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Contributed Paper

Using fisher-contributed secondary fins to fill critical shark-fisheries data gaps

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Abstract: Developing-world shark fisheries are typically not assessed or actively managed for sustainability; one fundamental obstacle is the lack of species and size-composition catch data. We tested and implemented a new and potentially widely applicable approach for collecting these data: mandatory submission of low-value secondary fins (anal fins) from landed sharks by fishers and use of the fins to reconstruct catch species and size. Visual and low-cost genetic identification were used to determine species composition, and linear regression was applied to total length and anal fin base length for catch-size reconstruction. We tested the feasibility of this approach in Belize, first in a local proof-of-concept study and then scaling it up to the national level for the 2017–2018 shark-fishing season (1,786 fins analyzed). Sixteen species occurred in this fishery. The most common were the Caribbean reef (*Carcharhinus perezi*), blacktip (*C. limbatus*), sharpnose (Atlantic [*Rhizoprionodon terraenovae*] and Caribbean [*R. porosus*] considered as a group), and bonnethead (*Sphyrna cf. tiburo*). Sharpnose and bonnethead sharks were landed primarily above size at maturity, whereas Caribbean reef and blacktip sharks were primarily landed below size at maturity. Our approach proved effective in obtaining critical data for managing the shark fishery, and we suggest the tools developed as part of this program could be exported to other nations in this region and applied almost immediately if there were means to communicate with fishers and incentivize them to provide anal fins. Outside the tropical Western Atlantic, we recommend further investigation of the feasibility of sampling of secondary fins, including considerations of time, effort, and cost of species identification from these fins, what secondary fin type to use, and the means with which to communicate with fishers and incentivize participation. This program could be a model for collecting urgently needed data for developing-world shark fisheries globally.

Keywords: anal fins, body length regression, length frequency, shark conservation, shark fishery management, shark fins

Uso de Aletas Secundarias Proporcionadas por Pescadores para Llenar Vacíos Importantes de Información sobre las Pesquerías de Tiburones

Resumen: Con frecuencia no se evalúan las pesquerías de tiburones del mundo en desarrollo ni cuentan con un manejo activo de sustentabilidad. Uno de los principales obstáculos para esto es la falta de información sobre las especies y la composición de los tamaños en las capturas. Probamos e implementamos una estrategia nueva y potencialmente aplicable en todas partes para la recolección de estos datos: la entrega obligatoria de las aletas

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secundarias de bajo valor económico (aletas anales) obtenidas de los tiburones desembarcados por parte de los pescadores y el uso de estas aletas para reconstruir las especies y tamaños en la captura. Usamos identificaciones genéticas de bajo costo e identificaciones visuales para determinar la composición de las especies y aplicamos una regresión lineal a la longitud total y a la de la base de la aleta anal para la reconstrucción del tamaño en captura. Probamos la viabilidad de esta estrategia en Belice, primero en un estudio de prueba de concepto y después subiendo al nivel nacional para la temporada de pesca de tiburón 2017–2018 (1,786 aletas analizadas). Se registraron 16 especies en esta pesquería. Las más comunes fueron *Carcharhinus perezi*, *C. limbatus*, *Rhizoprionodon terraenovae* y *R. porosus* (consideradas como un grupo) y *Sphyrna* cf. *tiburo*. Las últimas tres especies fueron desembarcadas principalmente por encima del tamaño maduro, mientras que con las dos primeras especies lo hacían por debajo del tamaño maduro. Nuestra estrategia demostró ser efectiva en la obtención de información crítica para el manejo de la pesquería de tiburones y sugerimos que las herramientas desarrolladas como parte de este programa puedan ser exportadas a otras naciones en esta región y aplicadas casi de manera inmediata si existen los medios para comunicarse con los pescadores e incentivarlos a proporcionar las aletas anales. Fuera del Atlántico Occidental tropical, recomendamos una mayor investigación de la viabilidad del muestreo de aletas secundarias, incluyendo la consideración del tiempo, esfuerzo y costo de la identificación de especies a partir de estas aletas; cuál tipo de aleta secundaria utilizar; y los medios mediante los cuales comunicarse con los pescadores e incentivarlos a participar. Este programa podría ser un modelo para la recolección de información de necesidad urgente para las pesquerías del mundo en desarrollo.

Palabras Clave: aletas anales, aletas de tiburón, conservación de tiburones, frecuencia de longitud, manejo de pesquerías de tiburón, regresión de longitud corporal

