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Shark ecology, the role of the apex predator and current conservation status

Felipe Galván-Magaña[a,*], José Leonardo Castillo-Geniz[b], Mauricio Hoyos-Padilla[c], James Ketchum[c], A. Peter Klimley[d], Sergio Ramírez-Amaro[e,f], Yassir Eden Torres-Rojas[g], Javier Tovar-Ávila[h]

[a]Instituto Politécnico Nacional, Centro Interdisciplinario de Ciencias Marinas, La Paz, Mexico
[b]Instituto Nacional de Pesca y Acuacultura, National Fisheries and Aquaculture Institute, Centro Regional de Investigación Pesquera Ensenada, La Paz, Mexico
[c]Pelagios-Kakunjá, La Paz, Mexico
[d]Biotelemetry Consultants and Contractors, Petaluma, CA, United States
[e]Instituto Español de Oceanografía, Centre Oceanogràfic de les Balears, Palma, Spain
[f]Laboratori de Genètica, Universitat de les Illes Balears, Palma, Spain
[g]Instituto de Ecología, Pesquerías y Oceanografía del Golfo de México, Universidad Autónoma de Campeche (EPOMEX-UAC), Campeche, Mexico
[h]Instituto Nacional de Pesca (INAPESCA), Centro Regional de Investigacion Pesquera (CRIP), La Cruz de Huanacaxtle, Nayarit, Mexico
*Corresponding author: e-mail address: galvan.felipe@gmail.com

Contents

Abstract

Feeding studies, since traditional stomach content analysis to stable isotopes analyses, provides insights into the trophic relationship among the apex predators and the ecosystems they inhabit. The Pacific Coast of Mexico (PCM) is inhabited by 62 known species (or 12%) of living sharks, which belong to 21 families and 34 genera. We divide the Pacific Coast of Mexico (PCM) into four regions for consideration: (1) the western coast of Baja California (WcBJ), (2) the Gulf of California (GC), (3) the Central Pacific Mexican (CPM), and (4) the Gulf of Tehuantepec (GT). Biodiversity is highest in the GC, with 48 shark species, followed by the WcBJ with 44 species, then the CPM with 28 species and the GT with 26 species. Few large species (>2 m in total length) function as top predators in any region, with a greater number of smaller shark species (<1.5 m total length). Information about the trophic ecology of different shark species is included to know the ecological role and position of each shark species within a food web to understand the dynamics of marine communities and the impact that each species has on trophic net, which is critical to effective resource conservation and responsible exploitation. The different shark species predate mainly on coastal or oceanic waters. The coastal sharks feed mainly on crustaceans and small fishes; whereas the oceanic species predate mainly on squids and fishes from mesopelagic to epipelagic habits. Also is included a summary of the IUCN Red List category assigned to all shark species from the Mexican Pacific. Thirty-one percent (19 species) of sharks in the Mexican Pacific are considered as threatened (Critically Endangered, Endangered or Vulnerable). Of these, 4.9% (3 species) are Endangered and 26.2% (15 species) are Vulnerable. In addition, since 2012 the fishing of shark and rays has been closed between 1 May and 31 July in the Mexican Pacific as a conservative management measure.

1. Introduction

The Northeast Pacific Ocean (NEP) is an extensive marine region encompassing the following large marine ecosystems: Eastern Bering Sea, Gulf of Alaska, California Current System, and Pacific Coast of Mexico (including the Gulf of California) (Fig. 1). The NEP includes sub-polar, temperate, subtropical and tropical realms. Its oceanography is varied and is influenced either by the cool North Pacific Drift or the warm Equatorial Counter Current. The Pacific Coast of Mexico (PCM) is the largest area within the NEP, with nearly 3117 km of coastline. This area is influenced by the Equatorial Counter Current that flows northward along the coast of Central America and brings tropical water up the coast of Mexico to the mouth of the Golf of California and the southern tip of Baja California Sur. A portion of this warm water continues northward along the western coast of the Baja Peninsula as far as Southern California, forming a gyre in the Southern California Bight (Zaytsev et al., 2003). The climate off the Pacific Coast of Mexico ranges from temperate to subtropical, becoming tropical in the South of the region where marine ecosystem diversity is generally greater. In the southern part of this area, many tropical habitats such as coral reefs, sandy and rocky shores, submarine canyons, estuaries, mangroves and coastal lagoons provide habitat for a wealth of marine species. A number of 891 species of fish have been reported in the Gulf of California (Brusca et al., 2005).

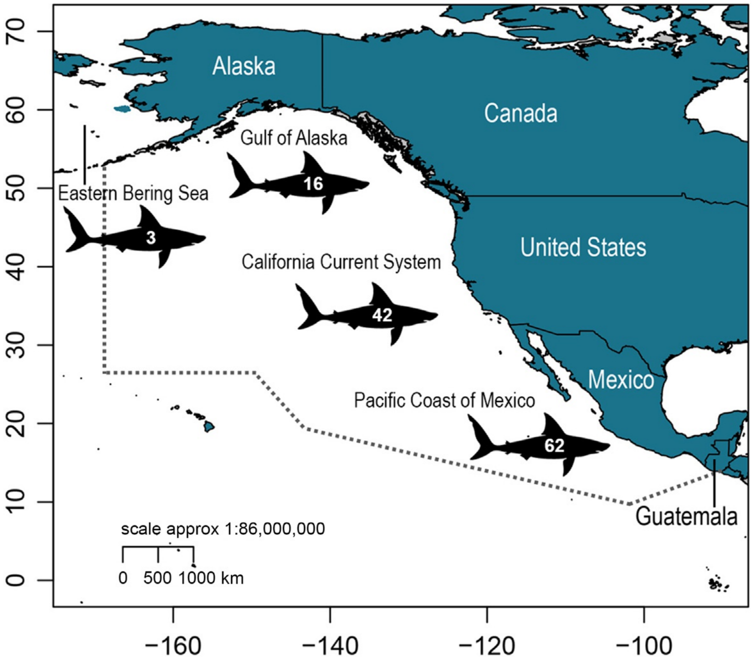

Fig. 1 Map of the Northeast Pacific Ocean (NEP). Sharks icons show the number of shark species for each of four marine ecosystems: Eastern Bering Sea, Gulf of Alaska, California Current System, and Pacific Coast of Mexico. Dotted lines indicate the edge of the Exclusive Economic Zone.

The economically important activities associated with the ocean along the Pacific Coast of Mexico are varied. The northern region is characterized by large-scale, profitable fisheries on species such as sardines, anchovies, and tuna, and coastal tourism has increased in recent years. The Gulf of California is the home of important fishing ports such as Mazatlan, Guaymas, Puerto Peñasco and Topolobampo as well as tourist destinations such as Los Cabos, La Paz, and Loreto. The coastal zone of the Baja peninsula has been impacted by mineral extraction at locations such as Santa Rosalia and La Paz. The economic activity along the southwestern coast of Pacific Mexico is confined to tourism with resorts in the cities of Manzanillo, Zihuatanejo, Ixtapa, Acapulco, Huatulco and Puerto Angel (Rivera-Arriaga and Villalobos, 2001).

For the purposes of this chapter, we divide the PCM into the four following regions: western coast of Baja California (WcBJ); Gulf of California (GC); Central Pacific Mexican (CPM), and Gulf of Tehuantepec (GT) (Fig. 2). The WcBJ is a region characterized by high productivity and diversity of marine resources, which are influenced by the California Current

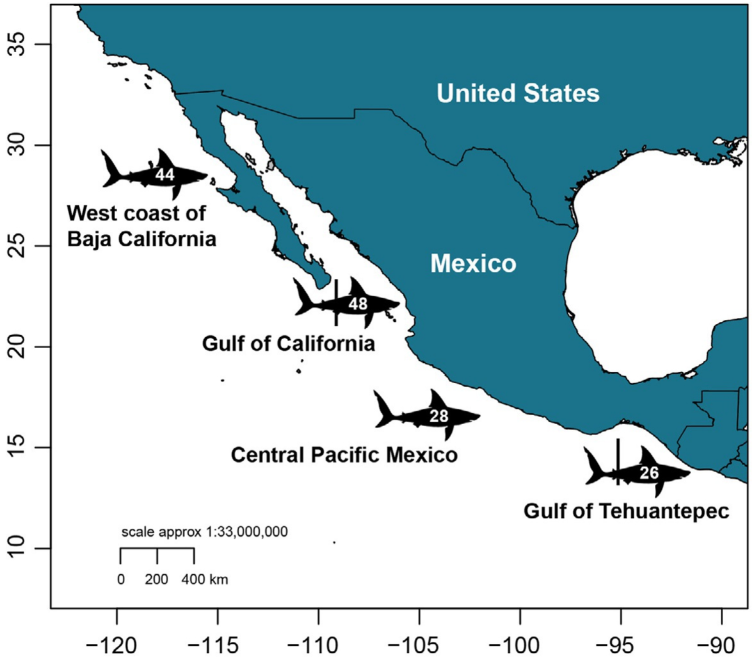

Fig. 2 Map of the Pacific Coast of Mexico (PCM). Shark icons show the number of shark species for four marine areas: Western coast of Baja California, Gulf of California, Central Pacific Mexico, and Gulf of Tehuantepec.

System that flows southward and generates costal upwelling along this region (Young, 2001; Zaytsev et al., 2003). The GC is a large, semi-enclosed sea extending 1100km in length and 100–200km in width. It is home to >900 islands are notable as a region of special biological significance due to its great habitat diversity (Brusca et al., 2005). The CPM is an oceanographic transition zone that combines fauna from the northern and southern regions of the Mexican Pacific. The topography of this region is complex due to the presence of extensive bays, coastal lagoons, estuaries, mangroves and coral reefs (Arriaga-Cabrera et al., 1998). The GT is large body water on the Pacific coast of the Isthmus of Tehuantepec in southeastern Mexico. A strong wind, the ‘Tehuanos’, blows periodically out over the waters of the GT, causing upwelling of nutrient-rich water that supports abundant sea life (Molina-Cruz and Martinez-López, 1994).

2. Sharks of the Pacific Coast of Mexico

Globally, there are ca. 524 known species of sharks (Ebert et al., 2017). The PCM is inhabited by 62 known species (or 12%) of living sharks, which belong to 21 families and 34 genera (Ehemann et al., 2018). Carcharhinidae is the most taxonomically diverse family with 8 genera and 19 species (Table 1; Fig. 3). Of these species, 12 belong to the genus *Carcharhinus*. Triakidae, the second most diverse family, is composed of three genera and seven species. Among the species in the PCM are iconic species from other families such as the Whale Shark *Rhincodon typus*, White Shark *Carcharodon carcharias*, and Basking Shark *Cetorhinus maximus*. There are only two known endemic species in the region: the Whitemargin Smoothhound *Mustelus albipinnis* and Peppered Catshark *Galeus piperatus*. The PCM has greater diversity of sharks compared with other major ocean regions across the NEP, such as the California Current System with 42 species of sharks, the Gulf of Alaska with 16 species, and the Eastern Bering Sea with 3 species (Ebert, 2003; Ebert et al., 2017) (Fig. 1).

The diversity of sharks within the PCM is not homogeneous. It is greatest in the GC with 48 species and the WcBJ with 44 species, followed by the CPM with 28 species and the GT with 26 species (Anislando-Tolentino et al., 2008; Bizzarro et al., 2009a,b,c; Cartamil et al., 2011; Castillo-Geniz et al., 2002; Ehemann et al., 2018; Ramirez-Amaro et al., 2013; Saldaña-Ruiz et al., 2017; Smith et al., 2009a; Soriano-Velásquez et al., 2006) (Fig. 2). Only 14 species of shark have been recorded in all 4 regions of the PCM (Table 1). This pattern of diversity is caused by ecological and environmental factors such as habitat diversity, sea temperature, salinity, and seafloor bathymetry. Climate change is likely to increase variation in many of these factors and affect shark populations and local species composition and, therefore, the functioning of the ecosystem at large (Harley, 2011; Pistevos et al., 2015).

