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REDUCING ELASMOBRANCH BY—CATCH IN THE ATLANTIC SEABOB (*XIPHOPENAEUS KROYERI*) TRAWL FISHERY OF GUYANA†

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Abstract: The Atlantic seabob *(Xiphopenaeus kroyeri)* trawl fishery is very important to Guyana, with 88 licensed industrial vessels harvesting about 15,000 mt annually, representing Guyana's most valuable seafood export. All vessels are already using both teleost by—catch reduction devices (BRDs) and turtle excluder devices (TEDs) to satisfy international market standards. However, the key stakeholder, the Guyana Association of Private Trawler Owners and Seafood Processors, is now seeking to access sustainable seafood markets through pursuing Marine Stewardship Council (MSC) certification. To this end, this study documents elasmobranch by—catch in the current fishery and examines the effectiveness of a modified TED (with a reduced bar spacing and the addition of a brace bar) in reducing elasmobranch by—catch. From July—August 2014, 131 tows were made, 80 of which represented simultaneous hauls with control and modified TEDs. One shark and 8 ray species were recorded. A statistically significant 40% decline in the elasmobranch catch rate was observed when using modified TEDs compared with control TEDs (mean by—catch rate dropped from 2.3 to 1.4 individuals per twin—trawl/h). Furthermore, modified TEDs significantly reduced the mean size of rays caught by 6.3%. This also resulted in a virtual elimination of 3 IUCN—designated 'Near Threatened' ray species in the by—catch, although having little effect on the capture of small—sized elasmobranch species, including the 'Critically Endangered' Caribbean Electric Ray *(Narcine bancroftii)*. We conclude that the modified TED was successful in reducing the by—catch of vulnerable elasmobranch species and should advance progress towards attaining by—catch standards required for MSC certification.

Key words: ray, shark, shrimp trawl fishery, TED, by—catch reduction

Introduction

The marine fisheries of Guyana comprise an offshore industrial trawl fishery for penaeid shrimps (numbering around 100 vessels), a semi—industrial deep slope fishery for Red Snapper (*Lutjanus campechanus*, numbering less than 50 vessels) and an inshore artisanal fishery for a variety of shrimp and finfishes (numbering around 1,200 vessels) as described in various national reports (e.g., Shepherd et al. 1999, FAO 2005, Greer 2005, Richardson 2013, MacDonald et al. 2015, Maison 2016). One of the most important species harvested is the Atlantic seabob shrimp (*Xiphopenaeus kroyeri*), targeted by both the inshore artisanal (Chinese seine vessels) and the offshore industrial trawl fleet, although 98% of the landings are taken by the industrial fleet (Richardson 2013). Offshore industrial trawling for Atlantic seabob began in Guyana in the mid—1980s, and the current fleet comprises 88 locally—owned, licensed seabob trawlers. The vessels are steel—hulled, standard Gulf of Mexico—type trawlers of 19—23 m in length and powered by inboard diesel engines. Since the late 1990s they have been using a quad—rig setup with 2 sledges to tow 4 trawls simultaneously (2 twin—rigs on each side of the vessel). The trawlers generally make 2—3 trips a month (about 30 per year). Trips vary in length from 3—4 days at the peak of the season (December—February) to 8—10 days when fishing is poorer. They fish 24 hours a day, generally making 4—6 hauls per day of 3—4 hour duration. Almost all of the annual harvest of around 15,000 mt is exported to the USA and European Union as frozen shell—off tails and is valued at around US$45 million per year, representing Guyana's most valuable seafood export (Maison 2016).

The shared shrimp and finfish resources of the Guianas—Brazil shelf have received considerable attention over the last few decades through the efforts of various joint scientific working groups. The most recent stock assessment was conducted in 2012/2013 (CRFM 2013) and supported the development of harvest control rules for this fishery (Medley 2014).

Stock assessments in the early 2000s raised concerns about the sustainability of the industrial trawl fishery operating at that time and indicated a need for better management, including a reduction in fishing effort (CRFM 2007). In response, the industrial seabob fleet size in Guyana was reduced by about 20% and an improved fishery management plan for the period 2013—2017 was developed under the EU—ACP Fish II Project, that included a requirement for all Atlantic seabob vessels to be equipped with vessel

†*This article is based on a presentation given in November 2014 at the 67th annual Gulf and Caribbean Fisheries Institute conference in Christ Church, Barbados*

monitoring surveillance (VMS) systems and additional by—catch reduction devices (BRDs) (SOFRECO 2013, Richardson 2013). This is essential for maintaining the standards required for product export to the major international markets. The key stakeholder in the industrial fishery, the Guyana Association of Private Trawler Owners and Seafood Processors (GAPTO&SP), is now seeking to access sustainable seafood markets, through pursuing Marine Stewardship Council (MSC) certification (Maison 2016), following the successful certification of the Atlantic seabob fishery in neighboring Suriname (Southall et al. 2011). By—catch reduction is particularly important for attaining MSC certification, since shrimp trawl fisheries are well known to have one of the highest by—catch rates of any fishery (Earys 2007). This poses a significant threat to the biodiversity of the shelf ecosystem and thus to the long—term sustainability of other fisheries, to food security, and to the livelihoods of local fisherfolk (FAO 2011). By—catch of sea turtles has already been effectively addressed in the Guyanese Atlantic seabob fishery by the mandatory use of standard TEDs in all trawls of the current fleet (no sea turtles were landed throughout this study, which corroborates anecdotal evidence from the trawl fishers). However, further reduction in the by—catch of elasmobranchs (sharks and rays) remains an issue of concern for the industry, especially given the particular vulnerability of this group to fishing pressure (Stevens et al. 2000, Frisk et al. 2001, Dulvy et al. 2014). Reducing elasmobranch by—catch in trawl fisheries is also highlighted in the International Plan of Action for Management and Conservation of Sharks (FAO 1999). Following the documented reduction in elasmobranch by—catch in the Atlantic seabob trawl fishery of Suriname with the introduction of BRDs and TEDs of similar design to those already in use by the Guyanese Atlantic seabob fishery (Willems et al. 2016), GAPTO&SP was keen to test a modified TED, with smaller bar spacing and the addition of a horizontal brace bar, to determine whether this would further reduce the by—catch of elasmobranchs.

There is currently no official reporting of by—catch and discards by the Guyanese industrial Atlantic seabob trawl fishery. As such, this research aims to reveal, for the first time, the species composition and by—catch rates of elasmobranchs during standard fishing operations of the Atlantic seabob fleet while using their standard BRDs and TEDs. This study also assesses the efficacy of a modified TED design in reducing that by—catch. This was done through onboard catch comparison observations and measurements during commercial Atlantic seabob fishing trips. By translating these results into fishery management policy, the current study intends to contribute to the by—catch reduction efforts by the industrial Atlantic seabob fishery of Guyana.