【摘要】: 发展中国家的鲨鱼渔业通常没有得到可持续性评估或积极管理; 其中一项基本障碍是缺乏关于物种和大小组成的渔获数据。我们测试并实施了一种可能广泛适用的新方法来收集这些数据, 即强制渔民上交捕获鲨鱼的低价值次级鱼鳍 (臀鳍), 并利用这些鳍确定捕获的物种及其大小。我们采用目测和低成本遗传鉴定的方法确定了渔获中的鲨鱼物种组成, 并基于体长和臀鳍基部长度的关系用线性回归对捕获鲨鱼的大小进行重建。我们在伯利兹测试了这种方法的可行性, 首先在局部地区进行概念验证研究, 然后在 2017–2018 年的鲨鱼捕捞季将其扩大到国家水平 (共分析 1786 个鱼鳍) 。该地区的渔场中有十六种鲨鱼, 最常见的是加勒比真鲨 (*Carcharhinus perezi*) 、黑边鳍真鲨 (*C. limbatus*) 、斜锯牙鲨 (大西洋斜锯牙鲨 [*Rhizoprionodon terraenovae*] 和加勒比斜锯牙鲨 [*R. porosus*] 被认为是一个群体), 以及窄头双髻鲨 (*Sphyrna* cf. *tiburo*) 。捕获的斜锯牙鲨和窄头双髻鲨的大小多数超过成年体型, 而加勒比真鲨和黑边鳍真鲨则大多低于成年体型。结果证明, 我们的方法可以有效地获得关键数据以管理鲨鱼渔业, 我们还建议将该项目开发的工具出口到该地域的其他国家, 且如果有与渔民沟通和激励他们提供臀鳍的渠道, 则可以立刻采取应用。在热带大西洋西部以外, 我们建议进一步研究对次级鱼鳍进行采样的可行性, 包括考虑时间、工作量、用鱼鳍进行物种鉴定的成本、使用什么鳍片类型以及采取什么方式与渔民沟通和激励参与。这个项目可以为全球发展中国家鲨鱼渔业收集迫切需要的数据提供范本。**【翻译: 胡怡思; 审校: 聂永刚】**

关键词: 鲨鱼渔业管理, 鱼翅, 臀鳍, 体长回归, 鲨鱼保护, 长度频率

Introduction

Sharks are targeted in many maritime countries for their fins, meat, and other products, and the majority of global capture is from low-income nations (Momigliano et al. 2014; Simpfendorfer & Dulvy 2017). There is evidence of widespread declines of exploited, unmanaged shark populations, and currently there are no documented examples of sustainably managed shark fisheries outside developed nations that conduct stock assessments and set catch limits for these animals (Simpfendorfer & Dulvy 2017). One of the fundamental requirements of fisheries management is species- and size-specific catch data (Musick et al. 2000; Dulvy et al. 2017), but for most developing-world shark-fishing nations this remains a critical information gap (Momigliano et al. 2014).

Studying the species composition of trade hubs can cost-effectively provide regionally or globally relevant information for shark conservation (e.g., Fields et al. 2018); however, obtaining this information at the scale required for fisheries management (i.e., at the fishery level) presents a logistical and financial challenge for regulatory authorities in many developing nations (Salas et al. 2007). This is especially true when managers are dealing with geographically dispersed, small-scale fishers, who individually contribute a minor amount to the total shark catch and land sharks in remote areas (e.g., Pérez-Jiménez & Mendez-Loeza 2015; Humber et al. 2017). In such cases, observer programs, frequent visits to landing sites, and other approaches for documenting catch can be useful but have high capacity requirements (Salas et al. 2007). One solution to this problem is to require these fishers to report their landings to the regulatory authority (e.g., through logbooks); however, this can be problematic when fisheries are composed of multiple species that are difficult to identify and where literacy is low and communication networks between fishers and government agencies are underdeveloped