The species composition in the PCM is dominated by coastal species (65%), whereas pelagic/oceanic (19%) and deep-sea species (16%) are less diverse (Table 1). Generally, species within the genus *Carcharhinus* occupy the coastal habitat, with the pelagic habitat occupied by members of the Alopiidae and Lamnidae. However, the habitats visited by these species vary temporally, spatially, and ontogenetically, and it is important to document and understand variation in this habitat dynamism for management and conservation of shark species (Grubbs, 2010).

Weighmann (2016) did not include the PCM as a ‘hotspot’ of chondrichthyan biodiversity. However, with the number of ray, skate, and chimaera species already reported from the region, Mexico’s Eastern Pacific may have one of the highest diversities of chondrichthyan fishes in the world. Coastal, neritic, and demersal shark species are the most well-studied group because they are the species most often targeted by artisanal

Table 1 List of sharks documented in the West coast of Baja California (WcBJ), Gulf of California (GC), Central Pacific Mexico (CPM), and Gulf of Tehuantepec (GT).

Species	Habitat	Family	WcBJ	GC	CPM	GT
Alopias pelagicus	Pelagic/ Oceanic	Alopiidae	X	X	X	X
Alopias superciliosus	Pelagic/ Oceanic	Alopiidae		X	X	X
Alopias vulpinus	Pelagic/ Oceanic	Alopiidae	X	X	X	X
Apristurus brunneus	Deep sea	Scyliorhinidae		X		
Apristurus kampae	Deep sea	Scyliorhinidae		X		
Apristurus nasutus	Deep sea	Scyliorhinidae		X		
Carcharhinus albimarginatus	Coastal	Carcharhinidae			X	
Carcharhinus altimus	Coastal	Carcharhinidae	X	X	X	X
Carcharhinus brachyurus	Coastal	Carcharhinidae	X	X	X	X
Carcharhinus cerdale	Coastal	Carcharhinidae		X		
Carcharhinus falciformis	Coastal	Carcharhinidae	X	X	X	X
Carcharhinus galapagensis	Coastal	Carcharhinidae		X	X	
Carcharhinus leucas	Coastal	Carcharhinidae	X	X	X	X
Carcharhinus limbatus	Coastal	Carcharhinidae	X	X	X	X
Carcharhinus longimanus	Pelagic/ Oceanic	Carcharhinidae	X	X	X	X
Carcharhinus obscurus	Coastal	Carcharhinidae	X	X	X	X
Carcharhinus porosus	Coastal	Carcharhinidae		X		X
Carcharhinus plumbeus	Coastal	Carcharhinidae			X	
Carcharodon carcharias	Pelagic/ Oceanic	Lamnidae	X	X		
Cephaloscyllium ventriosum	Coastal	Scyliorhinidae	X	X		
Cephalurus cephalus	Deep sea	Pentanchidae		X	X	
Centroscyllium nigrum	Deep sea	Squalidae	X			

Table 1 List of sharks documented in the West coast of Baja California (WcBJ), Gulf of California (GC), Central Pacific Mexico (CPM), and Gulf of Tehuantepec (GT).—cont'd

Species	**Habitat**	**Family**	**WcBJ**	**GC**	**CPM**	**GT**
Cetorhinus maximus	Pelagic/ Oceanic	Cetorhinidae	X			
Chlamydoselachus anguineus	Deep sea	Chlamydoselachidae	X		X	
Echinorhinus cookei	Coastal	Echinorhinidae	X	X		
Galeocerdo cuvier	Coastal	Carcharhinidae	X	X	X	X
Galeorhinus galeus	Coastal	Triakidae	X	X		
Galeus piperatus	Deep sea	Scyliorhinidae		X		
Ginglymostoma cirratum	Coastal	Ginglymostomatidae		X	X	X
Ginglymostoma unami	Coastal	Ginglymostomatidae		X		
Heterodontus francisci	Coastal	Heterodontidae	X	X		
Heterodontus mexicanus	Coastal	Heterodontidae	X	X		
Hexanchus griseus	Deep sea	Hexanchidae	X	X		
Isistius brasiliensis	Deep sea	Dalatiidae	X			
Isurus oxyrinchus	Pelagic/ Oceanic	Lamnidae	X	X	X	X
Isurus paucus	Pelagic/ Oceanic	Lamnidae	X			
Lamna ditropis	Pelagic/ Oceanic	Lamnidae	X			
Megachasma pelagios	Pelagic/ Oceanic	Megachasmidae	X			
Mustelus albipinnis	Coastal	Triakidae	X	X		
Mustelus californicus	Coastal	Triakidae	X			
Mustelus dorsalis	Coastal	Triakidae	X			
Mustelus henlei	Coastal	Triakidae	X	X		
Mustelus lunulatus	Coastal	Triakidae	X	X		X
Nasolamia velox	Coastal	Carcharhinidae	X	X	X	X
Negaprion brevirostris	Coastal	Carcharhinidae		X	X	X

Continued

Table 1 List of sharks documented in the West coast of Baja California (WcBJ), Gulf of California (GC), Central Pacific Mexico (CPM), and Gulf of Tehuantepec (GT).—cont'd

Species	Habitat	Family	WcBJ	GC	CPM	GT
Notorynchus cepedianus	Coastal	Carcharhinidae	X	X		
Odontaspis ferox	Coastal	Odontaspididae	X	X		
Parmaturus xaniurus	Deep sea	Pentanchidae	X			
Prionace glauca	Pelagic/ Oceanic	Carcharhinidae	X	X	X	X
Pseudocarcharias kamoharai	Pelagic/ Oceanic	Pseudocarchariidae	X			
Rhincodon typus	Pelagic/ Oceanic	Rhincodontidae		X		
Rhizoprionodon longurio	Coastal	Carcharhinidae	X	X	X	X
Somniosus pacificus	Deep sea	Sominiosidae	X			
Sphyrna corona	Coastal	Sphyrnidae		X	X	X
Sphyrna lewini	Coastal	Sphyrnidae	X	X	X	X
Sphyrna media	Coastal	Sphyrnidae		X	X	X
Sphyrna mokarran	Coastal	Sphyrnidae		X	X	X
Sphyrna tiburo	Coastal	Sphyrnidae		X	X	X
Sphyrna zygaena	Coastal	Sphyrnidae	X	X	X	X
Squalus suckleyi	Coastal	Squalidae	X			
Squatina californica	Coastal	Squatinidae	X	X		
Triaenodon obesus	Coastal	Carcharhinidae	X	X		X
Triakis semifasciata	Coastal	Triakidae	X	X		

fisheries. Neritic species are concentrated especially in river mouths, estuaries, bays, and marine lagoons. Primary production in those environments provides the necessary nutrients and food year-round for the development of trophic chains composed of chondrichthyan species. The diversity and abundance of coastal shark species exhibit 'downs' and 'ups' between years because of various factors. Extended winter or summer seasons reduce primary productivity at sea, while decreasing rainfalls depress coastal nutrient levels, both of which affect communities and assemblages. Oceanographic phenomena like the El Niño and La Niña also impact coastal shark

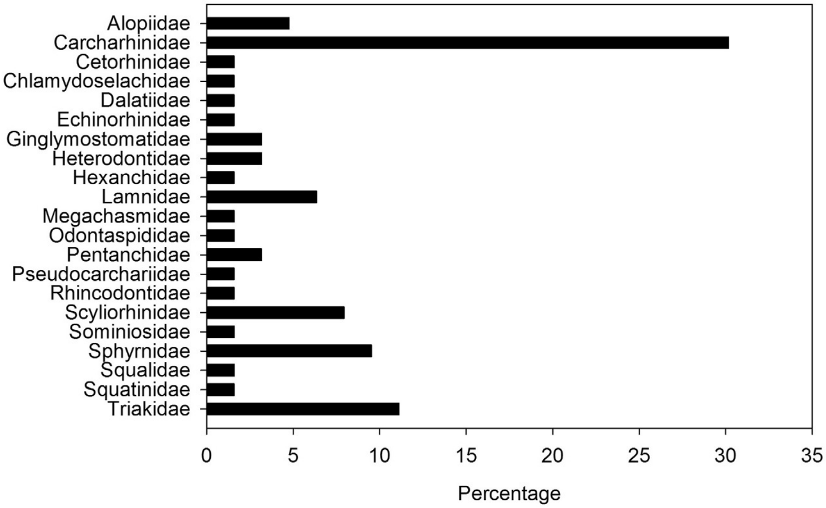

Fig. 3 Percentages of species of shark in the Northeast Pacific Ocean by families.

populations, forcing species to occupy different areas or refuges. ‘The Blob’, an atypical warm mass of water that originated in the northeast Pacific off Alaska, affected the entire California Current system during 2015 and 2016. The thermal anomalies were higher than the 1998–99 El Niño and impacted the shark fauna along the entire west coast of Baja. Yields and catches of blue shark, *Prionace glauca*, dropped below the average during those years as the logbooks and observer program reported (INAPESCA unpublished data). There were impacts on the fauna in Sebastián Vizcaino Bay (SVB), which is a large bay characterized by high productivity located in the middle of the west coast of the Baja peninsula. It is home to a high diversity of elasmobranchs year-round (Cartamil et al., 2011). Juvenile blue sharks dominate by number and weight in the commercial catches year by year. During 2015 and 2016, blue shark landings diminished to a minimum level, whereas shortfin mako catches increased threefold. Blue sharks almost disappeared from the bay and found refuge in deeper waters. The occupation of SVB by the shortfin mako can be explained by its preference for the comparatively high sea temperatures created by ‘The Blob’ (INAPESCA unpublished data).

The second group of sharks present in the Pacific Ocean surrounding Mexico consists of oceanic and pelagic species, which are distributed in the northern and central Pacific regions. Those species are very sensitive to changes in oceanographic conditions, especially to SST (Sea Surface

Temperature). The three most important species are the blue shark, shortfin mako shark, and silky shark. They are highly migratory.

It is widely recognized that sharks play a key role in the transfer of energy between upper trophic levels within marine ecosystems (Bizzarro et al., 2017; Wetherbee and Cortés, 2004). There are apex predators such as the white shark *Carcharodon carcharias*. Also present are filter feeders such as the whale shark *Rhincodon typus*. Finally, there are suction-crushing species such as the horn shark *Heterodontus francisci* and opportunistic scavengers such as the peppered catshark *Galeus piperatus*. While a few large species >2 m in total length function as top predators, a greater number of species are mesopredators <1.5 m in total length that are prey for larger species (Ferretti et al., 2010). This is reflected by the high connectivity of sharks in food web models (Bascompte et al., 2005) and the limited effect of any single apex predator on a particular prey species (Ellis and Musick, 2007). In this sense, the impact of removing sharks from a marine ecosystem is complex and varied. On the one hand, the removal of apex predators can cause changes in prey behaviour and survival rates that result in trophic cascades or collapses of trophic levels below the apex predator, disrupting ecosystem functioning and biodiversity (Ferretti et al., 2010).

Apex predators can be key to preventing outbreaks of mesopredators and the consequent ecological, financial and social problems (Prugh et al., 2009). An example of this effect is given by Myers et al. (2007), who observed that overfishing of shark in the Atlantic Ocean led a population explosion of the Cownose Ray (*Rhinoptera bonasus*), which in turn reduced Bay Scallop (*Argopecten irradians*) populations to such low levels that a century-old scallop fishery was forced to close. Comprehending the ecological role and the position of each shark species within a food web is the first step to clarifying the dynamics of marine communities and the impact that each species has on trophic networks (Lucifora et al., 2012), which is critical to effective resource conservation and responsible exploitation.

