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ARTICLE

Performance of Two Survey Gears Targeting Elasmobranchs in a Shallow, Subtropical Estuary

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Abstract
Fishery-independent surveys have become increasingly prevalent in recent decades for monitoring the population trends of highly mobile species like elasmobranchs (sharks and rays). Despite the utility of gear evaluations for streamlining costs and increasing the efficiency of fishery-independent surveys, these assessments are sparse for elasmobranch-specific surveys. Catch data were examined from a fishery-independent longline and gill-net survey that targeted elasmobranchs in Florida's southern Indian River Lagoon from July 2016 to September 2018. The goal of the study was to assess the effects of the type of longline bait that is used (Striped Mullet *Mugil cephalus* versus Atlantic Mackerel *Scomber scombrus*) and the size of gill-net mesh (15.2- versus 20.3-cm stretch mesh) on the species composition, catch per unit effort (CPUE), and size distribution of captured elasmobranchs. Elasmobranchs were caught more often in the gill net than on the longline. Striped Mullet yielded a significantly higher CPUE of elasmobranchs than Atlantic Mackerel did. Although Striped Mullet caught more sharks than Atlantic Mackerel did, the mean length of the sharks did not differ between groups that were captured with the two bait types. Species composition differed with respect to bait type; significantly more Bull Sharks *Carcharhinus leucas* and Atlantic Sharpnose Sharks *Rhizoprionodon terraenovae* were caught with Striped Mullet. Elasmobranch abundances were similar between the two sizes of gill-net mesh. However, species composition differed, with a greater abundance of both Atlantic Stingrays *Hypanus sabinus* and Bull Sharks caught in the 15.2-cm mesh. Elasmobranchs that were caught in the 20.3-cm mesh were significantly larger than those caught in the 15.2-cm mesh. The length distributions for the common species (Bull Sharks, Atlantic Stingrays, and Bluntnose Stingrays *H. say*) differed significantly with respect to the two mesh sizes. This study is the first assessment of a standardized elasmobranch-specific survey in this nationally significant estuary and increases our understanding of the performance of complementary gear types for targeting sharks and rays in a shallow lagoonal system.

Elasmobranchs (sharks and rays) are essential components of marine food webs as both predators and prey (Navia et al. 2017). Additionally, these species are an important food source in some countries (Davidson et al. 2016) and support valuable ecotourism industries around the world (Gallagher and Hammerschlag 2011; Corcoran et al. 2013). Unfortunately, the life history strategies of many elasmobranchs (including their long lifespans, slow growth rates, late sexual maturity, and small number of offspring) make these fishes highly susceptible to population declines due to overfishing (Stevens et al. 2000) and habitat loss (Knip et al. 2010). These declines have elicited fisheries management and conservation measures in recent decades, such as the development of the first fishery

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management plan (FMP) for sharks in 1993 by the National Marine Fisheries Service (NMFS; NMFS 1993). Critical to the effectiveness of these FMPs are estimates of trends in abundance from fishery-independent surveys, which are still needed for many species (Belcher and Jennings 2009). The NMFS's Cooperative Atlantic States Shark Pupping and Nursery (COASTSPAN) survey uses standardized gear designs (longlines and gill nets) and sampling protocols to gather data on coastal shark nurseries along the U.S. Atlantic coast (NMFS 1997). These data are used to estimate abundance indices for young-of-the-year and juvenile sharks for stock assessments (NMFS 1997). However, despite their implementation in fishery-independent surveys, there has been limited assessment of the effectiveness of longlines and gill nets for targeting elasmobranchs.

While longlines and gill nets have long been used in commercial shark fisheries (Trent et al. 1997; Morgan and Carlson 2010), these passive gear types are also commonly used in fishery-independent elasmobranch surveys (e.g., COASTSPAN) due to their relative low costs, ability for deployment from smaller vessels, and suitability for a wide range of habitat and bottom types (Rago 2005). Longlines are used worldwide in varied marine habitats (e.g., pelagic, benthic) to harvest many fish species (He 2006). In addition to factors such as hook size (Erzini et al. 1996, 1997) or soak time (Ward et al. 2004), the type of bait that is used for bottom longlines has been well documented to influence the size and species selectivity of the gear (Hubert et al. 2012). Commercially available baitfish such as Striped Mullet *Mugil cephalus*, mackerels (Scombridae), or Atlantic Menhaden *Brevoortia tyrannus* are commonly used for longlines, depending on their availability, the target species' preference, or the durability of the bait (Belcher and Jennings 2009). However, the influence of bait type on selectivity and efficiency (Belcher and Jennings 2009) could bias the abundance estimates of a fishery-independent survey. The use of multiple bait types introduces bias, so it is important to determine the most efficient and effective bait type to use to achieve the goals of a survey and efficiently estimate abundance.

Gill nets are another passive fishing gear that is frequently used worldwide to harvest fish (He 2006). The mesh size of a gill net can influence selectivity for certain lengths of fish (Shoup and Ryswyk 2016). In general, larger mesh sizes catch larger fish (Holst et al. 1996; He 2006), but mesh sizes can also affect how securely fish of certain sizes are caught (Hubert et al. 2012). For example, while smaller individuals may escape through the mesh, larger individuals may not become entangled (Hubert et al. 2012). Other factors that have been shown to influence the efficiency of gill nets include material or diameter, soak time (Hubert et al. 2012), and the hanging ratio of the net (Hovgård and Lassen 2000).

Despite the increased prevalence of elasmobranch monitoring research in the past few decades (e.g., Simpfendorfer et al. 2002; Froeschke et al. 2013; Kessel et al. 2016), rarely are bait comparison and gear efficiency studies undertaken prior to implementation. In addition to ensuring the efficacy of chosen gear types in capturing target species, these comparisons can be critical for minimizing bycatch of nontarget species or sizes (Carlson and Cortés 2003; Foster et al. 2012), developing cost-effective strategies for sampling (McAuley et al. 2007), and implementing long-term monitoring programs.

