The pelagic thresher shark *Alopias pelagicus*, and silky shark *Carharhinus falciformis* typically dominated the catches. A shift of the fleet to the west coast off Baja California Peninsula has lead to a notable change in species composition of catches with the blue shark *Prionace glauca*, becoming the dominant species. The shortfin mako represented only a small proportion of the bycatch in such vessels (Vélez–Marín *et al*. 2000).

Onboard monitoring of longliners based in Manzanillo allows data on biology and occurrence of the shortfin mako to be collected. Here we report information on distribution, morphometrics, and catch composition collected from 1986 to 2003 by observers of the Instituto Nacional de Pesca of Mexico. We also report on the occurrence and distribution of neonates and juveniles and provide evidence on potential nursery areas for shortfin mako. Recent assessment suggest that pelagic sharks cannot sustain current levels of fishing pressures, consequently shorfin mako and other lamnid sharks are listed as globally Vulnerable in the IUCN Red List (Camhi 2008). Given the lack of knowledge on natural history of large pelagic sharks, this information will contribute to the understanding of a shared stock within US and Mexican waters.

Materials and Methods

Vessels and fishing gear. Operations of longline fleet started in 1986 with four vessels based in Manzanillo, Colima. Since 1992 only one vessel operates targeting billfish, tuna, sharks and other large pelagic species. Sampling was carried out from 1986–2003 by observers of Instituto Nacional de Pesca (INAPESCA). Technological characteristics of such vessels and fishing strategy that might contribute to differences in fishing power remained mostly the same since the first surveys. However, sometimes, sets for testing provoked amplitude of ranges. The vessels are Japanese longliners of 44 m length with 120 ton of storage capacity. Average time of the submerged gear was 8 h and line-hauling ranged from 6–11 h depending on the catch. Length of the main line ranged between 25,200– 75,000 m and the number of hooks from 500 to 1,500. The material of the main line is 4 mm diameter polyamide. Branch lines and buoys lines measured from 9–22 m and 11–12 m, respectively. The branch lines were attached to the main line every 50 m. Acrylic buoys of 30 cm diameter were placed every 5 hooks. Hooks commonly used were Japanese-tuna No. 3.8 of 65 mm length, 30 mm width and 4 mm in diameter. Operating depth of hooks ranged from 61.4 m to 87.4 m. The bait used included small white mullet (*Mugil curema*) and chub mackerel (*Scomber japonicus*) (Santana-Hernandez *et al*. 1998).

Data collection. Observers onboard identified and quantified all catch species. Routinely, oceanic and atmospheric information were recorded, as well as the fishing strategy (i.e setting the fishing gear in zig-zag). Shorfin mako specimens were measured and sexed, and only a randomly selected subsample was weighed. Measurements were done in straight line including total length (TL) and fork length (FL) in centimeters, and total weight (W) in kg. For comparison with other studies, linear regressions were performed between sizes (TL–FL).

Data analysis. Lengths (TL= total length and FL= furcal length) and weights (W) were tested for sex-specific differences. The relationship of W (kg) and FL (cm), described by the equation $W = a(FL)^b$ was calculated through power regression in Minitab (Ver. 14.2, Minitab Inc), and sex-specific differences between these relationships were tested using analysis of covariance (ANCOVA). Sizes (LT) were converted to age using the inverse equation of von Bertalanffy with the parameters: L_∞= 411 cm, k= 0.05 y^{-1}, to= -4.7 years estimated for shortfin mako from the Northwest of Mexican Pacific (Ribot-Carballal *et al*. 2005). Age 0 and 1 were plotted to show the distribution of early juveniles.

Maps of effort distribution and catch (number) per set by the fleet from 1986 to 2003 were built at 1x1 degree. Also, for comparison purposes, average catch per unit of effort (CPUE) was calculated as number of sharks per 1000-hooks. The overall sets with positive catch (> 0) of shortfin makos were plotted by quarter. To infer on the location of nursery areas, distribution maps were built to identify the occurrence of age-0 and age-1 shortfin makos.

