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ARTICLE

Seasonal Abundance and Size Structure of Sharks Taken in the Pelagic Longline Fishery off Northwestern Cuba

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Abstract
The Straits of Florida comprise an important migratory route for apex predators moving among the Gulf of Mexico, Atlantic Ocean, and Caribbean Sea. Off Cuba's northwestern coast, various gear types are used by Cuban fishers, including small-scale pelagic longlines. We report here the results of a 2011–2019 monitoring program for the longline fleet based in Cojímar, Cuba. This fleet comprises 134 small vessels targeting mostly swordfish (family Xiphiidae), billfishes (family Istiophoridae), tunas (family Scombridae), and sharks (class Chondrichthyes) within 20 km of Cuba's coast. Most operations are nocturnal with 11–12-h sets comprising an average of 56 hooks on 6,643 m of mainline. Five orders, eight families, and 18 species of sharks were documented in this fishery. Two carcharhinids (Silky Shark *Carcharhinus falciformis* and Oceanic Whitetip Shark *C. longimanus*) and two lamnids (Longfin Mako *Isurus paucus* and Shortfin Mako *I. oxyrinchus*) were the most abundant shark species caught, with shark CPUE averaging 1.98 sharks/trip (SD = 0.938). Catch abundance showed seasonal differences, with Silky Sharks and Longfin Makos more common in winter and Oceanic Whitetip Sharks more common in summer and autumn. Bimodal size structure in some species suggests multiple life stages utilizing the area, while the predominance of young sharks in species including the Oceanic Whitetip Shark suggests the importance of the area as juvenile habitat, possibly as a

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pupping and/or nursery ground. This characterization of the Cuban longline fishery is an important step forward for Cuba's National Plan of Action for Sharks and demonstrates the potential impacts that small-scale fisheries can have on vulnerable sharks.

Sharks (class Chondrichthyes) comprise a widespread group of large marine fishes with important evolutionary, ecological, and economic roles (Musick et al. 2000). Because of their generally slow growth rate, slow rate of reproduction, and late sexual maturity, sharks are highly vulnerable to overfishing (Cortés 2000). Some shark populations declined considerably over the past five decades (Baum et al. 2005; Baum and Blanchard 2010), including populations in the northwestern Atlantic Ocean (Baum et al. 2003; Howey-Jordan et al. 2013) and the Gulf of Mexico (Baum and Myers 2004; Shepherd and Myers 2005). Although the specific magnitude of these declines has been debated (Burgess et al. 2005), there is little doubt that many shark species are at risk of extinction globally (Dulvy et al. 2014).

Large-scale, industrialized fisheries interacting with sharks may be relatively well studied, but small-scale, artisanal fisheries represent a considerable portion of global shark landings (Bonfil 1994; Smith et al. 2009) and can have a significant impact on the abundance and size composition of shark species (Pinnegar and Engelhard 2008). Information on the scale of artisanal fisheries and their effects on coastal and pelagic marine ecosystems is largely lacking (Dulvy et al. 2014).

In Cuba, sharks have long been an important fisheries resource. Cuban literature of the 1920s described the capture and sale of sharks by U.S. companies (Martínez 1947); however, official record keeping was not initiated in Cuba until 1959 (Baisre 2018). As in other Latin American countries such as Mexico (Castillo-Geniz et al. 1998), sharks in Cuba have historically represented a source of employment and food supply for fishing communities. The Cuban shark fishery has two components, an artisanal fleet of small, private boats based at so-called "sport" fishing ports (under Cuba Fisheries Law 129/2019, this activity is classified as non-state commercial fishing and is not equivalent to recreational fisheries or fishing for sport per se) and the state fishery (fishing cooperatives) of small to midsized boats responsible for the official production of shark landings (Claro and Robertson 2010; PAN-Tiburones 2015). Between 1959 and 2015, annual shark production by the Cuban state fishery started with modest growth and peaked at 2,644 metric tons dressed weight in 1981, then declined and in recent years and has stayed around 500 metric tons dressed weight (Figure 1; PAN-Tiburones 2015).

Despite the historical socioeconomic importance of sharks in Cuba, long-term fishing data and species biological information are lacking. Unfortunately, no official records of shark production by the "sport" artisanal fishery exist. The limited information on the state fishery dates back to the 1960s, documenting only species composition and seasonal variation of landings (Baisre 2005; PAN-Tiburones 2015). National fisheries statistics have traditionally reported sharks in a single category, with only the Nurse Shark *Ginglymostoma cirratum* reported separately. More recently, Cuba developed a National Plan of Action for the Conservation and Management of Chondrichthyes (NPOA-Sharks; PAN-Tiburones 2015), facilitated by the Food and Agriculture Organization of the United Nations and with assistance from the international scientific community. The NPOA-Sharks outlined, for the first time, actions and tasks to identify research needs and regulatory requirements for shark fisheries management and conservation in Cuba. As a result of Cuba's interest in generating information on sharks and its fisheries, progress has been made in understanding shark species diversity (Aguilar et al. 2014) and connectivity and migratory patterns for some pelagic species, including those of conservation concern (Hueter et al. 2017, 2018). Productivity–susceptibility analyses also have been conducted to identify the vulnerability of various species to fishing pressure in Cuba (Puga et al. 2018).

The Straits of Florida are an important migratory pathway for shark apex predators moving into and out of the

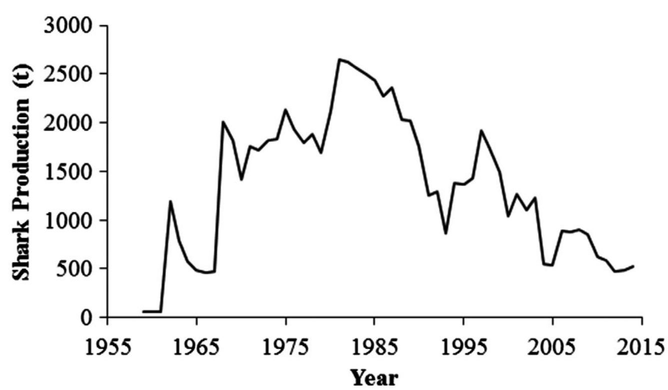

FIGURE 1. Historical shark production (metric tons dressed weight) reported for the state fishery in Cuba for the period from 1959 (when record keeping was begun) to 2015. These landings do not include production by the artisanal "sport" fishery, which was not monitored during this period. Modified from PAN-Tiburones 2015.

Gulf of Mexico (Kohler et al. 1998). Many of these shark species are the basis of important fisheries in Mexico and the USA, 2 of the top 10 shark-fishing countries in the world (Musick et al. 2000; FAO 2018; Okes and Sant 2019). Deep, oceanic environments are found close to the northern coast of Cuba, bringing pelagic sharks within range for the Cuban artisanal fishing fleet. Forty-five years ago, Guitart (1975) documented Silky Sharks *Carcharhinus falciformis*, Shortfin Makos *Isurus oxyrinchus*, Night Sharks *C. signatus*, Bigeye Threshers *Alopias superciliosus*, and Oceanic Whitetip Sharks *C. longimanus* as frequently caught by this fleet on pelagic longlines off northern Cuba. Later, Baisre (2005) documented Longfin Makos *I. paucus*, hammerheads *Sphyrna* spp., Tiger Sharks *Galeocerdo cuvier*, Blue Sharks *Prionace glauca*, and Bignose Sharks *C. altimus* as species also caught in this fishery, albeit with lower frequency. This artisanal longline fishery continues to this day in Cuba's northwestern territorial waters, primarily targeting swordfish (family Xiphiidae), billfishes (family Istiophoridae), tunas (family Scombridae), and sharks.

The goal of this study was to document the characteristics of this longline fleet presently based on the northwestern coast of Cuba and describe the seasonal variation in shark catches and length structure in this fishery. Results of this study are expected to help identify measures needed to manage pelagic shark fisheries for sustainability in Cuba.