Florida's Indian River Lagoon (IRL) has historically supported diverse bony fish and elasmobranch communities (Gilmore 1977), but the collection of fishery-independent data for elasmobranchs in the IRL has been sporadic over the last 40 years. Past reporting on IRL elasmobranchs has utilized bycatch data from sea turtle surveys that used large-mesh gill nets known as "tangle nets" (Snelson and Williams 1981; Snelson et al. 1984) or data from targeted juvenile teleost collections that were caught by using seines, cast nets, gill nets, otter trawls, and other types of gear (Gilmore 1977). However, the exact method of capture for each individual or species was not reported by Gilmore (1977), and although Snelson and Williams (1981) mentioned the overall aspects of the most commonly used tangle nets (90–229 m long, 3.7 m deep, with 30.5–40.6-cm stretch mesh of braided nylon), the authors were not consistent in reporting the exact gear type or gear specifics (i.e., mesh size) that caught each individual. While the most comprehensive past reporting came from Gilmore (1977) and Snelson and Williams (1981), several elasmobranch species have also been reported in the Florida Fish and Wildlife Conservation Commission (FWC)–Fish and Wildlife Research Institute's fisheries-independent monitoring surveys (Tremain and Adams 1995; Tremain et al. 2004). This program has surveyed fish populations in the IRL since the 1990s to monitor long-term trends by using seine nets and, formerly, multipanel experimental gill nets, ranging from approximately 7.5- to 15-cm stretch mesh (Tremain and Adams 1995; Adams and Paperno 2007). However, the monitoring did not specifically target elasmobranchs and mesh size was not reported for each elasmobranch that was captured in the aforementioned studies. Lastly, Curtis et al. (2011) analyzed 30 years of distribution and size data on Bull Sharks *Carcharhinus leucas* in the IRL from several sources including gill-net data from Snelson and Williams (1981), Snelson et al. (1984), FWC–Fish and Wildlife Research Institute's fisheries-independent monitoring survey gill-net data, bycatch data from University of Central Florida and Kennedy Space Center sea turtle netting studies, and longlining from a short-term shark-tagging study by the University of Florida. However, these data only concentrated on Bull Sharks and primarily focused on the northern IRL. Therefore, there is currently no understanding of the performance of these standardized gear types for targeting the elasmobranch community in this vast inshore system. The objective of this study was to assess the effects of longline bait type and gill-net mesh size on the catch per unit effort (CPUE), species composition, and size distribution of elasmobranchs caught in a fishery-independent survey targeting elasmobranchs in the IRL. While spatiotemporal patterns in catch composition and subsequent linkages with environmental conditions were not the focus here, the gear performance data collected herein will help elucidate these relationships in future studies of the region.

Study Site

The IRL is a shallow lagoonal estuary that spans approximately 253 km (157 mi) on Florida's east coast from the Ponce de Leon Inlet to Jupiter Inlet (Gilmore 1977) and is one of 28 estuaries designated as an "estuary of national significance" by the Environmental Protection Agency's National Estuary Program (EPA 2018). Three bodies of water constitute the lagoon complex: the IRL proper, the Banana River, and the Mosquito Lagoon. The study area encompassed the southern portion of the IRL (Figure 1) and was divided into five major regions (Sebastian, Vero Beach, Fort Pierce, Jensen, and the St. Lucie River). Each major region was then further divided into two subregions, A and B (Figure 1A). The subregional divisions were determined by sampling logistics (i.e., the area that is possible to sample in 1 d).

METHODS

Survey design.— The regions were sampled quarterly as part of a long-term elasmobranch abundance survey in the southern IRL. Each subregion was haphazardly sampled using a bottom longline and gill net for 1 d per quarter (winter = January–March; spring = April–June; summer = July–September; fall = October–December) for a total of 10 sampling days per quarter. The longline and gill net were set as a combination when possible, deployed 15 min apart and >0.5 km away from each other. When set as a combination, the gill net was deployed up-current of the longline to minimize any attraction of animals to the gill net due to the nearby bait. Location, timing, weather, and currents affected whether the gear was set in combination or if only one gear type was deployed. For example, gill nets could not be set in high current areas or areas of high boat traffic, and the duration of time required to process and sample animals dictated how many sets could be deployed in a single day. All of the sampling was conducted during daylight hours. The latitude and longitude at the start and end of each set and the minimum and maximum depth (m) of the area over which each gear spanned were retrieved from the onboard GPS and sonar (GPSMAP 7612xsv sonar, Garmin USA).

The bottom longline design followed the standardized COASTSPAN gear design (NMFS 1997), and was comprised of a 300-m mainline of 6.4-mm (#8) braided nylon line with 50 removable gangions spaced 6 m apart. Each gangion consisted of 1 m of 91-kg test monofilament, a size 120 stainless steel longline snap with a 4/0 swivel, and a Mustad 39960D nonstainless steel 12/0 circle hook with the barb depressed and no offset. For each longline set, 25 hooks were baited with Atlantic Mackerel *Scomber scombrus* and 25 hooks were baited with Striped Mullet. Bait size was not standardized because the size of the fish that were used for bait varied; however, all efforts were made to cut the baits into similar-sized pieces. Bait type did not alternate between each hook; instead, 25 hooks were baited as a group for each bait type. The order of which bait type was set first was random, and the change in the bait was denoted by an empty longline snap (i.e., a snap without a gangion attached) that was attached to the longline. The longline was set parallel to the shoreline and allowed to fish for 30 min to minimize mortality of smaller sharks.

The gill net consisted of a 100- × 3-m [length × depth] panel of 15.2-cm stretch mesh that was made of 0.47-mm (#8) nylon monofilament (double-knotted and single-selvaged with a breaking strength of 5 kg) and a panel of 20.3-cm stretch mesh of the same material and dimensions. Both panels of mesh had a 0.5 hanging ratio. The gill-net mesh sizes were larger than is specified in the COASTSPAN standardized gill-net design in order to target batoid (ray) species that inhabit inshore waters in order to complement the subadult shark species that were targeted with the longline. The two panels were fished as a single gear and set perpendicular to the shoreline for a soak time of 45–60 min to minimize mortality of smaller sharks.

Animal sampling.— All elasmobranchs captured in the gear were identified to the species level and measured. The fork length (FL, the tip of snout to the fork of the caudal fin) was measured for each shark and the disc width (DW, the distance between the wing tips) was measured for each batoid. Elasmobranchs were classified as immature or mature based on published species- and sex-specific lengths at maturity.

Data analyses.— Although several aforementioned factors affected whether the longline and gill net were set as a combination, both unpaired and combination sets were analyzed hereafter unless otherwise stated. Following the methods described in Belcher and Jennings (2009), the number of positive sets and encounter rate for each elasmobranch species were calculated for each bait type and