Results

Catches and spatial/temporal distribution. Catches of shortfin mako were low compared to other sharks and other large pelagic species as billfishes. Numerically shortfin mako represents only 0.05% of total catch of all species and 1.19% of sharks. A total of 784 (47.3% female, 44.7% male) shortfin makos were caught in the analyzed period. From the total catch of shortfin mako during 1986 to 2003, 31.1% were caught in the first quarter of the year, followed by the second and third quarter with, 26.7% and 24.8%, respectively. The remaining 17.2% of the total makos were caught in the fourth quarter of the year. Despite the fleet operation all over Mexican EEZ, historical data collected by observers show that shortfin mako was mainly captured in the northwest Mexican Pacific in particular along the west coast of Baja California to Islas Revillagigedo and in the vicinity of Islas Marías. Catch per set of shortfin makos yielded higher values in southwest Cabo San Lucas and Islas Marías than in the remaining areas of occurrence. In terms of catch per unit of effort (CPUE), average yield of shortfin mako was 0.04 (± 0.031) individual per 1000 hooks during the period 1986-2003. Catch per set for the entire period is dominated by a large proportion of sets with one individual (95%), followed by set with two (3%) and three organisms (1.3%). Set with four shorfin makos represent only 0.8%. Notably no catches were recorded in the area of the center of Mexican Pacific (Fig. 1).

Maps of catches by quarter pooling all years show that makos occurred in deep waters off Baja California Peninsula west coast of the continental shelf. From January to March (first quarter) makos seem to be closer to Baja California Peninsula and were recorded in the mouth of the Gulf of California (Fig. 2a). A wide dispersion of makos was observed during April to June and July to September, when isolated individuals occurred in southern areas of the Gulf of Tehuantepec (Fig. 2b-c). With exception of the quarter of July to September mako sharks were always caught at the Revillagigedo islands. In quarter of October to December makos were distributed in all the northwest of the Mexican Pacific (Fig. 2d).

Length composition. From the total (784) shortfin makos captured, 722 were biologically examined. The mean size of males was 142 cm FL ranging from 55 to 220 cm FL (sd = 23.2 cm; n = 351). Mean size of female was 143 cm FL ranging from 69 to 264 cm FL (sd = 24.5 cm; n = 371). The length frequency distribution shows small individuals of both sexes of 70 cm FL. Both sexes are represented by a modal size of 150 cm FL (Fig. 3), whereas females show also a mode at 120 cm FL. There was no significant difference in the average length (FL) for males and females (ANOVA, F = 0.81, P = 0.367, df = 721).

Average total weight of males was 32.5 kg with a range of 10-70 kg (sd = 12.9 kg; n = 138), and females average weight was 34.5 kg with a range of 7-72 kg (sd = 12.6 kg; n = 124). No significant sex-specific differences in average weight was found (ANOVA, F = 1.55, P = 0.214, df = 260).

