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OCCURRENCE OF IMMATURE SHARKS IN ARTISANAL FISHERIES OF THE SOUTHERN GULF OF MEXICO

Ocorrência de tubarões imaturos na pesca artesanal do sul do Golfo do México

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ABSTRACT

A common feature of Mexican artisanal fisheries is the high proportion of immature sharks in catches. Immature sharks have been historically caught in the southern Gulf of Mexico; however, there is a lack of catch rate estimates. Fishery-dependent sampling in the states of Tabasco (2007-2010 and 2012-2014) and Campeche (2011-2014) was conducted to estimate catch rates of immature sharks of large shark species (species reaching > 150 cm of total length). The catch rate of the 12 recorded species was < 1 shark/fishing day. Immature individuals accounted for a high percentage of the sharks caught in Tabasco (94.5%) and Campeche (90%). We suggest the coast of both states is a juvenile shark habitat for the 12 species. Sharks with predominantly coastal habitats are probably more vulnerable to anthropogenic impacts in the study area, including artisanal fisheries, the oil industry, and coastal development.

Keywords: shark nurseries, juvenile shark habitat, fishery management, Campeche Bank.

RESUMO

Uma característica comum da pesca artesanal mexicana é a alta proporção de tubarões imaturos nas capturas. Tubarões imaturos foram historicamente capturados no sul do Golfo do México. No entanto, há uma falta de estimativas da taxa de captura. A amostragem dependente da pesca nos estados de Tabasco (2007-2010 e 2012-2014) e Campeche (2011-2014) foi realizada para

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estimar as taxas de captura de tubarões imaturos de grandes espécies de tubarões (espécies atingindo > 150 cm de comprimento total). A taxa de captura das 12 espécies registradas foi < 1 tubarão/dia de pesca. Indivíduos imaturos representaram uma alta porcentagem dos tubarões capturados em Tabasco (94,5%) e em Campeche (90%). Sugere-se que a costa de ambos os estados se constitui um habitat para tubarões juvenis das 12 espécies. Os tubarões com habitats predominantemente costeiros são provavelmente mais vulneráveis aos impactos antropogênicos na área de estudo, incluindo a pesca artesanal, a indústria petrolífera e o desenvolvimento costeiro.

Palavras-chave: *berçários de tubarões, habitat de tubarões juvenis, manejo pesqueiro, Banco Campeche.*

INTRODUCTION

In the southern Gulf of Mexico (GOM), 21 shark species are the target or bycatch of at least 18 multi-specific and multi-gear coastal artisanal fisheries operating seasonally in multiple fishing areas from the coastal zone to the edge of the continental shelf (Pérez-Jiménez & Méndez-Loeza, 2015). A common feature of these fisheries in Mexico is the high proportion of immature sharks in their catch (Castillo-Géniz *et al.*, 1998; Saldaña-Ruíz *et al.*, 2019). For example, the catch of immature sharks was worryingly high during the 1980s and 1990s in the Mexican GOM (Bonfil, 1997; Castillo-Géniz *et al.*, 1998), where some shark nursery areas have been documented (Bonfil *et al.*, 1990; Applegate; Soltelo-Macias & Espinosa-Arrubarrena, 1993; Bonfil, 1997; Castillo-Géniz *et al.*, 1998; Hueter *et al.*, 2007; Cuevas-Gómez *et al.*, 2020).

In addition to fishing exploitation, it is known that other anthropogenic activities such as coastal development and pollution via terrestrial runoff impact coastal habitats (Knip; Heupel & Simpfendorfer, 2010). For example, in the Mexican GOM, most of the shark nurseries are also important fishing grounds for fishing communities (Castillo-Géniz *et al.*, 1998), and specifically in the southern GOM, habitat degradation and pollution are of concern due to the oil and natural gas industry (Yáñez-Arancibia *et al.*, 2009).