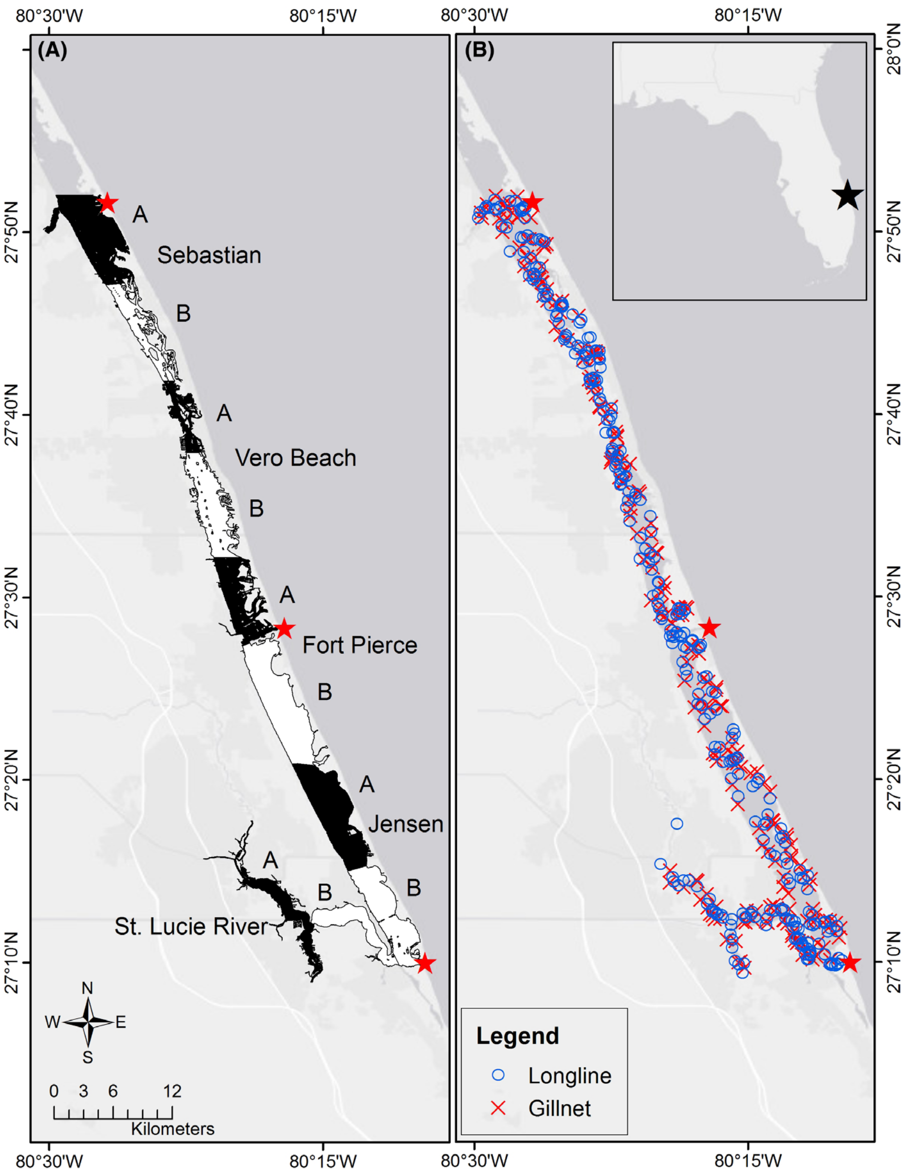

FIGURE 1. Study area in the southern Indian River Lagoon with **(A)** the subregions outlined and **(B)** the map of the longline and gill net sets from 2016–2018. The red stars indicate inlets.

mesh size. A positive set was defined as a longline or gill net set that caught at least one individual of the given species, and the encounter rate was calculated as the number of positive sets divided by the total number of sets of the particular gear.

Catch per unit effort for each set was calculated as the number of individuals divided by the set soak time in hours, and CPUE (mean ± SE) was calculated for each bait type and mesh size. These data were then tested for normality. Upon failing to follow a normal distribution, the CPUE data were square-root-transformed. However, transforming the data did not result in a normal distribution; thus, the Mann–Whitney test was used to compare CPUEs between bait types and between mesh sizes for all of the elasmobranch species combined. The proportion of bycatch versus elasmobranchs for each gear type in a combination set was calculated and averaged (expressed as mean ± SE) across all combination sets for each bait type and mesh size.

Using CPUE as a metric, a single-factor permutational multivariate analysis of variance (PERMANOVA; Anderson 2001) was used to assess differences in species composition between longline bait types and between gill-net mesh sizes. The CPUE data from positive sets (i.e., sets where at least one elasmobranch was caught) were square-root-transformed, and a Bray–Curtis similarity matrix, type III (partial) sums of squares, and 999 unrestricted permutations of the raw data were used (Anderson 2001). If a significant difference ($P \leq 0.05$) was found by the PERMANOVA analysis, a similarity percentage (SIMPER) analysis was used to identify which species contributed to the differences in species composition between bait types or mesh sizes (Clarke 1993). A distance-based test for homogeneity of multivariate dispersions (PERMDISP) was also used to examine the sample dispersion in the PERMANOVA as a potential explanation for rejection of the null hypothesis (Anderson 2006). All analyses were run by using Primer software v.7.0.13 (Clarke and Gorley 2015).

The FL and DW data for sharks and rays, respectively, were examined for normality using the Shapiro–Wilk normality test. A two sample *t*-test for normal data or the Mann–Whitney *U*-test for nonnormal data were used to compare shark FL between bait types and mesh sizes for all shark species combined and for the most abundant shark species. The same tests were used to compare DW between mesh sizes for all batoid species combined and for the most abundant batoid species. Length-frequency distributions of the three most abundant species were examined for each mesh size. For each species that had 10 or more individuals caught in each mesh size, the Kolmogorov–Smirnov (K–S) test was used to test for differences in length distributions. Differences in length distributions between bait types were not examined because there were no species with 10 or more individuals caught by each bait type.

RESULTS

Catch Summary

A total of 514 individual sets were completed from July 2016 to September 2018 (Figure 1B), of which 82% ($n = 420$) were deployed as combinations (i.e., a paired longline and gill net set). Hereafter, the results that are presented include both unpaired and combination sets unless otherwise stated. Encounter rates and overall catches differed for the two gear types. The overall encounter rate of elasmobranchs was higher in the gill net (68%) than on the

TABLE 1. Catch numbers and encounter rates for each elasmobranch species that was captured during gill net and longline sets. Encounter rate (ER) is reported as the number of sets that caught at least one individual of the species (the number of positive sets [NPS] divided by the total number of sets [gill net $n = 220$, longline $n = 294$]).