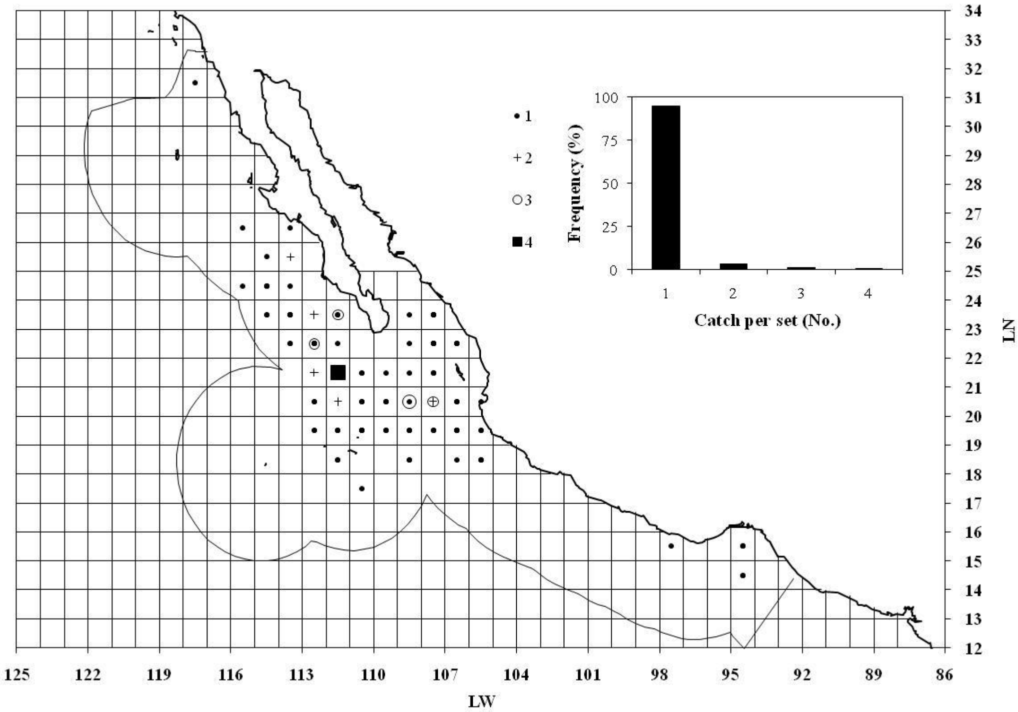

Figure 1. Distribution of the catch per set and frequency of catch per set (bars).