METHODS

Fishery surveys.— Surveys were conducted at the port of Ernest Hemingway, a private "sport" fishing port located in Cojímar, northwestern Cuba, near the entrance to the Cojímar River east of Havana Harbor (Figure 2). Depending on weather conditions, boat activities, and other logistical factors, biological researchers from the University of Havana's Center for Marine Research visited the port an average of three times per week from November 2011 to March 2019. Information on fishing operations was collected by interviewing fishers and fishing port managers. Data collection from intercepted boats upon their return to port included catch composition, fishing gear, fishing times and areas, bait type, targeted species, and bycatch. Morphometric data from landed specimens were collected when possible; specimens did not always arrive at port in whole condition. Port managers assisted with other information, such as boat numbers and sizes, gear types, and seasons and areas fished by the overall fleet at Cojímar.

Catch per unit effort and relative abundance.— Catch per unit effort (CPUE) was calculated as the number of sharks caught per trip. The CPUE was analyzed by year and month to discern possible patterns. For seasonal trends, we defined winter as January–March, spring as April–June, summer as July–September, and autumn as October–December. To understand the representation of the primary shark species in the catch, two indices of relative abundance were calculated and were compared for annual and monthly shark catches: nominal CPUE (total number of sharks/number of trips) and average CPUE (mean number of sharks/number of trips) with respective 25th and 75th quartiles. Normality of CPUE–years and CPUE–months was tested using the Kolmogorov–Smirnov test. If normality of the data was rejected, the nonparametric Kruskal–Wallis test was used to compare CPUE for years and months. In addition, to understand species composition over time, the proportion of a given species in the total number of sharks caught (PTS) was calculated for the primary species.

Biological sampling.— Individuals were identified to the lowest possible taxon using identification keys (Guitart 1979; Sander 2010). Lengths were measured as shark total length, precaudal length (PCL), and fork length. Additionally, we recorded the distance from the first dorsal fin to the second dorsal fin (DD) in incomplete specimens (carcasses). Logistic constraints during landing made specimen weight determination impossible. Specimens were sexed and dissected to analyze for reproductive condition. Maturity for males was judged observing clasper condition (calcification and rotation); clasper length (internal and external) was recorded to correlate with shark length and complement the maturity assignment. Maturity for females was judged by observing ripe oocytes, uterine capsules, or evidence of pregnancy. Sex ratio of the main species was analyzed by 2-month periods to avoid missing values. We constructed histograms by maturity stage and box plots for the main species to analyze data behavior and to identify outliers.

RESULTS

Fishing Operations

Consistent with the findings of Aguilar et al. (2014), our surveys found the artisanal, pelagic longline fishery in Cojímar operates primarily within 20 km from shore and targets large species, including Swordfish *Xiphias gladius*, Sailfish *Istiophorus platypterus*, White Marlin *Kajikia albida*, Blue Marlin *Makaira nigricans*, and Dolphinfish (also known as mahi-mahi) *Coryphaena hippurus*. Sharks and scombrids are opportunistically caught and retained. Fishing gear to catch these species varies according to seasonal availability, with the primary fishing seasons being October–March for Swordfish and April–September for Sailfish and marlins. In Cojímar, 90% of the fishing trips are nocturnal targeting Swordfish, whereas diurnal longline sets are used to target billfishes. Fishing vessels are

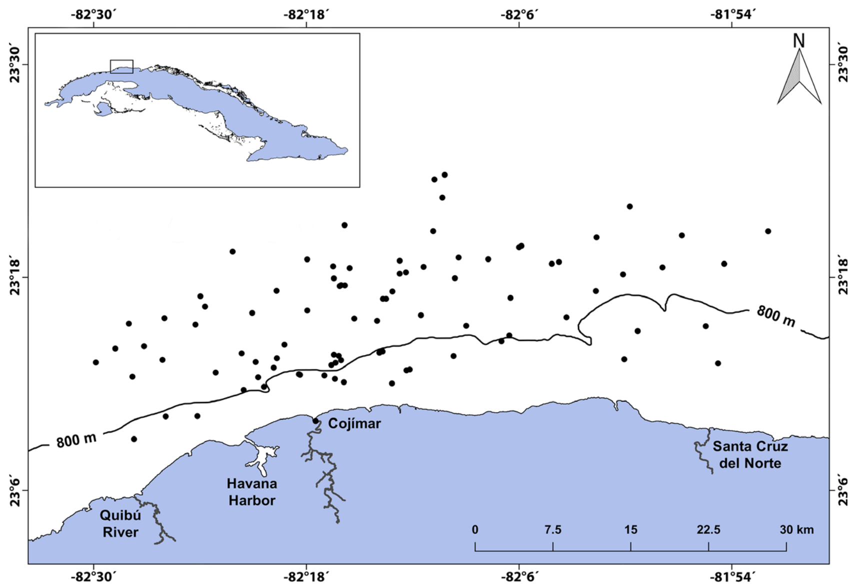

FIGURE 2. Fishing grounds for the Cojímar longline fleet off the northwestern coast of Cuba. The small rectangle in the inset indicates the area where fishing occurs. Dots are start and end points of pelagic longline sets to show the fishing area.

constructed of wood or fiberglass and range from 12 to 30 ft in length (3.7 to 9.1 m), with most being either 15–19 ft (4.6–5.8 m; 34%) or 20–24 ft (6.1–7.3 m; 47%). Vessel crews typically comprise 2–3 persons, with larger vessels operated by more crew. Radios or GPS units are not used on the boats, and landmarks are used for orientation to navigate and set gear.

Fishing trip duration ranged from 17 to 24 h. Only one set is deployed per trip. Most soak times of nocturnal sets range from 7 to 8 h (12.9%), 9 to 10 h (23.35%), or 11 to 12 h (47.1%). Most soak times of diurnal sets range from 3 to 4 h (45.3%) or from 5 to 6 h (34.5%). The primary fishing gear used is size 2-16 J-hooks; circle hooks are rarely used. Gangions are made with wire and nylon. The mean number of hooks in nocturnal sets is 57 (range = 10–120, SD = 15; $n = 2{,}016$), with a mean mainline length of 6,660 m (range = 1,200–13,000, SD = 2,257; $n = 2{,}091$). Mean number of hooks in diurnal sets is 82 (range = 25–151, SD = 31; $n = 227$), with a mean mainline length of 4,019 m (range = 1,000–11,000, SD = 1,795; $n = 233$). Mainlines and gangions are deployed and retrieved by hand. In addition to pelagic longlines, the Cojímar fleet occasionally uses other gear types, including vertical lines and hand lines. A variety of species are used for bait, predominantly salted clupeids, cyprinids (e.g., Silver Carp *Hypophthalmichthys molitrix*) or other species, including needlefish (e.g., Flat Needlefish *Ablennes hians* and Keeltail Needlefish *Platybelone argalus*), halfbeaks (e.g., Balao *Hemiramphus balao* and Ballyhoo *Hemiramphus brasiliensis*), or mackerels (e.g., Atlantic Mackerel *Scomber scombrus*), and small sharks, including young Oceanic Whitetip Sharks caught in the area.

Catch Composition

Longline shark catches of the Cojímar fleet comprise primarily pelagic and large coastal species. We recorded a total of 826 individuals in our 2011–2019 surveys. Overall elasmobranch catch composition of the fleet, combining all types of gears, comprised 18 species belonging to five orders and eight families (Table 1). Species such as the Smooth Dogfish *Mustelus canis*, Cuban Dogfish *Squalus cubensis*, and Bigeye Sixgill Shark *Hexanchus nakamurai* are caught on vertical line and hand line gears set in deep water. Excluding vertical line and hand line catches, the top six species of sharks dominating the catches by number were as follows: Silky Sharks (22%), Longfin Makos (20%), Oceanic Whitetip Sharks (15%), Shortfin Makos (12%), Tiger Sharks (11%), and Bigeye Threshers (6%) (Table 2). Table 3 summarizes the species composition of the catch tabulated by month of the year during our 2011–2019 surveys. It is noteworthy that two Giant Mantas *Mobula birostris* were recorded in the bycatch (Tables 2, 3), especially since this elasmobranch is now classified as Endangered on the International Union for Conservation of Nature Red List of Threatened Species (IUCN Red List) (Marshall et al. 2020). These two mantas were entangled with a gangion or hooked in a pectoral fin (wing).