	Longline						Gill net					
	Mackerel			Mullet			15.2-cm mesh			20.3-cm mesh		
Species	*n*	NPS	ER (%)	*n*	NPS	ER (%)	*n*	NPS	ER (%)	*n*	NPS	ER (%)
Batoids	10	8	3	1	1	<1	210	80	36	235	81	37
Atlantic Stingray *Hypanus sabinus*							110	52	24	50	31	14
Bluntnose Stingray *Hypanus say*	2	2	1	1	1	<1	29	22	10	91	34	15
Bullnose Ray *Myliobatis freminvillei*							2	1	<1	1	1	<1
Cownose *Rhinoptera* spp.							49	12	5	60	14	6
Smalltooth Sawfish *Pristis pectinata*	2	2	1									
Smooth Butterfly Ray *Gymnura micrura*							5	5	2	8	7	3
Southern Stingray *Hypanus americanus*	6	5	2				6	6	3	14	13	6
Spotted Eagle Ray *Aetobatus narinari*							8	6	3	11	11	5
Sharks	18	16	5	74	52	18	106	48	22	74	36	16
Atlantic Sharpnose Shark *Rhizoprionodon terraenovae*	3	3	1	10	9	3						
Blacknose Shark *Carcharhinus acronotus*	2	1	<1	3	2	1						
Blacktip Shark *Carcharhinus limbatus*							1	1	<1			
Bonnethead Sharks *Sphyrna tiburo*	3	3	1	5	5	2	23	11	5	10	3	1
Bull Shark *Carcharhinus leucas*	7	7	2	42	27	9	79	35	16	62	33	15
Finetooth Shark *Carcharhinus isodon*				3	3	1	2	2	1	1	1	<1
Nurse Shark *Ginglymostoma cirratum*				5	5	2						
Sandbar Shark *Carcharhinus plumbeus*	3	3	1	6	6	2	1	1	<1	1	1	<1
Total individuals	28	22	7	75	52	18	316	108	49	309	101	46

longline (23%; Table 1). There was a significant difference between the depths in which each gear of a combination set was deployed (Mann–Whitney U-test = 30,414, $P <$ 0.001). The median depth of all of the longline sets that were part of combination sets was 1.75 m, and the mean depth was 1.89 ± 0.74 m (mean ± SD). The median depth of gill net sets that were part of combination sets was 1.35 m and the mean depth was 1.42 ± 0.49 m. The Bull Shark was the most abundant species caught in the survey, and when the two gears were fished together, Bull Sharks were caught more often in the gill net (20% of the combination sets) than on the longline (4% of the combination sets).

A total of 103 individuals from 10 species were captured on 67 of 294 longline sets. The most abundant shark species were Bull Shark and Atlantic Sharpnose Shark *Rhizoprionodon terraenovae*, together comprising 67% of the total shark longline catch. Batoids were rarely caught on the longline, with the exception of 11 individuals (Table 1).

A total of 625 individuals from 12 species were caught in 150 of 220 gill net sets. The most abundant shark species were Bull Shark and Bonnethead *Sphyrna tiburo*, comprising 97% of the total shark gill-net catch. The most abundant batoid species were Atlantic Stingray *Hypanus sabinus* and Bluntnose Stingray *H. say*, which comprised 63% of the total ray gill-net catch (Table 1).

Nontarget animals (bycatch) dominated the catch on the longlines (Supplemental Table 1 available separately online). Bycatch comprised 97% of the total catch with Atlantic Mackerel bait and 90% of the total catch with Striped Mullet bait. By contrast, the gill net caught lower proportions of bycatch, comprising 52% of the total catch in the 15.2-cm mesh and 24% of the total catch in the 20.3-cm mesh. Ariid catfishes (Hardhead Catfish *Ariopsis felis* and Gafftopsail Catfish *Bagre marinus*) comprised 49% of the total gill-net bycatch and 96% of the total longline bycatch.

Longline Bait Type Effects on Estimates of Elasmobranch Abundance, Composition, and Size

Twenty-eight elasmobranchs representing eight species were caught on hooks baited with Atlantic Mackerel, while 75 elasmobranchs representing eight species were caught on hooks baited with Striped Mullet. Every shark species was caught more frequently with Striped Mullet than with Atlantic Mackerel. The longline was not effective for catching rays; however, the few rays that were caught on the longline were caught almost exclusively with Atlantic Mackerel, with the exception of one Bluntnose Stingray that was caught with Striped Mullet (Table 1).

The total number of individuals that were caught with Striped Mullet was nearly three times as great as the number that were caught with Atlantic Mackerel (Figure 2), and the overall difference in CPUE between bait types was significant (Mann–Whitney U-test = 1,235.0, $P < 0.001$). The mean CPUE for hooks baited with Striped Mullet (mean ± SE = 2.20 ± 0.25 individuals/hour) was more than double the mean CPUE for hooks baited with Atlantic Mackerel (0.84 ± 0.17 individuals/hour). The PERMANOVA analysis revealed a significant difference (pseudo $F_{[1,\ 72]} = 2.3057$, $P = 0.046$) in the species composition of elasmobranchs caught with Atlantic Mackerel versus Striped Mullet. The differences in species composition between bait types were not due to sample dispersion (PERMDISP $P = 0.182$), and the bait types had similar mean deviations from the centroid. The SIMPER analysis revealed that Bull and Atlantic Sharpnose sharks were the top two species that contributed to these differences, with both species caught in greater abundance with Striped Mullet than with Atlantic Mackerel (Table 2). Encounter rates for Bull and Atlantic Sharpnose sharks were also higher with Striped Mullet than with Atlantic Mackerel (Table 1).

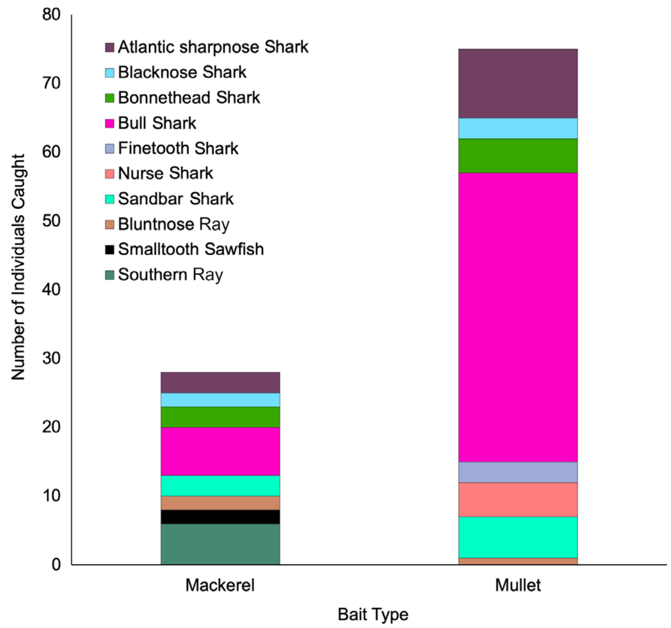

FIGURE 2. Species composition that was caught with each type of longline bait.

The FLs of sharks caught with Atlantic Mackerel ranged from 53.3 to 122.1 cm, while the FLs of sharks caught with Striped Mullet ranged from 46.8 to 138.1 cm. The mean FL for all sharks combined was not significantly different between bait types (Mann–Whitney U-test = 529.0, $P = 0.656$). The FL of the most abundant species, Bull Sharks, caught with Atlantic Mackerel ranged from 66.0 to 122.1 cm, while those caught with Striped Mullet ranged from 67.3 to 138.1 cm. There was no significant difference in the mean FL of Bull Sharks between bait types (Mann–Whitney U-test = 69.0, $P = 0.100$). The sample sizes were not robust enough to compare the DWs of batoids caught on the longline ($n = 11$).