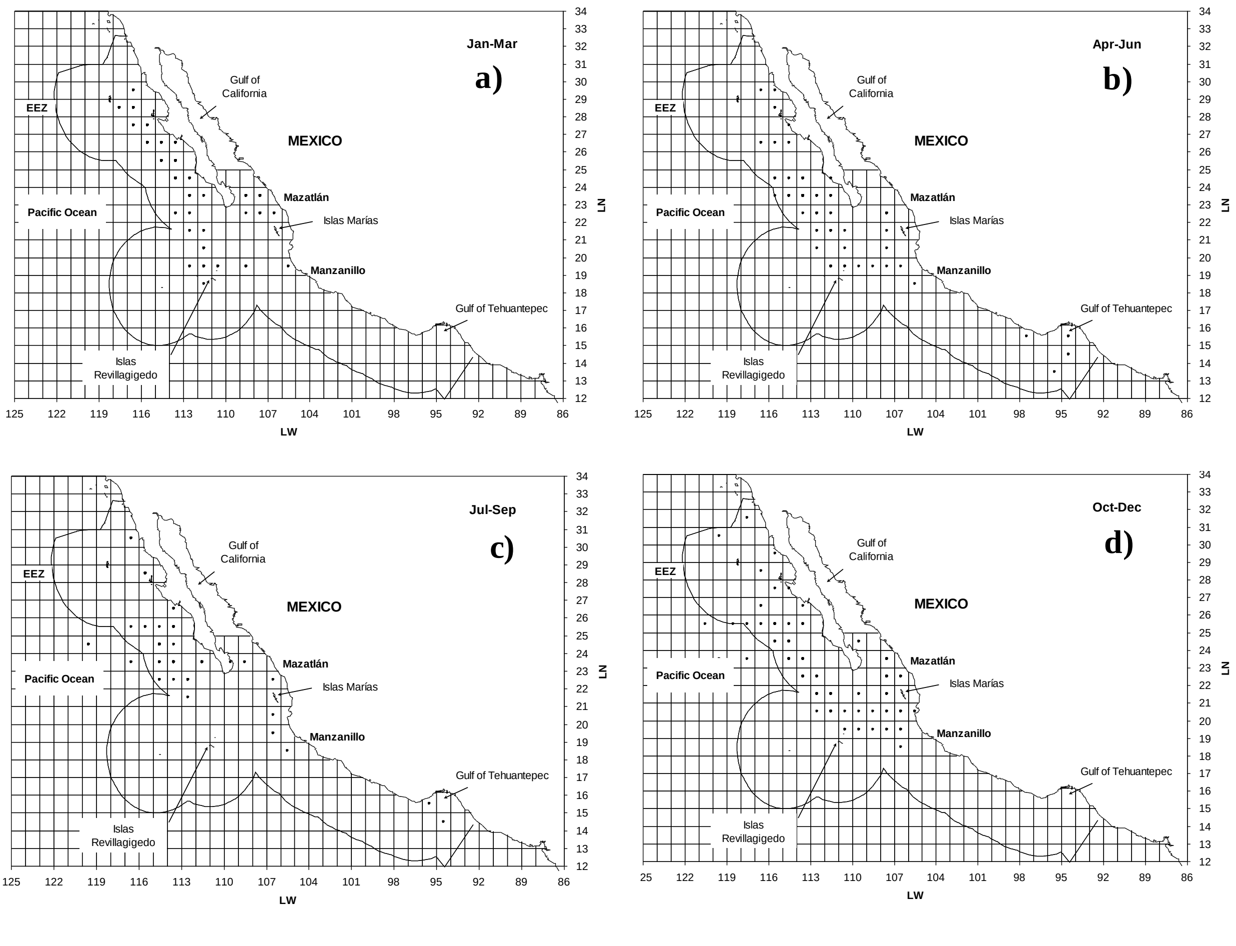

Figure 2. Distribution of the shortfin mako catches by quarter.

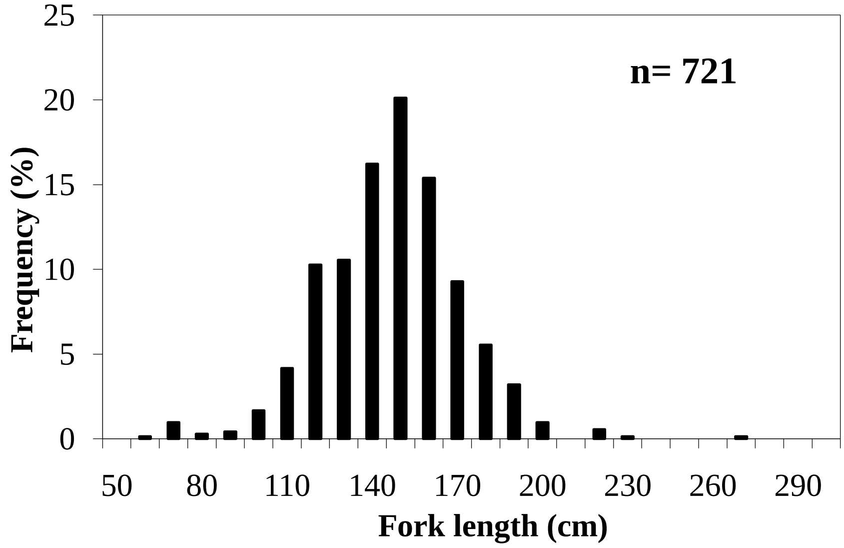

Figure 3. Length frequency distribution shortfin mako taken from the Pacific Ocean of Mexico (n= 722).

Morphometrics. No statistical differences between FL (cm) -TL (cm) relationship were observed by sex (ANCOVA, F= 0.31, P = 0.579), therefore linear regression was calculated together with the following parameters estimates: TL = 8.159+1.039(LF) (r^2 = 0.98, n = 408). Also, there were no statistical differences between sexes in the relationship between W (kg) and FL (cm) (ANCOVA, F= 2.6, P > 0.05). Thus, data were also pooled and the value of the parameters of best fit were: W = 6.8E-5(FL)$^{2.\ 627}$ (r^2 = 0.82; n = 260) (Fig. 4).