Particularly, intense fishing exploitation in the 1980s and 1990s is thought to be why the shark fishery is at its maximum sustainable yield (MSY), according to the National Fishing Chart (DOF, 2018). For that reason, several regulations have been established by the Mexican government, including the protection of neonates, early juveniles, and gravid females through spatial and temporal closed seasons (DOF, 2007, 2014). However, information on catch rates of immature sharks by fishing gear is needed to generate a baseline and evaluate the effectiveness of these regulations, particularly for large shark species (species reaching > 150 cm total length), which are the most vulnerable to fishing (Smith *et al.*, 1998; Walker, 1998). Thus, the objective of this study was to estimate the catch rate of immature individuals of large shark species by different fishing gears used in artisanal fisheries in the southern GOM.

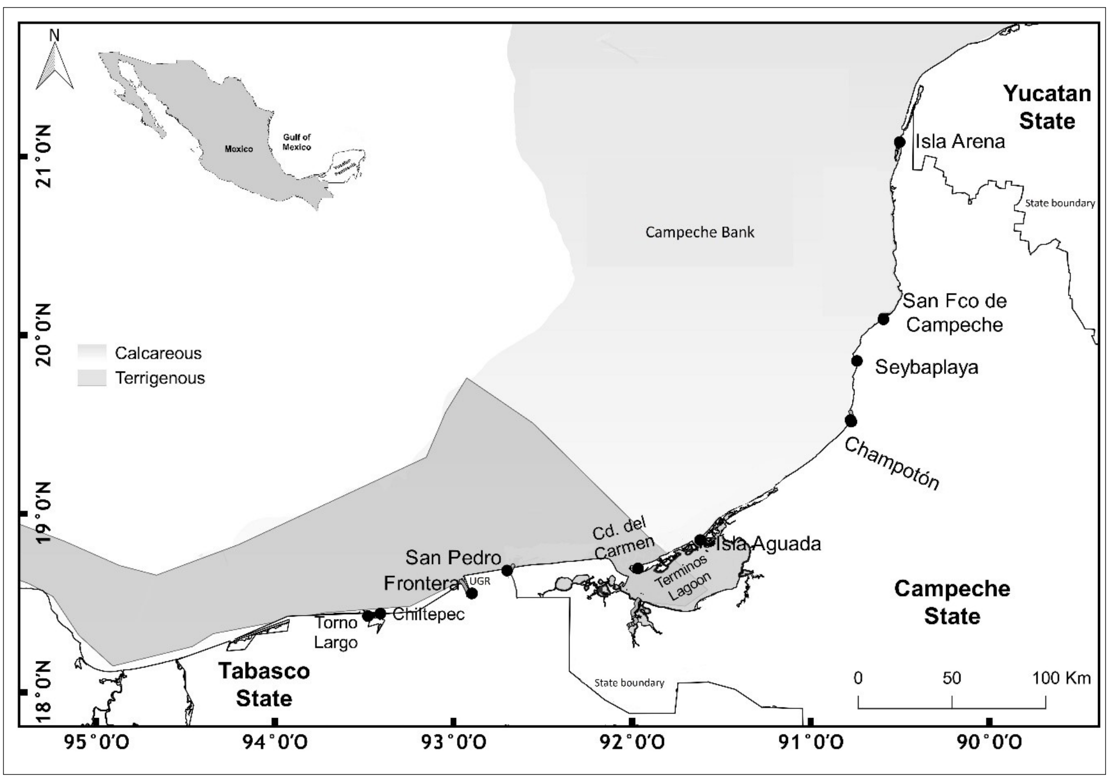
MATERIALS AND METHODS

Study area

The study area is located in the western Yucatan Peninsula and is divided in i) the central and north Campeche continental shelf, with reef areas and no river discharges, and

ii) the southwest Campeche and Tabasco continental shelves with river discharges and oil platforms (Figure 1). Rivers cause a shelf sedimentation transition from calcareous to terrigenous at Terminos Lagoon (Kemp *et al*., 2016), located on the southern Campeche. On the coast of Tabasco, the Usumacinta/Grijalva River (UGR), which ranks second in freshwater discharge to the GOM, generates a large plume that strongly influences fisheries production over large areas of the continental shelf (Kemp *et al*., 2016). The extended continental shelf, the Campeche Bank, that surrounds the Yucatan Peninsula (Piñeiro *et al*., 2001) has a width varying from 30 to 216 km and a depth range of 10-200 m (Gío-Argaez; Machain-Castillo & Gaytán-Caballero, 2002). The western Campeche Bank, where Tabasco and Campeche are located, is characterized by a warm tropical climate enriched with nutrients from land, supporting a great diversity of coastal life and habitats (Yáñez-Arancibia *et al*., 1999).