Compared to teleost fishes, sharks are characterized by relatively conservative life-history traits (e.g. growth rate, fecundity) and are, thus, considered K-selected species (Cailliet et al., 2005; Stevens et al., 2000). Life-history traits of sharks vary widely, particularly depending on their reproductive traits: gestation period (from 2 to 42 moths), reproductive mode (egg-laying, live-bearing), egg hatching period (from 1 to 27 months), maternal investment (yolk-only, uterine milk, oophagosity, uterine cannibalism, placentation), fecundity (from 1 to 400 offspring), offspring size (from 20 to 1800 cm long), age at maturity (1.5 to >30 years), and longevity

(5 to >50 years) (Compagno, 1990; Cortés, 2000; Dulvy and Reynolds, 2002). Additionally, most sharks display slow growth, long gestation periods, late maturity, low fecundity and productivity and long-life cycles (Cailliet et al., 2005; Camhi et al., 1998; Cortés, 2000). These biological traits generally result in low reproductive potential and low capacity to increase population size after perturbation by a stressor. This has serious implications for shark populations, limiting their capacity to sustain fisheries and to recover from declines (Cailliet et al., 2005; Cavanagh and Gibson, 2007).

3. Trophic ecology of sharks off the Pacific Coast of Mexico by area

3.1 West coast of Baja California (WcBJ)

3.1.1 White shark (Carcharodon carcharias)

The White Shark inhabits temperate waters of the Pacific, Atlantic, and Indian Oceans. Here, we build upon existing knowledge about the trophic ecology of the White Shark in the Mexican Pacific. Adult white sharks have been reported in Guadalupe Island and the central part of the Gulf of California (Galvan-Magaña et al., 2010; Hoyos-Padilla et al., 2016), while the juveniles have been frequently observed on the west coast of the Baja California Peninsula (Benson et al., 2018; Castillo-Geniz et al., 2016; Oñate-González et al., 2017; Santana-Morales et al., 2012).

3.1.2 White Shark Guadalupe Island

Guadalupe Island is considered a 'hot spot' for White Sharks in the eastern Pacific. White sharks are present at the island between July and January, with August to December as the peak months (Domeier and Nasby-Lucas, 2007). Using ultrasonic telemetry to track white sharks, Hoyos-Padilla et al. (2016) were able to describe a differential use of the island by the different life-history stages. The data collected suggest that juveniles arrive at Guadalupe Island from nursery grounds on the mainland after they have reached at least 180 cm TL; then they remain around the island for several months (up to 14), potentially taking advantage of the diversity of prey. They remain close to the island throughout the day between the surface and 50 m depth in warm waters from 14 to 20 °C to feed on prey abundant in shallow waters, such as Bat Rays *Myliobatis californica* (Domeier and Nasby-Lucas, 2007). In addition, juveniles show patterns such as shallow dives during the night that could be related to feeding. There are several diurnal migrators present in

Guadalupe Island surface waters at night that are potential prey for juvenile White Sharks including squid (*Onychoteuthis banksi*, *O. borealjaponica*, and *Dosidicus gigas*), two types of mackerel (*Scomber japonicus* and *Auxis thazard*), sardines (*Sardinops caerulea*), flying fish (*Cypselurus californicus*), and anchovies (*Engraulis* spp.) (Gallo-Reynoso, 1994).

It has been argued that the distribution of large White Sharks at Guadalupe Island is potentially associated with foraging and the seasonal cycles of pinnipeds (Domeier, 2012). White sharks at Isla Guadalupe behead pups of Guadalupe fur seals and ambush Northern elephant seals in deep areas (Gallo-Reynoso et al., 2008; Hoyos-Padilla, 2009). Although seal carcasses have been observed floating at the surface, the predation event has not been witnessed. In addition, satellite (Domeier, 2012) and acoustic tracking (Hoyos-Padilla et al., 2016) data indicate that White Sharks routinely make daily dives to depths in excess of 100 m when around Guadalupe, though the reason for this remains a mystery.

Skomal et al. (2015) tested an autonomous underwater vehicle (AUV) for directly observing the behaviour, habitat use, and feeding ecology of White Sharks near Guadalupe Island. The four white sharks tracked during this study spent, on average, 80% of the time at depths >100 m and only 5% of their time at depths <25 m. Collectively, these observations suggest that predation events occur below the surface. In other areas, it has been established that White Sharks avoid the surface and remain at depths down to 50 m while near pinniped rookeries in autumn and winter. This is consistent with a silhouette-based ambush hunting strategy (Klimley, 1994). Skomal et al. (2015) observed White Sharks approaching, bumping, and biting the AUV at depths ranging from 53 to 90 m, thereby providing direct evidence of predatory behaviour at depth. These data suggest that White Sharks take advantage of great underwater visibility to search for seals in deep water adjacent to seal colonies where they ambush and disable pinnipeds and, perhaps, follow the carcass to the surface (Hoyos-Padilla, 2009). It is also possible that White Sharks take advantage of seals in Guadalupe Island before they go to their pupping grounds to give birth in California and Baja California or to their offshore migration to the west.

3.1.3 White Shark Gulf of California

According to Jaime-Rivera et al. (2014) the White Shark has an ecological role that links food webs in Pacific offshore and nearshore areas from Mexico. They found evidence that some sharks from Isla Guadalupe move into the Gulf of California, according to the isotopic contribution of the jumbo squid to dermal tissue. Large cephalopods are an important diet component of white sharks and are indicators of habitat use (Smale and Cliff, 2012); therefore, this species can be considered a main prey item there. Moreover, jumbo squid recruitment in the Gulf of California occurs during April and May and population size in April is estimated at ~136 million individuals (Morales-Bojórquez et al., 2012). This is the same season when most white sharks have been caught in the gulf (Galvan-Magaña et al., 2010).

3.1.4 White Shark Baja California Peninsula

Although modern technology has elucidated interesting facts about adolescent and adult movements, almost nothing is known about juveniles. Until very recently the understanding of young-of-the-year biology was based largely on the incidental take of juveniles and pregnant females, and stomach content analyses from a relatively small number of individuals (Klimley, 1985a,b). Given the considerable shift in diet and differences in geographic location, inferences about juveniles based on adult behaviour are questionable (Dewar et al., 2004).

In Mexico, Santana-Morales et al. (2012) documented between 1999 and 2010 the incidental catch of 111 juvenile White Sharks during surveys of the artisanal and commercial fisheries along the Pacific coast of Baja California, and opportunistically collected stomach samples. Sharks ranged in size from 123 to 274 cm total length (TL). Most (79.8%) were young-of-the-year (YOY) (≤175 cm TL) and the remainder were juveniles (>175–300 cm TL). Of the four documented fishing-gear types, bottom gillnets were used to capture 74.7% of the individuals, followed by drift gillnet (18.0%), artisanal seine net (4.5%), and surface longline (2.7%). Catch data indicate that the continental shelf is an important habitat for YOY and juveniles in the region, with a possible core nursery area in Bahia Sebastian Vizcaino, where 66 YOY specimens were captured. Stomach content analysis for 14 juveniles are consistent with previous studies showing that the species feeds primarily on bony fish and demersal elasmobranchs including *Thunnus* spp., *Scomber japonicus*, *Atractosion nobilis*, *Myliobatis californica*, *Mustelus* spp., unidentified Scombridae family., cephalopods (order Teuthoidea), crustaceans, and egg capsules of *Raja* spp. The latter prey in their stomach indicates that they feed in the coastal waters (Santana-Morales et al., 2012). These stomach contents observed by Santana-Morales et al. (2012) closely resemble the prey composition previously reported for juveniles by Klimley (1985a,b) in the west coast of North America. A 149.5-cm-TL White Shark was found with 12 of its own teeth in its stomach. The size range of these teeth (between 3 and 6.5-mm crown height) corresponds to its embryonic stage (Kabasakal and Özgür-Gedikoğ, 2008), suggesting that the shark was recently born during the summer months in coastal Baja California waters. Furthermore, Malpica-Cruz et al. (2013) attributed high $\delta^{13}C$ values of YOY white sharks to consumption of benthic fishes inside Bahia Sebastian Vizcaino. Tamburin et al. (2019) found that the isotopic composition of YOY white sharks supports the hypothesis that these sharks reside and forage in Bahia Sebastian Vizcaino and/or similar inshore regions along Baja California for extended timeframes. Yet they may move between the inshore regions in both northern and southern Baja.

3.2 Pelagic sharks from the western coast of Baja California

3.2.1 Blue Shark (Prionace glauca)

The blue shark *Prionace glauca* is the main species caught in the western coast of Baja California. It is the most abundant and widespread shark (Ramirez-Amaro et al., 2013). Despite its importance, there are very few studies on its feeding habits. Hernández-Aguilar et al. (2016) reviewed 368 samples from the artisanal fishery in the western coast of Baja California Sur. The trophic spectrum of *P. glauca* was 13 cephalopods, 7 fish, 3 crustaceans, 1 macroalgae, 1 bird, and 1 elasmobranch. Using the Index of Relative Importance (IRI) the most important prey were Red crab (*Pleuroncodes planipes*), followed by three species of squid: *Gonatus californiensis*, *Ancistrocheirus lesueurii*, and *Haliphron atlanticus*. They conclude that blue shark is a predator that feeds mostly on squid, showing considerable vertical migrations given that its prey have epipelagic, mesopelagic, and benthic habitats. Markaida and Sosa-Nishisaki (2010) analysed 893 blue shark stomach contents from the western coast of Baja California, which indicate that this shark consumes mainly cephalopods of the following species: *Histioteuthis heteropsis*, *Gonatus californiensis*, *Argonauta* spp., and *Vampyroteuthis infernalis*. The pelagic crustacean red crab (*Pleuroncodes planipes*) was one of its main prey. Using stable isotopes analysis indicates that blue shark can feed in coastal and oceanic waters (Maya-Meneses et al., 2016; Polo, 2013; Polo-Silva et al., 2012). Also Méndez Da Silveira (2015) found in the blood and muscle of blue sharks isotopes from the tip of Baja California values that indicate the trophic habitat of this shark is dominated by oceanic waters. The trophic level of blue shark in Baja California Sur waters is of 4.05, which indicate as tertiary consumer (Hernández-Aguilar et al., 2016).

3.2.2 Silky Shark (Carcharhinus falciformis)

A total of 263 stomach contents were analysed. The index of relative importance (IRI) showed that silky sharks fed mainly on red crabs *Pleuroncodes planipes* and jumbo squid *Dosidicus gigas* followed by chub mackerel *Scomber japonicus* (Cabrera Chavez-Costa et al., 2010). Also, differences exist between the main prey of juveniles and adults. The smaller silky sharks fed mainly on *D. gigas*; whereas the larger specimens consumed more *S. japonicus*. Cabrera Chávez-Costa (2003) used stable isotopes in silky shark muscle to distinguish between the trophic habits of males and females, and between juveniles and adults. The results indicate that individuals of both sexes feed in oceanic waters. Also, Méndez Da Silveira (2015) conducted isotopic analyses of silky sharks in the southern region off Baja California which indicates that the silky shark feed in coastal and oceanic habitats.

3.2.3 Smooth Hammerhead Shark (Sphyrna zygaena)

Little information exists worldwide on trophic habits of this species. In two areas of the western coast of Baja California, studies indicate this species feeds mainly on fish species in one area: *Mugil cephalus* (30%), *Sardinops caeruleus* (23%), *Brotula* spp. (19%), *Synodus evermanni* (1.4%); and cephalopod species in another area, including *Pholidoteuthis boschmai* (28%), *Onychoteuthis banksii* (36.2%), *Ancistrocheirus lesueurii* (27.1%), *D. gigas* (28.7%), and *Stenoteuthis oualaniensis* (3.7%) (Ochoa Diaz, 2009).

Also, stable isotopes in muscle were analysed for this species off the western coast of Southern Baja California. This indicates that females and males predate within different trophic habitats. Males tend to be more oceanic, compared to females whose carbon source indicates they are more coastal (Ochoa Diaz, 2009). Méndez Da Silveira (2015) examined stable isotope values from animals around the tip of Baja California, where this species feeds in oceanic waters.