Materials and Methods

Survey area, vessels and gear

Fishing trips were conducted on the Guyanese continental shelf, in the area typically used by the industrial seabob fishing fleet, 15—30 km from shore in 18—20 m of water depth on muddy substrates (Figure 1). Sampling was conducted during regular commercial seabob fishing trips of several GAPTO&SP industrial trawlers. These vessels (21 m in length, 450 hp engines) use a quad—rig setup with sledges to tow 4 trawls simultaneously (Figure 2A). The nets were 11—15 m in length, have a mesh size of 4—5 cm in the wings and 2.5—3.5 cm in the cod—end, have drop chains on the footrope to improve bottom contact of the trawl, and are fitted with mandatory BRDs and TEDs. The BRDs comprise a square mesh panel (10 x 10 meshes, 10 cm mesh size) on the upper surface of the net, behind the TED. The standard TED is an oval—shaped metal grid (86 x 107 cm) constructed with 1.3 cm thick aluminum bars and set at about 45 degrees near the cod—end (Figure 2B). Some vessels use the maximum bar spacing allowed for TEDs, i.e. 10.2 cm (4 in), while others use a smaller spacing of 8.9 cm (3.5 in). In this study we used a mixture of the standard 8.9 cm and 10.2 cm bar spacing TEDs as our control TED to compare with the modified TED of the same dimensions, but with considerably reduced bar spacing of 4.45 cm (1.75 in), as well as a horizontal brace bar (Figure 2C).

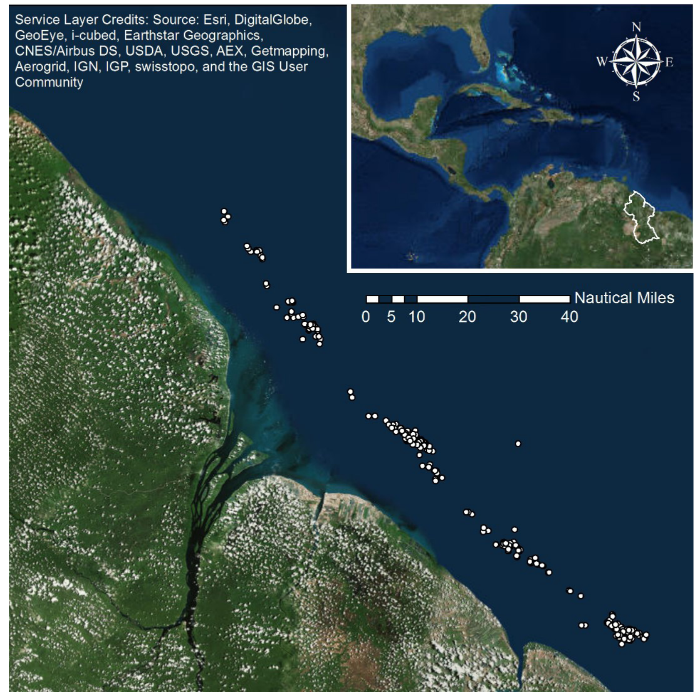
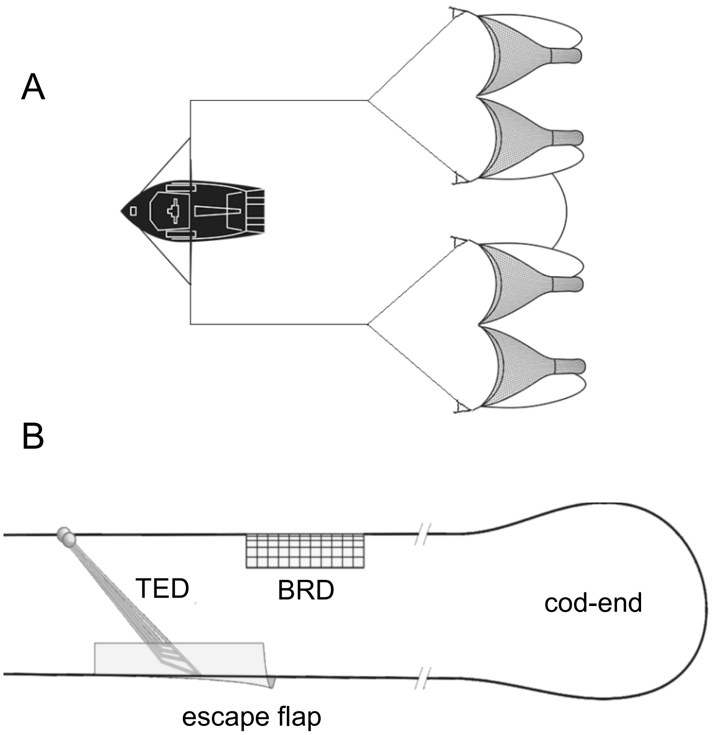


FIGURE 1. *Satellite image showing the start and end coordinates (white circles) for sampled Atlantic seabob hauls during the study. Inset highlights Guyana on the northern coast of South America.*

At—sea data collection

Data were collected continuously throughout the 24 h fishing operation over the entire duration of several commercial fishing trips. All hauls involved the simultaneous deployment of 4 cod—ends (i.e., a quad—rig configuration comprising twin—trawls, one on each side of the vessel;



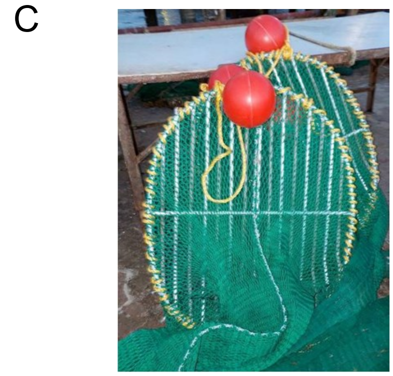


FIGURE 2. *Diagrams of fishing gear. A. quad-rig bottom trawler setup to illustrate the arrangement of the 4 trawl nets fished simultaneously. Note that a much smaller 'try net' (not shown) is also towed off the center of the stern to inform the captain of the catch rate. Image adapted from FRDC (2016). B. Cod—end of the trawl net showing the arrangement of the slanted TED and square mesh panel BRD. Image adapted from Willems et al. (2013). C. The modified TED showing the reduced bar spacing of 4.45 cm (1.75 in) and the additional horizontal brace bar.*

Figure 2A) and a central try—net (hauled hourly to gauge the catch volume), and generally lasted about 4 h. Control TEDs were fitted to the 2 port trawls and the modified TEDs were fitted to the 2 starboard trawls whenever available. A handheld GPS was used to record the coordinates, towing speed and duration of each haul. At the end of each haul, all trawls were hoisted and emptied on deck, keeping the catch of the 2 port (control TEDs) and 2 starboard (modified TEDs) trawls separate for the purpose of sampling the by—catch. It was not feasible to separate the catch of the 2 trawls on each side, therefore, a quad—rig haul provided 2 sample replicates; one from the twin—trawls on the port side and the other from the twin—trawls on the starboard side.

All sharks and rays were manually sorted from the catch and identified to species. Data collected for each elasmobranch included gender, fork length (FL, cm) and girth for sharks, and straight disc width (DW, cm) for rays; measurements were made with a flexible tape.