Figure 1 – Study area in the southern Gulf of Mexico, showing Tabasco and Campeche states and the monitored fishing ports. The calcareous and the terrigenous region division is shown on the Campeche Bank



Fishery-dependent sampling

Biological and fishery data from artisanal fisheries were obtained through a monitoring program of landings in ten fishing ports in Tabasco and Campeche (Figure 1). Data were recorded during 3-4 days monthly in 2007-2010 and 2012-2014 in Tabasco, and 2011-2014 in Campeche. Fishers carried out fishing trips of 1-5 days depending on the target species and the fishing area, in small outboard-motored boats 7.5-9 m in length, made of fiberglass. The nominal Catch Per Unit of Effort (CPUE) was estimated as the number of immature sharks caught per fishing day (± SD). The CPUE was estimated for each species by fishing gear (*e.g.*, gill-nets and longlines; Table I). The CPUE estimations included fishing trips with and without shark catches. Only individuals from species whose maximum total length (TL) was > 150 cm (large shark species) were included in the analysis.

Fishing effort

The fishing effort recorded was 2,785 fishing days in Tabasco and 4,080 fishing days in Campeche. Fishing gears used in Tabasco were three types of longlines with circular hooks (hook sizes of 3-3.5, 4.5, and 6-8 cm shank length) and one type of gill-net made of nylon (15-18 cm mesh size). Longlines with the smallest hooks were used to target snappers (Family Lutjanidae), those with medium-sized hooks to target gafftopsail sea catfish (*Bagre marinus*) and the southern stingray (*Hypanus americanus*), and longlines with the largest hooks to target large sharks. Finally, gill-nets were used to target snook (*Centropomus undecimalis*) (Table I).

Fishing gears used in Campeche were two types of gill-nets made of nylon (9-11.5 and 15-18 cm mesh size) and one type of gill-net made of polyamide multifilament (32-38 cm mesh size). Gill-nets with the smallest mesh size were used to target small shark species (*Rhizoprionodon terraenovae*, *Sphyrna tiburo*, and *Carcharhinus acronotus*) and mackerels (*Scomberomorus maculatus* and *S. cavalla*). Gill-nets with medium-sized mesh size were used to target snook (*C. undecimalis*), and gill-nets with the largest mesh size to target spotted eagle rays (*Aetobatus narinari*) and bull shark (*Carcharhinus leucas*) (Table I).