TABLE 2. The SIMPER analysis revealed the species that contributed to significant (PERMANOVA, $P \leq 0.05$) differences in species composition between longline bait types.

Species	Average abundance		Average dissimilarity ± SD	Contribution (%)	Cumulative contribution (%)
	Mackerel	Mullet			
Bull Shark	0.32	0.62	25.06 ± 1.03	30.48	30.48
Atlantic Sharpnose Shark	0.14	0.18	11.13 ± 0.58	13.54	44.02
Sandbar Shark	0.14	0.12	10.11 ± 0.52	12.30	56.32
Southern Stingray	0.25	0.00	9.21 ± 0.51	11.21	67.53
Bonnethead	0.14	0.10	8.15 ± 0.49	9.91	77.44

Gill-Net Mesh Size Effects on Estimates of Elasmobranch Abundance, Composition, and Size

A total of 315 elasmobranchs from 12 species were caught in the 15.2-cm mesh while 309 elasmobranchs from 11 species were caught in the 20.3-cm mesh. Greater numbers of Bonnetheads, Bull Sharks, and Finetooth Sharks *C. isodon* were caught in the 15.2-cm mesh compared to the 20.3-cm mesh. The 20.3-cm mesh caught greater numbers of five batoid species (Bluntnose Stingray, Cownose Ray *Rhinoptera bonasus*, Smooth Butterfly Ray *Gymnura micrura*, Southern Stingray *H. americanus*, and Spotted Eagle Ray *Aetobatus narinari*) than the 15.2-cm mesh. However, the 15.2-cm mesh caught more Atlantic Stingrays and Bullnose Rays *Myliobatis freminvillei* than the 20.3-cm mesh. Encounter rates between the 15.2-cm and 20.3-cm mesh varied among the top species. Atlantic Stingrays, Bull Sharks, and Bonnetheads were encountered more often in 15.2-cm mesh, Bluntnose Stingrays were encountered more frequently in the 20.3-cm mesh, and Cownose Rays were encountered nearly equally in both mesh sizes (Table 1).

The overall CPUE between the two mesh sizes was not significantly different (Mann–Whitney U-test = 9,570.5, $P = 0.18$). The mean CPUE for the 15.2-cm mesh (1.88 ± 0.19 individuals/hour) was nearly equal to the mean CPUE for the 20.3-cm mesh (1.72 ± 0.21 individuals/hour). However, the PERMANOVA analysis revealed a significant difference (pseudo $F_{[1,\ 204]} = 3.7202$, $P = 0.003$) in species composition between the 15.2-cm and 20.3-cm mesh (Figure 3). These differences were not due to sample dispersion (PERMDISP $P = 0.086$), and the mesh sizes had similar mean deviations from the centroid. The SIMPER analysis revealed that the main differences between the two mesh sizes were due to the greater abundance of both Atlantic Stingrays and Bull Sharks in the 15.2-cm mesh (Table 3).

The FLs of sharks caught in the gill nets ranged from 44.5 to 142.6 cm in the 15.2-cm mesh and 58.6 to 141.0 cm in the 20.3-cm mesh. The mean FL for all sharks combined caught in the 20.3-cm mesh was 93.82 ± 21.87 cm (mean ± SD), and was significantly greater than the mean FL for all sharks caught in the 15.2-cm mesh (83.57 ± 19.55 cm; Mann–Whitney U-test = 2,294.5, $P = 0.004$). For Bull Sharks, the FL of those caught in the 15.2-cm mesh ranged from 56.5 to 142.6 cm, while those caught in the 20.3-cm mesh ranged from 66.0 to 141.0 cm. The mean FL of Bull Sharks caught in the 20.3-cm mesh (98.58 ± 21.21 cm) was significantly greater than the mean FL of those caught in the 15.2-cm mesh (88.89 ± 19.39 cm; Mann–Whitney U-test = 1,343.5, $P = 0.011$). Bonnetheads and Bull Sharks were the only shark species that had 10 or more individuals caught in each mesh size. The K–S test revealed significant differences in length distributions between mesh sizes for Bull Sharks ($P = 0.016$) but not for Bonnetheads ($P = 0.168$). Bull Sharks at 50–110 cm FL were caught with higher frequency in the 15.2-cm mesh, whereas Bull Sharks in the 110–130 cm FL range were caught more often in the 20.3-cm mesh (Figure 4A).

The disc widths of batoids caught in the 15.2-cm mesh ranged from 19.0 to 102.8 cm compared to 21.2 to 105.4 cm for batoids caught in the 20.3-cm mesh. The mean DW of rays caught in the 15.2-cm mesh (44.04 ± 25.67 cm

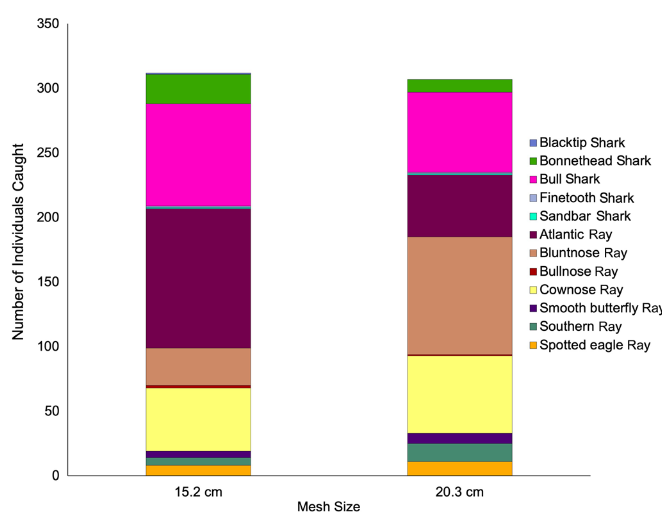

FIGURE 3. Species composition caught with each gill-net mesh size.

TABLE 3. The SIMPER analysis revealed the species that contributed to significant (PERMANOVA, $P \leq 0.05$) differences in species composition between gill-net mesh sizes.

