



Characteristics and species composition of a small-scale shark fishery in Puerto Rico: Jurisdictional issues enable legal landings of prohibited and endangered species

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ABSTRACT

Shark fishing is increasingly regulated in the Caribbean region. We present new information on the characteristics, landings, species composition, and size composition of the shark fishery of Puerto Rico, a U.S. Caribbean territory, and discuss current regulatory issues. Sharks are mainly landed in a small-scale targeted fishery operating in territory jurisdiction (coast to 17 km) that supplies local demand for inexpensive fish. There are at least 16 species caught: a small number of large Tiger (*Galeocerdo cuvier*) and Blacktip (*Carcharhinus limbatus*) sharks and many small but adult Sharpnose sharks (*Rhizoprionodon* spp.) accounted for >80% of landed weight. The catch of Sharpnose sharks was significantly skewed to males. Juvenile Scalloped Hammerhead sharks (*Sphyrna lewini*) were the second-most caught species but accounted for a small proportion of the landed weight and value given their small size. Differences between territory and U.S. federal regulations (17 km-370 km jurisdiction) leads to legal territory landings of federally prohibited species, especially Scalloped Hammerhead sharks, which might undermine the conservation potential of federal regulations. Scalloped Hammerhead sharks are also listed under the U.S. Endangered Species Act (ESA) making ongoing catches more problematic from a legal perspective. Scalloped Hammerhead shark catch reduction could have minimal livelihood impacts because of their low value, which presents an opportunity for stakeholders to engage on catch reduction measures. This study provides new details on how and why different shark species are caught in Puerto Rico, which could facilitate better management that protects threatened species and maintains livelihoods for people.

1. Introduction

Shark fisheries are increasingly targeted for regulation as evidence of widespread overexploitation has emerged (Ward-Paige et al., 2010; MacNeil et al., 2020; Quinlan et al., 2021; Talwar et al., 2022). One of the main challenges of regulating shark fisheries is the non-selective nature of the gear, generally resulting in catches of species with wide variation in their intrinsic vulnerability to overexploitation (Smart et al., 2020). Management often must be tailored to the most vulnerable species caught and it may be difficult for fishers to operate given that they may be unable to avoid catching these species or that prohibiting them

has severe livelihood impacts (Smart et al., 2020; Booth et al., 2021). Successful regulation of shark fisheries first requires basic information about the species and size composition of the catch, the gear being used to catch each species, and value of each species to fisher livelihoods (Smart et al., 2020; Booth et al., 2021; Quinlan et al., 2021).

Puerto Rico is a U.S. Caribbean territory, with the U.S. National Marine Fisheries Service (NMFS) managing fishing activities from 17 – 370 km (9 to 200 nautical miles [nm]) from the nearest coastline point, hereafter referred to as ‘federal waters’, and the Commonwealth of Puerto Rico managing fishery resources within 17 km (9 nm) of the coast, hereafter referred to as ‘territorial waters.’ Shark meat is

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consumed in Puerto Rico in several forms including turnovers ('pastelillos'), kebabs ('pinchos'), or filets (Rodríguez et al., 2022) and the fishery once rivalled many other important local fisheries in size (Matos-Caraballo, 2012). Fisheries data on sharks since 2011 are scarce, perhaps in part because a zero-shark quota was implemented for NMFS Highly Migratory Species Division's (HMS) Commercial Caribbean Small Boat (HMS CCSB) permit holders, which may have dissuaded fishers with this permit from reporting their catch. HMS CCSB permit holders in Puerto Rico recently petitioned NMFS to allow limited shark landings, resulting in new regulations implemented in 2021 (Rule 86 FR 22882) that allow permit holders a daily catch limit of three sharks of certain species. The HMS Atlantic prohibited species list also applies to the HMS CCSB permit available to Puerto Rico and additional species were also prohibited given concerns about the status of their stocks. Of particular concern is the Caribbean Distinct Population Segment (DPS) of Scalloped Hammerhead sharks (*Sphyrna lewini*), which includes Puerto Rico, because they are listed as 'Threatened' under the Endangered Species Act (ESA; Rule 79 FR 38213). The Caribbean territories are the only U.S. jurisdictions that have direct control of the management of this DPS, which makes these areas important for implementing the ESA listing to achieve DPS recovery. While Puerto Rico's fishing regulations do have gear specific restrictions relevant to the shark fishery, such as prohibitions of longlines longer than three miles, gill-netting within 300 m from any river mouth, and gillnet mesh sizes larger than six inches, species specific territorial regulations have not yet been aligned with federal regulations. This means that federally prohibited species, including Scalloped Hammerhead sharks, can still be landed if caught in territorial waters. This lack of consistency means that federal species prohibitions cannot readily be enforced at landing sites because jurisdiction depends on capture location, which cannot easily be ascertained on land.