Biological data

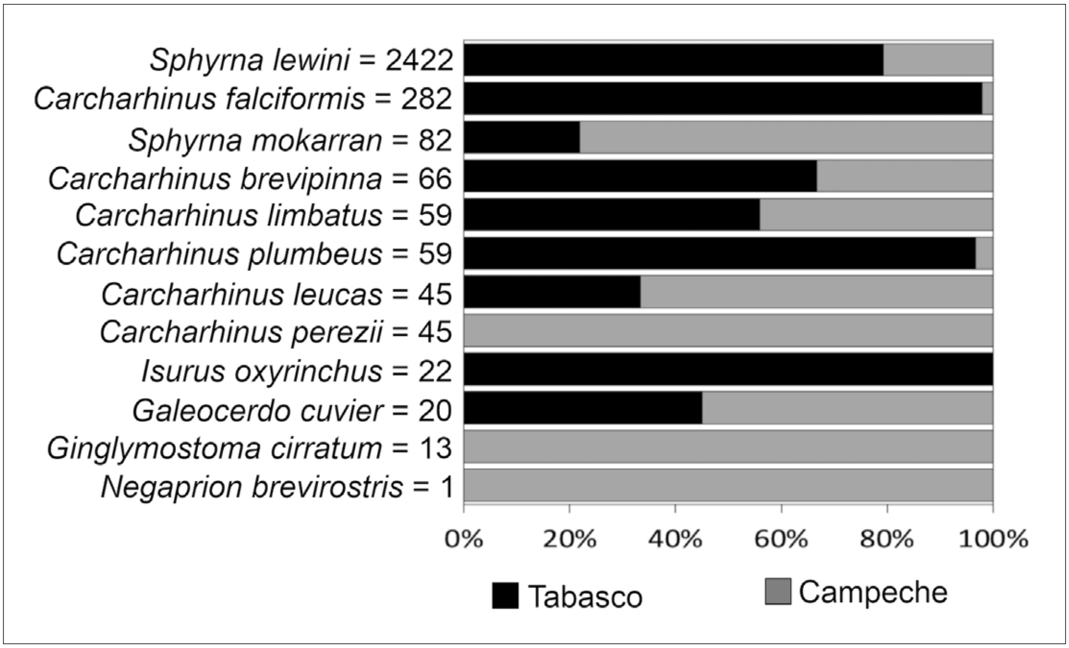
Males with flexible and uncalcified claspers were classed as immature, according to Clark and von Schmidt (1965). Females with no evidence of ovulation or pregnancy or parturition (embryos or uterine eggs present or uterus distended) were classed as immature, according to Walker (2005) and Pérez-Jiménez and Sosa-Nishizaki (2010). Immature sharks landed were counted and measured to the nearest centimeter, using total stretched length (TL) on a horizontal line from the tip of the snout to the upper tip of the caudal fin (Compagno, 1984). The number of *Sphyrna lewini* measured depended on the landing process; sometimes, only a sub-sample of at least 50% was measured.

Differences in the mean size of immature individuals between Campeche and Tabasco were tested with a *t*-test for two independent samples. If assumptions of homogeneity of variances (Levene test) and normality (Shapiro-Wilks test) were not met, a Mann-Withney test was used (Zar, 1996). The percentage of immature individuals by species in each state was calculated from the total number of sharks recorded for each species. Finally, immature individuals were divided into neonates and juveniles to describe their size range by species. Neonates were distinguished from juveniles by having fresh, unhealed, or healing umbilical scars in placental species or those individuals at or near the birth size of aplacental species (Castro, 1993).

RESULTS

A total of 3,116 immature individuals of 12 large shark species were recorded, 77% (n = 2,392) in Tabasco and 23% (n = 724) in Campeche. The most frequent species was *S. lewini,* with 78% of the records, followed by *Carcharhinus falciformis* with 9%. Most records of both species occurred in Tabasco (Figure 2). Immature individuals accounted for 94.5% and 90% of the total sharks recorded in Tabasco and Campeche, respectively. More than 60% of the sharks recorded by species were immature, except for *C. leucas* (with 37% in Tabasco) and *Carcharhinus limbatus* (with 50% in Campeche). There were five species in which only immature individuals were recorded (*C. falciformis*, *Carcharhinus perezii*, *Isurus oxyrinchus*, *Galeocerdo cuvier*, and *Negaprion brevirostris*) (Table II).

Figure 2 – The proportion of immature sharks of 12 species caught by artisanal fisheries in Campeche (grey bars) and Tabasco (black bars)



The highest number of immature sharks caught and CPUE value were estimated for fishing trips using longlines with medium-sized hooks (4.5 cm) in Tabasco (N = 2,142; CPUE 1.11±2.8 immature sharks/day) and for fishing trips using gill-nets with a small mesh size (9-11.5 cm) in Campeche (N = 625; CPUE = 0.19±0.35 immature sharks/day) (Table III, Figure 3). Also, among the six most frequent species, more than 50% of immature sharks were caught with the longline with medium-sized hooks in Tabasco, except for *S. mokarran*, with 62% of the individuals caught with gill-net with a small mesh size in Campeche (Figure 3). CPUE by species was low for all gears (< 1 immature shark/fishing day). The highest CPUE was estimated for *S. lewini* in fishing trips using longlines with medium-sized hooks (0.88 immature sharks/day) and gill-nets with medium-sized mesh size (0.69 immature sharks/day) in Tabasco (Table III).