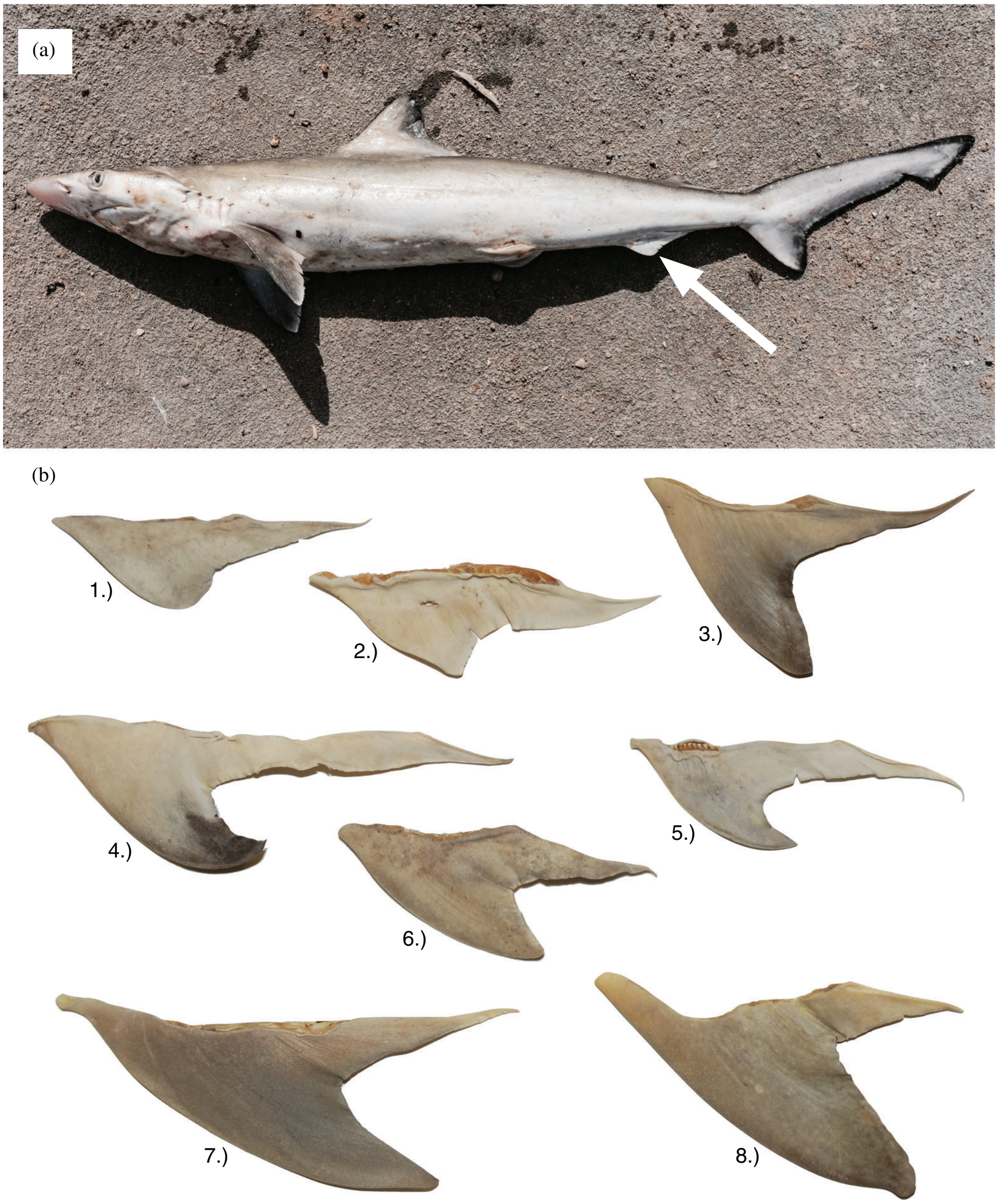

Figure 1. (a) Location of anal fin on a shark and (b) anal fins from 9 landed species (1, sharpnose sharks; 2, bonnethead shark; 3, Caribbean reef shark; 4, great hammerhead shark; 5, scalloped hammerhead shark; 6, blacktip or blacknose shark; 7, tiger shark; 8, lemon shark).

(Salas et al. 2007). Fishers also tend to report catches by aggregated species weights rather than by catches of individuals of known size and maturity, which can be less informative for management.

We devised an alternative approach for obtaining essential species and size-composition data on shark fisheries that requires fishers to remove and store anal fins (a secondary fin) (Fig. 1a) from each landed shark and periodically submit them to the regulatory authority. Secondary fins have little to no commercial value, which means fishers will not lose substantial income from participating. A combination of morphological identification, DNA testing, and regressions of fin size to body size can be used to reconstruct the fishery's species and size-composition from these fins (Clarke et al. 2006). We successfully implemented the approach in Belize, which provided novel information on their domestic shark fishery, and considered how other nations could adopt this type of program to obtain critical information necessary to manage their shark fisheries.

Methods

Belize Shark Fishery

Belize is a small Central American nation on the Caribbean Sea, which is bordered by 2 more populous and major shark-trading nations (Mexico to the north and Guatemala to the west and south) (Dent & Clarke 2015). There is a seasonal shark fishery in Belize (1 November −30 August) that employs ~75 fishers who work in small groups of 3–10 that are all permitted to fish the same managed-access areas based on their traditional use of the area (Fujita et al. 2017) (Supporting Information). All fishers are individually required to hold an annually renewed shark-fishing license and each group is required to submit a logbook of the aggregated weights of sharks landed by species. A group representative obtains an export license and then transports salted meat and dried fins by sea to Guatemala, largely focusing export there because it is closer to the primary shark-fishing communities in southern and central Belize. Many of the Belizean shark fishers also have family and business connections in Guatemala (Zeller et al. 2011). Salted shark meat is mainly consumed during the Catholic Lenten season (March-April), with the dried fins being re-exported to Asia for use in shark fin soup (Zeller et al. 2011). To target sharks, Belizean shark fishers are permitted to use monofilament gillnets no longer than 91.44 m long. There are no restrictions on mesh size, length of longlines, number of hooks, or hook size. Mesh size on gillnets are generally 5–10 cm, and longline hooks are from 10/0 to 18/0. All gear types catch a wide range of sizes of sharks (D.C. and J.Q., personal observation). Gillnets are anchored to the bottom, and longlines are usually anchored to the bottom when fishing inside or along the barrier reef or inside atolls. Some fisher groups also drift longlines in pelagic waters (D.C. and J.Q., personal observation). Most fisher groups form camps on islands near their fishing grounds and use both longlines and gillnets. The catch is processed at these camps before being transported to the mainland or border, making it difficult for regulatory agencies to directly collect species- and size-specific catch data without permanently stationing someone at these remote camps or making frequent inspections. With emerging evidence that the fishery has depleted some species (Caribbean reef shark [*Carcharhinus perezi*]) (Bond et al. 2012), recent international treaty obligations (e.g., Convention on International Trade of Endangered Species [CITES]), and growing environmentalist and public concern about sharks in Belize (Craft 2016), there is heightened interest in improving shark fisheries management. There is sparse and relatively outdated information on the species and size composition of the catch (Pikitch et al. 2005; Zeller et al. 2011), which limits implementation of fisheries management measures. These basic conditions and obstacles are almost universal in developing-world shark fisheries (e.g., Pérez-Jiménez & Mendez-Loeza 2015; Humber et al. 2017).

Secondary Fin Sampling

From 2007 to 2011, we sought to determine the feasibility of obtaining and identifying secondary fins from a group of shark fishers that camped and fished at Turneffe Atoll (Area 6 [Supporting Information]). The group leader was asked to excise the anal fin (Fig. 1a) from all landed sharks, dry them in the sun, and store them in a dry plastic bag until we could collect them twice a year. We compensated this representative at US$0.50 per fin, which was enough to incentivize fin collection, not enough, we believed, to affect fishing effort given that the compensation was trivial compared with the value of their catch. After reviewing the results of the feasibility study, the Belize Fisheries Department (BFD) adopted the program and requested that all groups of licensed shark fishers collect anal fins in a similar manner and have a representative submit them when they renewed their license in Belize City in December–January. Fishers were not compensated for these efforts, but the BFD indicated to the fishers that approval of future licenses for individuals was partly conditional on regular submission of these fins by their fisher group to BFD.