3.3 Coastal sharks of the western coast of Baja California

3.3.1 Tope Shark (Galeorhinus galeus)

The Tope Shark was classified as a high trophic level piscivorous predator in this area, feeding mainly on the teleost fish *Synodus* spp. (51.68%), *Sardinops sagax* (11.66%), and *Scomber japonicus* (11.2%), and in smaller proportions on *Octopus bimaculatus* (6.67%) (Di Filippo, 2018). Stable isotope analyses of this species found values of $\delta^{13}C$ and $\delta^{15}N$ which indicated that juveniles and females are associated more with coastal environments, compared to adults and males which feed more in oceanic waters. However, there is a trophic difference in the usage of resources within the stages of development, but not between sexes. An increase in trophic level was also observed as organisms increased in size, which may be related to an increase in energy demand by larger organisms, or a strategy to avoid competition and/or predation (Di Filippo, 2018).

3.3.2 Sicklefin Smooth-hound (*Mustelus lunulatus*)

This dogfish is an important species in the artisanal fisheries of the western coast of Baja California Sur. Their diet includes 3 species of cephalopods, 29 crustacean species, and 9 fish species. According to the relative prey index of relative prey (PSIRI), the red crab *Pleuroncodes planipes* was the most important prey species (39.94%) followed by the crustacean *Hemisquillia californiensis* (19.46%) in the Northwest Baja California Sur; while in the tip of Baja California the crab *Platymera gaudichaudii* was the most important (25.87%), in addition to two species belonging to the genera *Achelous* spp. (4.43%) and *Portunus* spp. (4.49%). This indicates that they reside in trophic level that ranged between 3.7 and 3.85 in both areas (Martínez, 2018). The isotopic analysis from muscle samples of *M. lunulatus* in the northwest of Baja California Sur indicate that this species feed mostly on crustaceans in benthic areas from deep sea. Within each category (sex, stage of maturity, season) no significant differences were found in the isotopic values.

3.3.3 Brown Smooth-hound (*Mustelus henlei*)

An analysis of 185 stomachs indicated that *Mustelus henlei* feed on 43 prey species, including cephalopods, crustaceans, and fishes. Using the Index of relative importance (IIR), the cephalopod *Lolliguncula diomedeae* (57.31%) and red crab *Pleuroncodes planipes* (32.29%) were the most important prey. The females feed mainly on *L. diomedeae* (53.74%), *P. planipes* (34.71%), and *Plathymera gaudichaudii* (2.01); whereas males feed on *L. diomedeae* (62.08%) and *P. planipes* (28.01%). This shark is a specialist species with a very narrow range of dietary diversity (Espinoza, 2012). Méndez Da Silveira (2015) analysed stable isotopes in muscle of this shark species which indicates that they inhabit oceanic waters.

3.3.4 Swell Shark (*Cephaloscyllium ventriosum*)

The food habits of *Cephaloscyllium ventriosum* are known through stomach contents analysis of 86 organisms from the northwest Baja California Sur. The percentage of prey-specific index of relative importance (%PSIRI) indicates that two most important prey were the crustacean *Hemisquilla ensigera californiensis* (31.32%) and the cephalopod *Octopus bimaculatus* (22.31%) (Baro, 2016).

3.3.5 Mako Shark (Isurus oxyrinchus)

The catch of this species by the artisanal fishery of the west coast of Baja California Sur is confined mainly to neonates and juveniles. This coastal area is a nursery area for this species. A total of 269 stomachs were examined by Velasco (2005), from which 31 prey were identified. The most important fishes in the diet were *Prionotus albirostris* (65% IRI) and *Scomber japonicus* (5%), while for cephalopods (27%), the squids *Dosidicus gigas* (23%) and *Ancistrocheirus lesueurii* (4%) were the most important prey. The juvenile mako shark was classified as specialist predator. By sex, the males had a diet less selective than females. The prey consumed by adults were mainly pelagic and of bigger size, whereas juveniles predate mainly on benthic prey such as *P. albirostris* (Velasco, 2005).

Using isotopic values of nitrogen (δ^{15}N), three trophic levels were found to be evident in different life stages. A higher trophic level was in juveniles ($\mu = 18.10‰ \pm 0.82$) and adults ($\mu = 18.72‰ \pm 0.57$). The most important prey was *S. japonicus* (δ^{15}N: 17.36‰) and *P. albirostris* (δ^{15}N: 16.73‰), with trophic position similar to the juvenile Mako Shark. Also the prey *Dosidicus gigas* (δ^{15}N: 15.68‰) had a similar trophic level compared to Mako Shark juveniles, but a lower trophic level in relation to adults. The prey *Mugil cephalus* (δ^{15}N: 11.02‰) and *P. planipes* (δ^{15}N: 12.30‰) had low values. Using carbon isotopes (δ^{13}C), the most important prey in oceanic waters was *Coryphaena hippurus* (−16.11‰), *Scomber japonicus* (−16.92‰), *P. albirostris* (−17.53‰), and *D. gigas* (−17.94‰). The less important prey were *Mugil cephalus* (δ^{13}C: −10.01‰) from coastal waters and *Pleuroncodes planipes* (δ^{13}C: −19.03‰) from oceanic waters. The combination of results using two methods (stomach contents and Carbon and Nitrogen isotopic values) discriminated the differences between juveniles and adults. The western coast of Baja California Sur is an important feeding area for Mako Shark juveniles (Velasco, 2005).

3.3.6 Horn Shark (Heterodontus francisci)

The dietary habits of the horn shark were examined in the Northwestern area of Baja California Sur during spring, summer, and fall of 2014 (Cortés, 2015). A total of 78 stomachs were collected. According to the Index of Relative Importance (%IRI), the most important prey were anomurans (66%), cephalopods (7.2%), lobsters (4.7%), fish (4.2%), and sea urchins (2.3%). The main prey were the anomuran *Blepharipoda occidentalis* (65.2%), the octopus *Octopus bimaculatus* (5.4%), the lobster *Panulirus interruptus* (4.7%), and the sea urchin *Echinometra vanbrunti* (2.6%). Females fed primarily on *B. occidentalis* (69.6%), *O. bimaculatus* (9.5%), and squid remains (3.6%); while males feed on *B. occidentalis* (33.3%), *P. interruptus* (8.7%), and the fish *Calamus brachysomus* (5.3%). Juveniles fed primarily on *B. occidentalis* (22.9%), the squid *Doryteuthis opalescens* (6.5%), and the anomuran *Lophomastix diomedeae* (2.5%); while adults fed on *B. occidentalis* (66.8%), *O. bimaculatus* (6.9%), and *P. interruptus* (6.2%). According to trophic niche breadth *H. francisci* is a specialist predator. This species was classified as a tertiary consumer with trophic position of 4.06 (Cortés, 2015).

Segura et al. (1997) found, in 108 stomachs from San Ignacio Lagoon, the following main prey using IRI: the gastropods (*Lucapinella milleri* and *Calyptraea* spp.), crustaceans (*Callinectes bellicosus*, *Penaeus* spp. and isopods), pelecypods, sipunculids (*Sipuncula nodosus*), cephalopoda (*Octopus* spp.), and the fish (*Syngnathus auliscus*). This horn shark was a third order consumer that consumed a variety of benthic species.

Rodríguez (2016), using the stable isotopes of δ^{13}C and δ^{15}N in 71 muscles from the Northwest Baja California Sur, indicates that *H. francisci* feed mostly in oceanic habits. There were no significant differences between males and females, or between adults and juveniles. Using the SIBER method the females (1.99) have a higher trophic niche breadth than males (1.62), and both adults (1.22) and juveniles (2.31) are generalists. The trophic position being 3.31 ± 0.29 and indicating that *H. francisci* is a third order predator.

3.3.7 Pacific Angel Shark (Squatina californica)

There is little information on feeding habits of this species in the western coast of Baja California Sur other than the stable isotope analysis completed by Valdivia (2013), which indicates that *S. californica* feeds in coastal areas and predates within the benthic habitat. No significant differences were found in the isotopic values between males and females, nor between juveniles and adults. This indicates that they share the same foraging areas.

3.4 Gulf of California (GC)

3.4.1 Whale Shark (Rhincodon typus)

The Gulf of California (GC) is considered a transitional zone where different currents converge (Kessler, 2006), which supports high productivity, rich biodiversity, and high levels of endemism (Brusca, 2010). The GC encompasses different marine and coastal ecosystems that support the feeding habits of many benthic and pelagic shark species. In the pelagic area, the Whale Shark (*Rhincodon typus*), which is a cosmopolitan species that lives in both epipelagic and neritic waters in tropical and warm-temperate regions around the world (Compagno, 2001), is common. In the eastern Pacific it is recorded from northern California to the northern coast of Chile (Compagno, 2001; Ebert et al., 2004), including the Pacific coast of Mexico and the Gulf of California (Wolfson, 1987). In the Gulf of California, Whale Shark aggregations are recorded near Cabo San Lucas (Wolfson, 1987), Bay of La Paz (Clark and Nelson, 1997; Ketchum et al., 2013; Ramírez-Macías et al., 2012) and Bahía de Los Angeles (Nelson and Eckert, 2007; Ramírez-Macías et al., 2012), as well as around offshore seamounts, particularly at El Bajo Espíritu Santo and Gorda Banks (Ketchum, 2003; Ketchum et al., 2013; Klimley and Butler, 1988; Ramírez-Macías et al., 2017). One of the first studies to understand the movements and migratory patterns of Whale Sharks was carried out in the Gulf of California (Eckert and Stewart, 2001). This study, and more recent ones, found that juvenile Whale Sharks move north and south within coastal areas of the Gulf of California, whereas adults move more in oceanic waters (Eckert and Stewart, 2001; Ramírez-Macías et al., 2017).

The Whale Shark is an elusive fish, and little was known about its ecology in the Gulf of California until the last 20 years. Whale Sharks show seasonal, interannual, and spatial segregation by sex and size in the southern Gulf of California (Eckert and Stewart, 2001; Ketchum, 2003; Ketchum and Lozano, 2000; Ketchum et al., 2013). Large aggregations of juveniles have been observed inshore within the southern portion of the bay, mainly juvenile males, whereas, offshore aggregations in deeper waters are composed of adults, mostly females (Ketchum, 2003; Ketchum et al., 2013). Whale shark prey abundance and preference have been described in coastal regions (Clark and Nelson, 1997; Hacohen-Domené et al., 2006; Ketchum et al., 2013; Nelson and Eckert, 2007, Taylor, 2007), as well as associations of the species with hydrographic features of lagoon and shelf waters (Wilson et al., 2001). Whale sharks associate with particular sea surface temperature in La Paz Bay, Mexico (19.6–29.8 °C) (Ketchum et al., 2013). However, information about habitat preferences of Whale Sharks and the characterization of their habitat is far from complete and studies on distribution associated with concurrent hydrographic and biological features are still lacking in many regions. In the Gulf of California, aggregations of Whale Sharks occur at bays and offshore seamounts (Clark and Nelson, 1997; Ketchum et al., 2013; Klimley and Butler, 1988; Nelson and Eckert, 2007), which may be important feeding and nursery grounds for the species.

Whale Shark habitat in the Bay of La Paz can be characterized by the dynamic physical and biological characteristics of the bay's waters (Ketchum et al., 2013). Hence, according to the variables analysed, whale shark habitat in the bay may be subdivided into: (1) coastal areas dominated by inshore processes such as tidal mixing and nutrient input from a coastal lagoon; (2) mixed areas with both inshore and offshore dynamics; and (3) oceanic areas dominated by offshore phenomena like the presence of thermal fronts and a sharp thermocline (Ketchum, 2003). The coastal south and southeastern areas of the Bay of La Paz harbours the highest abundance of whale sharks, especially juveniles with a density of ∼4 sharks/km^2 (Ketchum et al., 2013). Such density of sharks is very similar to the one recorded for Ningaloo Reef in Australia (4 sharks/km^2; Taylor, 1994), but much smaller than the 4 sharks/ha recorded for Gladden Spit in Belize (Heyman et al., 2001). The southern bay is influenced by its location near a current convergence zone off the narrowest portion of the Mogote sandbar (Jiménez-Illescas et al., 1997) and lies within the strong tidal currents off Punta Prieta (Ketchum et al., 2013). These two features promote intense secondary production during most of the year, which supports a high biomass and a zooplankton community structure composed mainly by copepods in this area (Ketchum et al., 2013). The latter had been also observed by previous studies (Palomares-García, 1996). In the southeastern bay, the tidal flows are dominant (Obeso-Nieblas et al., 2002), and act in conjunction with the outflow of nutrients from a coastal lagoon (Ensenada de La Paz) and the local topography (Signoret and Santoyo, 1980) to have a strong influence on the density and composition of zooplankton (Ketchum et al., 2013). Hence these two coastal areas provide highly favourable environmental conditions and preferred prey for juvenile Whale Sharks. In the northwestern part of the bay, a mixed area, the abundance of juvenile sharks was lower and adult sharks occurred more frequently here than in the south (Ketchum et al., 2013).