Regulating the Puerto Rican shark fishery is challenging in part because there is a lack of species-specific landings data, along with the jurisdictional complications. To better understand these issues, we document the species and size (length and weight) composition of shark landings from February 2019 to August 2021. Specifically, our objectives were to (1) characterize the relative importance of shark species to the catch observed at landing sites in terms of number of individuals and weight, as well as obtaining basic biological data (sex, sizes) and information on the fishery and market and (2) assess potential regulatory issues associated with this fishery involving landings of federally prohibited and ESA-listed species.

2. Materials and methods

Visits to ports and seafood vendors/ local fish markets known as 'pescaderías' were opportunistically made from February 2019 to August 2021 (Fig. 1). Facilities were visually scanned for sharks in areas open to the public and if sharks were not observed vendors or fishers were asked if they had any sharks on the premises. With the collaboration and permission of fishers or vendors, all observed sharks were visually identified to the lowest taxon possible, sexed, and weighed or weights were provided by fishers. Standard measurements of total length (TL) were made with a tape measure if the individual was intact. Some fishers voluntarily identified whether sharks were the primary target of the day's fishing activity, which was recorded as 'targeted' or 'incidental'. We also recorded the gear type used to catch each shark, the advertised or stated prices for its meat (USD/kg) and whether shark fins and other non-meat products were on sale at the facility and, if so, recorded their prices. The total number and weight of observed sharks by species was tabulated for each facility, including zeroes. We summed the total observed weight of sharks by year across all locations as a minimum estimate of fishery production. The relative species composition (species percentage of total) was calculated in terms of number of individuals and by weight. Sex ratios for common species were tested for deviations from unity using a binomial test. A tissue sample (fin clip taken with scissors) was removed from 10 sharks of uncertain species identity (all Sharpnose sharks, genus *Rhizoprionodon*) in July 2021 and stored in 95% reagent grade ethanol for cytochrome oxidase 1 DNA barcoding using PCR primers and protocols for PCR and sequencing following Wong et al. (2009). Sequences were input into the BOLD Systems Identification Engine (http://www.boldsystems.org/index.php/IDS_OpenIdEngine) and compared to the 'Species Level Barcode Records'. We identified the specimens to species if their sequence was identical to vouchers of one species and no others, excluding non-vouchered specimens in this database that were mined from GenBank.

3. Results

A total of 162 port or 'pescadería' visits were made over 139 days (1–2 sites visited per day) from February 2019 to August 2021 in 10 municipalities around the island but mostly in San Juan and its nearby towns (Fig. 1). All months were sampled with a minimum of 3 sampling days (October) and a maximum of 21 sampling days (March), with a



Fig. 1. Municipalities where pescadería and port visits were conducted from February 2019 to August 2021.

median of 11 sampling days per month. Sharks were observed on 91 days (65%) and occurred in every month of the year. The mean number of sharks observed per day was 2.324 (std dev = 6.4). When fishers indicated whether sharks were targeted, 235 out of 259 (90.7%) were. Shark landings documented were classified at each site by gear type for each individual catch (Table 1). Fishers targeting sharks were observed to be using either pelagic longlines (~ 240 m long, with ~ 5 hooks line⁻¹ uniformly using Mustad 12/0) or bottom set gillnets (ranging from 120–275 m long). Longlines caught moderate- to large-sized sharks while gillnets mainly caught small sharks. All observed landings of Silky (*Carcharhinus falciformis*), Bluntnose Sixgill (*Hexanchus griseus*), Narrowfin Smooth-Hound (*Mustelus norrisi*), Cuban Dogfish (*Squalus cubensis*), and Night (*C. signatus*) sharks (Table 1) were incidental (24 out of 259 sharks: 9.3%). Gear types that caught sharks incidentally were electric reel, rod and reel, and fish traps (Table 1). Observed prices for shark meat advertised at the point of sale (n = 289) ranged from USD 3.30–8.81 kg⁻¹ but most observations were USD 7.71 kg⁻¹ (271 out of 289). Only twice in our sampling did we observe an advertised price for fins (USD 22.04 kg⁻¹). On a few occasions we observed fishers cleaning and fileting landed shark carcasses and discarding the fins along with the carcass in the sea. Another shark product we observed was shark liver oil sold in 375 ml bottles with prices ranging from USD 15–25 bottle⁻¹.