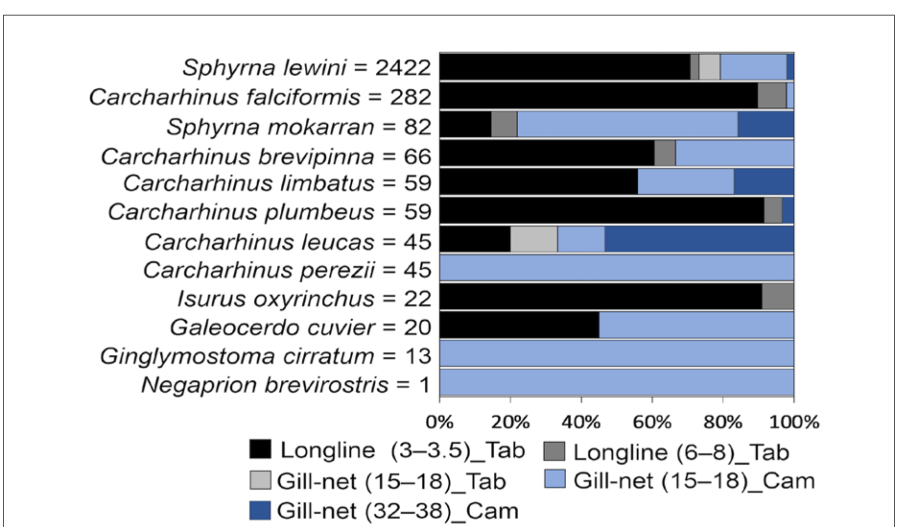


Figure 3 – The proportion of immature sharks of 12 species caught by fishing gears in Campeche (blue scale, Cam) and Tabasco (black and grey, Tab)

A total of 228 neonates of seven species and 1,892 juveniles of 12 species were measured (Table IV). Neonates were recorded for *S. lewini*, *C. falciformis*, *C. brevipinna*, *C. limbatus*, *C. plumbeus*, *C. leucas*, and *I. oxyrinchus*. The smallest neonate was a 35.5 cm TL individual of *S. lewini*, and the largest was an 87 cm TL of *C. falciformis*. The smallest juvenile was an individual of *S. lewini* (54 cm TL) and the largest was an individual of *S. mokarran* (305 cm TL) (Table IV). The mean size of immature sharks of *S. lewini* (U = 35611, P < 0.0001), *C. limbatus* (U = 42.5, P < 0.0001), *C. leucas* (t = 10.4, P < 0.0001), and *S. mokarran* (U = 141.5, P < 0.01) was significantly smaller in Tabasco than in Campeche, and there was no difference for *C. brevipinna* (t = -1.4, P = 0.16). There were not enough data to test for size differences in the other seven species. The smallest mean size was recorded for *C. limbatus* (68 cm TL) in Tabasco and the largest for *S. mokarran* (199 cm TL) in Campeche (Table IV).

DISCUSSION

Neonates and juvenile sharks have historically been recorded in artisanal fisheries along the Mexican GOM and the Caribbean Sea (summary in Table V); however, these studies do not estimate catch rates by fishing gears. The present study determined that although fishing effort targeting multiple teleost and elasmobranch species in coastal waters of the southern GOM is intense, the catch rates of immature individuals of large sharks were low (< 1 shark per fishing day). However, most of the sharks caught were immature individuals in both states (Tabasco 94.5% and Campeche 90%). This is because not all fishing gears were used to target sharks. For example, fishing gears used to target sharks operated in areas with a higher abundance of small shark species (off northern Campeche) or others were used to target large individuals (longline with large hooks or polyamide multifilament with large mesh size).