The Whale Shark is a filter feeder that feeds on a variety of prey, from zooplankton to small fish and squid (Last and Stevens, 1994). In contrast to other filter-feeder elasmobranchs such as the Basking Shark, *Cetorhinus maximus*, and the Manta Ray, *Mobula birostris*, Whale Sharks can capture larger prey by active suction filtering behaviour; however, individuals depend on dense aggregations of planktonic and nektonic prey (Colman, 1997), such as copepods, euphausids, sardines, and anchovies (Compagno, 1984). Juvenile Whale Sharks in the Gulf of California feed by active and stationary (or vertical) suction, and by ram-filtering (or passive feeding) between active and stationary bouts (Ketchum et al., 2013; Nelson and Eckert, 2007). For juvenile sharks, active suction is associated with dense copepod patches (70–85%), stationary suction with more sparse copepods (20–40%), and ram-filtering with the lowest concentration of copepods (<25%) in Bay of La Paz and Bahía de Los Angeles (Ketchum et al., 2013; Nelson and Eckert, 2007). The most abundant copepods found in the Bay of La Paz were *Acartia sp.*, *Undimula sp.* and *Corycaeus sp.* (Hacohen-Domené et al., 2006).

3.4.2 White Shark (Carcharodon carcharias)

The White Shark is also found in the Gulf of California. Galván-Magaña et al. (2010) found 38 records of White Shark captures and reliable sightings for the Gulf of California. The main locations of occurrence were El Golfo de Santa Clara (13 records), followed by Santa Rosalia (4), and San Pedro Martir and San Pedro Nolasco Islands (3 each). Presence of juveniles (≤300 cm total length) was highest from January to May (10 records) and mostly restricted to the upper Gulf, mainly in the relatively shallow waters off the fishing town of El Golfo de Santa Clara, and this is probably associated with foraging. Juveniles apparently show a dietary preference for benthic and coastal fishes (Klimley and Nelson, 1984; Tricas and McCosker, 1984). The northern Gulf of California is habitat for seasonally large schools of medium- to large-sized fish such as the endemic corvina (*Cynoscion othonopterus*) and totoaba (*Totoaba macdonaldi*), which could be consumed by juveniles. Records of subadults and adults (300–400 cm TL) were more common from December to May (eight records), but less frequent from June to October (five records). The stomach contents were identified for some adults and consisted of bottlenose dolphins (*Tursiops truncatus*), unidentified whale remains, and California sea lions (*Zalophus californianus*).

3.4.3 Smooth Hammerhead Shark (Sphyrna zygaena)

Another pelagic shark species known to inhabit the GC is the Smooth Hammerhead Shark. This is a coastal-pelagic and semi-oceanic species that occurs on the continental shelf, to 200 m depth (Ebert, 2003). One possible pupping ground and nursery area for this species is the northern GC. In general, the trophic spectrum of *S. zygaena* in the GC it is represented by 23 prey species, where according with the index of relative importance (IRI) mesopelagic cephalopods like *Dosidicus gigas* (75%), *O. banksii* (11%), *S. oualaniensis* (8%), and *A. lesueurii* (4%) are the main prey species in its diet (Ochoa Diaz, 2009). The Smooth Hammerhead shows ontogenetic differences based on stable isotopes (Ochoa Diaz, 2009), where females seem to feed more on the coast and the males feed more in oceanic areas and mainly on epipelagic fish. Adults of both sexes consume mesopelagic squids and juveniles consume predominantly benthic prey species.

3.4.4 Scalloped Hammerhead Shark (Sphyrna lewini)

A related species that demonstrates similar feeding behaviour to the Smooth Hammerhead Shark is the coastal and semi-oceanic pelagic Scalloped Hammerhead Shark. Adults occupy the southern Gulf of California from late spring to late fall and may arrive coincident with an assemblage of pelagic fishes coming from the tropical eastern Pacific Ocean (Klimley and Butler, 1988). This species spends daytime hours around offshore seamounts where they form schools before making nighttime migrations away to forage in the pelagic environment (Klimley and Nelson, 1984). Female hammerheads dominate the large schools that exist at seamounts and offshore islands (Klimley and Nelson, 1981). They compete among each other for a central position within the schools, where males pair with the largest dominant females (Klimley, 1985a,b). The male copulates with the female, as the two descend in the water column from a shallow depth, and this is likely to occur over deep water near the schooling sites (Salinas-de-León et al., 2017). The females migrate offshore at an earlier age than males, and by doing so increase their rate of growth leading to a larger body mass than males prior to reaching sexually maturity (Klimley, 1987). Supporting this hypothesis was the migration of an immature Scalloped Hammerhead equipped with an archival tag from coastal waters, apparent in the recorded shallow dive depths during both day and night, to an offshore seamount, evident from shallow daytime depths and deep nighttime depths (Hoyos-Padilla et al., 2014). The dive records on the archival tag are consistent with the females remaining in schools to shallow waters above seamounts, and their deep dives when moving away from the seamount into deep water to feed at night. Individuals have been observed to make nighttime migrations to a distance of 20 km from a seamount and return to it the following day (Klimley, 1993). The schools appear to depart from the seamount in response to upwelling of cool, deep waters, only to return with warmer waters (Klimley and Butler, 1988).

Juvenile Scalloped Hammerheads inhabit the shallow coastal bays of the eastern coast of Baja California (Klimley, 1987) and western coast of the

Mexican mainland (Torres-Huerta, 2004). Many species of sharks use coastal–estuarine environments as nursery grounds. These areas offer abundant food resources to the young, and better protection from predators than would be afforded to them in the pelagic environment (Clarke, 1971; Simpfendorfer and Milward, 1993). Bush and Holland (2002) mentioned that sharks use nursery areas where there are accessible food items (i.e. catchable prey), and high prey abundance (i.e. nutrient-rich habitat). Based on isotopic mixing models, Torres-Rojas et al. (2013) suggest that *S. lewini* feed on prey present in the Gulf of California, therefore this region could be considered a nursery area with abundant food for this shark species.

The offshore movement of female Scalloped Hammerhead at an earlier age than males and the use of coastal areas by juveniles in the southern Gulf of California results in different diets between sexes and over ontogeny. To illustrate this, prey species, grouped according to habitat, are shown in pie-shaped diagrams for both sexes (Fig. 4). In order to detect ontogenetic divergence, the diet is further separated for sharks of less than or equal to and >160 cm TL. This division was chosen because males did not enter the offshore schools until within this size class while females in the 100 cm size class were seen in the offshore schools (Fig. 5). As might be expected from their early offshore movement, females in the <160 cm size class fed on a higher percentage of pelagic prey than did males of similar sizes. Mesopelagic prey formed 27.5% and epipelagic prey 5.5% of the female total IRI, while such prey composed only 18.1% and 3.6% of the male total IRI. Furthermore, the diet of the females was composed of only 15.1% benthic prey in comparison to 40.9% of the IRI of male sharks.

A subsequent analysis of the feeding habits of juvenile Scalloped Hammerheads also identified differences suggesting that males and females occupy different habitats based on their stomach contents (Aguilar-Castro, 2003). In females a 44.6% IRI comprised three pelagic squid (*Abraliopsis affinis*, *Dosidicus gigas*, and *Onychoteuthis banksia*) and one pelagic fish (*Scomber japonicus*), whereas in males a 33.0% IRI was composed of only one pelagic squid (*Abraliopsis affinis*) and one pelagic fish (*Scomber japonicus*). The early offshore movement of females was found to result in an increase in their predatory success while similar size males, which remained inshore, did not increase their predatory success (Klimley, 1987). It is suggested that early offshore migration of females results in more rapid growth, allowing females to reach maturity at the larger size necessary to support embryonic young at a similar age to males, matching the female reproductive lifetime to that of the male (Hoyos-Padilla et al., 2014).

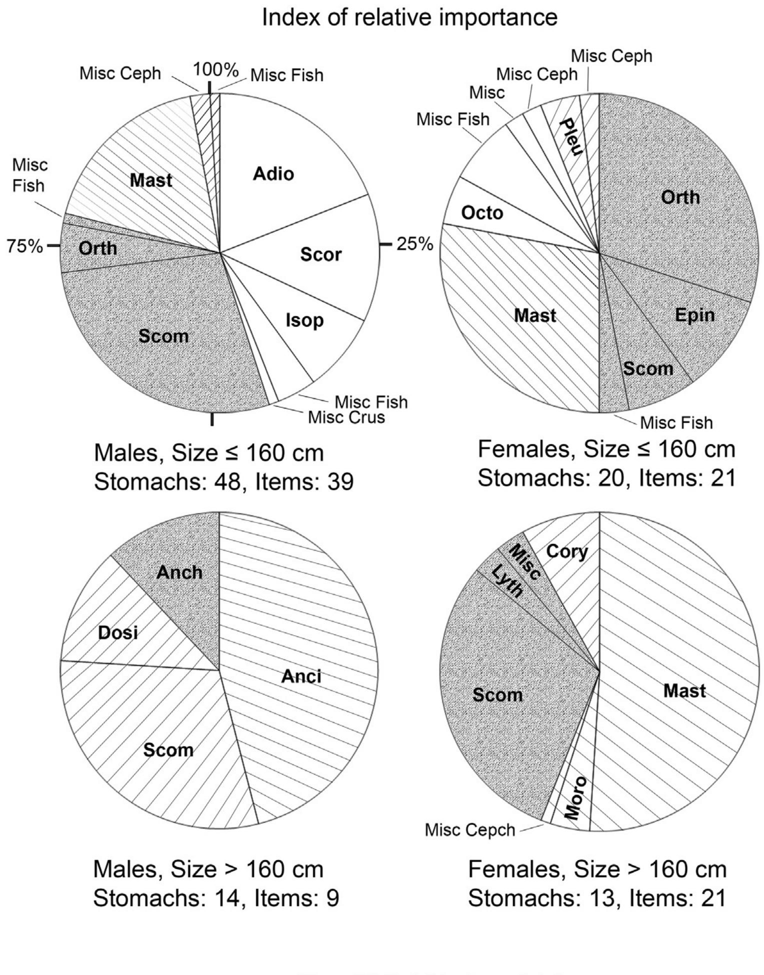

Fig. 4 Relative importance of prey species for male and female Scalloped Hammerhead Sharks < and >160 cm captured by fishermen from May to October 1978–81 from Juncalito (25° 48′N, Il1° 18′W) to San Jose del Cabo (23° 03′ N, 109° 39′ W). Adio = *Adioryx suborbitalis*, Scor = *Scorpaena sonorae*, Isop = Isopoda, Scorn = *Scomber japonicus*, Orth = *Orthopristis inornatus*, Mast = *Mastigoteuthis* sp., Epin = *Epinephalus* sp., Octo = *Octopus* sp., Pleu = *Pleuroncodes planipes*, Anci = *Ancistrocheirus lesueuri*, Scomb = *Scomberomorus sierra*, Dosi = *Dosidicus gigas*, Anch = *Anchoa* sp., Moro = *Moroteuthis robustus*, Lyth = *Lythrulon flaviguttatum*, and Cory = *Coryphaena hippurus*. *Taken from Klimley, A.P. 1987. The determinants of sexual segregation in the scalloped hammerhead, Sphyrna lewini. Environ. Biol. Fishes, 18, 27–40.*