Catch By Year and Month

The average number of trips for which landings were recorded was 45 per year (range = 38–74), with a mean of 90 sharks recorded per year (range = 33–170). Nominal CPUE by year showed a positive trend from 0.83 sharks per trip in 2011 to a maximum of 3.70 in 2016, with a

TABLE 1. Elasmobranch species composition of recorded catch by gear type in Cojímar, Cuba, fishing during the monitoring program (2011–2019). Abbreviations are as follows: LL-D = diurnal longline sets, LL-N = nocturnal longline sets, HL = hand line, and VL = vertical line.

	Fishing gear				
Species and total	LL-D	LL-N	HL	VL	Total
Silky Shark *Carcharhinus falciformis*	4	174	1		179
Longfin Mako *Isurus paucus*	1	162			163
Oceanic Whitetip Shark *Carcharhinus longimanus*	5	115			120
Shortfin Mako *Isurus oxyrinchus*		95			95
Tiger Shark *Galeocerdo cuvier*	1	88			89
Bigeye Thresher *Alopias superciliosus*	1	48			49
Blue Shark *Prionace glauca*		45			45
Night Shark *Carcharhinus signatus*	1	29			30
Great Hammerhead *Sphyrna mokarran*		10			10
Smooth Dogfish *Mustelus canis*				7	7
Smooth Hammerhead *Sphyrna zygaena*		3			3
Cuban Dogfish *Squalus cubensis*				3	3
Dusky Shark *Carcharhinus obscurus*	1	1			2
Giant Manta *Mobula birostris*		2			2
Scalloped Hammerhead *Sphyrna lewini*		2			2
Blacknose Shark *Carcharhinus acronotus*		1			1
Caribbean Reef Shark *Carcharhinus perezii*		1			1
Bigeye Sixgill Shark *Hexanchus nakamurai*				1	1
Requiem sharks (no species ID) *Carcharhinus* spp.		17			17
Makos (no species ID) *Isurus* spp.		2			2
Hammerheads (no species ID) *Sphyrna* spp.		1			1
Total	14	796	1	11	822

TABLE 2. Annual recorded catches of elasmobranchs by species in the Cojímar longline fishery during the monitoring program (2011–2019).

	Year											
Species and total	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total	%	Cumulative %
Silky Shark	4	8	5	22	28	46	16	28	21	178	22	22
Longfin Mako	9	9	16	27	32	29	22	11	8	163	20	42
Oceanic Whitetip Shark	4	3	17	21	27	29	2	17		120	15	57
Shortfin Mako	2	4	16	21	15	14	9	14		95	12	69
Tiger Shark	3	4	6	13	21	21	14	6	1	89	11	80
Bigeye Thresher	1	6	3	11	3	14	2	8	1	49	6	86
Blue Shark	1	1	3	10	19	8	1	2		45	6	91
Night Shark	2		3	7	5	5	3	5		30	4	95
Great Hammerhead				1	1	2	1	4	1	10	1	96
Smooth Hammerhead	1			2						3	0.4	97
Giant Manta								2		2	0.2	97
Scalloped Hammerhead					1			1		2	0.2	97
Dusky Shark		1		1						2	0.2	97
Caribbean Reef Shark				1						1	0.1	98
Requiem sharks (no species ID)	6	4	3	1	1	2				17	2	100
Makos (no species ID)		1		1						2	0.2	100
Hammerheads (no species ID)				1						1	0.1	100
Total	33	41	72	140	153	170	70	98	32	809	100	

TABLE 3. Monthly recorded catches of elasmobranchs by species in the Cojímar longline fishery during the monitoring program (2011–2019).

	Month												
Species and total	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Silky Shark	22	28	12	21	17	4	8	9	6	11	23	17	178
Longfin Mako	21	30	18	12	3	5	7	8	16	6	17	20	163
Oceanic Whitetip Shark	5	2	2	7	7	11	18	9	21	9	16	13	120
Shortfin Mako	6	19	9	8	3	2	12	3	12	5	10	6	95
Tiger Shark	13	6	11	8	3	1	9	1	7	7	12	11	89
Bigeye Thresher	7	7	5	2	3	4	3	3	2	1	7	5	49
Blue Shark	2	2	2	3	2	3	4	7	4	4	8	4	45
Night Shark	1	1		5	2	4	1	3	1	2	6	4	30
Great Hammerhead	3	2	1	2								2	10
Smooth Hammerhead		1									1	1	3
Giant Manta								1	1				2
Scalloped Hammerhead			1	1									2
Dusky Shark		2											2
Caribbean Reef Shark					1								1
Requiem sharks (no species ID)	3				1	1	1			2	6	3	17
Makos (no species ID)				1	1								2
Hammerheads (no species ID)											1		1
Total	83	100	61	70	43	35	63	44	70	47	107	86	809

secondary peak of 2.58 in 2018. The average annual CPUE of all shark species was 1.98 sharks per trip (SD = 0.938). Average CPUE by years showed an oscillating positive trend from 2011 to 2019, with maximum values of 0.36 (SD = 0.311) in 2016 and 0.234 (SD = 0.215) in 2018. The 2016 peak coincided with the nominal CPUE using the total captures (Figure 3A).

The average number of trips recorded per month for all years combined was 55 (range = 33–69). The pattern of trips per month was variable with values >60 in February, May, September, November, and December. Recorded catch by month also was variable, averaging 67 sharks landed (range = 35–107). Lower landings were recorded in May–June and August, with higher values in November to February. Nominal CPUE by month was higher in February and November and lower in May–June. Mean monthly CPUE of all shark species was 1.22 sharks per trip (SD = 0.296). The mean CPUE by months was stable without any clear pattern (Figure 3B). The Kolmogorov–Smirnov test for CPUE–years (KS = 0.210, $P < 0.01$) and CPUE–months (KS = 0.176, $P < 0.01$) indicated that the normality assumption was not met. The Kruskal–Wallis nonparametric test did not detect significant differences in CPUE–years ($H = 12.62$, $P = 0.12$) or CPUE–months ($H = 6.80$, $P = 0.82$).

Catch, Relative Abundance, and Sex Ratio of Main Species

Silky Shark.— Trends in annual shark catch and CPUE in number of sharks per trip for Silky Sharks were proportional, except for 2019, due to incomplete data for the last year of the survey (Figure 4A). The proportion of total Silky Sharks to total sharks landed (PTS) showed a subtle positive trend increasing in recent years (Figure 4A). Catch of Silky Sharks by month was seasonally "U-shaped" (Figure 5A), with minimum monthly catches in the late spring and summer (June–September) and maximum catches in late autumn and winter (November–February). Despite this seasonality of landings, the relative abundance indices CPUE and PTS followed each other closely by month (Figure 5A). Grouping the sex of Silky Shark landings by 2-month periods (to avoid zero-catch survey months), we observed that September–October (female : male = 4:1; χ^2 = 5.4, $P = 0.020$) and November–December (female : male = 4.9:1; $\chi^2 = 9.78$, $P = 0.002$) catches comprise significantly more females than males from an expected 1:1 ratio. For the entire sample, the sex ratio was dominated by females (female : male = 1.9:1; $\chi^2 = 14.8$, $P = 0.0001$).