A total of 323 individual sharks of at least 16 species (Table 1, Fig. 2) were observed with a total observed weight of 4646 kg. The number of individuals observed by year was 131 (2019), 111 (2020), and 81 (2021). Year-round sampling was only conducted in 2019 and for that year we observed 3576 kg of shark landings, comprising 131 individuals sampled in 86 site visits. For all sampling the most important species by weight were Tiger (*Galeocerdo cuvier*), Sharpnose (i.e., *Rhizoprionodon* spp.) and Blacktip (*Carcharhinus limbatus*) sharks (Fig. 3). Tiger sharks alone made up over 80% of the observed landed weight despite being a

Table 1

Species counts of observed landings with federal status (Prohibited or Legal) in U.S. Caribbean. * Prohibited if Caribbean Sharpnose, *Rhizoprionodon porosus*. Gear types: Longline (LL), Gillnet (GN), Electric Reel (ER), Rod and Reel (RR), and Fish Trap (FT).

Common name	Species	Count	Federal Status	Gear type used to catch
Sharpnose shark	<i>Rhizoprionodon</i> sp.	154	Prohibited*	99% GN, 1% RR
Scalloped Hammerhead shark	<i>Sphyrna lewini</i>	46	Prohibited	100% GN
Processed shark	NA	40		
Tiger shark	<i>Galeocerdo cuvier</i>	16	Legal	100% LL
Silky shark	<i>Carcharhinus falciformis</i>	15	Prohibited	80% ER, 20% RR
Blacktip shark	<i>Carcharhinus limbatus</i>	14	Legal	71% GN, 29% RR
Cuban Dogfish shark	<i>Squalus cubensis</i>	11	Legal	91% ER, 9% FT
Great Hammerhead shark	<i>Sphyrna mokarran</i>	10	Prohibited	100% GN
Dusky Smooth-hound shark	<i>Mustelus canis</i>	5	Legal	80% ER, 20% FT
Blacknose shark	<i>Carcharhinus acronotus</i>	2	Legal	100% RR
Bull shark	<i>Carcharhinus leucas</i>	2	Legal	100% GN
Caribbean Reef shark	<i>Carcharhinus perezi</i>	2	Prohibited	50% LL, 50% RR
Bluntnose Sixgill shark	<i>Hexanchus griseus</i>	2	Prohibited	100% ER
Night shark	<i>Carcharhinus signatus</i>	1	Prohibited	100% ER
Longfin Mako shark	<i>Isurus paucus</i>	1	Prohibited	100% RR
Narrowfin Smooth-hound shark	<i>Mustelus norrisi</i>	1	Legal	100% ER