Fin-Based Species Identification

All anal fins were first visually sorted, and similar-looking fins were grouped together. We then hypothesized the species identity of each fin type based on inspections of anal fins of live animals captured in Belize (e.g., Pikitch et al. 2005; Chapman et al. 2011) and photographs. The hypothetical species identity was then tested for individual fins through cytochrome oxidase I gene (COI) DNA barcoding conducted with universal primers from and following the protocol of Ward et al. (2005). The DNA was extracted using the Qiagen DNAeasy kit (Qiagen, Valencia, California); specifically, the manufacturer's protocol for animal tissues was used. In the case of fin tissue that was desiccated and hard to cut with a scalpel, the protein digestion step was extended by 2–4 hours by adding an additional 10 μL of Proteinase K halfway through the digestion. Bidirectional Sanger DNA sequencing was carried out on an ABI 3730xl DNA Analyzer (Thermo Fisher Scientific, Waltham, MA, U.S.A.). The resulting COI sequences were used as query searches in freely available online databases: BLAST of National Center for Biotechnology (NCBI) GenBank (https://blast.ncbi.nlm.nih.gov/Blast.cgi) and species-level barcode records from BOLD of the Fish Barcode of Life Initiative (http://www.boldsystems.org). Species identity was confirmed when the unknown sequence had a 100% percent-identity match with a single species in GenBank, and BOLD indicated this species diagnosis was certain. We then further examined the fins for morphological characters that reliably distinguished them. These characters included overall shape, apex coloration, texture, and fin height-to-base ratio (Supporting Information).

Anal fins were submitted to BFD by fisher group representatives from December 2017-August 2018. Each representative's name, home address, and managed-access areas they were permitted to fish in were recorded. Individual fins were first identified using morphological characters established in the feasibility study. Unusual looking or damaged fins were later identified using a DNA barcoding protocol modified for degraded DNA (Fields et al. 2015). The DNA was extracted by incubating small pieces of tissue, approximately 2 mm^2 in 200 μL of 10% Chelex100 Resin (Bio-Rad Laboratories, Hercules, CA, U.S.A.) at 60°C for 20 minutes and then at 99°C for 25 minutes. Sequencing and sequence identification were performed as previously described. Some form of genetic testing was routinely needed for 3 species pairs: Atlantic sharpnose (*Rhizoprionodon terraenovae*) and Caribbean sharpnose (*R. porosus*), scalloped hammerhead (*Sphyrna lewini*) and great hammerhead (*Sphyrna mokarran*), and blacktip (*Carcharhinus limbatus*) and blacknose (*Carcharhinus acronotus*) sharks. The sharpnose species are small bodied, have broadly similar life-history traits, and are difficult to identify even as whole animals (Mattos et al. 2001; Carlson & Baremore 2003). Given that they are both highly productive, we elected to group them for the purpose of this study, and no genetic analyses were conducted to separate the 2 species. Hereafter, use of *sharpnose* refers to the grouping of Atlantic and Caribbean sharpnose sharks. The blacktip and blacknose sharks are morphologically distinct from all other species but visually indistinguishable from one another. The mini-DNA barcoding assay outlined in Fields et al. (2015) was used to determine species of origin of all fins in this category. The protocol yields 2 amplicons: the entire COI and a smaller amplicon within the COI. The blacktip and blacknose shark exhibit ~5% sequence divergence within the smaller amplicon, and we used our own reference sequences to resolve which of these 2 species the fin came from. For the species pair, great and scalloped hammerhead, we employed a real-time PCR protocol to rapidly and cost-effectively (~US$1 per anal fin) identify them to the species level. With this technique target-specific primers and fluorescent dyes are used to determine whether PCR amplification occurred due to the presence of the target's nucleic acid template, which eliminates the need for sequencing (Cardeñosa et al. 2018). The last stage of this protocol generates melt curves; their shape and melt temperature were used to determine which species was present (i.e., scalloped or great hammerhead) (Cardeñosa et al. 2018).

Body-Size Regression

We investigated the possibility of using the anal-fin base (AFB) to regress the total length (TL) of the individual for the 4 most common species in the fishery: Caribbean reef, blacktip, sharpnose, and bonnethead (*Sphyrna cf. tiburo*) (Fields et al. 2016.). Three visits were made to fishing camps south of Belize City, and these two parameters were measured in whole specimens that had been landed by fishers. We also measured AFB and TL in live sharks captured in Belize, southeastern Florida, and eastern Gulf of Mexico during research operations. We plotted the relationship between parameters for all 4 species by plotting TL by length of the AFB (Fig 2). Anal fins collected were individually measured and the species-specific regression equation was applied to estimate TL of individuals from which the anal fin came. Anal fins were only measured if they were complete (i.e., origin of the fin and free rear tip were both intact). A measuring tape was used to measure a straight line from the tissue in front of the first row of cartilage at the origin of the fin through to the end of the free rear tip. Anal fins can sometimes become curled while drying but in such cases we were easily able to open them to lie in their natural position for measurement. We then used the estimated lengths to reconstruct the length frequency distribution of landings of these species for the 2017–2018 fishing season (Fig. 3). To determine what individuals were caught above and below length at maturity, length at maturity was sourced from published literature on the closest region to Belize available: Caribbean reef, Tavares (2009); blacktip, Carlson et al. (2006); sharpnose, Mattos et al. (2001), Carlson and Baremore (2003), and Motta et al. (2007); bonnethead, Lombardi-Carlson et al. (2003) (Fig. 3). Only complete anal-fin measurements contributed to the length frequency histograms, but both complete and incomplete anal fins (e.g., missing free rear tip) contributed to the overall counts for each species (Table 2).