Cuevas-Gómez *et al*. (2020) determined that eastern Tabasco and southern Campeche (a region with rivers) is a nursery area for *S. lewini*. They identified that the smaller individuals were present in this region, and larger individuals were more common on the central and northern Campeche. The spatial difference in distribution could be explained by the biophysical characteristics of the study area, such as higher turbidity towards Tabasco than to the central and northern Campeche. The present study shows that other large shark species show a similar pattern because smaller individuals were recorded in Tabasco than in central and northern Campeche. The discharge of the Usumacinta/Grijalva River and other rivers in Tabasco and southern Campeche causes high seasonal turbidity and fluctuations in the salinity, which are two of the most important factors explaining the occurrence of neonates and early juveniles in coastal habitats (Yates *et al*., 2012, 2015). In particular, the use of turbid coastal habitats is considered an anti-predator strategy employed by early stages, and these habitats also provide abundant prey (Yates *et al*., 2015).

Multiple shark species sometimes use the same coastal nursery because of abundant food and reduced predation (*e.g.,* Castro, 1993; Simpfendorfer & Milward, 1993; Yates *et al*., 2015). Conventional theory suggests that nursery areas provide the most advantageous habitat for young sharks; however, not all species will have nursery areas, and not all areas where juvenile sharks occur would function as nurseries (Heupel; Carlson & Simpfendorfer, 2007). Heupel, Carlson and Simpfendorfer (2007) proposed three criteria to identify nursery areas based on the records of neonates and young of the year (YOY): 1) sharks are more commonly encountered in the area than in other areas, 2) sharks tend to remain or return for extended periods, and 3) the area or habitat is repeatedly used across years. Following these criteria, Cuevas-Gómez *et al*. (2020) identified a nursery area for *S. lewini* in Tabasco and southern Campeche (rivers' region) using fishery-dependent data and local ecological knowledge from fishers. Although data for the other 11 large shark species is limited to test the criteria, the occurrence of smaller immature sharks of *C. limbatus*, *C. leucas*, and *S. mokarran* in Tabasco and southern Campeche versus central and northern Campeche suggests a similar pattern to *S. lewini*. However, as more data is obtained to test Huepel's criteria, the coast of both states can be considered a communal young shark habitat.

CPUE for large sharks was also low in another study from the southern GOM (Pérez-Jiménez *et al*., 2015). For example, CPUE for *S. lewini* was 0.73 sharks/day using longline to target gafftopsail sea catfish and stingrays and 0.3 sharks/day using longline to target large sharks. The lowest CPUE (0.17 sharks/day) was estimated for *C. leucas* and *C. plumbeus* with the longline used to target large sharks (Pérez-Jiménez *et al*., 2015). The low CPUE was because the longline to target large sharks was used opportunistically as the second or third gear in fishing trips to target gafftopsail sea catfish and stingrays or snappers. In the southern GOM, fishers alternate or combine two or three fishing gears to increase the fishing trip profitability (Pérez-Jiménez *et al*., 2015; Pérez-Jiménez *et al*., 2020). In the northern Quintana Roo, Mexican Caribbean Sea, also low CPUE values (< 1.5 shark/day) have been estimated in the longline to target large sharks (Marcos-Camacho *et al*., 2016). Another study estimated low CPUE (< 1 shark/trip) for large shark species in the Gulf of California, except for *S. lewini*, with 6.5 shark/trip in autumn (Bizzarro *et al*., 2009).

In particular, species that spend most or all of their lives in coastal waters are thought to be more vulnerable to varying coastal processes, habitat degradation, and fishing pressure than species using nearshore areas for only part of their lifespan (Knip; Heupel & Simpfendorfer, 2010). Specifically, there are various strategies of coastal habitat use through ontogeny among large shark species, and those with higher dependence on inshore habitats (*e.g.*, *C. brevipinna*, *C. limbatus*, *C. leucas*, *C. plumbeus*, *G. cirratum,* and *N. brevirostris*) are more vulnerable to anthropogenic activities than those less dependent on these habitats (Knip; Heupel & Simpfendorfer, 2010). On the other hand, the presence of immature individuals of oceanic species, such as *I. oxyrinchus* and *C. falciformis*, should be studied in the future to determine their habitat use in the study area. Particularly, Bonfil (1997) recorded neonates and early juveniles of *C. falciformis* in northern Campeche Bank, proposing a nursery area for this species.