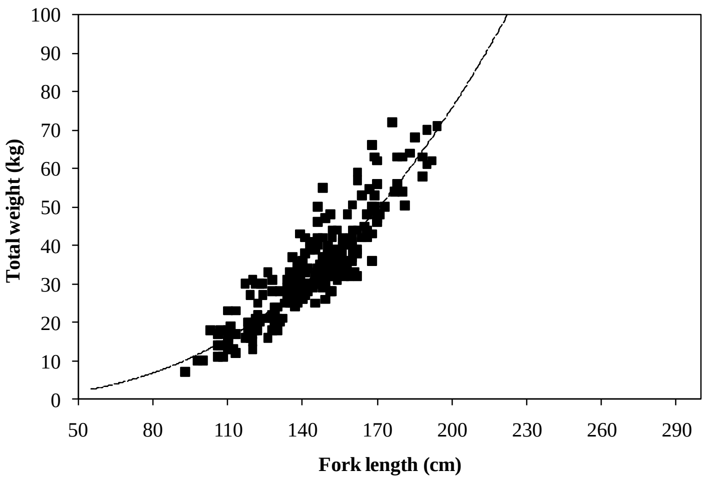

Figure 4. Weight-length relationship for the shortfin mako from the Pacific Ocean of Mexico.

Accounting all the period it was found that shortfin makos age-0 averaged 72.5 cm FL (83.5 cm TL) with a size range from 55 to 88 cm FL (63-100 cm TL) were captured in the west of Baja California Sur in January, April and May with SST of 24.5°C, 19.3°C, and 19°C, respectively. Sets of shortfin makos age-0 had an average sea surf temperature (SST) of 22°C ranging from 18.5-27°C. Age-1 shortfin makos averaged 100 cm FL (110.4 cm TL) having a size range from 92 to108 cm FL (103-116 cm TL) were present offshore waters of Baja California Peninsula, between Islas Marías and the Gulf of California mouth, and in the Revillagigedo archipelago (Fig. 5) with an average SST of 22°C ranging from 18.5-27°C. Isolated catches of age-1 shorfin mako occurred in Cabo Corrientes, South Islas Marias. Information related to the catch of individuals of age-0 and age-1 is given in Table I. The smallest mako of 55 cm FL weighted 3.0 kg and was captured in January 27, 2002 in Revillagigedo at SST = 24.5ºC (Fig 5).

Table I. Data of shortfin makos captured by the longliners. FL= Fork length (cm), TL= Total length (cm), Temperature in Celcius degrees, Sex (f= female, m= male), position (LN, Latitude North, LW= Longitud West), and dates.

Month	Day	Year	T°C	LN	LW	FL	TL	Age	Sex
Jan	27	2002	24.5	19.6	112	55	63	0	m
May	20	1998	19.5	23.3	113	68	78	0	m
May	21	1998	19.6	23.3	113	68	78	0	m
Apr	19	1998	19.0	23.3	114	69	76	0	m
May	4	1998	19.0	26.6	116	69	80	0	f
Apr	29	1998	22.5	-	-	70	82	0	f
May	5	1998	22.5	24.2	114	70	83	0	f
Aug	6	2000	26.1	28.0	115	70	84	0	f
May	6	2000	21.0	23.0	114	73	85	0	m
Jan	25	1998	22.0	25.2	114	74	86	0	f
Jul	26	2000	21.7	25.4	114	83	95	0	m
Jan	20	1998	22.0	26.0	114	85	96	0	f
Jan	27	1998	21.0	26.2	114	88	100	0	m
Jan	28	1998	21.0	26.0	115	92	106	1	f
Mar	23	1998	20.0	23.0	112	92	103	1	m
Mar	16	1996	23.0	22.0	107	93	104	1	f
Feb	24	1998	21.0	24.0	113	94	106	1	m
Jul	5	1999	27.0	23.0	108	94	107	1	m
Jan	30	1998	18.5	28.0	117	95	108	1	m
Oct	5	1989	27.0	20.0	106	96	103	1	f
Dec	20	1986	24.0	23.0	107	98	110	1	f
Jun	8	2002	21.0	23.0	113	100	110	1	m
Jan	30	1998	18.5	28.0	117	100	110	1	m
Aug	7	2000	23.4	25.0	113	100	112	1	m
Oct	5	2000	23.1	25.0	115	100	115	1	f
Jan	30	2002	24.8	20.0	111	101	111	1	f
Jan	30	1998	18.5	28.0	117	101	112	1	f
Mar	13	1987	23.0	23.0	108	103	113	1	f
Jan	30	1998	18.5	28.0	117	104	115	1	f
Jan	31	1998	18.5	29.0	116	105	115	1	f
Oct	24	2001	26.0	21.0	112	106	116	1	m
Mar	17	2002	22.8	22.0	112	106	114	1	m
Jun	6	2002	20.5	23.0	113	106	115	1	m
Jun	8	2002	21.0	23.0	113	106	116	1	m
Jun	6	2002	20.5	23.0	113	108	114	1	f
	age-0, mean (s.d.)					72.5(8.7)	83.5(9.7)		
	age-1, mean (s.d.)					100(5.10)	110.7(4.30)		