	Average abundance				
Species	15.2 cm	20.3 cm	Average dissimilarity ± SD	Contribution (%)	Cumulative contribution (%)
Atlantic Stingray	0.66	0.37	20.29 ± 0.94	25.47	25.47
Bull Shark	0.46	0.42	18.13 ± 0.86	22.77	48.24
Bluntnose Stingray	0.23	0.48	15.15 ± 0.76	19.02	67.25
Cownose Ray	0.20	0.27	9.19 ± 0.49	11.53	78.79

[mean ± SD]) was significantly smaller than the mean DW of rays caught in the 20.3-cm mesh (50.95 ± 23.31 cm; Mann–Whitney *U*-test = 15,418.0, $P < 0.001$). For Atlantic Stingrays, the DW of those caught in the 15.2-cm mesh ranged from 19.0 to 32.0 cm, while those caught in the 20.3-cm mesh ranged from 21.2 to 30.0 cm. The DWs of Atlantic Stingrays were significantly different between mesh sizes (Mann–Whitney *U*-test = 1,230.5, $P < 0.001$). The mean DW of Atlantic Stingrays caught in the 15.2-cm mesh (24.29 ± 2.28 cm) was smaller than the mean DW of those caught in the 20.3-cm mesh (25.83 ± 1.77 cm). The DWs of Bluntnose Stingrays were not significantly different between mesh sizes (two sample *t*-test, $t = 1.067$, df = 111, $P = 0.289$). The mean DW of Bluntnose Stingrays in the 15.2-cm mesh was 42.62 ± 10.43 cm (range 22.0–65.2 cm) while the mean DW of those caught in the 20.3-cm mesh was 40.68 ± 7.56 (range 24.3–60.5 cm). Atlantic Stingrays, Bluntnose Stingrays, and Cownose Rays were the only batoid species with 10 or more individuals caught in each mesh size (Table 4). The K–S tests showed that species-specific length distributions differed between mesh sizes for Atlantic Stingrays ($P < 0.001$) and Bluntnose Stingrays ($P = 0.042$), but did not differ for Cownose Rays ($P = 0.828$; Table 4). Atlantic Stingrays from 15 to 25 cm DW were caught more frequently in the 15.2-cm mesh while individuals from 25 to 30 cm were caught more frequently in the 20.3-cm mesh (Figure 4B). Bluntnose Stingrays from 20 to 25 cm and 65 to 70 cm DW were caught more frequently in the 15.2-cm mesh while individuals from 25 to 60 cm were caught more frequently in the 20.3-cm mesh (Figure 4C).

DISCUSSION

Overall Catch

This study was the first to examine the performance of two concurrently set survey gear configurations for targeting elasmobranchs in the IRL. Although previous studies in the IRL have collected data on elasmobranchs opportunistically or in wider surveys that were targeting broader fish communities, a lack of standardization in those studies prevented a comprehensive understanding of the gear performance for targeting elasmobranchs in this large estuarine system. While several studies have compared various gear configurations in subtropical estuaries (e.g., Reis and Pawson 1999; Carlson and Cortés 2003; Belcher and Jennings 2009), to our knowledge this is the first study to use the specific combinations of Striped Mullet and Atlantic Mackerel for longlining and 15.2-cm and 20.3-cm meshes for gillnetting for comparison in this type of shallow, subtropical lagoonal estuary.

The use of two different types of gear in this study allowed for the evaluation of the performance of the gear in targeting elasmobranchs. The longline was used to target primarily sharks, while the gill net was used as a complementary gear to catch batoids. The batoid catch numbers for the two gear types (11 on the longline versus 444 in the gill net) validate the use of this combination of gear types for targeting both groups of elasmobranchs. However, the total number of individuals that were caught on the longline was only approximately 17% of the total for the gill net. Higher catches in gill nets than on longlines have been reported elsewhere (Erzini et al. 2003; Walker et al. 2005). Nonetheless, animals that were caught on the longline appeared to be in better condition than those that were caught in the gill net, as the short (1 m) gangion likely allowed the animals to swim around and hooked animals were subject to shorter soak times than those in the gill net. Additionally, considering that these two gear types were evaluated for targeting an elasmobranch community rather than a specific species, the occurrence of certain species exclusively on the longline should not be ignored (e.g., Smalltooth Sawfish and Nurse Shark *Ginglymostoma cirratum*).

The ability to set the gear in certain areas of the lagoon is a potential contributor to the different catch rates. Deeper waters and strong currents prevented the use of the gill net in certain areas (i.e., inlets), whereas the longline could be set in a wider range of locations, thereby increasing the

TABLE 4. Size ranges for each species caught by each gear type. The size ranges for sharks are reported in fork length (FL). The size ranges for batoids are reported in disc width (DW), with the exception of the Smalltooth Sawfish, which is reported in FL. The last column shows the results of the Kolmogorov–Smirnov (K–S) test for comparing differences in species-specific length distributions in the gill net, reported with *P*-values in parentheses.

	Longline				Gill net				
	Mackerel		Mullet		15.2 cm		20.3 cm		
Species	*n*	Size range (cm)	*n*	Size range (cm)	*n*	Size range (cm)	*n*	Size range (cm)	K–S (*P*)
Batoids									
Atlantic Stingray					110	19.0–32.0	50	21.2–30.0	2.593 (0.00)
Bluntnose Stingray	2	49.5–63.5	1	56.9	29	22.0–65.2	91	24.3–60.5	1.390 (0.042)
Bullnose Ray					2	32.4–36.0	1	33.9	
Cownose Ray					49	46.6–102.8	60	47.2–100.5	0.626 (0.828)
Smalltooth Sawfish	2	273.8–321.0							
Smooth Butterfly					5	30.2–84.0	8	35.6–70.8	
Southern Stingray	6	34.2–90.6			6	35.7–63.5	14	37.5–75.6	
Spotted Eagle Ray					8	47.5–87.3	11	54.5–105.4	
Sharks									
Atlantic Sharpnose Shark	3	53.3–84.1	10	46.8–79.5					
Blacknose Shark	2	92.2–95.9	3	90.8–112.0					
Blacktip Shark					1	57.5			
Bonnethead	3	89.0–92.4	5	57.5–74.4	23	44.5–95.6	10	63.8–82.6	1.113 (0.168)
Bull Shark	7	66.0–122.1	42	67.3–138.1	79	56.5–142.6	62	66.0–141.0	1.551 (0.016)
Finetooth Shark			3	59.9–87.1	2	75.5–79.4	1	80.1	
Nurse Shark			5	130.0[a]					
Sandbar Shark	3	58.5–70.1	6	57.7–69.5	1	60.2	1	58.6	

[a]Fork length was only measured for 1 of the 5 Nurse Sharks.