Results

Feasibility Study

A total of 408 anal fins were collected in 2007–2011 from the Turneffe Atoll group and assigned, using DNA barcoding, to nine shark species (Table 1). With the exception of the hammerheads hypothetical category that was only sorted to genus, all hypothetical visual species identifications were confirmed as being correct with DNA barcoding. The substantial morphological variation between species enabled many of them to be visually identified to species level with a high degree of confidence, primarily based on shape characters (i.e., falcate or not falcate, fin height relative to base, dusky or black markings on

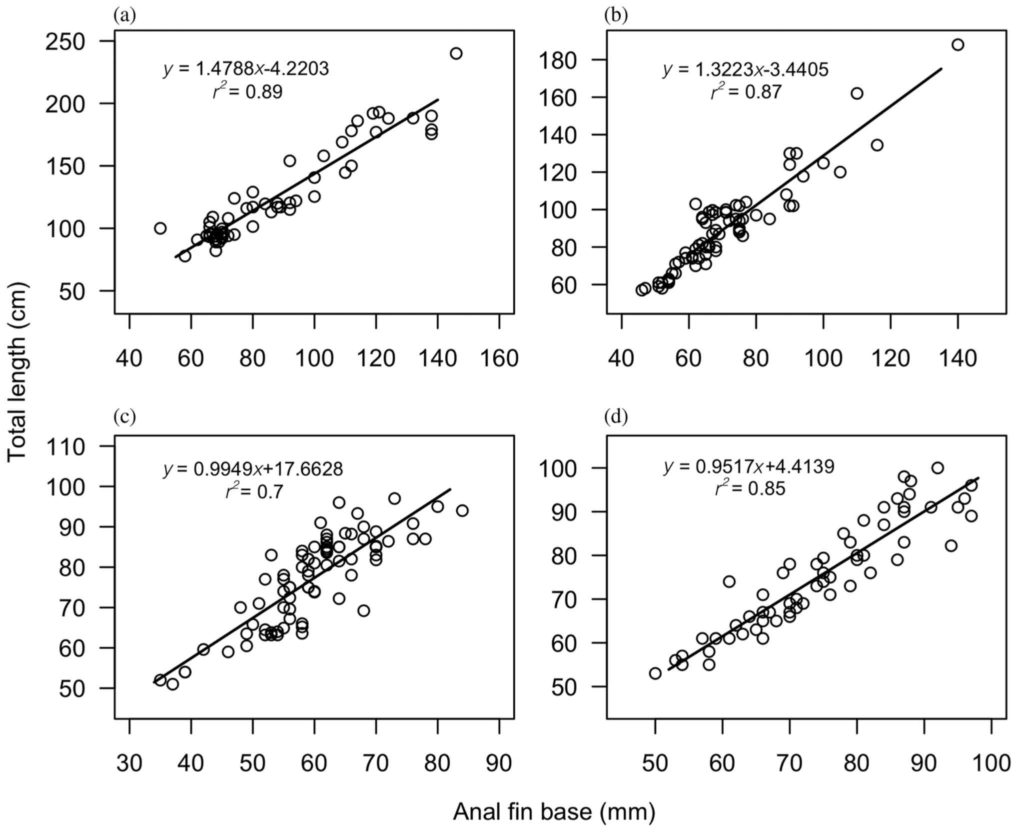

Figure 2. Correlation between total body length and anal-fin base length of the 4 most common sharks caught in Belize fishery: (a) Caribbean reef shark, (b) blacktip shark, (c) sharpnose sharks, and (d) bonnethead shark.

Table 1. Shark species identified through DNA barcoding of tissue from anal fins provided by fishers at Turneffe Atoll ($n = 408$) and a description of key morphological characteristics.

Common name	*Scientific name*	n	*Fin description*
Caribbean sharpnose	*Rhizopriondon porosus*	163	fin height < base, rounded apex
Bonnethead	*Sphyrna cf. tiburo*	2	fin height < base, pointed apex
Caribbean reef	*Carcharhinus perezi*	171	fin height ∼ = base, apex dusky
Blacktip	*Carcharhinus limbatus*	28	fin height ∼ = base, whole fin white
Great hammerhead	*Sphyrna mokarran*	7	falcate
Scalloped hammerhead	*Sphyrna lewini*	2	falcate
Tiger	*Galeocerdo cuvier*	1	fin height ∼ = base, whole fin brown, pointed apex, rough texture
Lemon	*Negaprion brevirostris*	33	fin height ∼ = base, whole fin brown, rounded apex, smooth texture
Bull	*Carcharhinus leucas*	1	fin height ∼ = base, apex black and sharply demarcated, rough texture

fin apex) (Fig. 1b & Supporting Information). The great hammerhead and scalloped hammerhead had highly falcate fins (Fig. 1b & Supporting Information) that could easily be sorted from the other species, but they required genetic identification to resolve them.