numerically minor component of the observed catch and they were exclusively caught on longlines (Fig. 2). The dominance of this species is because of the relatively large sizes of caught individuals, several of which were above the size at first maturity (Fig. 3). Most landed Blacktip sharks were also above the size at first maturity (Fig. 3). After excluding dressed carcasses or filets that could not be identified beyond the level of 'shark' on site, the most observed taxon in terms of numbers were Sharpnose sharks, which could not be identified to species but based on geographic distribution records (<https://www.iucnredlist.org/species/61407/3103881#geographic-range>) are most likely Caribbean Sharpnose (*Rhizoprionodon porosus*), with a total of 151 individuals and comprising 46.9% of all identifiable sharks examined (Fig. 3). Nearly all (99%) of their observed catch occurred in gillnets (Table 1) and measured individuals ranged from 39.9–98.0 cm TL (Fig. 3). There was a significant deviation from a 1:1 sex ratio, with a strong male skew (Table 2). Seven Sharpnose shark individuals sampled in a pescadería in July 2021 were subjects for DNA barcoding the mitochondrial cytochrome oxidase I (COI; ~ 476-627 base pairs). Six of them were 100% matches to a large number of voucher Caribbean Sharpnose sharks contained in BOLD but they also matched 3 barcodes mined from GenBank (Accession numbers MT152407.1, MT152563, MG703545) attributed to Brazilian Sharpnose sharks (*R. lalandii*). One Puerto Rican specimen was a 100% match to vouchers of Atlantic Sharpnose (*R. terranova*) collected in Mexico. The second-most observed species was the Scalloped Hammerhead shark, with 46 individuals comprising 14.3% of all identified sharks examined (Fig. 2). All Scalloped Hammerhead sharks were presumed immature based on their small size and ranged from 57–108 cm total length (Fig. 3). All were caught in gillnets (Table 1). On 27 August 2021, eight juvenile hammerhead sharks were sampled at a pescadería and morphological and DNA barcoding assessment (following Wong et al., 2009) showed that four were Scalloped Hammerhead sharks and four were Great Hammerhead sharks (*S. mokarran*). The size ranges of the Scalloped Hammerhead sharks were 66.5 cm to 77.0 cm TL and the Great Hammerhead sharks were 73.5 cm to 78.5 cm TL. The Great Hammerhead sharks all had a recently healed umbilical scar, indicating that these sharks were young-of-year (Fig. 4). The fisher reported that these hammerheads were caught in a single gillnet on the north coast.

4. Discussion

We show that there is a substantial and consistent targeted shark fishery in Puerto Rico. This fishery operates to meet local demand for shark meat, which we document is normally sold for \$7.71 kg⁻¹. We observed a minimum of 3576 kg of sharks at landings sites in 2019. Fins do not appear to be a primary product or driver of this fishery, as we rarely found fins on sale and observed instances of fishers cleaning sharks and discarding the fins. The dominant species in this fishery by weight are Tiger, Sharpnose and Blacktip sharks, with Tiger sharks mainly being caught with longlines and the other two species being caught mainly with gillnets. The large volume of Sharpnose sharks is driven by high catches, whereas a small catch of large individuals underpins the importance of Tiger and Blacktip sharks. The importance of Tiger sharks aligns with a recent haphazard retail market survey of shark meat in Puerto Rico that recorded this species in 32% of samples (Rodríguez et al., 2022). The nearly uniform price of shark meat available at seafood vendors/ local fish markets for sale to consumers indicates that weight is the main determinant of price; thus, these species are also the most valuable overall. Tiger and Blacktip sharks are not federally prohibited and are part of shared regional stocks beyond Puerto Rico (Bernard et al., 2021; Legare et al., 2020), which means interjurisdictional assessment and management will be required to ensure sustainability of the fishery. These two species represent optimal targets for a potentially sustainable fishery in Puerto Rico because fishers obtain high yields from catching a small number of large individuals, many of which are likely mature.