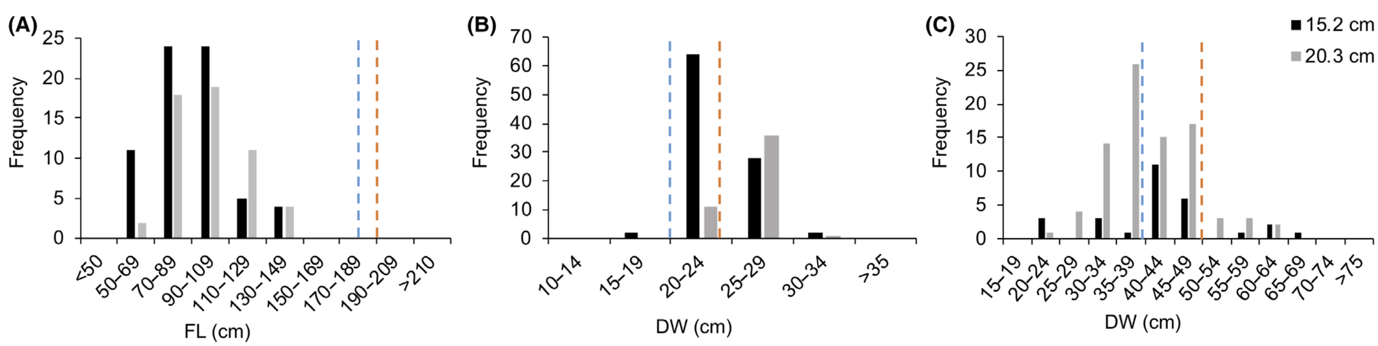

FIGURE 4. Length-frequency distribution of **(A)** Bull Sharks, **(B)** Atlantic Stingrays, and **(C)** Bluntnose Stingrays that were caught in the gill net. The black and gray bars represent catches in the 15.2- and 20.3-cm mesh, respectively. The dashed lines indicate FL or disc width (DW) at sexual maturity for females (orange) and males (blue). The estimated lengths at sexual maturity were from Natanson et al. (2014) for Bull Sharks, Snelson et al. (1988) for Atlantic Stingrays, and Snelson et al. (1989) for Bluntnose Stingrays.

possibility of encountering elasmobranchs. Although setting the gear as combination sets when and where possible (82% of the total sets) was meant to minimize biases due to spatial constraints of the gear, there was a significant difference between the depths in which each gear type of a combination set was deployed. These differences could help explain some of the differences in catch composition between the two gear types. It is possible that the longline gear was not fishing correctly or efficiently in high-current areas, thereby contributing to lower catch rates; however, high-current areas in the IRL are limited to near the inlets, which comprised only a small portion of the entire study area in which the longline was deployed.

Although suitable for more dynamic areas, the lower catch rates on the longline could also be explained by the fact that animals need to be feeding in order to be captured, a behavior that is influenced by myriad factors (Løkkeborg et al. 2014), whereas the gill net may catch animals that are present in the area but not actively feeding. Future studies should further investigate factors that affect the feeding behavior of fish such as hunger state, temperature, current, and prey density (Løkkeborg et al. 2014), all of which may affect catch rates in surveys that use baited lines.

The rate of bycatch is another potential contributor to the differences in catch numbers between the two gear types. As more fish are caught in a fishing gear, the gear efficiency decreases until it is saturated (Hansen et al. 1998; Hubert et al. 2012). The high abundance of teleost bycatch, specifically ariid catfishes, relative to elasmobranchs on the longline could have resulted in decreased availability of hooks for elasmobranchs. On the other hand, accumulation of bycatch in the gill net could have made the net more visible to elasmobranchs and thus easier to avoid or could have reduced the available space in the net for elasmobranchs. Conversely, bycatch in the gill net could have also attracted more sharks to the net, as there was some evidence of in-net predation. Nonetheless, the higher rates of bycatch on the longline likely contributed to its low target catch numbers. These characteristics render the longline less cost-effective than the gill net in this study system.

It is evident that the gill net was more efficient at capturing elasmobranchs in terms of total numbers; however, some species were caught exclusively on the longline (e.g., Atlantic Sharpnose, Blacknose, and Nurse sharks, and Smalltooth Sawfish). The absence of these species in the gill net may be explained by possible low abundances in the area; Atlantic Sharpnose and Blacknose sharks are absent from the main literature of the area (Gilmore 1977; Snelson and Williams 1981). However, Carlson and Cortés (2003) achieved the highest CPUE for Atlantic Sharpnose and Blacknose sharks in the Gulf of Mexico in 8.9-cm mesh rather than larger mesh sizes. Therefore, it is possible that the nearly twofold greater mesh sizes used in this study allowed Atlantic Sharpnose and Blacknose sharks to swim through the net and avoid entanglement. As for the absence of larger species from the gill net such as Nurse Sharks and Smalltooth Sawfish, these species were also rarely captured by Gilmore (1977), although Snelson and Williams (1981) later postulated that the Smalltooth Sawfish had been extirpated from most of the IRL. However, in this study, individuals of these two species were captured on the longline in deeper waters near inlets where the gill net could not be set, which could explain their absence from the gill-net catch.

This study provides insight into how gear characteristics might affect the size composition of elasmobranch catch. Both gears captured mature individuals of smaller shark species (e.g., Bonnetheads and Atlantic Sharpnose Sharks); however, mature individuals of larger species (e.g., Bull Sharks) were absent from the survey. Although Bull Sharks were the most abundant species in the survey, the lack of large, mature Bull Sharks is likely due to their rare occurrence in the shallow lagoon rather than an effect of gear bias, as Bull Sharks larger than 190 cm are thought to leave the lagoon to move to offshore adult habitats (Curtis et al. 2011). While small Bull Sharks were abundant across both gears used in this survey, if the goal of a future survey was to target young-of-the-year or small juvenile Bull Sharks to investigate potential nursery areas, the 15.2-cm mesh would likely be more efficient than the 20.3-cm mesh at capturing the desired size-class. However, future studies on hook selectivity may help improve efficiency such that depending on a study objective, certain hook sizes can be used to capture individuals of a target size. Additionally, during the entire survey only eight hooks were bitten off (0.05% of the total longline hooks) in a total of seven longline sets (2.4% of the longline sets), so it is not expected that the use of monofilament leaders contributed to a loss of larger sizes or species of sharks that would lead to significantly underestimated abundances.

For batoids, although mature individuals of smaller species (e.g., Atlantic Stingrays and Bluntnose Stingrays) were captured in the gill net, no large, mature Spotted Eagle Rays were captured despite their year-round presence in the lagoon (Snelson and Williams 1981; DeGroot 2018). Therefore, the capture of only young-of-the-year and immature individuals of this species is likely due to size selectivity of the gill net as well as the material, as larger rays are able to break through the monofilament netting (M. J. Ajemian, personal observation).

Bait Type

Bait type has been shown to affect catch rates of sharks (Belcher and Jennings 2009; Driggers et al. 2016), and it is possible that the higher catches of sharks on the longline with Striped Mullet is driven by bait preference. Striped Mullet is locally abundant in the IRL (Gilmore 1977), a common prey species for Bull Sharks in the lagoon (Snelson et al. 1984; Curtis et al. 2013), and also widely commercially available throughout Florida. On the other hand, Atlantic Mackerel is distributed in the open sea in the northwestern Atlantic from Labrador, Canada to North Carolina (Studholme et al. 1999) and does not naturally occur in the lagoon system. However, its low cost, commercial availability, and prevalence in other elasmobranch surveys (e.g., Branstetter and Musick 1993; Grubbs et al. 2007; Drymon et al. 2012) warranted the use of Atlantic Mackerel for comparison in this survey. Bait loss should also be considered, either from deployment or due to deterioration of the bait, which can affect catch rates (Ward et al. 2004). Moreover, scavengers can contribute to bait loss and the soft skin of Atlantic Mackerel likely makes it easier to feed on compared to the tougher skin of Striped Mullet. While Atlantic Mackerel was observed to be absent from hooks after retrieval more often than Striped Mullet was, the presence or absence of the bait on each hook was not recorded in this study. Future work should further examine bait condition as a possible influence on catch rates.