Fisheries Monitoring

A total of 1,378 anal fins were submitted to BFD by fishing-group representatives ($n = 13$) from December 2017–August 2018. The 13 fishers who submitted fins each represented one group of 3–10 fishers,

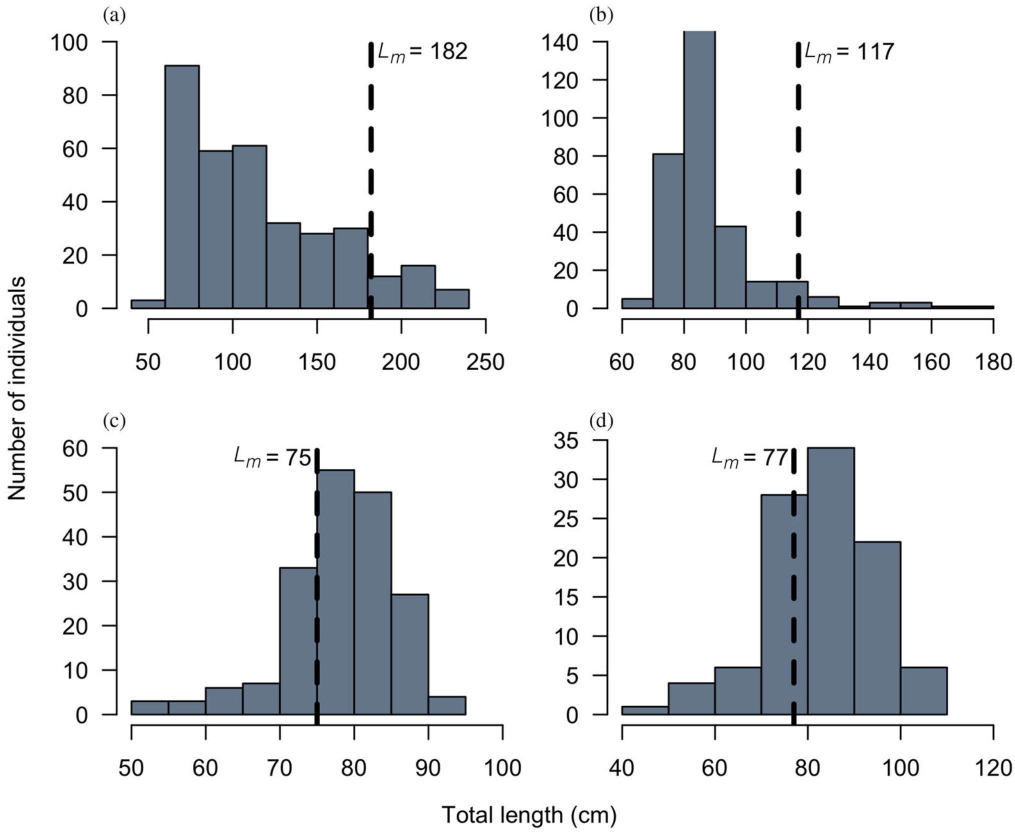

Figure 3. Estimated length frequency of individuals caught from the 4 most commonly landed sharks in the Belize fishery: (a) Caribbean reef shark, (b) blacktip shark, (c) sharpnose sharks, and (d) bonnethead shark (dashed line, length at maturity in centimeters).

Table 2. Shark species and number caught by Belizean fishers nationwide from December 2017-August 2018 ($n = 1{,}378$).

Common name	*Scientific name*	n
Caribbean reef	*Carcharhinus perezi*	465
Blacktip	*Carcharhinus limbatus*	370
Sharpnose	*Rhizoprionodon spp.*	225
Bonnethead	*Sphyrna cf. tiburo*	115
Great hammerhead	*Sphyrna mokarran*	51
Tiger	*Galeocerdo cuvier*	36
Scalloped hammerhead	*Sphyrna lewini*	26
Lemon	*Negaprion brevirostris*	24
Silky	*Carcharhinus falciformis*	18
Blacknose	*Carcharhinus acronotus*	17
Bull	*Carcharhinus leucas*	11
Atlantic sixgill	*Hexanchus vitulus*	6
Dogfish	*Mustelus spp.*	6
Night	*Carcharhinus signatus*	4
Shortfin mako	*Isurus oxyrinchus*	3
Spinner	*Carcharhinus brevipinna*	1

combining all or most of the fins from the fishers at their camp. Participating group representatives came from Belize City, Dangriga, Riversdale, Barranco, Placencia, and Punta Gorda (Supporting Information), covering most of the coastal fishing communities south of Belize City. Every managed access area was represented with the exception of Area 1 (which has only 2 licensed shark fishers) and Area 8 (no licensed shark fishers). There was a positive correlation between the number of licensed shark fishers using each managed access area and the number of representatives that submitted anal fins from that area (linear regression not shown, $r^2 = 0.95$).

Identification efforts, both morphological and molecular, revealed 16 species (Table 2) occurring in the fishery in 2017–2018. Most were identified entirely through morphological characters; genetic testing was required for only a few groups. Blacktip and blacknose were identified using the smaller amplicon (150 base pair), and every anal fin provisionally identified visually as blacktip was successfully extracted and identified to the species level (either blacktip [95.6%] or blacknose [4.4%]). The scalloped and great hammerhead identification based on real-time PCR methods also resulted in 100% success in identifying fins to species level (great [58.6%], scalloped [41.4%]). Unusual and damaged fins, which required molecular identification (150/650 bp), were successfully identified to species or genus (*Mustelus* spp.) in 91.5% of cases, remaining cases failed to amplify after multiple attempts. Nearly all of the less-encountered species, once identified genetically, had anal fins that were visually distinguishable (Supporting Information). Of all fins tested, 97.3% were successfully identified to the species level; 2.7% could not be amplified or sequenced.