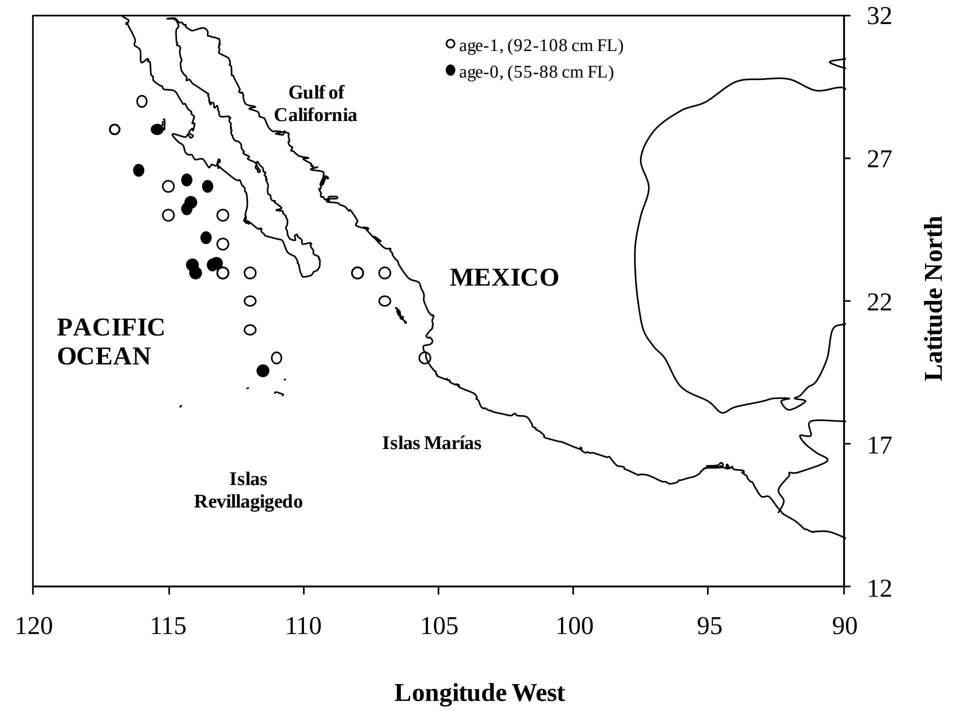

Figure 5. Distribution of the small shortfin mako occurring in the catches of the longliners.

Discussion

The present study shows that the shortfin mako may occur in almost all the EEZ of the Mexican Pacific. Despite the long period of data set analyzed, limited catch of shortfin mako make inference of any pattern of abundance impossible, in this case, occurrence of mako shark can be interpreted by presence-absence criteria. During the development of the Mexican oceanic fishery in the eighties and nineties, dominant shark species in the catch were the pelagic thresher shark, *Alopias pelagicus*, and the silky shark, *Carcharhinus falciformis* which were mistakenly reported as *A. vulpinus* and *C. limbatus*, respectively (Mendizabal–Oriza *et al*. 2001). The shift of fleet to new fishing areas in the vicinity of Baja California Peninsula led to changes in catch composition, with prevalence of species that tolerate water mixtures of lower temperatures such as blue shark, *Prionace glauca* (Strasburg 1958; Cailliet *et al*. 1983). Despite of the fleet operation in the EEZ, shortfin mako catches were sporadic and almost insignificant compared to US pelagic fishery (Holts 1988). Occurrence of makos in the Gulf of Tehuantepec (GOT) is highly interesting because it is considered as a dynamic zone influenced by the Costa Rican current, characterized by seasonal upwelling (Stumpf 1975) and with similar dynamic oceanographic conditions, as the west coast of Baja California Sur, where mako sharks occur. In South America, information on shortfin makos is limited and restricted to their occurrence. Martínez (1999) described the shark fishery in Ecuador with evidence of juvenile mako sharks.