Data analysis

Data from all hauls were used to examine species composition and size of shark and ray specimens. To describe the elasmobranch by—catch rates for the current standard fishing operations, data from all 182 hauls made with control TEDs were used (Table 1). To compare elasmobranch by—catch rates between the two TED designs, we used only data from the 80 hauls in which control and modified TEDs were fished simultaneously (Table 1). Furthermore, when comparing individual species catch rates and sizes between the 2 TED designs, only species that accounted for at least 3% of shark and ray by—catch were considered, to avoid

TABLE 1. *Summary of commercial fishing trips and hauls sampled in the industrial Atlantic seabob trawl fishery of Guyana. se—standard error; min—minutes.*

Trip dates				Mean towing speed		Mean duration of haul			No. haul replicates (twin—trawls)	
Start	End	Days	No. of hauls (quad—rig)	km/h	se	hr:min	min	se	Control TED	Modified TED
12 Jul 2014	19 Jul 2014	8	41	4.4	0.09	3:42	222	3.5	82	0
24 Jul 2014	1 Aug 2014	9	47	2.2	0.04	3:50	230	4.1	47	47
10 Aug 2014	15 Aug 2014	6	20	6.1	0.10	4:46	286	5.6	30	10
18 Aug 2014	22 Aug 2014	5	17	5.8	0.05	4:14	254	17.1	17	17
27 Aug 2014	29 Aug 2014	3	6	4.3	0.20	4:49	289	16.8	6	6
Total		31	131	4.7	0.08	4:02	242	3.7	182	80

problems associated with small sample sizes.

Parametric statistical testing was used, since assumptions of normal distribution and homogeneity of variance were satisfied in all cases. All statistical analyses were performed using the IBM SPSS Statistics, version 19 software program. Shark and ray by–catch rates per haul were standardized to the number of individuals caught per twin–trawl haul per hour and differences in mean by–catch rates between the control and modified TEDs were assessed using paired *t*–tests from individual hauls. Differences in mean size of all sharks and rays taken by control TEDs versus modified TEDs were analyzed with 2 sample *t*–tests for the 3 most numerous species: Smooth Butterfly Ray (*Gymnura micrura*), Longnose Stingray (*Hypanus guttatus*) and Smalleye Smoothhound (*Mustelus higmani*). The comparison of mean size for all elasmobranchs combined used DW of the ray species and FL of the Smalleye Smoothhound.

Results

Five fishing trips were monitored during July–August 2014 on 3 different GATPO&SP vessels. This represented 31 days of at–sea sampling, over 528 h of trawling, and 131 quad–rig hauls (262 twin–trawl replicate samples) (Table 1). The mean duration of each haul was 4 h 2 min and the mean towing speed was 4.7 km/h, with very little variation among them (Table 1). A total of 51 hauls were conducted using only control TEDs in all of the trawls and a further 80 hauls where completed in which control TEDs and modified TEDs were used simultaneously (Table 1).

Species composition

The elasmobranch by–catch in trawls with control TEDs comprised a single shark species, the Smalleye Smoothhound and 8 ray species: Caribbean Electric Ray (*Narcine bancroftii*), Chola Guitarfish (*Pseudobatos percellens*), American Cownose Ray (*Rhinoptera bonasus*), Longnose Stingray, Sharpsnout Stingray (*Fontitrygon geijskesi*), Southern Stingray (*Hypanus americanus*), Smooth Butterfly Ray and Smalleye Round Ray (*Urotrygon microphthalmum*). These include 3 'Near Threatened' and one 'Critically Endangered' species according to the IUCN Red List (Table 2).

The one shark and 4 ray species together accounted for 98% (by number) of the elasmobranch by–catch when using control TEDs, with the Smooth Butterfly Ray alone accounting for more than half (61%) and the Longnose Stingray for almost a quarter (22%) of the total elasmobranch by–catch (Table 2). The other 3 common by–catch species each accounted for at least 3%: Smalleye Smoothhound (8%), Smalleye Round Ray (3%) and Sharpsnout Stingray (3%). The remaining 2% of the elasmobranch by–catch comprised Caribbean Electric Ray, Chola Guitarfish, American Cownose Ray and Southern Stingray (Table 2).

The elasmobranch by–catch species composition of trawls with modified TEDs was very similar to that of the trawls with control TEDs, with one shark and 5 ray species being taken, and the same 5 top–ranking species accounting for 99% of the elasmobranch by–catch (Table 2). However, 3 ray species which occurred in very small numbers in the trawls with control TEDs, including in simultaneous hauls with modified TEDs (American Cownose Ray, Chola Guitarfish and Southern Stingray), were not found in the by–catch of the trawls with modified TEDs (Table 2).

By–catch rates

Elasmobranch by–catch rates recorded during standard fishing operations (i.e., using trawls with control TEDs, n = 182 hauls) are summarized in Table 3. The mean (± stan-

TABLE 2. *Elasmobranch by–catch species taken by the industrial Atlantic seabob trawl fishery in Guyana, showing species composition, total number caught, and relative abundance of each species (as percent of total) caught in trawls with standard control TEDs (n = 182 twin–trawls) and modified TEDs (n = 80 twin–trawls). Also shown is the status of each species by IUCN Red List categories: DD–'Data Deficient'; LC–'Least Concern'; NT–'Near Threatened'; CR–'Critically Endangered'.* [1]Nomeclature: rays (Last et al. 2016), shark (Compagno 2002).

	Order[1]	Family[1]	Species[1]	Common name[1]	IUCN category	Total no.	No. in Control TED	No. in Modified TED
Rays	Rajiformes	Narcinidae	*Narcine bancroftii*	Caribbean Electric Ray	CR	15	0.7	1.1
		Rhinopteridae	*Rhinoptera bonasus*	American Cownose Ray	NT	8	0.6	0
		Urotrygonidae	*Urotrygon microphthalmum*	Smalleye Round Ray	LC	56	3.2	2.5
		Gymnuridae	*Gymnura micrura*	Smooth Butterfly Ray	DD	1187	61.5	75.2
	Myliobatiformes	Dasyatidae	*Fontitrygon geijskesi*	Sharpsnout Stingray	NT	51	3.1	1.6
			Hypanus guttatus	Longnose Stingray	DD	366	22.4	12.2
			Hypanus americanus	Southern Stingray	DD	5	0.4	0
	Rhinopristiformes	Rhinobatidae	*Pseudobatos percellens*	Chola Guitarfish	NT	6	0.4	0
Sharks	Carcharhiniformes	Triakidae	*Mustelus higmani*	Smalleye Smoothhound	LC	140	7.7	7.4
Totals	**4 orders**	**7 families**	**9 species**			**1834**	**1399**	**435**

TABLE 3. *Comparison of mean standardized by-catch rates (number individuals per twin-trawl per hour of fishing) for shark and ray species in all hauls with control TEDs (n = 182) and in catch comparison hauls where control and modified TEDs were fished simultaneously (n = 80 hauls). Results are from paired t—tests. * indicates statistical significance.*