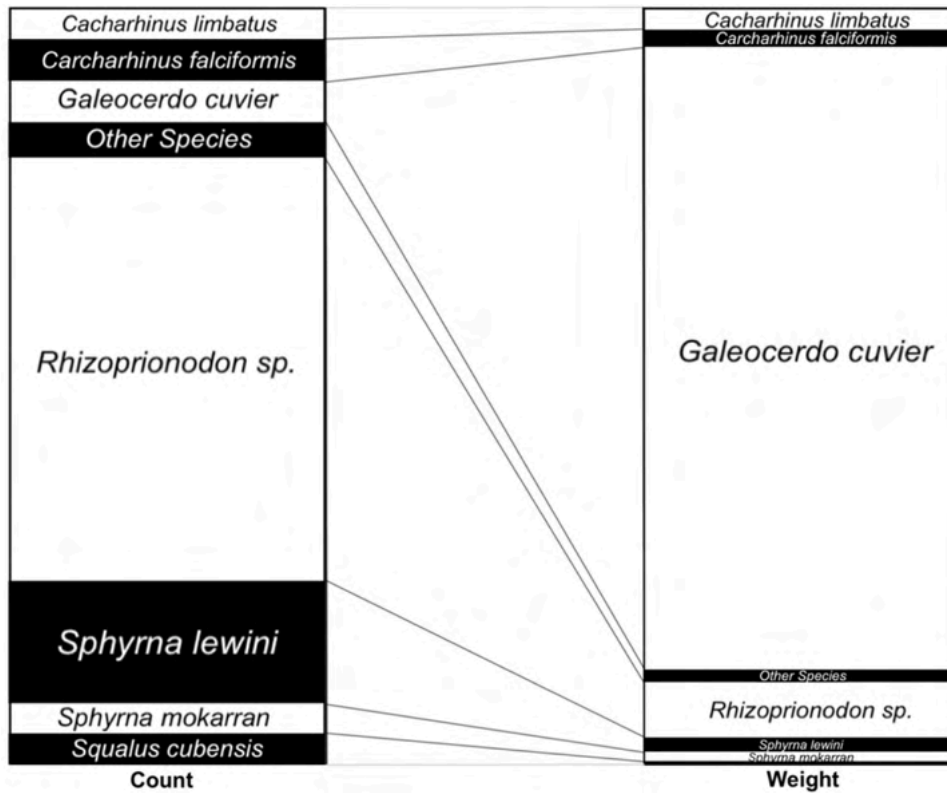


Fig. 2. Relative species contributions to observed shark landings from February 2019 to August 2021 by count of individuals (left) and aggregated weight (right).

In terms of numbers the most landed of 16 recorded species were Sharpnose sharks, with most individuals above the size at first maturity when caught and a strong skew towards males. The species identity of most caught Sharpnose sharks was not determined because there are no known diagnostic field characters available but six of seven specimens subject to DNA barcoding matched voucher sequences of the Caribbean Sharpnose shark. They also matched 3 Brazilian Sharpnose sharks sequences mined from GenBank taken from unvouchered specimens, which we consider to likely be misidentifications of Caribbean Sharpnose sharks. One Puerto Rico specimen was identified as Atlantic Sharpnose shark. Retention of Caribbean but not Atlantic Sharpnose sharks is prohibited in federal waters, but it is likely that the fishery is mainly catching Sharpnose in territorial waters using gillnets. Scalloped Hammerheads were the second-most landed species and all those observed were juveniles caught in gillnets. Many were close to the size at birth indicating that parturition occurs in Puerto Rico territorial waters. Young-of-the-year Great Hammerheads are also caught in the gillnet fishery in some of the same locations as Scalloped Hammerheads. Scalloped Hammerheads are known to use coastal habitats such as bays and river mouths as nursery areas in other parts of the world (e.g., [Corgos and Rosende-Pereiro, 2022](#)), while Great Hammerhead nursery areas are not well characterized ([Macdonald et al., 2021](#)). Mapping and characterizing the habitat of juvenile Hammerheads around Puerto Rico using established criteria (i.e., [Heupel et al., 2007](#)) could lead to the delineation of nursery areas for these species in Puerto Rico territorial waters.

Our study reveals that most of the landed weight and value of this fishery consists of non- prohibited species (Tiger and Blacktip sharks) but there are ongoing landings of federally prohibited species (including Caribbean Sharpnose sharks and ESA-listed Scalloped Hammerheads). Resolving jurisdictional ambiguity is therefore a priority for this fishery: if federal regulations were uniformly applied to territorial waters, then most individual sharks landed in fishery would be prohibited. The fishery would then need to reduce or eliminate landings of species like