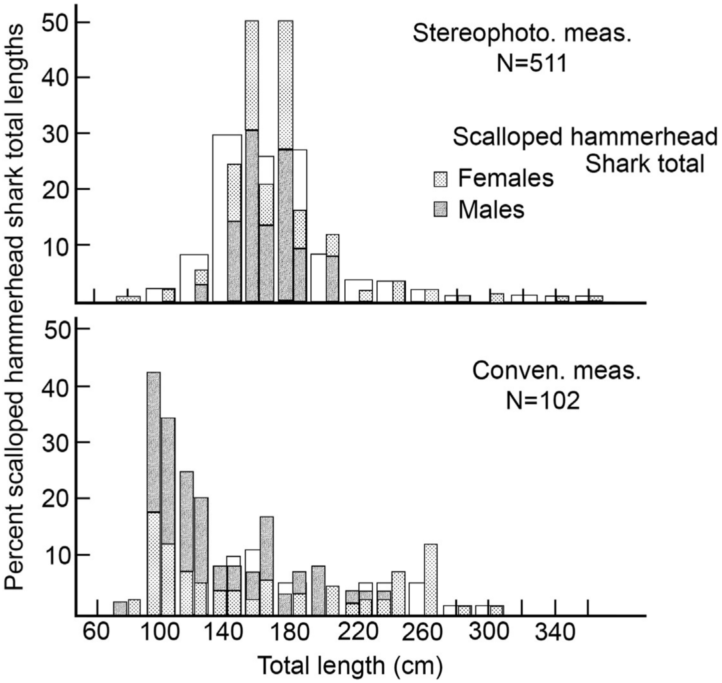

Fig. 5 Percentages of lengths in different classes of Scalloped Hammerhead Sharks either measured by stereocamera in offshore schools (top) or by tape measure (bottom) from catches by fishermen in the Gulf of California. Cross-hatched bars are male, stippled bars female, and clear bars pooled frequencies. *Taken from Klimley, A.P. 1987. The determinants of sexual segregation in the scalloped hammerhead, Sphyrna lewini. Environ. Biol. Fishes, 18, 27–40.*

In the case of the feeding habits of juvenile hammerheads, the isotopic composition of individuals captured in the southeastern GC was similar to that of other predators that consume coastal benthic species (Blanco-Parra et al., 2012), where the main prey species consumed by smaller sharks (<100 cm) are squids. On the other hand, those individuals of >100 cm consumed more fish, which indicated changes in their feeding behaviour, but the lack of differences in the stable isotope of carbon suggests that juvenile populations of *S. lewini* did not differ in foraging habits (Torres-Rojas et al., 2013). Therefore, the presence of *S. lewini* in different ontogenetic stages in the GC is probably due to this shark using benthic coastal areas as feeding grounds.

3.4.5 Pacific Angel Shark (*Squatina californica*)

In the coastal areas of the GC, benthic shark species are common. The Pacific Angel Shark (*Squatina californica*), which is a benthic elasmobranch, is commonly found in soft bottom habitats, including shallow bays and estuaries (Ebert, 2003). In the GC, the Pacific Angel Shark matures at 75.6 cm for males and 77.7 cm for females (Romero-Caicedo et al., 2016). It has a seasonal presence, indicating a migration during the summer associated with reproductive activities (Galvan-Magaña et al., 1989). According to the IRI, the most important prey species of *S. californica* are the jack *Decapterus macrosoma* (47.5%), the daisy midshipman *Porichthys analis* (15.9%), the lizardfish *Synodus evermanni* (8.0%), and the crustacean *Sicyonia penicillata* (8.0%) (Escobar-Sanchez et al., 2006, 2011).

In the coastal areas of the GC small sharks are commonly captured, also called *cazón*, where the presence of the genus *Mustelus* and *Rhizoprionodon longurio* stand out. *Mustelus* comprises about 25 species of small benthic sharks that inhabit tropical and temperate waters on the continental shelves of all oceans. There are two principal species in the GC, *M. californicus* and *M. lunulatus*, which are distributed in temperate-warm and tropical seas. The former is distributed from northern California (US) to the coasts of Colima (Mexico) and the latter from northern California to southern Peru, including the Gulf of California (Compagno, 1984). One of the main differences between these shark species is the size at maturity. Females of *M. californicus* mature between 78 and 80 cm TL and males between 72 and 74 cm. In contrast, females of *M. lunulatus* mature between 94 and 99 cm and males between 89 and 94 cm. In the northern GC the feeding habits of these two species were analysed. The trophic spectrum was represented by 14 prey species for *M. californicus* and 11 prey species for *M. lunulatus*, the most important prey in both shark species was the crustacean *Squilla bigelowi* (Mendez-Loeza, 2004). This crustacean species is from benthic habitats, which distributed throughout the Gulf of California, being abundant in the northern part and, possibly, is the stomatopod species with the highest density of organisms in the area (Hendrickx and Salgado-Barragán, 1991). Ontogenetic differences in feeding behaviour were reported for both *Mustelus* species. According to Ellis et al. (1996), the differences in diet are controlled by factors such as shark size, structure of the mouth and dentition, and shark distribution in relation to its potential prey and other predatory species. Therefore, the dietary differences between shark species are probably associated with physiological differences.

3.4.6 Pacific Sharpnose Shark (Rhizoprionodon longurio)

The Pacific Sharpnose Shark (*Rhizoprionodon longurio*) is a small coastal species that lives over soft muddy and sandy bottoms of the continental shelf of the eastern tropical Pacific. *R. longurio* shows marked seasonal movement patterns in the GC (Marquez-Farias et al., 2004) and the Gulf seems to be an important pupping area (Bizzarro et al., 2000). The feeding habits of *R. longurio* were described by Alatorre-Ramirez et al. (2013) who mentions that this shark species has a high feeding activity overnight on benthic and coastal-pelagic prey species, implying that individuals makes vertical migrations in the water column.

Some studies have been reported that *R. longurio* segregates by sex and size in the GC (Castillo-Geniz, 1990), which could result in different prey being consumed by sharks of different sex and maturity stages. Castillo-Geniz (1990) found the Serranidae fish (*Diplectrum* spp.) and Family Muraenidae as main prey of this shark. This ontogenetic diet variation is associated with prey-predator relationships (Abrams, 2000). Based on the IRI, adult females consumed a higher amount of benthic species, while males consumed a higher amount of epipelagic fish. On the other hand, juvenile male sharks consumed mostly benthic prey, while juvenile females consumed mostly epipelagic prey, which confirms the ontogenetic segregation of this shark species (Alatorre-Ramirez et al., 2013; Castillo-Geniz, 1990; Castillo-Geniz et al., 1996).

3.5 Central Pacific Mexican (CPM)

Despite the richness of shark species in the Central Pacific Mexican (CPM), very limited information about the trophic ecology of sharks, and thus their position within the food web and role in the ecosystem, exists for the region. The only available studies in the CPM are those from Barajas-Calderón (2015, 2018) on the feeding habits and trophic ecology of the Silky Shark, *Carcharhinus falciformis*, from the coasts of the State of Jalisco. Some studies of the food habits of the Scalloped Hammerhead Shark, *Sphyrna lewini*, have also been undertaken in the state of Nayarit and Southern Sinaloa at the entrance of the Gulf of California (Hernández-Corona, 2011; Rentería-Bravo, 2016; Rentería-Bravo et al., 2019), a transitional oceanographic zone between the CPM and the GC (Lavín and Marinone, 2003).

Barajas-Calderón (2015) determined, based on analysis of the contents of 110 stomachs, that the main prey of juvenile *C. falciformis* in the CPM according to the index of relative importance were the cephalopod, *Dosidiscus gigas* (%IRI = 32.1), followed by teleosts (%IRI = 24), the squid, *Ancistrocheirus lesueuri* (%IIR = 15.1) and the swimming crab *Portunus xantussi affinis* (%IRI = 11.3). Some results of this study indicated a sexual segregation of the population in this region, but an overlap in the diet of both sexes at some size intervals contradicted such conclusion. The species was found to tend to be a specialist predator, feeding on the most abundant species in the region, except at the youngest stages (94–121 cm of total length, TL) when it is a generalist.

The analysis of stable isotopes (nitrogen, δ^{15}N and carbon, δ^{13}C) as well as the content of 168 stomachs of *C. falciformis* (60–229 cm of TL) caught by the artisanal fishery during 2012–16 in Jalisco showed no differences in the diet by sex or season of the year (Barajas-Calderón, 2018). A total of 33 prey taxa were identified of which, according to the prey-specific index of relative importance (%PSIRI), the Pacific thread herring, *Opisthonema* spp. (%PSIRI = 13.5%), *Portunus xantusii affinis* (%PSIRI = 12.7%) and *A. lesueurii* (%PSIRI = 8.8%) were the most important prey species in the diet. Stable isotope proportions determined for 63 muscle samples and 17 samples from the most important prey species demonstrated a lack of difference between the isotopic niches of both sexes and among sharks across seasons. However, significant differences were found in both isotopes by maturity stage, indicating different feeding areas and prey of different trophic levels. The δ^{15}N mean value was 16.37, while the mean value for δ^{13}C was 17.05 with the relationship C:N of 3.4. The isotopic mixing model indicated that *A. lesueurii* was the most important prey. The trophic level calculated with both methodologies turned out very similar, 4.4 with the stomach contents and 4.1 with stable isotopes analysis.

Analysis of the stomach contents of 177 *S. lewini* caught from 2007 to 2017 in Nayarit and Southern Sinaloa indicated that the diet of females and males was not significantly different, according to the ANOSIM test ($R = 0.004$, $P = 0.44$). Additionally, regardless of size group (<100 and >100 cm of TL) teleosts were the main prey. However, as in previous studies further north into the GC (Torres-Rojas et al., 2006), it was found that the importance of teleosts decreased with size (%IRI = 93 and 77, respectively). The second most important preys in sharks <100 cm of TL was crustaceans (%IRI = 5) followed by cephalopods (%IRI = 2), whereas in sharks >100 cm of TL cephalopods presented a larger importance (%IRI = 23) and crustaceans were absent in their diet (Rentería-Bravo, 2016; Rentería-Bravo et al., 2019). The change in the diet in relation to shark size has been related to movements towards oceanic areas during the night to feed, returning to the coast during the day (Smale and Cliff, 1998; Torres-Rojas et al., 2006).

The correlation between the stomach contents and the age of sharks from Nayarit and Southern Sinaloa ($n = 177$), estimated directly through the count of growth band counts in their vertebrae, showed that teleosts were the main preys in all age groups (%PSIRI = 62.8, 72 and 68.4 for 0–1, 1–2 and 2–3 years age groups, respectively). Nevertheless, the importance of crustaceans in the diet decreased with age (%PSIRI = 24.8, 15.3 and 4.9), whereas cephalopods increased in importance (%PSIRI = 12.5, 12.7 and 26). The gradual change of preferred prey with age might be related to incursions into oceanic waters. *Sphryna lewini* has been characterized by the traditional model of ontogenetic distribution proposed for sharks, in which juveniles reside in coastal areas from birth until they reach maturity, when they migrate to the adult's feeding grounds, as a strategy to avoid predation and have access to different sources of food (Klimley and Nelson, 1981; Knip et al., 2010). The overall trophic level of juvenile sharks (4.1) indicated that juveniles in this region are a tertiary predator in the ecosystem (Rentería-Bravo, 2016; Rentería-Bravo et al., 2019).

3.6 Gulf of Tehuantepec (GT)

The Gulf of Tehuantepec (GT) is characterized by intense oceanographic physical dynamics (Lavín and Marinone, 2003). Changes in salinity, temperature, and dissolved oxygen fluctuate according to wet and dry seasons, with two subsystems. The Oaxaqueño subsystem, with upwelling periods that lead to low temperatures, low dissolved oxygen, and high nutrient concentration, and the Chiapaneco subsystem, with strong influence of coastal lagoons and river discharges (Tapia-Garcia et al., 2007). The abiotic characteristics of the GT supports complex benthic, benthopelagic, and pelagic food webs, which strongly influence the distributional patterns of many shark species in the region.