Species	TED	Mean catch rate (no. per twin—trawl/h)	se	Reduction in catch rate	Paired *t*—value	p—value
Longnose Stingray	Control (all)	0.472	0.048			
	Control	0.493	0.071	66.1%	5.01	<0.001*
	Modified	0.167	0.034			
Sharpsnout Stingray	Control (all)	0.071	0.019			
	Control	0.088	0.029	74.0%	2.77	0.007*
	Modified	0.023	0.015			
Smalleye Round Ray	Control (all)	0.062	0.022			
	Control	0.061	0.019	47.7%	1.87	0.065
	Modified	0.032	0.012			
Smooth Butterfly Ray	Control (all)	1.287	0.141			
	Control	1.448	0.214	28.4%	3.79	<0.001*
	Modified	1.037	0.202			
All ray species	Control (all)	1.940	0.170			
	Control	2.151	0.257	59.2%	5.59	<0.001*
	Modified	1.273	0.212			
Smalleye Smoothhound	Control (all)	0.149	0.025			
	Control	0.139	0.033	27.4%	1.10	0.276
	Modified	0.101	0.021			
All elasmobranch species	Control (all)	2.089	0.175			
	Control	2.289	0.264	40.0%	5.55	<0.001*
	Modified	1.374	0.220			

dard error) standardized by—catch rate for all elasmobranchs was 2.09 (± 0.18) individuals/h. By—catch rate for sharks only was 0.15 (± 0.03) individuals/h, and for rays only was 1.94 (± 0.17) individuals/h.

By—catch rates obtained when fishing with both TED designs simultaneously (n = 80 hauls) are compared in Table 3. For control TEDs the mean standardized by—catch rates were very similar to those obtained when using all hauls with control TEDs; i.e., for all elasmobranchs it was 2.29 (± 0.26) individuals/h, for sharks only it was 0.14 (± 0.03) individuals/h and for rays only it was 2.15 (± 0.26) individuals/h (Table 3). However, when using the modified TEDs there were significant reductions in by—catch rate compared to the control TEDs. For all elasmobranchs combined there was a 40.0% reduction to 1.37 (± 0.22) individuals/h, while for all rays combined the significant reduction was 59.2% with the by—catch rate dropping to just 1.27 (± 0.21) individuals/h (paired *t*—tests: $p < 0.001$in both cases; Table 3). Significant declines in the by—catch rate were observed for 3 ray species: Sharpsnout Stingray (74.0%), Longnose Stingray (66.1%) and Smooth Butterfly Ray (28.4%) (paired *t*—tests: $p < 0.01$ in all cases, Table 3). Substantial declines were also observed for Smalleye Round Ray (47.7%) and for the Smalleye Smoothhound (27.4%), although these were not statistically significant (paired *t*—tests: $p > 0.05$ in both cases, Table 3).

Size frequency

The majority of elasmobranchs taken as by—catch were small (Figure 3, Table 4). In trawls with control TEDs the Smalleye Smoothhound had a mean size of just 22.3 (± 0.4) cm FL and 8.2 (± 0.2) cm girth, with the largest being 47 cm FL and the smallest 16 cm FL (Figure 3, Table 4). The mean DW for rays caught in trawls with the control TED was 24.5 (± 0.3) cm, with the largest being 79 cm and the smallest just 4 cm (Figure 3, Table 4). Three of the 4 ray species commonly found in the by—catch of trawls with control TEDs had a mean DW considerably greater than 10 cm: Smooth Butterfly Ray (26.6 cm), Longnose Stingray (20.0 cm) and Sharpsnout Stingray (32.5 cm), while the fourth species, Smalleye Round Ray, had a mean DW of 9.4 cm (Table 4). Similarly, with the modified TED, most of the elasmobranchs captured were small (shark: mean size 21.8 [±0.6] cm FL and 7.9 [±0.3] cm girth, range 17—37 cm FL; rays: mean DW 23.0 [± 0.3] cm, range 5—55 cm; Figure 3, Table 4). The size frequency distributions of rays taken by trawls with control TEDs and those with modified TEDs were similar except for a virtual absence of the larger size classes (> 36 cm DW) when using the modified TED (Fig-

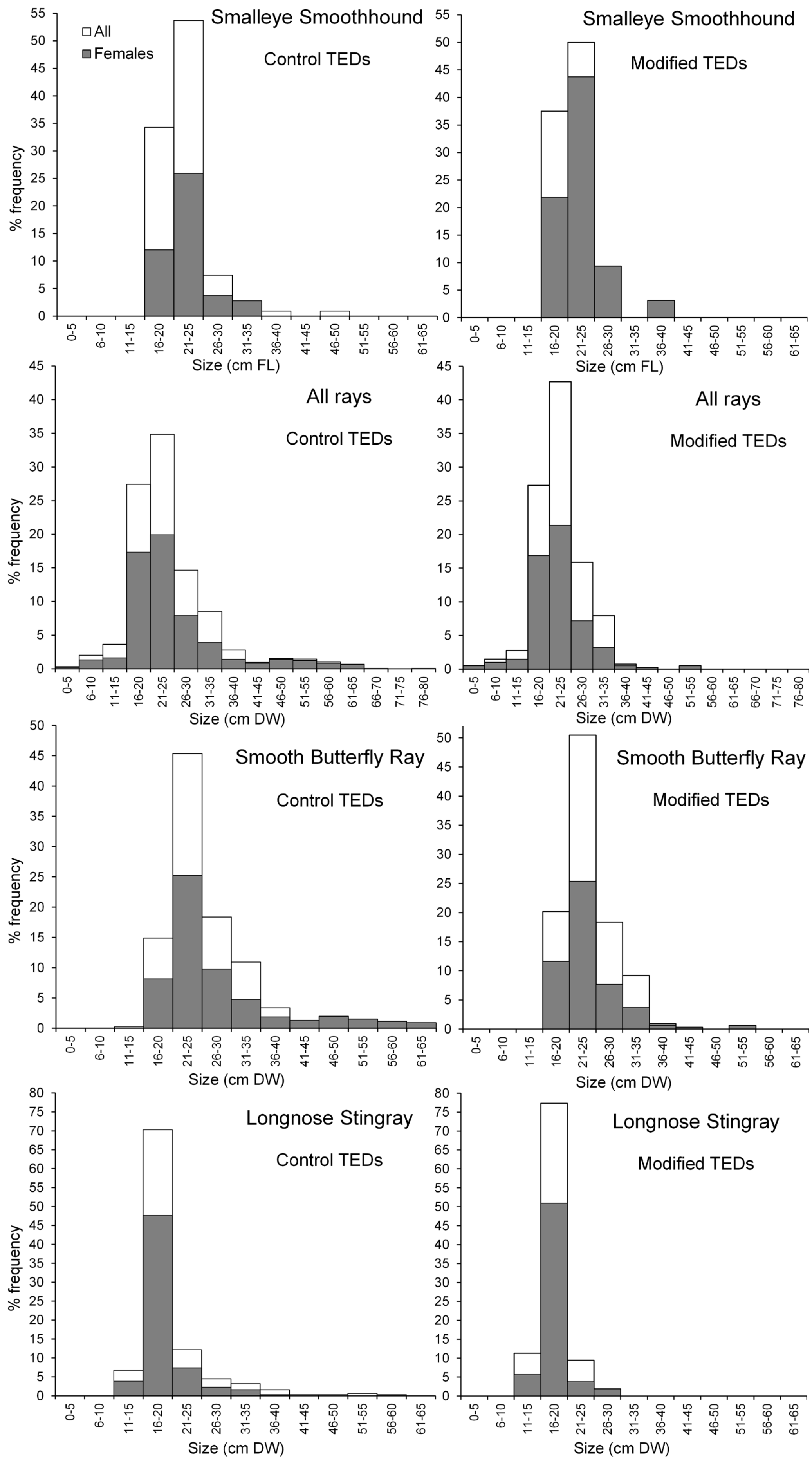


FIGURE 3. *Size frequency distributions for prominent shark and ray by–catch species shown by gender for trawls fitted with control TEDs and modified TEDs.*