Longfin Mako.— Landings of Longfin Makos were higher during 2014–2016, and the CPUE also shows the same trend (Figure 4B). The PTS index showed a relatively flat trend. Longfin Mako CPUE and PTS indices indicated highest relative abundance of this species in January–March, with the lowest values in May. January–February (female : male = 1.9:1; χ^2 = 4.45, $P = 0.035$) and March–April (female : male = 2.8:1; χ^2 = 6.26, $P = 0.012$) differed from an expected 1:1 sex ratio in favor of females. For the entire sample, the sex ratio

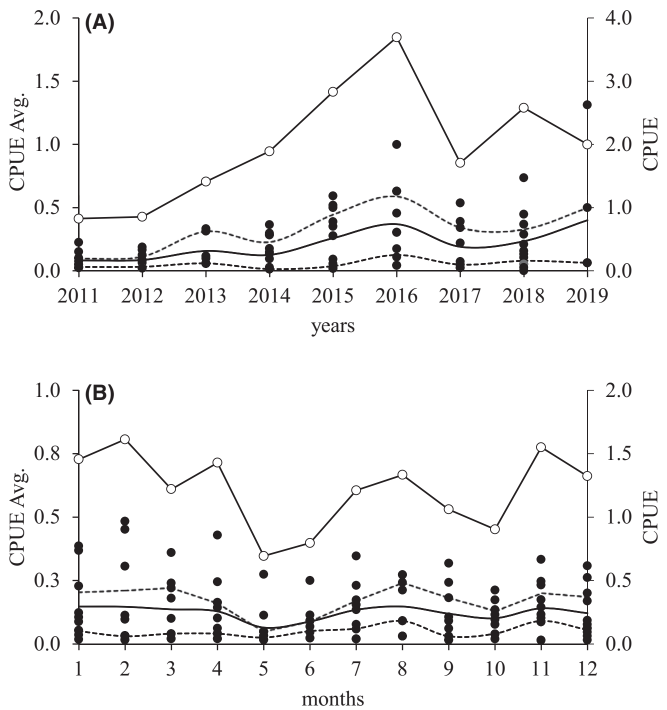

FIGURE 3. Observed CPUE (black dots) by **(A)** year and **(B)** month of all the species taken by the Cojímar longline fleet during the monitoring program (2011–2019). Nominal CPUE (white dots) is the total sharks per number of trips, and average CPUE (solid line) is the mean number of sharks per number of trips with the 25th and 75th quartiles (dashed line).

was dominated by females (female : male = 1.6:1; χ^2 = 6.23, $P = 0.012$).

Oceanic Whitetip Shark.— Catches of Oceanic Whitetip Sharks presented similar trends to the Longfin Mako but with an abrupt decline in 2017 (Figure 4C). Other than that year, CPUE and PTS annual indices tracked each other similarly to those of the Longfin Mako. Seasonal catch was lowest in February–March and peaked in July and September (Figure 5C). Both CPUE and PTS monthly indices showed a similar pattern to the catch. No 2-month period showed a sex ratio significantly different from 1:1; however, the sex ratio of the entire sample favored females (female : male = 1.6:1; χ^2 = 5.69, $P = 0.017$).

Shortfin Mako.— Contrary to the pattern described for the three previous sharks, Shortfin Mako annual landings and indices were relatively uniform from 2013 through 2018 (Figure 4D). The PTS index showed a slow decrease from 2013 to 2016. Monthly catches and indices presented maximum and minimum values in February and June, respectively (Figure 5D). No significant difference in sex ratio was found for any 2-month period. Female Shortfin Makos were more abundant in our sample than males, but the difference was not statistically significant in any 2-month period or for the entire sample (female : male = 1.2:1; $\chi^2 = 0.56$, $P = 0.45$).

Tiger Shark.— Annual Tiger Shark catches and CPUE showed a dome-shaped trend, with a maximum in 2015–2017 (Figure 4E). The Tiger Shark PTS index, on the other hand, stayed relatively flat throughout the survey period. Monthly catch and abundance indices of Tiger Sharks showed a mixed pattern of availability in the fishing ground (Figure 5E). Tiger Shark abundance increased in autumn and winter, with a drop-off in February, but then also showed a spike in midsummer. There were no significant differences in sex ratio per 2-month period or for the entire sample (female : male = 1.4:1; $\chi^2 = 2.32$, $P = 0.12$).

Bigeye Thresher.— Annual catches and CPUE of Bigeye Threshers both showed an oscillating, biennial pattern with peaks in 2012, 2014, 2016, and 2018 (Figure 4F). In comparison the PTS index remained relatively flat throughout the entire survey period. Monthly catches of Bigeye Threshers were higher in late autumn and winter (November–March), with a less prominent peak in June (Figure 5F). Both monthly CPUE and PTS indices were flat with no clear pattern over the years of the survey. January–February (female : male = 4.6:1; $\chi^2 = 4.45$, $P = 0.035$) and November–December (female : male = 4.6:1; χ^2 = 4.45, $P = 0.035$) periods had significantly more females, and for the entire sample the sex ratio was dominated by females (female : male = 2.8:1; $\chi^2 = 10.25$, $P = 0.0014$).

Length Composition of Primary Species

Silky Shark.— Length-frequency distribution of Silky Sharks (both sexes combined) was bimodal, with peaks at 75–90 cm PCL and 165–210 cm PCL and low frequency for 120–165 cm PCL (Figure 6A). The mean length for combined sexes of Silky Sharks was 136 cm PCL (range = 59–226; SD = 50; $n = 66$); mean lengths of females and males were 141 cm PCL (range = 59–226; SD = 52; $n = 48$) and 123 cm PCL (range = 65–196; SD = 46; $n = 18$), respectively. Mean lengths of immature and mature females were 103 cm PCL (range = 59–172; SD = 31; $n = 28$) and 194 cm PCL (range = 169–226; SD = 17; $n = 20$), respectively; mean lengths of immature and mature males were 98 cm PCL (range = 65–190; SD = 16; $n = 11$) and 163 cm PCL (range = 106–196; SD = 30; $n = 7$), respectively (Figure 7A).

Longfin Mako.— Length-frequency of this species was highest at 180–210 cm PCL (Figure 6B). Mean length of combined sexes was 208.7 cm PCL (range = 85–334; SD = 58; $n = 108$); mean lengths of females and males were 224 cm PCL (range = 85–334; SD = 63; $n = 67$) and 183 cm PCL (range = 108–330; SD = 34; $n = 41$), respectively. Mean length of immature and mature females were 157 cm PCL (range = 85–210; SD = 41; $n = 18$) and 253 cm PCL (range = 180–334; SD = 47; $n = 46$), respectively; mean