The Silky Shark (*Carcharhinus falciformis*) is generally considered a circumtropical oceanic and coastal-pelagic species (Compagno, 1984). In the GT, adult sharks dominate the catches, (Torres-Rojas et al., 2013); however, Ronquillo (1999) mention that silky shark use the coastal waters of south-west Mexico as nursery grounds Thus, this region may serve as an important feeding area for this shark species. The trophic spectrum of *C. falciformis* was composed of two cephalopod species, one crustacean species, and eight fish species. Based on the index of relative importance (%IRI), *Dosidicus gigas* (34.0%), *Diodon hystrix* (21.7%), *Euthynnus lineatus* (17.6%) and *Isopistus remifer* (10.1%) were the most important components in the diet (Flores-Martinez et al., 2016). The prey consumed are mostly epipelagic-oceanic (e.g. *E. lineatus*) and mesopelagic oceanic (e.g. *D. gigas*) but also coastal species (e.g. *D. hystrix*), which indicate that this shark species prefers oceanic habitats where it consumes cephalopods but also migrates to the coastal zone where it consumes nearshore prey. Also Cabrera Chavez-Costa (2000) found that the crab *Portunus xanthusii affinis*, and the cephalopod *Gonatus* spp. were the most important prey for *C. falciformis*. Barranco (2008), on the other hand, found that the main prey of this shark were *Portunus xantusii*, cephalopods *Argonauta* spp., and the Black Skipjack *Euthynnus lineatus*. Using stable isotopes, Barranco (2008) found that silky shark fed on prey from oceanic waters ($\delta^{13}C$ −16.70 to −14.55‰). The trophic level of the silky shark was 4.34, which designates this species as a tertiary consumer.

The ontogenetic feeding behaviour of *C. falciformis* indicates differences in diet composition, suggesting trophic segregation. Cabrera Chavez-Costa et al. (2010) found differences in the main prey preferred by juveniles vs. adults, where juveniles fed on *D. gigas* and larger specimens consumed more *Scomber japonicus*. Segregation by gender and maturity stage is common in other Carcharhinids (Lowe et al., 1996; Torres-Rojas et al., 2013), and is probably associated with reducing food competition. The niche variation hypothesis (Giller, 1984) states that niche width tends to increase with intraspecific competition, either through an increase in the within-phenotype component of the niche (behavioural flexibility) or an increase in the between-phenotype component (differences among individuals). Flores-Martinez et al. (2016) report high niche width and low trophic overlap values observed for *C. falciformis*, which may reflect intraspecific competition where adult and juvenile males are found offshore but consume different main prey species (*Euthynus lineatus* for adult males, *D. gigas* for juvenile males) and juvenile females are found inshore where they feed on *Diodon hystrix*.

In contrast to *C. falciformis*, *S. lewini* is a coastal and semi-oceanic hammerhead shark (Torres-Rojas et al., 2013). The prey consumed by *S. lewini* (16 species) in the GT are both epipelagic (e.g. *C. orqueta*) and demersal (e.g. *Pomadasys panamensis*) (Flores-Martinez et al., 2016), which are characterized by being distributed in waters <100 m deep (coastal habits). The latter provides further evidence that *S. lewini* undertakes vertical migrations in the water column as reported in the GC (Klimley, 1987). The lack of differences in diet of juvenile *S. lewini* in the GT, suggests that males and females of the same size feed on similar prey species in the same area (Flores-Martinez et al., 2016). This pattern has been reported for the GC (Torres-Rojas et al., 2006, 2009, 2013), that is, juveniles feeding on small fish and crustaceans in benthic areas (Klimley, 1987) probably related with segregation by size to avoid cannibalism (Bush, 2003; Lowe et al., 1996). Cabrera Chavez-Costa (2000) found that *S. lewini* feeds on various crustaceans, the squid *Ancistrocheirus* spp., and on fishes of the families Carangidae, Cynoglossidae, Mullidae, Ophichtydae, Ophididae, and Serranidae. Whereas Aguilar-Castro (2010) found that the shrimp *Litopenaeus vannamei*, the squid *Mastigoteuthis dentata* and the fishes *Auxis* spp. and *Euthynnus lineatus* were the most important prey in the diet of *S. lewini*.

Using stable isotopes, García (2018) found that the highest $\delta^{15}N$ values in both sexes of *S. lewini* were present in the neonate stage (14.1‰ females and 13.8‰ males) and the lowest values in adults (12.9‰ females and 12.7‰ males), which indicates feeding segregation by size. The average values of $\delta^{13}C$ changed little between stages in both sexes. This value was higher in females (−14.8 to −11.97‰) than males (−14.0 to −12.2‰), in both stages they feed in coastal areas. The decreasing trends of $\delta^{15}N$ and $\delta^{13}C$ suggest progressive changes in the diet as ontogenetic development progresses, rather than a sudden change in diet at a given size.

A diet comparison between *S. lewini* and *C. falciformis* in the GT reflects low trophic overlap, likely as a result of spatial segregation (Flores-Martinez et al., 2016). Potier et al. (2007) found that the presence of epipelagic and mesopelagic prey species can be used to categorize predators as primarily shallow or deep feeders, respectively. Flores-Martinez et al. (2016) found that *C. falciformis* were predominantly epipelagic feeders preying on scombrid fishes (*E. lineatus*). Demersal prey, such as *P. panamensis* and *C. orqueta*, were more abundant in the *S. lewini* diet. Alejo-Plata et al. (2007) report high catch rates of *C. falciformis* with pelagic fishing gear, while *S. lewini* are more commonly caught with demersal fishing gears. Thus, although both shark species were captured in the GT, it is well known that *C. falciformis* benefit more from the pelagic food chain than *S. lewini* (Torres-Rojas et al., 2015).

Another coastal shark present in the GT is the Pacific Sharpnose Shark (*Rhizoprionodon longurio*), which is a common coastal species of the eastern tropical Pacific and is important in the artisanal fisheries in Mexico. Feeding studies on this species in Mexico have shown differences in some aspects of its food habits. For the GT, 37 prey species were identified. The IRI showed that the main prey of *R. longurio* in this area were benthic fish (e.g. congrid *Rynchoconger nitens* 59%) (Alderete, 2007). This was in contrast to the GC, where the prey species are both pelagic and benthic fishes (*Opisthopterus dovii*, 24%, family Ophichthidae, 18%, Bothidae, 17%) and cephalopods

(*Argonauta* spp., 15%, and *Loliolopsis diomedeae*, 12.3%). Based on isotopic composition the juveniles and adults feeding behaviours are similar, which means that all Sharpnose Sharks feed in the same areas (Conde, 2009). On the other hand, the same author found significant differences between the diets of juvenile males and adults in the GC, which coincides with other studies in the region (Alatorre-Ramirez et al., 2013). These differences might be because *R. longurio* of the two areas (GT and GC) do not migrate between them, which mean that they are separate populations or stocks. Another shark species occurring in the GT is *Nasolamia velox*, which feeds mainly on *Portunus xanthusiii affinis*, *Squilla biformis* and fishes of the family Ophichthydae (Cabrera Chavez-Costa, 2000).

4. Conservation status

Shark conservation and management proposals have been strengthened during the past decades as progress has been made on the huge task of assessing the conservation status of all sharks (around 524 species in total). This work has been undertaken by the International Union for the Conservation of Nature (IUCN) Species Survival Commission's Shark Specialist Group volunteer network, following the IUCN Red List Categories and Criteria (https://www.iucnredlist.org). The IUCN Red List of Threatened Species is widely recognized as the most comprehensive, scientifically based source of information on the global status of plant and animal species. Threatened species are listed as Critically Endangered (CR), Endangered (EN) or Vulnerable (VU). Species that are close to meeting the threatened thresholds are classified as Near Threatened (NT); while those evaluated as having a low risk of extinction are classified as Least Concern (LC). Finally, species that cannot be evaluated due to insufficient knowledge are classified as Data Deficient (DD). In this chapter, those new species (e.g. newly described species, new records) are listed as Not Evaluated (NE). Periodic species-specific evaluations mean that IUCN Red List assessments can be used as a tool for measuring and monitoring changes in the status of shark abundance and diversity over time (Cavanagh and Gibson, 2007).

A summary of the IUCN Red List category assigned to all shark species (60 species) from the Mexican Pacific is presented in Table 2. Thirty-one percent (18 species) of Mexican Pacific sharks are considered threatened (Critically Endangered, Endangered or Vulnerable). Of these, 5% (3 species) are Endangered and 25% (15 species) are Vulnerable (Fig. 6). The families with all species threatened are Alopiidae, Odontaspididae, and Rhincodontidae; while

Table 2 Summary information on the IUCN Red List categories for all shark species recorded from the Pacific Coast of Mexico.

SPECIES	Common name	Category	Source
Alopias pelagicus	Pelagic Thresher	VU	Reardon et al. (2009)
Alopias superciliosus	Bigeye Thresher	VU	Amorim et al. (2009)
Alopias vulpinus	Common Tresher Shark	VU	Goldman et al. (2009a)
Apristurus brunneus	Brown Catshark	DD	Huveneers et al. (2015a)
Apristurus kampae	Longnose Catshark	DD	Huveneers et al. (2015b)
Apristurus nasutus	Largenose Catshark	DD	Huveneers et al. (2004)
Carcharhinus albimarginatus	Silvertip Shark	VU	Espinoza et al. (2016)
Carcharhinus altimus	Bignose Shark	DD	Pillans et al. (2009)
Carcharhinus brachyurus	Copper Shark	NT	Duffy and Gordon (2003)
Carcharhinus cerdale	Pacific Smalltail Shark	NE	
Carcharhinus falciformis	Silky Shark	VU	Rigby et al. (2017)
Carcharhinus galapagensis	Galapagos Shark	NT	Bennett et al. (2003)
Carcharhinus leucas	Bull Shark	NT	Simpfendorfer and Burgess (2009)
Carcharhinus limbatus	Blacktip Shark	NT	Burgess and Branstetter (2009)
Carcharhinus longimanus	Oceanic Whitetip Shark	VU	Baum et al. (2015)
Carcharhinus obscurus	Dusky Shark	VU	Musick et al. (2009a)
Carcharhinus porosus	Smalltail Shark	DD	Lessa et al. (2006)
Carcharhinus plumbeus	Sandbar Shark	VU	Musick et al. (2009b)
Carcharodon carcharias	White Shark	VU	Fergusson et al. (2009)
Cephaloscyllium ventriosum	Swellshark	LC	Villavicencio-Garayzar et al. (2015)

Continued

Table 2 Summary information on the IUCN Red List categories for all shark species recorded from the Pacific Coast of Mexico.—cont'd

SPECIES	**Common name**	**Category**	**Source**
Cephalurus cephalus	Lollipop Catshark	DD	Valenti (2009)
Cetorhinus maximus	Basking Shark	VU	Fowler (2009)
Chlamydoselachus anguineus	Lizard Shark	LC	Smart et al. (2016)
Echinorhinus cookei	Prickly Shark	DD	Finucci (2018)
Galeocerdo cuvier	Tiger Shark	NT	Simpfendorfer (2009)
Galeorhinus galeus	School Shark	VU	Walker et al. (2006)
Galeus piperatus	Peppered Catshark	LC	Heupel (2006)
Ginglymostoma cirratum	Nurse Shark	DD	Rosa et al. (2006)
Ginglymostoma unami	Pacific Nurse Shark	NE	
Heterodontus francisci	Horn Shark	DD	Carlisle (2015)
Heterodontus mexicanus	Mexican Hornshark	DD	Garayzar (2006)
Hexanchus griseus	Bluntnose Sixgill Shark	NT	Cook and Compagno (2005)
Isistius brasiliensis	Cookiecutter Shark	LC	Kyne (2018)
Isurus oxyrinchus	Shortfin Mako Shark	VU	Cailliet et al. (2009)
Isurus paucus	Longfin Mako	VU	Reardon et al. (2006)
Lamna ditropis	Salmon Shark	LC	Goldman et al. (2009b)
Megachasma pelagios	Megamouth Shark	LC	Simpfendorfer and Compagno (2015)
Mustelus albipinnis	White-Margin Fin Houndshark	DD	Cronin (2009)
Mustelus californicus	Gray Smooth-Hound	LC	Perez-Jimenez et al. (2015)
Mustelus dorsalis	Sharptooth Smooth-Hound	DD	Leandro (2004)