The low longline catch rates for batoids may be partly explained by the different buccal morphologies and feeding strategies of batoids. The batoids that were encountered in this study are all benthic feeders and use suction to grasp prey from the bottom or excavate prey from the substrate (Motta and Huber 2012; Jacobsen and Bennett 2013). Some studies have suggested the small subterminal mouths of Pelagic Stingrays *Pteroplatytrygon violacea* as a possible explanation for the species' lower catch rates on larger circle hooks (Piovano et al. 2010; Godin et al. 2012). Therefore, the similar morphology of the dasyatid rays that were present in this study may have contributed to the low longline catch rates. Despite low catch rates, 10 of the 11 batoids that were caught on the longline were caught with Atlantic Mackerel. Driggers et al. (2016) postulated that higher catches of Clearnose Skates *Raja eglanteria* caught with northern shortfin squid *Illex illecebrosus* versus Atlantic Mackerel were due to their small gape size and the more malleable and easily manipulated squid. As mentioned previously, Atlantic Mackerel is relatively softer than Striped Mullet, perhaps explaining why batoids were more often caught on Atlantic Mackerel than on Striped Mullet in this study.

Mesh Size

Overall, the larger mesh size caught larger elasmobranchs, consistent with other findings (Carlson and Cortés 2003; McAuley et al. 2007; Baremore et al. 2012). However, significant differences in lengths as well as species composition between the two mesh sizes supports the use of multiple mesh sizes when aiming to survey an overall community of elasmobranchs rather than targeting only specific life stages or size-classes. Walker et al. (2005) found that for most shark species in a southeastern Australian shark fishery, catches peaked at a certain mesh size and then decreased as mesh size both increased and decreased. Therefore, adding one or more panels (i.e., with 10.2- and/or 25.4-cm mesh) to the gill net that was used in this study may help determine whether there are higher species-specific catch rates for a particular mesh size.

Differences in net characteristics could explain the discrepancies between the current study and previous surveys that have been undertaken in the IRL by Gilmore (1977) and Snelson and Williams (1981). Gilmore (1977) used small-mesh (0.3–6.7 cm) beach seines, as well as gill nets with unspecified mesh sizes, for targeting juvenile fish. Snelson and Williams (1981) used tangle nets with 30.5–40.6-cm stretch mesh that were constructed from braided nylon and used primarily for targeting sea turtles. As previously mentioned, mesh sizes can affect the size selectivity of the gear (Rago 2005; Hubert et al. 2012); thus, these differences in mesh sizes could account for the differences in species and sizes among these three studies. Snelson and Williams (1981) caught Bull Sharks ranging from 73 to 249 cm TL in small- and large-mesh tangle nets, with most individuals measuring between 120 and 180 cm TL. However, the authors did not specify which size sharks were caught in the small- versus large-mesh tangle nets. Meanwhile, the Bull Sharks that were caught in the present study ranged from 65.1 to 175.6 cm TL, with approximately 75% of individuals measuring between 80 and 130 cm TL. Cownose Rays ranged from 45.0 to 82.5 cm DW in large-mesh tangle nets (Snelson and Williams 1981); however, the size range of the Cownose Rays that were caught in this study was nearly 20 cm wider (47.2–100.5 cm DW). Lemon Sharks *Negaprion brevirostris* ranging from 158.0 to 258.1 cm TL were the only other species that Snelson and Williams (1981) specifically recorded in the large-mesh tangle nets. Lemon Sharks were absent from the current study, as was any shark measuring greater than 142.6 cm FL. In addition to different mesh sizes contributing to the disparities in size ranges and species composition between Snelson and Williams (1981) and the current study, other factors such as location or time of day, especially as it relates to fish activity (Rago 2005), could have also influenced catches. The current sampling was conducted solely in the daytime in the southern IRL while Snelson and Williams (1981) sampled the northern portions of the IRL system (including Mosquito Lagoon and Banana River) and deployed gill nets at night as well.

While the size selectivity of a gill net is influenced by its mesh size (Rago 2005; Hubert et al. 2012), previous studies suggest that gill-net material has less of an influence on size selectivity but can affect catch efficiency. For example, monofilament nets have been shown to yield higher catches of several teleost species than multifilament nets do (Larkins 1963; Collins 1979). While they should not be directly compared, it is possible that differences in net material between the current study (monofilament net) and Snelson and Williams' (1981) study (braided nylon net) could be a contributor to the differences in abundance, species composition, and species lengths between the two studies. Moreover, mesh of thinner diameters have lower breaking strengths compared to thicker materials (Holst et al. 1996; Carlson and Cortés 2003; Walker et al. 2005); thus, monofilament nets would likely have lower breaking strengths than multifilament nets and large animals may be able to break through the mesh and escape more easily.

CONCLUSIONS

The results presented herein demonstrate that choice of bait and mesh size can have significant effects on catch numbers, species composition, and size distributions of elasmobranchs that are caught in shallow subtropical estuarine systems. The use of two different mesh sizes enabled sampling of a larger size range of elasmobranchs than a single mesh size would have yielded. However, addition of a smaller mesh size, such as a panel of 10.2-cm mesh, would likely help to optimize the overall elasmobranch catch by capturing smaller target species and individuals. While the combination of two longline bait types as a supplement to the gill net allowed for additional species to be captured, using a more widely appealing bait like Striped Mullet appears to be a better choice than Atlantic Mackerel, considering that only two of the species (Smalltooth Sawfish and Southern Stingray) that were caught were unique to Atlantic Mackerel. Striped Mullet also proved to be more durable and cost-effective for this study, considering that it can be locally sourced and a lower average proportion of bycatch was caught on Striped Mullet than on Atlantic Mackerel.

Overall, this study revealed valuable information on the performance of these gear types for sampling the elasmobranch community in this highly used estuary. Due to the paucity of elasmobranch-specific surveys in the IRL region, gear performance data are highly timely, as they can help to optimize protocols for quantifying changes in elasmobranch diversity and abundance. The results from the standardized gear designs and methods will provide recommendations for gear selection in future studies when targeting similar species or sampling in similar habitats and will provide information to aid in developing efficient and cost-effective sampling strategies.

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SUPPORTING INFORMATION

Additional supplemental material may be found online in the Supporting Information section at the end of the article.