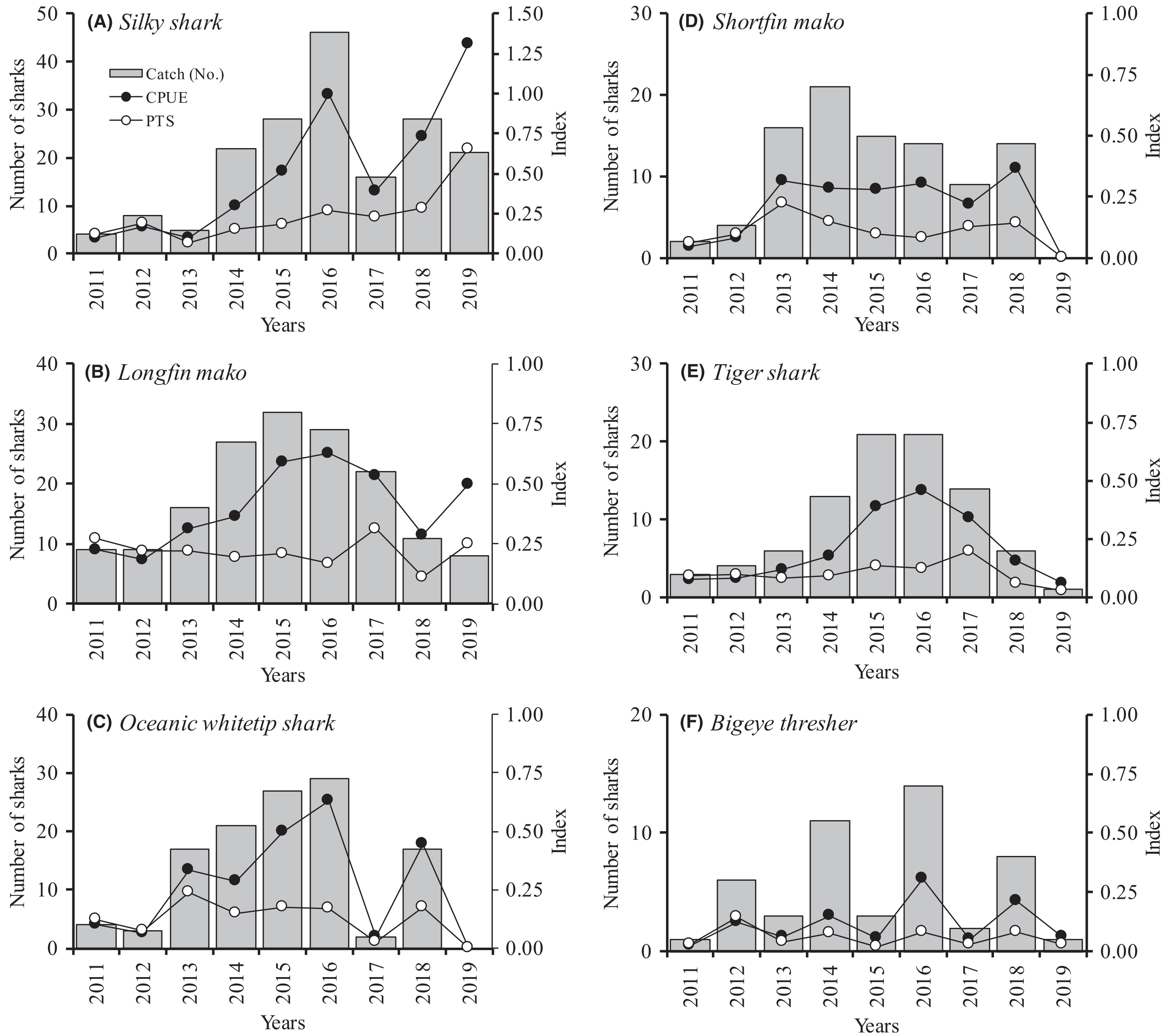

FIGURE 4. Annual recorded catches (bars) and indices of relative abundance (CPUE and percentage of total sharks [PTS]) for six main shark species taken by the Cojímar longline fleet during the monitoring program (2011–2019). Catch per unit effort (black dots) is measured as the number of sharks per trip; PTS (white dots), which is sharks as a percentage of total sharks, is expressed as a proportion of the total.

length of immature and mature males were 155 cm PCL (range = 108–185; SD = 24; $n = 16$) and 207 cm PCL (range = 175–330; SD = 34; $n = 21$), respectively (Figure 7B).

Oceanic Whitetip Shark.— Length-frequency of Oceanic Whitetip Sharks was higher at 90–105 and 135–150 cm PCL, followed by an abrupt decline from 150 cm PCL to larger sizes (Figure 6C). Mean length of combined sexes was 114 cm PCL (range = 56–195; SD = 34; $n = 74$); mean lengths of females and males were 106 cm PCL (range = 60–195; SD = 37; $n = 40$) and 124 cm PCL (range = 56.3–169; SD = 27; $n = 34$), respectively. Mean lengths of immature and mature females were 95 cm PCL (range = 60–155; SD = 25; $n = 34$) and 170 cm PCL (range = 143–195; SD = 26; $n = 7$), respectively; mean lengths of immature and mature males were 117 cm PCL (range = 56–159; SD = 26; $n = 24$) and 149 cm PCL (range = 125–169; SD = 18; $n = 7$), respectively (Figure 7C). Three neonate Oceanic Whitetip Sharks with open umbilical scars were

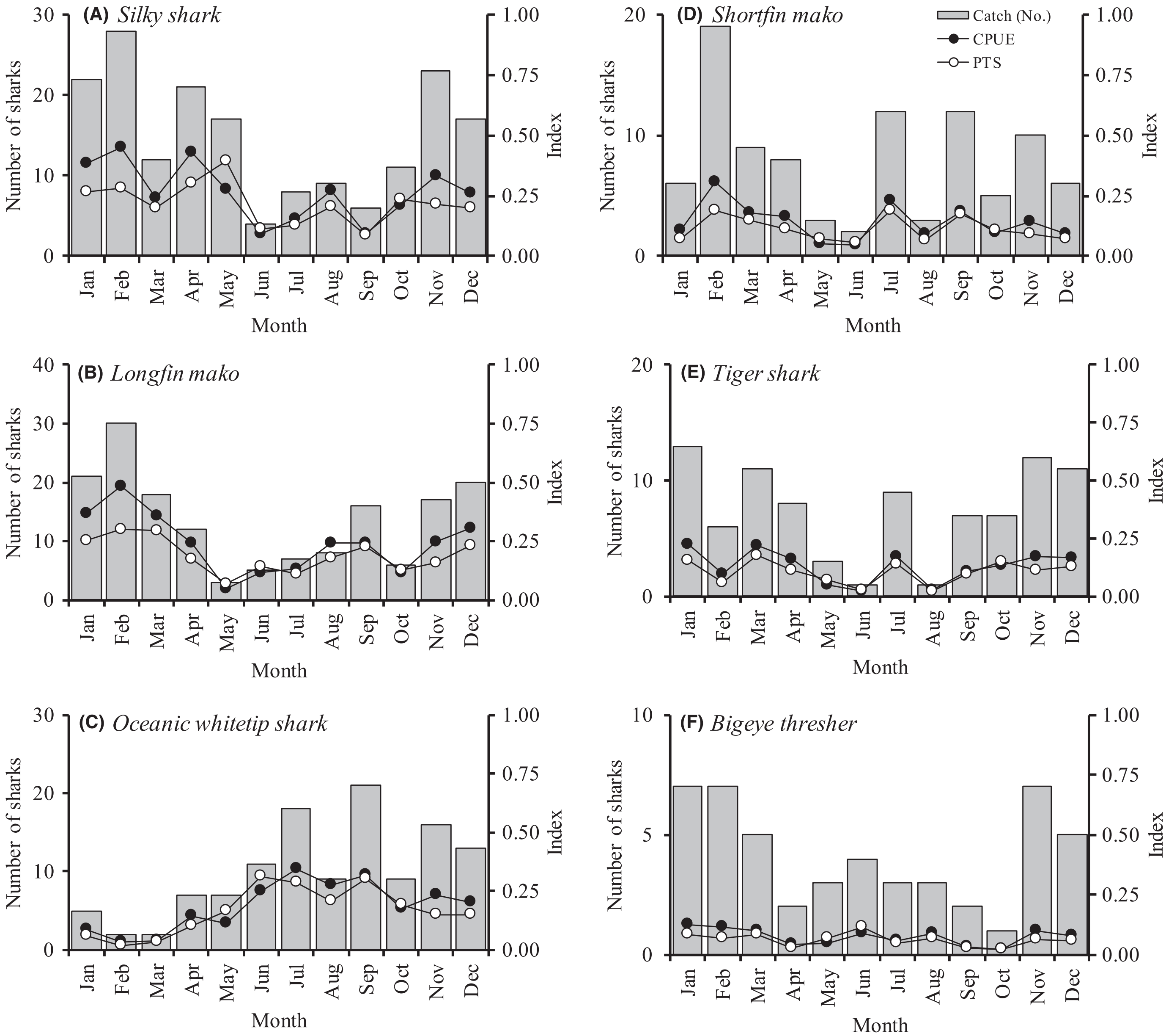

FIGURE 5. Monthly recorded catches (bars) and indices of relative abundance (CPUE, PTS) for six main shark species taken by the Cojímar longline fleet during the monitoring program (2011–2019). Catch per unit effort (black dots) is measured as the number of sharks per trip; PTS (white dots), which is sharks as a percentage of total sharks, is expressed as a proportion of the total.

observed in the catch on December 4, 2013, July 25, 2018, and September 22, 2018.