TABLE 4. *Comparison of mean size of shark and ray species taken as by—catch in trawls with control TEDs versus modified TEDs. Results shown are from 2—sample t—tests. Overall elasmobranch size data are shown for ray DW and shark FL. * indicates statistical significance.*

			Control			**Modified**			**Comparison**		
	Species	**Unit**	**Size range (cm)**	**Mean (± se) size (cm)**	**Total no.**	**Size range (cm)**	**Mean (± se) size (cm)**	**Total no.**	**Size reduction**	**2—Sample *t*—value**	**p—value**
Rays	Longnose Stingray	DW	13-58	20.02 ± 0.33	313	14-26	18.13 ± 0.31	53	9.4%	4.15	<0.001*
	Sharpsnout Stingray	DW	20-79	32.50 ± 2.12	44	24-34	28.43 ± 1.63	7	12.5%	1.56	0.129
	Smalleye Round Ray	DW	4-15	9.36 ± 0.43	45	5-17	11.45 ± 1.25	11	-22.3%	-1.59	0.136
	Smooth Butterfly Ray	DW	15-64	26.55 ± 0.29	860	16-55	24.20 ± 0.27	327	9.4%	5.97	<0.001*
	Total ray species	DW	4-79	24.48 ± 0.26	1,291	5-55	22.95 ± 0.28	403	6.3%	4.05	<0.001*
Sharks	Smalleye Smoothhound	FL	16-47	22.30 ± 0.41	108	17-37	21.84 ± 0.63	32	2.1%	0.59	0.553
		Girth	6-15	8.21 ± 0.15		6-15	7.91 ± 0.29		3.7%	0.92	0.180
	All elasmobranchs		4-79	24.31 ± 0.24	1,399	5-55	22.86 ± 0.26	435	6.0%	3.2	<0.001*

ures 3 and 4). This was particularly notable for females of the commonly caught mid—sized rays (Smooth Butterfly Ray and Longnose Stingray, Figure 3). In line with this, the mean size of rays taken by trawls with modified TEDs was significantly smaller (by 6.3%) than for those taken by trawls with control TEDs (2—sample t—test: t = 4.05, n = 1,291, 404, p < 0.001, Table 4, Figure 4). This pattern holds for the 2 most commonly occurring ray species in the by—catch (Smooth Butterfly Ray and Longnose Stingray), both of which show a statistically significant and 9.4% reduction in mean size when using the modified TEDs (p < 0.001 in both cases; Table 4, Figure 4). For the shark (Smalleye Smoothhound) there is a much smaller difference in the size range taken by trawls with the 2 different TEDs, and although the mean size (FL and girth) of Smalleye Smoothhound is slightly smaller with the modified TEDs (2.1% smaller length and 3.7% smaller girth), the differences are not significant (p > 0.05 in both cases; Table 4, Figure 4).

Discussion

This study represents the first documentation of the elasmobranch by—catch in the Guyanese industrial Atlantic seabob fishery. Additionally, the efficacy of a modified TED design in further reducing the by—catch of sharks and rays currently taken in the standard trawls which are all fitted with TEDs (referred to in this study as control TEDs) is examined.

By—catch in the current fishery

The elasmobranch by—catch in the industrial Atlantic seabob trawl fishery, as it currently operates with all trawls fitted with a BRD and a downward—excluding TED, comprises one shark and 8 ray species. The catch is dominated by 2 mid—sized rays: Smooth Butterfly Ray and Longnose Stingray, both listed as 'Data Deficient' by the IUCN Red List (Grubbs and Ha 2006; Rosa and Furtado 2016). These 2 species alone account for 83% by number of the elasmobranch by—catch. A further 8% of the catch comprises the small, relatively abundant bottom—dwelling shark, Smalleye Smoothhound, considered by the IUCN Red List as being of 'Least Concern' (Faria and Furtado 2006). All other ray species represented 3% or less of the catch. However, of the 2 small—sized rays (Smalleye Round Ray and Caribbean Electric Ray), the latter, representing 1% of the catch, is considered 'Critically Endangered' by the IUCN Red List (de Carvalho, McCord and Myers 2007). Furthermore, 3 of the mid— to large—sized rays taken as a small component of the by—catch (American Cownose Ray (0.6%), Sharpsnout Stingray (3%), Chola Guitarfish (<0.5%)) are listed as 'Near Threatened' (see Barker 2006, Charvet—Almeida and Almeida 2006, and Casper and Burgess 2009, respectively). This highlights the importance of further reducing the elasmobranch by—catch if the fishery is to be considered sustainable over the long—term, based on the MSC standards.

Interestingly, the industrial seabob fishery in neighboring Suriname, which has also incorporated very similar BRDs (11 x 11 mesh square of 15 cm—stretched mesh) and TEDs (of the same dimensions and orientation, and with 10 cm bar spacing) in their trawls, shares the same key ray by—catch species composition (Willems et al. 2016) with a similar sample size (n = 1,229 ray specimens) to our own study (n = 1,291). For example, the 4 most abundant ray species in the by—catch of both fisheries accounted for 99.3% by number of the Surinamese ray by—catch (Willems et al. 2016) and 97.8% of the Guyanese ray by—catch. The only difference lies with the rarely caught species, of which there is just one in the Suriname fishery (American Cownose Ray) and an additional 3 recorded in our study for the Guyana fishery (Caribbean Electric ray, Chola Guitarfish and Southern Stingray).

By—catch rates observed in the current fishery are low for sharks (0.15 individuals/h) compared to rays (1.9 individuals/h). Of particular interest however, is a comparison of the