There were positive correlations between TL and AFB in all 4 of the common sharks in the fishery: Caribbean reef ($r^2 = 0.89$), blacktip ($r^2 = 0.87$), sharpnose ($r^2 = 0.7$), and bonnethead ($r^2 = 0.85$) (Fig. 2). Sharpnose and bonnethead sharks were primarily landed above size at maturity for these species (Fig. 3), whereas Caribbean reef and blacktip sharks were primarily landed below size at maturity. Overall, ~20% of fins had part of the base cut off and thus could not be measured (Caribbean reef, 27.1%; blacktip, 13%; sharpnose, 16.4%; bonnethead, 12.2%).

Discussion

Collection of anal fins proved to be an effective approach for obtaining species- and size-specific information on shark landings critical for effective science-based management. The anal fins of most landed species, including the most common ones in the fishery, were visually identifiable and could be rapidly and accurately sorted after collection. The DNA testing was required for rarely encountered species the first few times they were obtained, for damaged fins, and for 2 species pairs (blacktip and blacknose and great hammerhead and scalloped hammerhead). The former were identified with the Fields et al. (2015) mini-barcode because the success rate for amplifying degraded DNA with this approach was 100%. The real-time PCR protocol (Cardeñosa et al. 2018) was used to identify the latter to further reduce costs and increase efficiency. This protocol gives near real-time identification, eliminating the need for sequencing, and small real-time thermal cyclers are relatively inexpensive and potentially portable (www.chaibio.com), enabling this type of approach to be employed anywhere with electricity and cover. Overall, DNA testing with barcoding or species-specific PCR is increasingly cost-effective and being used to characterize species composition of shark fisheries worldwide (Bineesh et al. 2017; Cardeñosa et al. 2018; Muttaqin et al. 2019), suggesting that the need for genetic testing for some fins is unlikely to be an insurmountable barrier to adoption of this approach in many countries.

We collected new information on the species composition of the shark fishery of Belize. Future refinements will include sorting anal fins by managed access area where they were caught and by gear type (drift longline, bottom longline, gillnet), which may be facilitated by more frequent submission or collections. The dominant species in terms of number of individuals landed in the Belize shark fishery were Caribbean reef, blacktip, sharpnose (Atlantic and Caribbean combined), and bonnethead sharks, all of which are caught in fisheries throughout the Western Caribbean (Perez-Jimenez & Mendez-Loeza 2015; Hacohen-Domené et al. 2020). Although 100% of sharpnose anal fins collected at Turneffe Atoll were *R. porosus*, we documented a few *R. terraenovae* and one *R. lalandii* in 2017–2018. The latter collection represented a northward range extension for the species. Several additional large-bodied species are present in the fishery, including two (great hammerhead, scalloped hammerhead) that are listed on Appendix II of CITES and as critically endangered by the International Union of the Conservation of Nature (https://www.iucnredlist.org). It is not clear whether all licensed fishers participated in this program because we did not know how many were represented by the anal fins turned in by the 13 participating representatives. We did not consider bycatch and subsistence fishing, but both are minor components of the total shark catch in Belize (Sabbagh & Hickey 2020). Nonetheless, given the large sample size obtained, wide distribution of participating representatives in terms of community of origin, and proportional representation by managed access area, we consider it likely that anal fins provided a representative sample of the species composition of the shark fishery for the 2017–2018 fishing season. This is bolstered by confidential logbooks submitted to BFD by fishing groups in which Caribbean reef, tiger (*Galeocerdo cuvier)*, hammerhead (uncertain species), blacktip, sharpnose, silky (*Carcharhinus falciformis)*, lemon (*Negaprion brevirostis*), bull (*Carcharhinus leucas*), and bonnethead were reported as being the most important species in the fishery by aggregated weight (58,852.6 kg total reported landings [BFD and National Shark Working Group, personal communication]). We detected 6 less frequently encountered species (Table 2) that were not reported in logbooks, and there was only one species reported in logbooks that we did not detect among the anal fins (blue shark [*Prionace glauca*]).

We found a positive correlation between TL and the length of the AFB in the 4 most common sharks in the

Belizean fishery, enabling us to reconstruct the size composition of each of these species in the landings (Figs. 2 & 3). Sharpnose sharks had a lower r^2 (0.70) than the other three species (0.89, 0.87, 0.85), which may be due to the narrower size range of individuals sampled of this species. It could also be due to the potential presence of up to 3 species of sharpnose (Caribbean, Atlantic, and Brazilian) in the fishery. We found that bonnethead and sharpnose sharks were primarily caught at sizes above the size at maturity. We also found that Caribbean reef and blacktips were primarily caught below the size at maturity. The capture of some adult blacktip and Caribbean reef sharks in the fishery indicates that the gear does not exclude larger individuals, which is probably due to the use of both longlines and gillnets that enable capture of a wide size range of sharks. Similarly, large anal fins (>25 cm) from great hammerhead sharks and tiger sharks demonstrated that capture of large animals is possible with the types of longline and gillnet gear being deployed. Segregation of life stages may be a potential cause for the blacktip catch being highly skewed to juveniles. The presence of neonates and juveniles and the near absence of adults has also been reported in other places (Hueter & Manire 1994). In contrast the juvenile skew in Caribbean reef sharks is less likely to be due to segregation of life stages because they all occur in the same reef habitats (Bond et al. 2012). If the length frequency distribution of the landings is an indicator of the length frequency distribution of the population, it suggests that Caribbean reef and blacktip sharks could be overexploited in Belize (Froese 2004). We suggest research and management attention is required for at least these 2 species, which could include measures such as the imposition of species-specific catch limits, lower size limits, gear modifications to reduce catch of juveniles, or closing fishing areas frequented by juveniles of these species.