Table 2 Summary information on the IUCN Red List categories for all shark species recorded from the Pacific Coast of Mexico.—cont'd

SPECIES	Common name	Category	Source
Mustelus henlei	Brown Smooth-Hound	LC	Perez-Jimenez et al. (2016a)
Mustelus lunulatus	Sicklefin Smooth-Hound	LC	Perez-Jimenez et al. (2016b)
Nasolamia velox	Whitenose Shark	DD	Ruiz et al. (2009)
Negaprion brevirostris	Lemon Shark	NT	Sundström (2015)
Notorynchus cepedianus	Broadnose Sevengill Shark	DD	Compagno (2009)
Odontaspis ferox	Smalltooth Sandtiger	VU	Graham et al. (2016)
Parmaturus xaniurus	Filetail Catshark	LC	Flammang et al. (2015)
Prionace glauca	Blue Shark	NT	Stevens (2009)
Pseudocarcharias kamoharai	Crocodile Shark	NT	Compagno and Musick (2009)
Rhincodon typus	Whale Shark	EN	Pierce and Norman (2016)
Rhizoprionodon longurio	Pacific Sharpnose Shark	DD	Smith et al. (2009b)
Somniosus pacificus	Pacific Sleeper Shark	DD	Ebert et al. (2009)
Sphyrna corona	Scalloped Bonnethead	NT	Mycock (2004)
Sphyrna lewini	Scalloped Hammerhead	EN	Baum et al. (2007)
Sphyrna media	Scoophead Shark	DD	Casper and Burgess (2006)
Sphyrna mokarran	Great Hammerhead	EN	Denham et al. (2007)
Sphyrna tiburo	Bonnethead Shark	LC	Cortés et al. (2016)
Sphyrna zygaena	Smooth Hammerhead	VU	Casper et al. (2005)
Squalus suckleyi	Spotted Spiny Dogfish	LC	Bigman et al. (2016)
Squatina californica	Pacific Angel shark	NT	Cailliet et al. (2016)
Triaenodon obesus	Whitetip Reef Shark	NT	Smale (2009)
Triakis semifasciata	Leopard Shark	LC	Carlisle et al. (2015)

EN, endangered; VU, vulnerable; NT, near threatened; LC, least concern; DD, data deficient; NE, not evaluated.

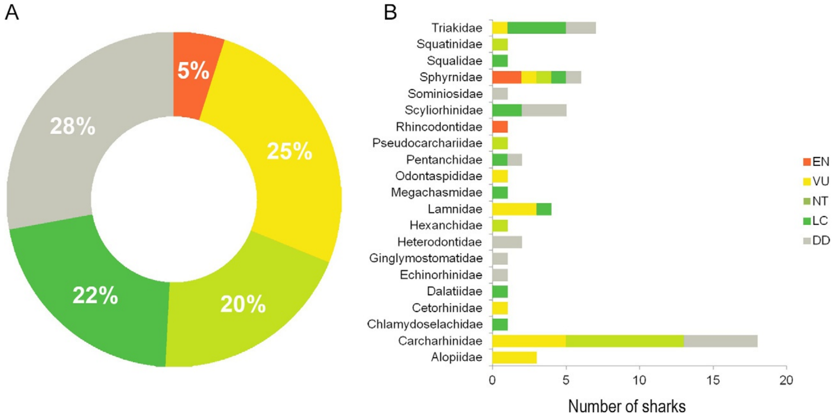

Fig. 6 Percentage of shark species ($n = 61$) from the Pacific Coast of Mexico within each IUCN Red List Category (A), and number of sharks evaluated by families (B). IUCN Categories: EN, Endangered; VU, Vulnerable; NT, Near Threatened; LC, Least Concern; DD, Data Deficient. The species Not Evaluated are not included.

the families with the highest number of species threatened are Lamnidae (75%), Sphyrnidae (50%), and Squalidae (50%) (Fig. 6). These threatened species must be monitored particularly closely and appropriate management and recovery plans for their populations should be implemented. Additionally, more scientific research should be conducted to better understand these species' biology, ecology, threats, and conservation needs.

A further 20% (12 species) of all Mexican Pacific sharks are Near Threatened, which means that they are close to qualifying for the threatened category in the foreseeable future, and about 22% (13 species) are catalogued as Least Concern. The remaining sharks 17 (28%) are Data Deficient, meaning that there is not enough information to assess their status reliably. Additionally, two species of sharks, the Pacific Nurse Shark *Ginglymostoma unami* and the Pacific Smalltail Shark *Carcharhinus cerdale*, have not yet been assessed.

The proportion of shark species in each of the IUCN Red List categories varies along the Pacific Coast of Mexico (Fig. 7). The highest percentage of threatened species (43%) is observed in the Mexican Pacific Central, followed by Gulf of Tehuantepec (38%), while lower percentages are in the West coast of Baja California (32%) and the Gulf of California (30%).

The principal driver of Mexican Pacific sharks decline is overfishing and habitat degradation as has been observed in other areas (e.g. Dulvy et al., 2016). Sharks have historically been an important food resource in Mexico (Applegate et al., 1993). The first record of shark catches in Mexico goes

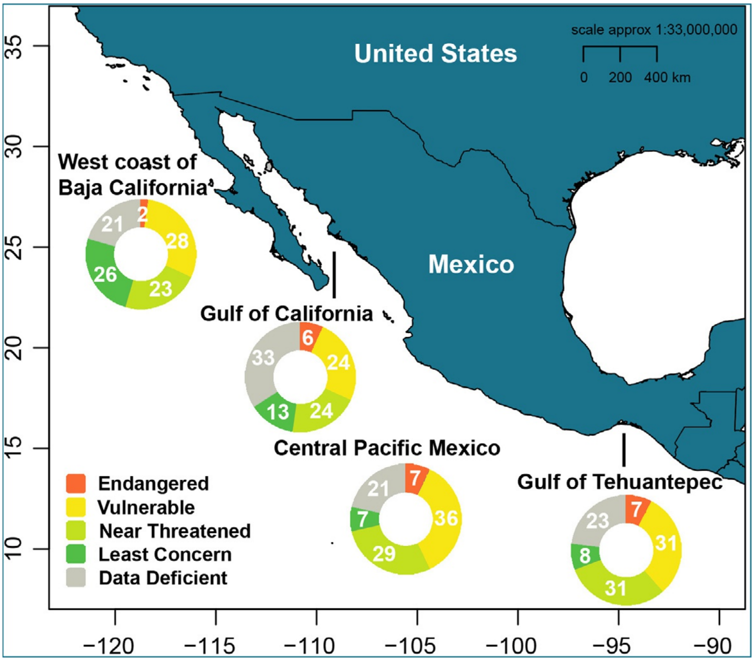

Fig. 7 Percentage of shark species in each IUCN status category for four marine areas along the Pacific Coast of Mexico: Western coast of Baja California (*n* = 44), Gulf of California (*n* = 44), Central Pacific Mexico (*n* = 28), and Gulf of Tehuantepec (*n* = 26). The species Not Evaluated are not included.

backs to 1890, when shark fins were first exported to Asia from the Baja California Peninsula. Since that time shark fisheries have increased dramatically in their size and geographical extent. Additionally, sharks are an important constituent of the Mexican diet and up to 90% of the Mexican harvest is consumed domestically (Bonfil, 1997).

Although in Mexico there are few industrial fisheries for sharks, an important proportion of the landings are actually produced by artisanal fisheries like in other parts of the world, especially in developing countries (Bonfil, 2002; Humber et al., 2017; Ramírez-Amaro and Galván-Magaña, 2019).

The rapid expansion of shark artisanal fishery over the past two decades has greatly increased fishing pressure on shark populations, which constitute a high percentage of the total world catch (Selgrath et al., 2018). In addition, sharks caught as bycatch represent approximately half of the reported shark landings according to worldwide official statistics, which makes it difficult to accurately assess the impact of fishing on elasmobranch populations (Bonfil, 2002).

Management of a sustainable shark fishery in Mexico has been complicated by the lack of reliable fisheries data. For example, historical shark landings data are grouped into five broad categories: tiburón (sharks >1.5 m in length), cazón (sharks <1.5 m), angelito (angel sharks), manta (batoids), and guitarra (guitarfishes) (SAGARPA, 2009). This reporting scheme gives little information about species composition and ignores the distinction between adults of small shark species and juveniles of large sharks (Ramírez-Amaro and Galván-Magaña, 2019). Moreover, historical landings probably greatly underestimate the actual take due to a lack of adequate record keeping (Castillo-Geniz et al., 1998).

Various management measures have been implemented for Mexico's shark fisheries. The first step for management was taken by the Mexican National Fisheries and Aquaculture Institute (INAPESCA), which recommended a moratorium on issuing new shark-fishing permits beginning in 1993 (Castillo-Geniz et al., 1998), which was carried out in 1998 (Sosa-Nishizaki et al., 2008). This was followed by the development of a National Action Plan for the Conservation and Management of sharks, rays, and related species in Mexico in 2004 by the Comision Nacional de Agricultura y Pesca and INAPESCA (CONAPESCA-INP, 2004).

In 2007, a major piece of legislation was adopted called 'Responsible Fishery Sharks and Rays; Specification for Use'. It includes regulations that are specific to artisanal fisheries (NOM-059-ECOL-2001; NOM-029-PESC-2006; DOF, Diario Oficial de la Federacion, 2007). This law prohibits the capture of three sharks: the Whale Shark *Rhincodon typus*, White Shark *Carcharodon carcharias*, and Basking Shark *Cetorhinus maximus*, as well as specifies fishing zones and seasons, authorizes gears, and requires permit holders to report data (DOF, Diario Oficial de la Federacion, 2007). In addition, since 2012 the fishing of shark and rays has been closed annually between 1 May and 31 July (DOF, Diario Oficial de la Federacion, 2012), mainly to protect pregnant females of several elasmobranch species during their reproductive season, particularly those that approach to the coast like *S. lewini* making them highly susceptible to be caught.

In 2015, the governments of Canada, the United States, and Mexico initiated a collaborative project through the Commission for Environmental Cooperation (CEC) to strengthen the conservation and sustainable trade of 56 North America taxa that are included in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The project aims to provide guidance in the form of five action plans for reducing illegal and/or unsustainable harvest and trade; improving biological knowledge to allow science-based management decisions; and promoting traceability, species conservation, and livelihoods of stakeholders, throughout trade (CEC, 2017). Eight priority shark taxa were selected: *Carcharhinus longimanus*, *Carcharodon carcharias*, *Cetorhinus maximus*, *Lamna nasus*, *Rhincodon typus*, *Sphyrna lewini*, *Sphyrna mokarran*, and *Sphyrna zygaena*. All of these species are currently listed in Appendix II of CITES (CITES, 2016). Note that all these species, with an exception of *Lamna nasus*, are distributed along the Pacific coast of Mexico.

Feeding studies, since traditional stomach content analysis to stable isotopes analyses has provides insights into the trophic relationship among sharks and the ecosystems they inhabit (Cortés, 1999; Dicken et al., 2017). Knowledge of the diet and trophic ecology of sharks improve our understanding of the ecological consequences of predator or mesopredator. Therefore, these studies provided wealth information on the status of the ecosystems within different geographic regions. In this sense, more feeding studies are necessary for the implementation of effective management initiatives in Mexico. All these management measures will initiate the recovery of sharks, whose populations play an important role in marine ecosystems, in the Pacific coast of Mexico. These management measures will also help to develop true adaptive management in the area, making the fisheries compatible with the conservation of marine ecosystems.

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