Shortfin Mako.— Length-frequency of Shortfin Makos was highest at 195–210 cm PCL (Figure 6D). Mean length of combined sexes of Shortfin Makos was 208 cm PCL (range = 89–411; SD = 57; $n = 42$); mean lengths of females and males were 232 cm PCL (range = 100–411; SD = 64; $n = 21$) and 183 cm PCL (range = 89–227; SD = 37; $n = 21$), respectively. Mean lengths of immature and mature females were 166 cm PCL (range = 100–217; SD = 49; $n = 4$) and 259 cm PCL (range = 199–411; SD = 51; $n = 15$), respectively; mean lengths of immature and mature males were 130 cm PCL (range = 89–157; SD = 31; $n = 4$) and 200 cm PCL (range = 160–227; SD = 24; $n = 14$), respectively (Figure 7D).

Tiger Shark.— Tiger Shark length-frequency was highest at 210–225 cm PCL, with lesser peaks at 150–195 and 240–255 cm PCL (Figure 6E). Mean length of combined sexes was 211 cm PCL (range = 100–310; SD = 49; $n = 57$); mean lengths of females and males were

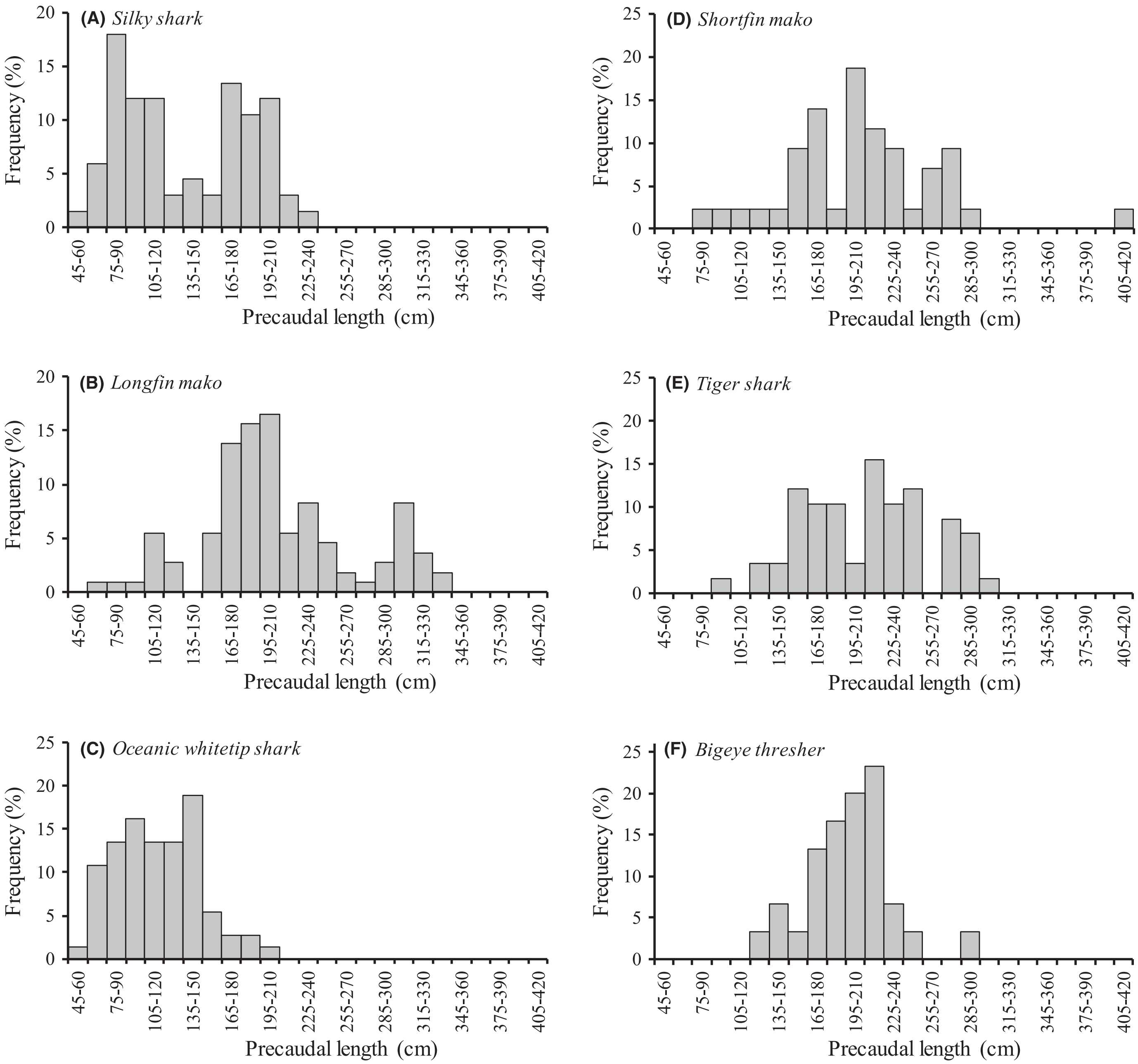

FIGURE 6. Length-frequency distribution of six main shark species taken by the Cojímar longline fleet during the monitoring program (2011–2019).

225 cm PCL (range = 130–310; SD = 47; $n = 35$) and 189 cm PCL (range = 100–276; SD = 45; $n = 22$), respectively. Mean lengths of immature and mature females were 151 cm PCL (range = 130–173; SD = 17; $n = 6$) and 247 cm PCL (range = 180–310; SD = 37; $n = 22$), respectively; mean lengths of immature and mature males were 161 cm PCL (range = 100–217; SD = 32; $n =$ 9) and 223 cm PCL (range = 161–276; SD = 45; $n = 7$), respectively (Figure 7E).

Bigeye Thresher.— Length-frequency of Bigeye Threshers peaked at 210–225 cm PCL (Figure 6F). Mean length of combined sexes was 197 cm PCL (range = 133–285; SD = 32; $n = 30$); mean lengths of females and males were 203 cm PCL (range = 133–285; SD = 31; $n = 25$) and 165 cm PCL (range = 138–180; SD = 17; $n = 5$), respectively. Mean lengths of immature and mature females were 137 cm PCL ($n = 1$) and 212 cm PCL (range = 169–285; SD = 25; $n = 20$), respectively; mean lengths of immature and

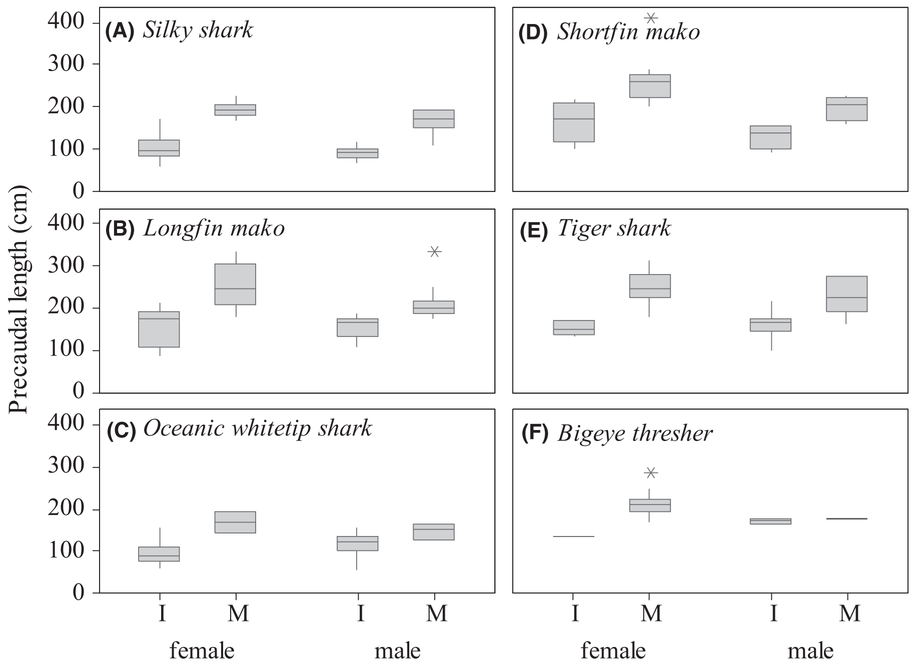

FIGURE 7. Boxplots of length ranges by sex and maturity stage of six main shark species taken by the Cojímar longline fleet during the monitoring program (2011–2019). In each box, the median (horizontal line) and quartiles (box dimensions) are shown. Asterisks denote outlier specimens. Abbreviations are as follows: I = immature and M = mature.

mature males were 174 cm PCL (range = 167–180; SD = 9; $n = 2$) and 178 cm PCL ($n = 1$), respectively (Figure 7F).