We were able to successfully implement collection of anal fins in Belize in large measure because shark fishers are regulated through annually renewable licenses, facilitating regular communication among stakeholders. This raises the question: Can this approach be implemented where communications between fishers and regulatory authorities are more sporadic and fisheries management is less developed? We suggest this approach could be implemented widely but would have to be modified to reflect local socioeconomic, cultural, and management conditions. For example, it may be necessary to incentivize anal-fin submission where fishers are not required to hold a shark-fishing license, including situations where sharks are mainly taken as bycatch or for subsistence or there are other barriers to compliance. One potential approach would be to incentivize anal-fin submission by paying for them, as we did in our feasibility study, and making occasional visits to shark-fishing communities to collect them. Dried anal fins were stored for over a year by fishers and still yielded sufficient DNA for identification purposes when needed. Several fishers in our program reported losing some fins, having some consumed by pets or pests, or being forced to throw them out because relatives were complaining about the odor. This indicates that more frequent contact between fishers and collectors from the regulatory agency would be beneficial. Of course, this approach is not a panacea, and there are some places where implementation barriers may be insurmountable, for example, fishers are hostile to regulatory authorities or the number of shark fishers is so high that widespread anal-fin submission would be extremely difficult to operationalize. Whereas the former requires engagement with these problems prior to implementing any type of fisheries monitoring or management, the latter problem could be addressed by adjusting the objective to obtaining a random sample of fishers as opposed to achieving widespread adoption or by operationalizing it at a local or state level as opposed to a national level. Overall, the widespread lack of data for most shark fisheries worldwide (Dent & Clarke 2015) suggests that even a partial adoption of this approach could be a worthwhile investment in many places.

Implementing this approach outside Belize will require some consideration of the species and size composition of the fishery, how easily anal fins can be identified, and geographic variation of size at maturity. The species occurring in the shark fishery of Belize are also commonly fished in other parts of the subtropical and tropical Western Atlantic (e.g., Bonfil 1997; Tavares 2009; González-Sansón et al. 2017). The anal-fin morphological keys and regression equations from this study could therefore be used in other countries with minimal modification, unless there are look-alike anal fins not encountered for these species in Belize. The relationship between total length and length of the anal fin base we developed is potentially useful for these species regardless of region of origin, although we recommend additional data collection to build as robust as possible TL–AFB correlations. Because size at maturity can be geographically variable we recommend using maturity data from sharks taken from as close as possible to the fishery area. We also recommend caution in assigning maturity in situations where regressed body lengths are close to the size at maturity for the species (i.e., most landings are from subadult sharks). Adopting this approach outside the subtropical and tropical Western Atlantic, in the Eastern Atlantic or Indo-Pacific regions, would first require studies of the morphology of the anal fins of species in their fisheries to determine how many species could be identified visually. Diversity of shark species is higher in the Indo-Pacific than the Atlantic, which could result in a higher proportion of ambiguities in anal-fin identification that could only be resolved with DNA testing. However, as in Belize, it is common for these fisheries to be highly skewed to a small number of common species (e.g., Appleyard et al. 2018), which in some cases could facilitate visual identification of most of the anal fins. The DNA testing could then be reserved for rarer types and ambiguities among common species. There is also 1 order of sharks, the Squaliformes, that lack anal fins. If these species were a major part of any fishery, another fin type (e.g., pelvic, second dorsal) would have to be collected. Finally, it is a more common practice outside the Caribbean for fishers to sell secondary fins for export as a low-value fin product (Cardeñosa et al. 2019). If this occurs in the fishery of interest there would be a need to incentivize submitting these fins to the regulatory agency as opposed to selling them, most likely by making submission a legal requirement or paying more per fin than their commercial value (likely <US$1 per fin). Although implementing a sampling program of this type requires careful design and some initial feasibility work, we do not envision insurmountable scientific barriers to achieving this in many shark-fishing nations.

Our results revealed important concerns about the sustainability of the domestic shark fishery in Belize : 2 of the 4 top species are commonly captured below the size at maturity and 2 additional species that are commonly caught are critically endangered and listed under CITES Appendix II. Our results provide a baseline from which to track changes in the species and size composition of the catch, which could be used to assess the effects of new regulations (e.g., an upcoming national phase out of monofilament gillnets and CITES implementation). We suggest that the tools developed as part of this program could be exported to other nations in this region and applied almost immediately if there were means to communicate with fishers and incentivize a sample of them to provide anal fins. Outside the tropical Western Atlantic, we recommend further investigation of the feasibility of sampling of secondary fins, including considerations of the time, effort, and cost of species identification from these fins, what secondary fin type to use, and the means to communicate with fishers and incentivize participation. Most importantly sampling of this nature could provide information that is fundamental for moving toward sustainable management of shark fisheries outside of highly developed countries, which is an important environmental and economic goal all over the world (MacNeil et al. 2020).

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Supporting Information

Managed-access fishing areas along the coast of Belize (Appendix S1), a map of Belize with locations of Turneffe Atoll and the coastal communities representatives were from (Appendix S2), and a key to identify shark species in Western Caribbean shark fisheries based on anal-fin morphology (Appendix S3) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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