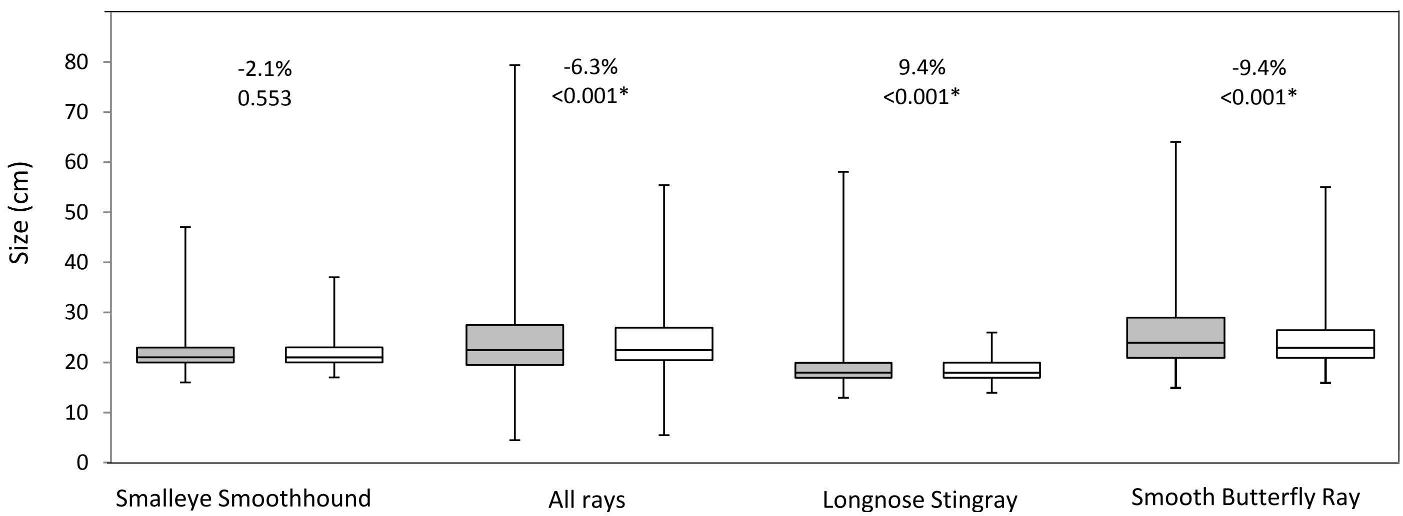


FIGURE 4. *Comparison of box and whisker plots for trawl nets fitted with control TEDs (grey boxes) and nets fitted with modified TEDs (white boxes) showing the minimum, maximum, first quartile, median, third quartile and median size for all rays and for prominent shark and ray by—catch species separately. Sizes are given as DW for rays and FL for sharks. Percentages signify changes in mean size when using the modified TEDs compared with the control TEDs. P—values for mean comparisons using 2—sample t—tests are shown and statistically significant changes are indicated by *.*

standardized by—catch rates between our study in Guyana when using the control TEDs and those reported in Suriname when using virtually the same BRD and TEDs. Our ray by—catch rate with control TEDs is an order of magnitude less than that reported for the Suriname fishery when using TEDs (Guyana: 1.9 ± 0.17 rays/h; Suriname: 15.3 ± 1.60 rays/h, Willems et al. 2016). There are several plausible explanations including: 1) the density of rays may be much greater on the Suriname fishing grounds; 2) the density of rays may be much lower during the summer when our study was conducted; and/or 3) rays may be less susceptible to capture during night tows. The most likely is that the density of rays are higher on the Suriname fishing grounds compared with Guyana possibly as a result of lower fishing pressure, given the smaller seabob trawl fleet size (20 vessels vs. 88 Guyanese vessels) but similar delimited fishing area, and the fact that the Suriname fishery is also a much younger fishery (started around 1996 vs. mid—1980s for the Guyanese Atlantic seabob fishery; see Willems et al. 2013). The catch rate of rays did show variation between the 14 months in the Suriname study, but there was no obvious seasonal pattern, and the lowest catch rates did not occur during the summer months (Willems et al. 2013). Although the Suriname study only fished during daytime, we found no difference in catch rates between day and night hauls in our study.

The mean size of rays caught in our study with the control TEDs is 24.5 cm DW, indicating that rays considerably larger than the bar spacing are still able to pass through the TED grill, presumably by folding or passing through sideways. This was also reported in the Surinamese study where the mean size was actually slightly larger (25.5 cm DW; Willems et al. 2016). The most obvious explanation for the slightly smaller size in our Guyana study is the use of some TEDs with a slightly smaller bar spacing than in the Surinamese study (i.e., 8.9 vs. 10 cm).

The similar species composition and mean sizes reported in Suriname corroborates the information that these 2 fisheries, operating in adjacent areas along the coast of Guyana and Suriname, are very similar in terms of their gear, fishing operations, and fishing ground habitats (Maison 2016). It also suggests that modifications made to the gear in Guyana are likely to have a similar impact on the elasmobranch by—catch if also implemented in the Suriname Atlantic seabob fishery. This is an important point, given that the MSC assessment team in Suriname (that achieved MSC certification of its seabob trawl fishery in 2011) raised concerns over the mortality of rays, indicating that this issue must be tackled in order to pass future MSC re—assessments in this fishery (Southall et al. 2011).

Comparison of TED performance

The modified TED design had no effect on the elasmobranch by—catch species composition compared with the control TED currently used in the Guyanese industrial Atlantic seabob fishery. For example, the 6 elasmobranch species caught by the modified TED design (1 shark and 5 rays) were the same species that accounted for 98.6% of the by—catch of the control TED design, and each species shared the exact same abundance rank across both TEDs. Although 3 species were not caught at all in the trawls with modified TEDs over the course of the study, they were caught in such low abundance in the control trawls (together representing < 1.4% of total elasmobranch by—catch) that their absence in the modified trawls does not provide convincing evidence that these TEDs consistently released them.

A notable result for the Guyanese Atlantic seabob fishery is the fact that the overall capture rate for all elasmobranchs combined fell by 40% when using the modified TEDs compared with the control TEDs. The change in capture rate varied among species, but most importantly the capture rate was significantly reduced for the 2 dominant species in the by—catch: Longnose Stingray (by 66.1%) and Smooth Butterfly Ray (by 28.4%). Also of importance was the substantial reduction in catch rate of the Sharpsnout Stingray (by 74.0%) since it is listed by the IUCN as 'Near Threatened' due to its limited habitat range and its frequent capture by industrial fisheries (Charvet—Almeida and Almeida 2006). Not surprising was the lack of significance in the observed reductions in catch rate for the very small—sized species: the Smalleye Round Ray and the Smalleye Smoothhound. The Suriname study even reported no significant effect of using a TED versus no TED on the mean size of the Smalleye Round Ray captured, citing their small size as the reason (Willems et al. 2016).

Of interest is the marked difference in the magnitude of catch reductions for the 2 similar—sized dominant ray species, with the Longnose Stingray showing a much greater reduction in catch rate than the Smooth Butterfly Ray. This difference was also reported in the Suriname study by Willems et al. (2016) when comparing the catch rates of these 2 species in trawls with and without TEDs. They suggested that this finding resulted from a difference in the morphology of the 2 species, with Longnose Stingrays having a thicker and more rigid disc, while the Smooth Butterfly Ray is thinner and more flexible, and thus more easily distorted and forced through the TED grill.