Mexico has made some efforts to protect coastal habitats in the southern GOM, establishing Natural Protected Areas, such as Centla Wetland Biosphere Reserve, Terminos Lagoon Flora and Fauna Protection Area, Petenes Biosphere Reserve, and Ría Celestun Biosphere Reserve. However, the success of these protected areas and the entire coastline needs an ecosystem approach to help reduce the impact of anthropogenic activities, including commercial and recreational fishing, tourism, shipping, oil production, and urban use. Such approach suggests that interactions between the environment and human activities are inseparable because humans are the primary driving force behind most ecological changes, and it relies on the need for a long-term perspective that is anticipatory, preventative, and sustainable (Yáñez-Arancibia & Day, 2004).

Regarding shark fisheries management, the Mexican Official Standard NOM-029-PESC-2006 (DOF, 2007) established a closed season to protect elasmobranch neonates and early juveniles in the Delta of the Grijalva/Usumacinta river and the Terminos Lagoon by prohibiting the use of gill-nets in June of each year. Also, the Mexican government established a closed season for the fisheries that target sharks and the fisheries that take them incidentally in the states of Tabasco, Campeche, and Yucatan from 15 May to 15 June and 1-29 August of each year (DOF, 2014). The enforcement of these measures could protect all life-history stages of the large shark species in the study area.

In conclusion, the coast of Campeche and Tabasco is a juvenile shark habitat for the 12 large shark species. Although catch rates of immature sharks were low in the study area, special attention should be given to those species with high dependence on coastal habitats (*e.g.*, *C. brevipinna*, *C. limbatus*, *C. leucas*, *C. plumbeus*, *G. cirratum*, and *N. brevirostris*) because they could be more vulnerable to the anthropogenic activities, including the multiple artisanal fisheries, the oil industry, and the coastal development.

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Table I – Fishing gears, target species, fishing effort, and the approximated fishing areas of the artisanal fisheries in Tabasco and Campeche, southern Gulf of México

Fishing gears (hook length or mesh size)	**Target species**	**Effort** (fishing days)	**Fishing area** (distance from the coast in km)		
			<20	20-50	>50
Tabasco					
Longline (3–3.5 cm)	Snappers	386			✓
Longline (4.5 cm)	Catfish and stingray	1933		✓	
Longline (6–8 cm)	Large sharks	257		✓	✓
Gill-net (15–18 cm)	Snook	209	✓		
Campeche					
Gill-net (9–11.5 cm)	Small sharks and mackerels	3250		✓	
Gill-net (15–18 cm)	Snook	309	✓		
Gill-net (32–38 cm)	Eagle rays and bull shark	521	✓		

Table II – Records of immature individuals of 12 large shark species in Tabasco and Campeche, southern Gulf of Mexico. %: the percentage that immature individuals accounted for from the total number of sharks recorded by species

Species	**Immature individuals**	**Tabasco**		**Campeche**	
		N	%	N	%
Sphyrna lewini	2,422	1,918	97.5	504	95.5
Carcharhinus falciformis	282	276	100	6	100
Sphyrna mokarran	82	18	93	64	79.5
Carcharhinus brevipinna	66	44	79	22	89
Carcharhinus limbatus	59	33	76	26	50
Carcharhinus plumbeus	59	57	60	2	100
Carcharhinus leucas	45	15	37	30	69
Carcharhinus perezii	45			45	100
Isurus oxyrinchus	22	22	100		
Galeocerdo cuvier	20	9	100	11	100
Ginglymostoma cirratum	13			13	87.5
Negaprion brevirostris	1			1	100
Total	3,116	2,392	94.5	724	90