Caribbean Sharpnose sharks and Scalloped Hammerheads and focus on species like Tiger and Blacktip sharks. More work on the species identity and status of Sharpnose sharks in Puerto Rico is needed to guide whether the federal prohibition on Caribbean Sharpnose sharks should be extended to territorial waters, an action that would criminalize retention of one of the most common and valuable species in this fishery. This study shows that the inshore gillnet fishery in Puerto Rico primarily lands adult males, which suggests sex segregation occurs (e.g., [Mattos et al., 2001](#)). It is possible that a habitat refuge from fishing exists for adult female Sharpnose sharks in Puerto Rico, which might promote sustainability and support an allowance of territorial landings of Caribbean Sharpnose sharks. In contrast, the federal prohibition of Scalloped Hammerheads should unquestionably be applied to territorial waters because fishing mortality that could impede DPS recovery is legally required to be addressed under the Endangered Species Act. Removing this species from the landings by itself would have limited economic and social impact because they contribute very little volume and value. However, they are mainly caught indiscriminately in gillnets alongside Blacktip and Sharpnose sharks, and teleosts that are more important to fisher livelihoods. One way to remove this species would be for the fishery to switch to targeting larger Tiger sharks with longlines and reducing or eliminating gill netting in shallow nearshore habitats. The cost of this would be the loss of Sharpnose and Blacktip shark landings, which is an important consideration given the numbers landed and their aggregated weight. It would be useful to further investigate whether it is possible to target Sharpnose and Blacktips while avoiding Scalloped Hammerheads. Possible approaches include changing fishing gear (e.g., replacing gillnets with longlines fitted with hooks large enough to catch Sharpnose and Blacktip sharks but too large for juvenile Hammerheads) or by setting gillnets in habitats where hammerheads are less common, if interspecific habitat segregation occurs. For example, Hammerhead nursery areas may be limited to certain locations around the island where existing fishing regulations already provide necessary legal protection (e.g., near river mouths [e.g., [Corgos and](#)