DISCUSSION

Shark landings of the Cojímar artisanal fishing fleet comprise mainly carcharhinids and lamnids, which are commonly encountered in pelagic longline fisheries (Mandelman et al. 2008). The common occurrence of pelagic species, such as Silky Sharks, Shortfin Makos, Longfin Makos, Oceanic Whitetip Sharks, and Bigeye Threshers, is similar to reports for the northwestern Atlantic Ocean, Gulf of Mexico, and Caribbean Sea by Cortés (2002) and the northern coast of Cuba by Guitart (1975) and Aguilar et al. (2014). Baum and Blanchard (2010) report similar species for U.S. Atlantic Ocean pelagic fisheries (1992–2005). Beerkircher et al. (2002) described Silky Sharks as the predominant species captured in the U.S. southeastern Atlantic Ocean in 1981–1983, followed by a decline in the catch of this species in 1992–2000. They also reported a similar trend in catches of the Night Shark, which was uncommon in the Cojímar fishery. In contrast, Martinez (1947) reported the Night Shark to be the main species in World War II–era shark fisheries operating off Cuba's northern coast, comprising almost 75% of the total catch. This dramatic change likely reflects overfishing of Night Sharks in the region (Baum et al. 2003; Santana et al. 2009) but could also be indicative of spatial and gear factors, such as fishing depth, that may have reduced catchability of this species (Watson and Bigelow 2014). Blue Sharks comprised 6% of the total sharks landed in our study, ranking 7th in shark species abundance, similar to results reported in Aguilar et al. (2014). Although the Blue Shark is a common pelagic species, its low representation in the Cojímar catch could be related to the temperature preference of this species (Watson et al. 2005) or changes in its prey type and distribution (Queiroz et al. 2010). We added two species to those previously documented for northwestern Cuban shark fisheries by Aguilar et al. (2014): Scalloped Hammerhead *S. lewini* and Dusky Shark *C. obscurus*, each represented by only two specimens in our surveys.

The highly migratory nature of shark species encountered by the Cojímar fleet affects localized relative abundance and, therefore, catch rate throughout the year. This is reflected in our findings that Silky Shark, Longfin Mako, Tiger Shark, and Bigeye Thresher catches are higher during winter months, whereas Oceanic Whitetip Shark catches are higher in summer–autumn months. All top six species recorded in our surveys have shown movements between the northwestern Atlantic Ocean and the Gulf of Mexico and Caribbean Sea, as reported by the National Marine Fisheries Service Cooperative Shark Tagging Program from 1962 to 2014 (Kohler et al. 1998; Kohler and Turner 2019). This research strongly indicates movement of multiple species of migratory sharks through the region north of Cuba, although the Kohler et al. studies used conventional tags yielding only tag–recapture vectors, so actual tracks of animal movement are unknown. In a separate study using satellite tags, two male Longfin Makos, one tagged in the eastern Gulf of Mexico and another with the Cojímar fishing fleet, showed similar seasonal movements through the Gulf of Mexico, Straits of Florida, and northwestern Atlantic Ocean, demonstrating connectivity among the waters of Cuba, Mexico, the Bahamas, and the USA (Hueter et al. 2017). These results underscore the importance of the Straits of Florida north of Cuba as a transit zone for migratory sharks, as seen for a number of other highly migratory fish species (Rooker et al. 2019).

Although shark CPUE was lowest at the beginning of our surveys (2011) and appeared to increase after that, trends in CPUE by years did not stand up to tests of statistical significance. It is possible that a learning curve was in effect during the study's early years as relationships with the fishers were being established, although the researchers involved had years of experience working in Cojímar. Beyond that, the time series of CPUE data is not large enough to make definitive conclusions about patterns or oscillations in monthly, seasonal, or yearly trends in actual abundance. Logistical challenges to the fishery, such as shortages of fuel and bait, no doubt have affected catches and CPUE at times, especially since 2017. Nevertheless, building upon this database should allow for statistically significant analyses in the future as Cuba's NPOA-Sharks continues to be implemented.

The length-frequency distributions for the six main species in our study reveal size and age differences in these species' use of the area (Figure 6). Combining all available years of data (2011–2019), Silky Shark and Longfin Mako catches show a bimodal distribution in length-frequency structure that suggests at least two age-classes using the area (Figure 6A, B). Shortfin Mako and Tiger Shark size distribution appears to be multimodal as well, but sample sizes are low (Figure 6D, E). Oceanic Whitetip Sharks, on the other hand, show a length-frequency distribution dominated by a large number of juveniles, including neonates. Similar reports of very young Oceanic Whitetip Sharks in this region have been published previously (Guitart 1975; Aguilar et al. 2014). Immature and mature individuals of both sexes were observed for all six of the main species (Figure 7); however, the abrupt decreases on the right side of the length-frequency distributions for Oceanic Whitetip Sharks (>150 cm PCL) and Bigeye Threshers (>225 cm PCL) suggest active migratory behavior of those species' juveniles out of the Cojímar fishing area (Figure 6C, F).

Conservation Concerns

Accurate assessment and effective management of shark fisheries are often deterred by a lack of species-specific biological and fishery data (Cortés et al. 2010). Successful conservation of shark populations requires detailed knowledge of their breeding and feeding habitats, their migratory routes, and their interactions with fisheries (Simpfendorfer et al. 2010; Queiroz et al. 2019; Williamson et al. 2019). Many shark species are data-deficient (Dulvy et al. 2008; Heupel and Simpfendorfer 2010) and are fished at above-recommended levels (Baum et al. 2003; Simpfendorfer et al. 2011; Dulvy et al. 2014). These combined factors can obscure population trajectories and the true extent to which shark species are threatened.

The main species of sharks landed in the Cojímar longline fishery are all considered vulnerable to some extent on the IUCN Red List, and all except for the Tiger Shark are listed under CITES Appendix II (CITES 2017). Silky Sharks, the most abundant shark species landed by the Cojímar fleet, is the secondmost captured shark species globally (Oliver et al. 2015) and one of the three-most traded species in the global shark fin trade (Tolotti et al. 2017). Silky Sharks have been estimated to have declined in abundance by 47–54% globally over the past 45 years, using standardized catch rate and spawning biomass indices (Rigby et al. 2017). Longfin and Shortfin makos are ranked second and fourth, respectively, in the Cojímar shark landings. These two mako species are currently listed as Endangered on the IUCN Red List (Rigby et al. 2019a, 2019b). Both are often retained by fishers for their meat and fins and globally are caught as target and bycatch species in pelagic fisheries (Fields et al. 2017). Concern has grown for the Shortfin Mako, particularly in the North Atlantic, leading to its recent listing under CITES Appendix II (CITES 2017). The Longfin Mako is also of serious conservation concern (Reardon et al. 2006) due to its apparent rarity, low fecundity, and poorly documented fisheries landings, exacerbated by its common misidentification as the Shortfin Mako in landings data (Cortés et al. 2010; Dent and Clarke 2015). The limited data for the Longfin Mako indicate strong declines, and it is suspected to have undergone a population reduction of 50–79% globally over the last 75 years, similar to its congener, the Shortfin Mako (Rigby et al. 2019a, 2019b).