The west coast of Baja California has been recognized as a Biological Activity Center (BAC) of strong upwelling activity where the mixture of currents from California and Costa Rica characterizes its oceanographic conditions (Lluch–Belda *et al*. 2000). The great level of biomass produced in the area is based on large fisheries for small pelagics. Thus, the occurrence of mako sharks and other highly migratory top predators (i.e: sharks, tunas and billfish) in the area coincides with the presence of important small pelagic foraging species (Squire & Au 1990). Therefore, occurrence of small shortfin makos in the west coast of Baja California, in the lower Gulf of California and in the vicinity of Islas Marías may be due to preferred environmental factors (De La Lanza–Espino 1991) and food supply suggesting closeness of a nursery. Based on length frequency distribution analysis, Hanan *et al*. (1993) suggest that the southern California area may be encompassed by the nursery area for makos. Off the west coast of United States, juvenile makos inhabit the coastal waters of California during spring-summer in temperatures ranging from 18º to 22ºC. Even though the mako shark can tolerate extreme temperatures owing its ability to balance heat turnover (Bernal *et al*. 2001), it is frequently found where cold and tropical waters mix such as those off Baja California shore. Although, in this study no data on pregnant females is available to contrast full term or full term embryos *vs* the size of small swimming makos, we believe that the west coast of Baja California and surrounding areas of Islas Revillagigedo and Islas Marías gather the environmental conditions for a nursery for shortfin makos representing an extension of the nursery from Southern California Bight in US waters (Taylor & Bedford 2001). Nurseries for shortfin mako were reported at similar latitudes (LN 20:00-LN 30:00) in the western Pacific (Shoou–Jeng & Hua–Hsun, 2005). Criteria to infer on nurseries for sharks were recently reviewed by Heupel *et al*. (2007) arguing that the seminal concept of nursery area proposed by Springer (1967) and Bass (1978) and its derivations (Branstetter 1990, Castro 1993) should be redefined. In particular, we consider that the review by Heupel *et al*. (2007) is a hybrid of the previous concepts of nursery areas that is more adequate for sharks associated to coastal systems. Little was discussed for sharks inhabiting oceanic environment such as shortfin mako, *I. oxyrinchus*, oceanic white tip, *Carcharhinus longimanus*, silky shark, *C. falciformis*, among others. However, the definition proposed by these authors offers a working framework for either testing or differentiating between nurseries, juvenile areas or birth place.

In Mexico a formal assessment of the status of pelagic sharks has not been carried out despite a long exploitation. However, regulation of the elasmobranch fisheries started in May, 2007 detailing gear and area restrictions. Regulation is accompanied by initiatives of monitoring fishing effort and catches of large vessels trough a Vessel Monitoring System (VMS) that will be mandatory of all the fleet. The status of shortfin makos in the waters of California is uncertain. Holts *et al*. (1998) report a small decrease in average size across the period 1981-1994, although it is unclear whether the effect is caused by historical changes in the mesh-size used on fishing vessels or by overexploitation.

Although the shortfin mako has a worldwide distribution and is considered a species of only intermediate productivity (Smith *et al*. 1998 and 2008), further investigation is needed on biological aspects of this species for determining if differences exist in the pattern of development (maturity, size) in its area of distribution. For instance, lengths of shortfin makos historically reported from California indicated that they are larger than those captured in Mexican waters (Hanan *et al*. 1993), however, as was said before, we caution that such results may be influenced by highly size-selective fishing such as gillnets used in the US fishery. Whether or not there are size structure differences in the catches of makos along California and Baja California, a global study combining the available information on mako sharks and other oceanic shark species will provide a better understanding of temporal and spatial distribution patterns by size and sex, information required for fisheries management.

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