Table III – Catch per unit of effort (CPUE) by fishing gears of immature individuals of 12 large shark species in the southern Gulf of Mexico. Fishing gear characteristics: mesh size (cm) for gill-nets and shank length of hooks (cm) for longlines. Codes for species: Slw (*S. lewini*), Cfc (*C. falciformis*), Smk (*S. mokarran*), Cbr (*C. brevipinna*), Cli (*C. limbatus*), Cpl (*C. plumbeus*), Cle (*C. leucas*), Cpe (*C. perezii*), Iox (*I. oxyrinchus*), Gcu (*G. cuvier*), Gci (*G. cirratum*), and Nbr (*N. brevirostris*)

Fishing gears	**Global CPUE**	**Species**											
		Slw	Cfc	Smk	Cbr	Cli	Cpl	Cle	Cpe	Iox	Gcu	Gci	Nbr
Tabasco													
Longline (3–3.5)	0.04±0.1	0.02	0.01										
Longline (4.5)	1.11±2.8	0.88	0.13	0.006	0.02	0.017	0.028	0.004		0.01	0.004		
Longline (6–8)	0.32±0.5	0.2	0.06	0.02	0.015		0.011			0.008			
Gill-net (15–18)	0.72±2.1	0.69						0.03					
Campeche													
Gill-net (9–11.5)	0.19±0.35	0.14	0.002	0.015	0.007	0.005		0.002	0.014		0.003	0.004	0.0003
Gill-net (15–18)	0.15±0.3	0.11				0.03	0.006						
Gill-net (32–38)	0.1±0.1	0.03		0.02				0.04					

Table IV – Number of neonates and juveniles measured and their size range (TL cm) by large shark species and the mean size of immature sharks in Tabasco and Campeche caught in artisanal fisheries in the southern Gulf of Mexico

Species	Neonates		Juveniles		Tabasco	Campeche
	No.	TL	No.	TL	TL (mean±SD)	
S. lewini	206	35.5-57	1335	54-178	75±23	96±27
C. falciformis	61	59-87	221	69-176	92±20	112±35
S. mokarran			82	101-305	154±39	199±55
C. brevipinna	4	65-69	62	75-166	126±32	110±34
C. limbatus	10	57-72	49	60-117	68±8	91±15
C. plumbeus	9	61-75	50	60-168	86±26	88±18
C. leucas	6	62-82	39	77-205	85±35	185±15
C. perezii			45	93-142		116±15
I. oxyrinchus	3	63-68	19	80 -193	112±33	
G. cuvier			20	94-263	121±35	195±59
G. cirratum			13	146-191		168±15
N. brevirostris			1	70		70

Table V – Occurrences of neonates and juveniles of large shark species in Mexican waters of the Gulf of Mexico and the Caribbean Sea

Species	Region	References
C. brevipinna	Campeche Bank.	1, 2
C. falciformis	Coasts of Tamaulipas, Veracruz and Tabasco, and northern Campeche Bank.	1, 2, 3, 4, 5
C. leucas	Lagoons: Madre (Tamaulipas), Alvarado (Veracruz), Terminos (Campeche) and, Yalahau and Chetumal Bay (Quintana Roo).	3, 6, 7, 8
C. limbatus	Coast of Tamaulipas and Tabasco, western Campeche Bank, and Terminos and Yalahau lagoons.	1, 2, 3, 8, 9
C. plumbeus	Western Campeche Bank.	1
S. lewini	Coasts of Tamaulipas, southwestern Campeche Bank, and Terminos and Madre lagoons.	1, 2, 3, 8, 10
S. mokarran	Southwestern Campeche Bank.	1, 2, 3

1: Castillo-Géniz (2001), 2: Pérez-Jiménez & Méndez-Loeza (2015), 3: Bonfil (1997), 4: Bonfil *et al*. (1990), 5: Castillo-Géniz *et al*. (1998), 6: Marin-Osorno (1992), 7: Applegate *et al*. (1993), 8: Uribe (1993), 9: Hueter *et al*. (2007), 10: Cuevas-Gómez *et al*. (2020).