An even greater concern exists for the Oceanic Whitetip Shark, the thirdmost landed shark species at Cojímar. It is one of three shark species most impacted by pelagic fisheries worldwide and has undergone significant population declines (Young et al. 2016), now listed as Critically Endangered on the IUCN Red List (Rigby et al. 2019c) and included under CITES Appendix II (CITES 2017). The neonates and very young juveniles observed in our surveys and in a previous study (Guitart 1975) suggest the presence of a nearby pupping area and a primary nursery area for this species off the northern coast of Cuba. This remains to be confirmed through further research, including tracking studies, but there is no doubt the area serves as juvenile habitat for this highly vulnerable species. Catches of these early life stages could compromise future recruitment to an already depleted population of Oceanic Whitetip Sharks.

Bigeye Threshers comprised 6% of the total shark landings in Cojímar. Thresher species are often aggregated in a single group as "thresher sharks" in fisheries data worldwide, making it difficult to determine the relative abundance of each species in regional catches (FAO 2018). The Bigeye Thresher is biologically vulnerable to fishing (Compagno 2001) due to its lowest rate of intrinsic population increase (0.002–0.009/year) of all the thresher sharks (Dulvy et al. 2008; Amorim et al. 2009) and therefore is listed as Vulnerable on the IUCN Red List (Rigby et al. 2019d).

Management of Cuba's Small-Scale Pelagic Longline Fisheries

In developing countries like Cuba, small-scale fisheries are of considerable importance for local economies, employment, and food security. Ultimately, a proper understanding of the socioeconomic value of fisheries is vital to the design and implementation of any successful management strategy (Temple et al. 2017). Lacking that information for the small-scale pelagic longline fisheries in Cuba, it is difficult to identify realistic and effective management and conservation options for these fisheries. However, unregulated and unreported exploitation by small-scale pelagic fisheries can negatively influence the abundance, distribution, and species composition of vulnerable taxa like sharks (Pinnegar and Engelhard 2008; Temple et al. 2017).

It is clear, therefore, that with the results presented here, several threatened species captured by the Cojímar fleet are at high risk, especially given that the fishing area is a zone of high migratory flux and connectivity (Queiroz et al. 2019). Due to that concern, there are several options to consider for the sustainability of these shark populations and the viability of these small-scale fisheries in Cuba. The first are the measures called for in the NPOA-Sharks, which includes actions to improve continuous gathering of catch, socioeconomic, and biological fisheries data throughout the country by Cuban government agencies and academic and environmental institutions. This will form the basis for realistic stock assessments and the design of appropriate management measures under Cuba Fisheries Law 129/2019, which establishes that fishing authorizations will be issued based on stock assessments.

Second, fishing gear can be regulated to meet conservation objectives. For pelagic longline fisheries, restrictions can be implemented on mainline length, the use of wire leaders on gangions, the number, size, and type of hooks, and fishing depth. Our study confirmed the Cojímar fleet's use of wire near hooks on gangions, particularly in nocturnal sets, which increases the retention of sharks (Santos et al. 2017). Changing longline leaders from wire to monofilament can allow some sharks to bite through and escape if captured (Shiffman and Hammerschlag 2016a), although several studies have compared wire leaders to monofilament leaders with conflicting results (Branstetter and Musick 1993; Ward et al. 2008; Romanov et al. 2010).

The use of circle hooks, as opposed to the more traditional J-hooks used by Cojímar fishers, can mitigate bycatch rates and fishing mortality of protected species (Shiffman and Hammerschlag 2016b). Studies of shark catchability as a function of hook type have produced mixed results for circle hooks. Despite no significant difference in catch rates of sharks for circle hooks versus J-hooks, Godin et al. (2012) found a significant reduction in at-vessel mortality of sharks when circle hooks were used. In 2004, the National Marine Fisheries Service instituted a policy requiring all U.S. pelagic longline vessels to use only circle hooks to avoid or reduce bycatch (NMFS 2006). Results of this regulatory change have varied, with some studies reporting no reduction of at-vessel mortality with circle hooks (Kerstetter and Graves 2006; Yokota et al. 2006; Curran and Bigelow 2011; Pacheco et al. 2011; Afonso et al. 2012; Curran and Beverly 2012), while others report reduced at-vessel mortality (Carruthers et al. 2009; Afonso et al. 2011). Physiological stress and physical trauma imposed during capture and handling can compromise the ultimate postrelease survival of discarded, bycaught sharks (Bonfil 1994; Skomal 2007). Thus, differences in duration of capture and handling and release methods can explain some of the discrepancies above. A change from J-hooks to circle hooks in the Cojímar fishery could potentially enhance shark conservation efforts in Cuba by reducing bycatch rates and postrelease mortality of vulnerable sharks. Because the Cojímar fishery is essentially a zero-discard fishery, however, such a gear change would have a negligible effect until catch limits and/or prohibitions on certain species are instituted by the Cuban government.

Effective fishing depth is another gear characteristic affecting interactions with sharks. A number of studies have researched the effects of deployment depth of pelagic longlines on catch results (Beverly et al. 2009; Bigelow and Mourato 2010; Watson and Bigelow 2014). Several studies of Oceanic Whitetip Sharks and Silky Sharks have revealed species-specific, vertical movement patterns that indicate extended time in waters less than 100 m (Tolotti et al. 2017; Andrzejaczek et al. 2018; Hueter et al. 2018), making these species vulnerable to shallow-set gear (Musyl et al. 2011; Howey-Jordan et al. 2013). Other studies show depth preferences, vertical diel patterns, and susceptibility on overnight longline sets for Longfin Makos, which spend extended time in depths less than 220 m (Hueter et al. 2017), whereas thresher sharks may be vulnerable to deep-set gear for tuna (Boggs 1992; Weng and Block 2004; Musyl et al. 2011). Sometimes a simple gear change can produce a significant desired effect. For example, Bigelow and Mourato (2010) and Watson and Bigelow (2014) predicted that the removal of one or more hooks nearest the floats on pelagic longlines would result in a reduction in the catch of Blue Sharks, Bigeye Threshers, and Oceanic Whitetip Sharks.

It is not a given that these various measures would each contribute to lower fishing mortality in every case, as there is considerable uncertainty about the mitigation effects of each measure or the ability to enforce such regulatory changes in the fishery (Clarke 2013). A risk-averse approach for the Cuban small-scale pelagic longline fishery, however, could begin to test the benefits of these various options. To promote the conservation of vulnerable sharks, the use of monofilament on gangions, large circle hooks set to fish below 100 m, and line-cutting or dehooking tools to quickly release sharks in the water (Gilman et al. 2014) are reasonable measures to implement now in this fishery. The economic cost of these measures, such as increased loss of gangions and hooks, would need to be accounted for and mitigated. Field testing of any gear modifications should be conducted only with the full participation and engagement of the fishers themselves. This is of vital importance for transparency, trust, and support of fishers to ensure open access to information and compliance with resulting management and conservation measures.

Our study highlights the impact and importance of the small-scale pelagic longline fishery and the susceptibility of vulnerable sharks to this fishery off northwestern Cuba. The overlap here between fishing effort and important migratory routes for pelagic sharks calls for more effective and timely monitoring of this fishery. Cuba has demonstrated commitment to shark conservation and fisheries management that is focused on sustainable use and the precautionary approach, through the NPOA-Sharks and Fisheries Law 129/2019. Funding, collaborative effort, and the timescales in which to find effective management measures remain a challenge in Cuba, but all are essential to achieve sustainability of sharks and the fisheries that impact them.

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