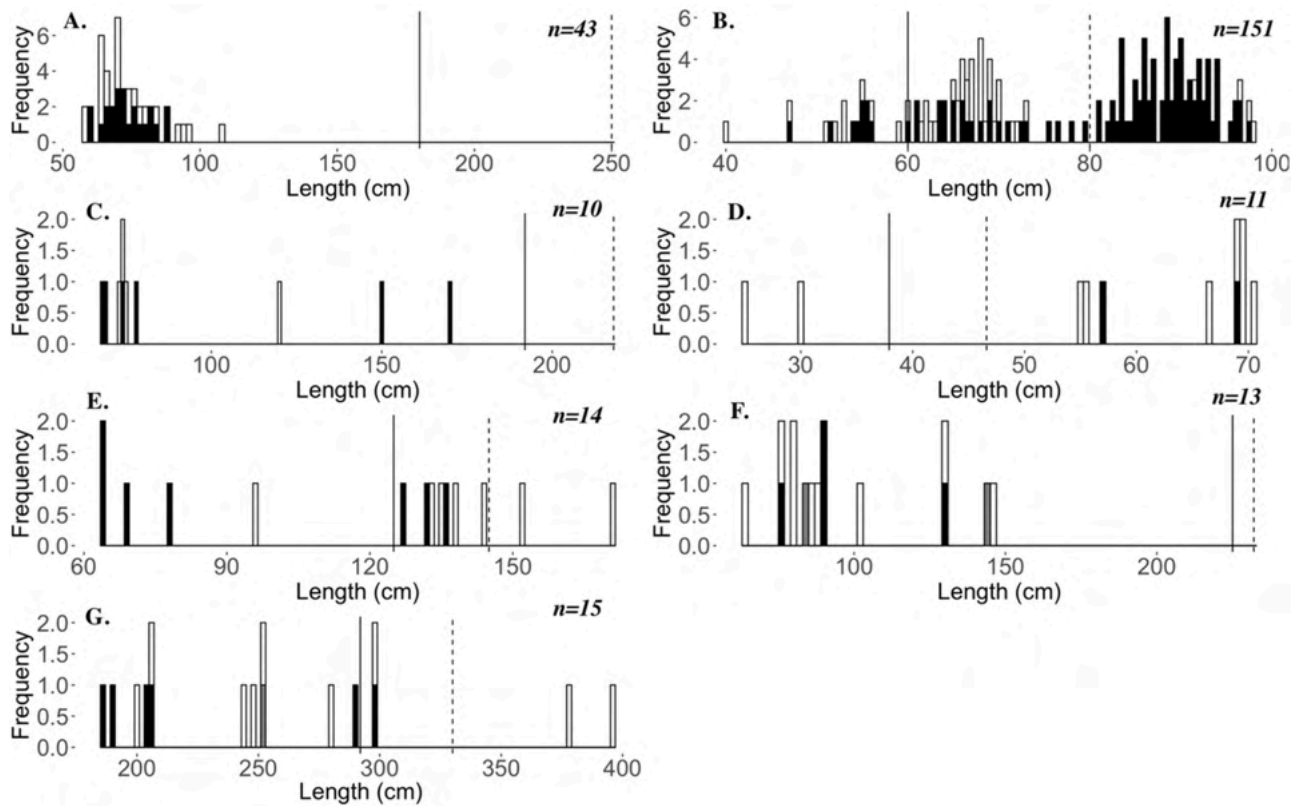


Fig. 3. Length frequency of observed catches of top caught species: A. Sharpnose sharks (*Rhizoprionodon* spp.), B. Scalloped Hammerheads (*Sphyrna lewini*), C. Great Hammerhead (*Sphyrna mokarran*), D. Cuban Dogfish (*Squalus cubensis*), E. Blacktip sharks (*Carcharhinus limbatus*) F. Silky sharks (*Carcharhinus falciformis*), and G. Tiger sharks (*Galeocerdo cuvier*). Observations of males are solid and females are open. If sex was not determined, but length was acquired the observations of those individuals are in greyscale. Lengths at first maturity are indicated by solid and dashed vertical lines for males and females respectively and were obtained from <https://www.sharkipedia.org>.

Table 2

Sex ratio of most landed species. Raw numbers are males: females. Significant deviations from unity (p-value < 0.05) are starred.

Species	Male	Female	Ratio p-value
<i>Rhizoprionodon</i> sp.	109	42	4.77E-08*
<i>Sphyrna lewini</i>	23	23	1
<i>Galeocerdo cuvier</i>	9	6	0.6072
<i>Carcharhinus falciformis</i>	9	4	0.2668
<i>Carcharhinus limbatus</i>	7	7	1
<i>Squalus cubensis</i>	2	9	0.06543
<i>Sphyrna mokarran</i>	6	4	0.7539

Rosende-Pereiro, 2022]) and it may be possible to close these areas to shark fishing or netting but permit netting in other locations where Sharpnose and Blacktip sharks occur.

5. Conclusions

We recommend continued engagement among stakeholders in Puerto Rico to achieve a legal, transparent, and sustainable fishery. First and foremost, it is necessary for territory and federal management bodies to better align species prohibitions to ensure management objectives are met and to promote clarity for fishers and enforcement agents. Areas of concern in this fishery are the ongoing landings of HMS prohibited species, in particular ESA listed Scalloped Hammerheads, from territorial waters in gillnets. Because this gear is non-selective for species and usually lethal when set for long periods, understanding where catch rates of problem species are highest is a first step to mitigating catches. The second step is to engage with the fishers to develop practical ways for them to avoid problem species while minimizing



Fig. 4. Juvenile Great Hammerheads (*Sphyrna mokarran*, left) and Scalloped Hammerheads (*S. lewini*, right), each one of four of the same species, observed in a pescadería in August 2021 that were caught in the same gillnet set on the north coast of Puerto Rico.

livelihood impacts. Other species in the fishery, with a few exceptions, are legal to harvest and many of them are larger, landed at adult sizes, and yield more meat per individual than juvenile Hammerheads. Focusing this fishery on high yield, non-prohibited species could provide sustainable production with limited impacts on threatened shark species, while helping secure food and livelihoods for people.

CRedit authorship contribution statement

Chapman Demian: Writing – review & editing, Writing – original

draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Espinoza Raimundo:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Schoen Sara N.:** Writing – review & editing, Investigation, Formal analysis, Data curation. **Morris Jack:** Supervision, Project administration, Methodology, Investigation, Conceptualization. **Hueter Robert:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Hagan Valerie:** Writing – review & editing, Methodology, Investigation. **Abrams Rodolfo:** Writing – review & editing, Supervision, Methodology, Investigation. **Soto Martin:** Writing – review & editing, Visualization, Methodology, Investigation, Conceptualization. **Sotomayor Paola:** Writing – review & editing, Investigation.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: [Table 2](#): Sex ratio of most landed species. Raw numbers are males: females. Significant deviations from unity (p -value < 0.05) are starred.

Data Availability

Data will be made available on request.

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