Of great significance is the fact that the use of the modified TED did affect the mean size of the elasmobranchs taken as by—catch, by allowing the larger specimens to pass out of the trawls, thus resulting in significant reductions in the overall catch rates of elasmobranchs. These results can indeed be attributed to the differing TED design, since the BRD dimensions remained the same across both trawl types. Overall, the mean DW for ray by—catch was reduced by 6.3% in the trawls fitted with the modified TED compared with the control TED trawls, although reductions in size were not the same across all species. The modified TEDs effectively eliminated the capture of any rays with a DW > 36 cm. As such, highly significant reductions in mean size were observed for both the dominant mid—sized ray by—catch species: Smooth Butterfly Ray and Longnose Stingray (both reduced by 9.4%), and a 12.5% reduction in size was noted for the mid—sized Sharpsnout Stingray, although this was not statistically significant. By contrast, the mean size of the small—sized ray species caught by both trawls, the Smalleye Round Ray, was actually larger by 22.3% in the trawls with modified TEDs, although again this was not statistically significant. It is not surprising that a reduction in the size of the TED bar spacing and addition of a horizontal brace bar had the greatest success in preferential exclusion of larger individuals of the larger—sized ray species, while most of the larger individuals of the small—sized species that were retained in the control TED trawls were still able to pass through the grill into the retained catch when using the modified TEDs. The smaller the individual, the more likely it is to pass through sideways, or fold and get forced through the TED grill. Since the maximum size of the Smalleye Round Ray is just 12 cm DW (Uyeno et al. 1983), it can be expected that most individuals would be small enough to pass or be forced through the modified bar spacing (4.5 cm) and be captured. With regard to the single shark species (Smalleye Smoothhound) in the by—catch, the modified TED did not significantly reduce the mean size caught, although they were generally smaller (by 2.1%). Given the fusiform shape and small size of this shark species, it is again not surprising that even a substantial reduction in bar spacing width (from 10.2 to 4.5 cm) was insufficient to prevent their capture. For example, the mean girth of Smalleye Smoothhound retained by the control TED (8.21 cm) would suggest a mean diameter < 2.6 cm, i.e. smaller than even the modified TED grill spacing, thus making little difference to the capture size.

Another important result for the fishery is the near elimination of mature females in the ray by—catch of the modified TEDs. Using published size—at—first—maturity data for females of the 2 most abundant ray species (Smooth Butterfly Ray, 34—36 cm; Longnose Stingray, 50—55 cm, Yokota and Lessa 2007) we found a substantial reduction from 10.9% to just 3.1% of mature females for the former species and a total elimination (from 0.5% to 0%) for the latter species. Given the concomitant reduction in the catch rate also, this represents an even more significant reduction in the capture of mature females. Like other fish, elasmobranch fecundity increases exponentially with size (Stevens et al. 2000), but compared with teleost fishes their fecundity is extremely low, such that it is especially important for larger females to remain in the breeding stock.

Based on these results, including our shipboard observations and a review of the literature on by—catch reduction, we have considered ways in which the efficacy of the modified TED could perhaps be further improved to reduce the capture of all elasmobranchs. Many of these elasmobranchs are considerably wider than the modified TED bar spacing (4.5 cm) and must therefore be passing through sideways or being folded and forced through, presumably with significant injury. A further reduction in vertical bar spacing may lead to a decline in the catch rate of Atlantic seabob that would be unacceptable economically, although using a bar spacing of just 1.7 cm in the Nordmore grids of the Brazilian artisanal Atlantic seabob fishery was reported to have no effect on the target catch (Silva et al. 2012). However, there are several alternatives that may be worth trying. First, the addition of one or 2 more horizontal brace bars to the modified TED may prevent the small—sized and flexible individuals, especially the rays, from being forced through the grill. Secondly, the industry currently uses oval—shaped TEDs, which are effective at retaining net shape while minimising stress and abrasion on the net itself. Rectangular—shaped TEDs have been reported to be more effective at reducing by—catch of wider animals (such as rays), as it allows more room for them to maneuver through the escape flap (Eayrs and Day 2004, Eayrs 2007). However, it is acknowledged that rectangular—shaped TEDs cause more abrasion of the net, leading to a decrease in net condition and TED efficiency (Eayrs and Day 2004). A compromise could be to use a hybrid of the 2 designs; e.g. a tombstone—shaped TED which would provide greater net width to accommodate shark and ray species attempting to escape than the oval shape, while causing less abrasion on the net than a rectangular design. Another approach could be to focus on the TED grid orientation. The TEDs currently being used in the Guyanese industrial trawl fishery are oriented for bottom exclusion. Eayrs and Day (2004) have suggested that top exclusion may be more effective in reducing mobile by—catch, while bottom exclusion TEDs are more effective at removing rubble and sponges. As no rubble or sponges were found in the cod—ends during this study, converting to a top exclusion TED may further limit the by—catch of sharks and rays.

We conclude overall that the modified TED was very successful in reducing important elements of the elasmobranch by—catch and should advance the progress towards attaining the by—catch standards required for MSC certification. However, we also recognize that the GAPTO&SP modified TED that we tested should not be slated for mandatory adoption without an examination of the impact on the target Atlantic seabob species, which was beyond the scope and feasibility of the current study. Likewise, the impact of by—catch reduction devices on the retained by—catch, which may provide an important add—on value in this fishery, should also be assessed before implementing new devices.

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Literature Cited

Barker, A. 2006. *Rhinoptera bonasus*. The IUCN Red List of Threatened Species. http://dx.doi.org/10.2305/IUCN.UK.2006.RLTS.T60128A12310195.en. (Viewed on 9/9/2014).

Casper, B. and G. Burgess. 2016. *Pseudobatos percellens*. The IUCN Red List of Threatened Species. http://dx.doi.org/10.2305/IUCN.UK.2016—3.RLTS.T161373A103935456.en. (Viewed on 3/8/2018).

Charvet—Almeida, P. and M.P. de Almeida. 2016. *Fontitrygon geijskesi*. The IUCN Red List of Threatened Species. http://dx.doi.org/10.2305/IUCN.UK.2016—3.RLTS.T60153A104171793.en. (Viewed on 3/8/2018).

Compagno, L.J.V. 2002. Sharks. In: K.E. Carpenter, ed. The living marine resources of the Western Central Atlantic. Volume 1: Introduction, molluscs, crustaceans, hagfishes, sharks, batoid fishes, and chimaeras. FAO Species Identification Guide for Fishery Purposes and American Society of Ichthyologists and Herpetologists Species Publication No. 5, Food and Agriculture Organization, Rome, Italy, p. 357—505.

CRFM. 2007. Report of the Third Annual CRFM Scientific Meeting, Kingstown, St. Vincent and the Grenadines, 17—26 July 2007. CRFM Fishery Report – 2007, Volume 2 – Fishery Management Advisory Summaries, Caribbean Regional Fisheries Mechanism, Kingstown, St Vincent and the Grenadines, 54 p. http://www.crfm.net/images/crfm_fishery_report_2007_volume_2.pdf

CRFM. 2013. Report of the Ninth Annual CRFM Scientific Meeting, Kingstown, St. Vincent and the Grenadines, 10—14 June 2013. CRFM Fishery Report – 2013, Volume 1, Suppl. 2— Report of the Inter—Sessional Meeting of the CRFM Shrimp and Groundfish Fishery Resource Working Group (SGWG), Guyana, 19 – 20 February 2013, Caribbean Regional Fisheries Mechanism, Kingstown, St. Vincent and the Grenadines, 85p. http://www.crfm.net/images/documents/miscellaneous/Agenda%20Item%209.1%20—%20Ref%20Doc%20—%20CRFM%202013c%20Ninth%20Scientific%20Meeting%20Report%20Vol%201%20Suppl%202.pdf

de Carvalho, M., M. McCord, and R. Myers. 2007. *Narcine bancroftii*. The IUCN Red List of Threatened Species. http://dx.doi.org/10.2305/IUCN.UK.2007.RLTS. .T63142A12622582.en. (Viewed on 9/19/2014).

Dulvy, N.K., S.L. Fowler, J.A. Musick, R.D. Cavanagh, P.M. Kyne, L.R. Harrison, J.K Carlson, L.N. Davidson, S.V. Fordham, M.P. Francis, and C.M. Pollock. 2014. Extinction risk and conservation of the world's sharks and rays. eLife 2014(3):e00590. http://dx.doi.org/10.7554/eLife.00590

Eayrs, S. 2007. A Guide to Bycatch Reduction in Tropical

Shrimp–Trawl Fisheries. Revised edition. Food and Agriculture Organization, Rome, Italy, 108 p.

Eayrs, S. and G. Day. 2004. Optimizing TED performance in tropical prawn–trawl fisheries: a review. Professional Fisherman 26(8):16–18.

FAO. 1999. International Plan of Action for reducing incidental catch of seabirds in longline fisheries. International Plan of Action for the conservation and management of sharks. International Plan of Action for the management of fishing capacity. Food and Agriculture Organization, Rome, Italy. 26 p.

FAO. 2005. Fishery country profile – the Republic of Guyana. http://www.fao.org/fi/oldsite/FCP/en/GUY/profile.htm (Viewed on 10/19/2014).

FAO. 2011. International Guidelines on Bycatch Management and Reduction of Discards. Final Report. Food and Agriculture Organization, Rome, Italy. 73 p.

Faria, V. and M. Furtado. 2006. *Mustelus higmani*. The IUCN Red List of Threatened Species. http://dx.doi.org/10.2305/IUCN.UK.2006.RLTS.T60204A12318622.en. (Viewed on 9/9/2014).

FRDC. 2016. Nets. Fisheries Research & Development Corporation. fish.gov.au/Fishing–methods/Nets. (Viewed on 11/4/2017).

Frisk, M.G., T.J. Miller, and M.J. Fogarty. 2001. Estimation and analysis of biological parameters in elasmobranch fishes: a comparative life history study. Canadian Journal of Fisheries Aquatic Sciences 58:969–981. http://dx.doi.org/10.1139/f2012–060

Greer, T.S. 2005. National report – Guyana. In: CRFM, ed. Report of the First Annual CRFM Scientific Meeting. CRFM Fishery Report 11. Caribbean Regional Fisheries Mechanism, Kingstown, St. Vincent and the Grenadines, p. 188–208.

Grubbs, R.D. and D.S. Ha. 2006. *Gymnura micrura*. The IUCN Red List of Threatened Species. http://dx.doi.org/10.2305/IUCN.UK.2006.RLTS.T60115A12305055.en. (Viewed on 9/9/2014).

Last, P.R., W.T. White, M.R. de Carvalho, B. Seret, M.F.W. Stehmann, and G.J.P. Naylor, eds. 2016. Rays of the world. Comstock Publishing Associates, Cornell University Press, London, UK, 790 p.

MacDonald, J., S. Harper, S. Booth, and D. Zeller. 2015. Guyana fisheries catches: 1950–2010. Working Paper # 2015 – 21, Sea Around Us, Fisheries Centre, University of British Columbia, Vancouver, BC, Canada, 18 p.

Maison, D. 2016. Fishery improvement project: Guyana Atlantic seabob. FIP Directory, https://fisheryimprovementprojects.org/fip/guyana–atlantic–seabob/. (Viewed on 12/20/2016).

Medley, P. 2014. Guyana Seabob HCR 2013/14. Technical Report. Nautilus Consultants, Peebles, UK, 12 p.

Richardson, S. 2013. National Report of Guyana. In: CRFM, ed. Report of the Ninth Annual CRFM Scientific Meeting, Kingstown, St. Vincent and the Grenadines, 10–14 June 2013. CRFM Fishery Report – 2013, Volume 1, Suppl. 1 – National Reports, Caribbean Regional Fisheries Mechanism Secretariat, Belize, p. 23–28.

Rosa, R. and M. Furtado. 2016. *Hypanus guttatus*. The IUCN Red List of Threatened Species. http://dx.doi.org/10.2305/IUCN.UK.2016–3.RLTS.T44592A104125099.en. (Viewed 3/7/2018).

Shepherd, D., A. Hackett, and R. Charles. 1999. National report of Guyana: Shrimp and groundfish fisheries of Guyana. In: FAO/WCAFC, eds. National reports presented and stock assessment reports prepared at the CFRAMP/FAO/DANIDA Stock Assessment Workshop on the Shrimp and Groundfish Fisheries on the Guiana–Brazil Shelf. Port–of–Spain, Trinidad and Tobago, 7–18 April 1997. FAO Fisheries Report 600. Food and Agriculture Organization, Rome, Italy, p. 21–42.

Silva, C.N.S., M.K. Broadhurst, J.H. Dias, A.P. Cattani, and H.L Spach. 2012. The effects of Nordmore–grid bar spacings on catches in a Brazilian artisanal shrimp fishery. Fisheries Research 127:188–193.

SOFRECO. 2013. Support to formulate fisheries management plans for Guyana, Suriname and Trinidad and Tobago. Technical Report. SOFRECO, Clichy, France. 53 p.

Southall, T., N. Pfeiffer, and S. Singh–Renton. 2011. MSC Sustainable fisheries certification of Suriname Atlantic seabob shrimp: public certi cation report. Food Certification International Ltd., Inverness, Scotland, UK, 273 p.

Stevens, J., R. Bonfil, N. Dulvy, and P. Walker. 2000. The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecosystems. ICES Journal of Marine Science 57:476–494. http://dx.doi.org/10.1006/jmsc.2000.0724

Uyeno, T., K. Matsuura, and E. Fujii. 1983. Fishes trawled off Suriname and French Guiana. Japan Marine Fishery Resource Research Center, Tokyo, Japan, 519 p.

Willems, T., J. Depestele, A. De Backer, and K. Hostens. 2013. Bycatch of rays in the trawl fishery for Atlantic seabob shrimp *Xiphopenaeus kroyeri* in Suriname: how effective are TEDs and BRDs? ILVO Communication No. 139, Instituut voor Landbouw en Visserijonderzoek (ILVO), Flanders, Belgium. 17 p.

Willems, T., J. Depestele, A. De Backer, and K. Hostens. 2016. Ray bycatch in a tropical shrimp fishery: Do Bycatch Reduction Devices and Turtle Excluder Devices effectively exclude rays? Fisheries Research 175:35–42. http://dx.doi.org/10.1016/j.fishres.2015.11.009

Yokota, L. and R.P. Lessa. 2007. Reproductive biology of three ray species: *Gymnura micrura* (Bloch & Schneider, 1801), *Dasyatis guttata* (Bloch & Schneider, 1801) and *Dasyatis marianae* (Gomes, Rosa & Gadig, 2000) caught by artisanal fisheries in northeastern Brazil. Cahiers de Biologie Marine 48:249–257.