Commercial fishing gear modification to reduce interactions between Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) and the southern flounder (*Paralichthys lethostigma*) fishery in North Carolina (USA)

Juan C Levesque, Christian Hager, Eric Diaddorio, Jason R Dickey

Bycatch of protected species in commercial fishing operations is a primary concern to fishery managers because it threatens the conservation, protection, and recovery of fragile species, such as the Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*). One potential solution to reduce the risk associated with commercial fishing operations is to design commercial fishing gear that is more selective in terms of interactions between Atlantic sturgeon and commercial fisheries. Given the need to reduce commercial fishery interactions, the overarching goal was to reduce Atlantic sturgeon fishery interactions and maintain southern flounder (*Paralichthys lethostigma*) catch in North Carolina. The specific objectives of this study were to design and evaluate the effectiveness of a modified gillnet. Overall, the results proved that lowering the profile and amount of webbing had a beneficial impact at reducing Atlantic sturgeon encounters and bycatch. The modified gillnet reduced bycatch and Atlantic sturgeon encounters by 49.4% and 60.9%, respectively. We also found the modified gear entangled 51.6% less southern flounder, which corresponded to a 32% reduction in total weight; the experimental sections entangled slightly larger individuals than the control sections. Our findings showed the number of Atlantic sturgeon encounters was positively associated with mean water depth, with more Atlantic sturgeon encountered in deeper than shallower waters; 75% were encountered at depths between 4.6 and 6.1 m. In addition, we found that 41% of the Atlantic sturgeon encountered were in warmer (26–30°C) than colder water.

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Commercial Fishing Gear Modification to Reduce Interactions between Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) and the Southern Flounder (*Paralichthys lethostigma*) Fishery in North Carolina (USA)

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ABSTRACT

Bycatch of protected species in commercial fishing operations is a primary concern to fishery managers because it threatens the conservation, protection, and recovery of fragile species, such as the Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*). One potential solution to reduce the risk associated with commercial fishing operations is to design commercial fishing gear that is more selective in terms of interactions between Atlantic sturgeon and commercial fisheries. Given the need to reduce commercial fishery interactions, the overarching goal was to reduce Atlantic sturgeon fishery interactions and maintain southern flounder (*Paralichthys lethostigma*) catch in North Carolina. The specific objectives of this study were to design and evaluate the effectiveness of a modified gillnet. Overall, the results proved that lowering the profile and amount of webbing had a beneficial impact at reducing Atlantic sturgeon encounters and bycatch. The modified gillnet reduced bycatch and Atlantic sturgeon encounters by 49.4% and 60.9%, respectively. We also found the modified gear entangled 51.6% less southern flounder, which corresponded to a 32% reduction in total weight; the experimental sections entangled slightly larger individuals than the control sections. Our findings showed the number of Atlantic sturgeon encounters was positively associated with mean water depth, with more Atlantic sturgeon encountered in deeper than shallower waters; 75% were encountered at depths between 4.6 and 6.1 m. In addition, we found that 41% of the Atlantic sturgeon encountered were in warmer (26–30°C) than colder water.

INTRODUCTION

Bycatch in commercial fishing operations is one of the biggest challenges for fisheries managers tasked with conserving, protecting, and sustaining marine resources (Read & Rosenberg, 2002; Harrington *et al*., 2005; Read *et al*., 2005). The Magnuson-Stevens Fishery Conservation and Management Act (MSFCA 1996) defines bycatch as "…fish which are harvested in a fishery, but which are not sold or kept for personal use, and includes economic discards and regulatory discards…" In general, bycatch is defined as any marine organism that is incidentally captured in some type of man-made gear or equipment (e.g., gillnets, trawls, and hopper dredges), and discarded back to the sea; discarded marine organisms are either dead or alive. Unfortunately, the survival rate for most bycatch species that are discarded is poorly understood (Davis, 2002). Discarded bycatch usually has little to no economic value and consists of non-targeted and undersized marketable fishes, unmarketable species, or marine animals protected under the Endangered Species Act (ESA), Marine Mammal Protection Act (MMPA) or Migratory Bird Act. Bycatch of protected species in commercial fishing operations is a primary concern to fishery managers because it threatens the conservation, protection, and recovery of fragile species. Due to strict regulations, it can also impact the economic sustainability of commercial fisheries because fishery managers are often forced to prohibit specific fishing gears and techniques (e.g., offshore drift monofilament gillnets). Many protected species have small populations and low reproductive rates (Hall *et al*., 2000); thus, even small levels of mortality may prevent population recovery or lead to extirpation (Secor *et al*., 2002). One of the challenges for fishery managers is that most protected species display migratory behavior and undertake seasonal migrations that occur in conjunction with economically valuable commercial fisheries, which compounds the problem (Lewison *et al*., 2004). Overlapping spatial and temporal distributions increases the risk and often leads to elevated fishery interaction rates. One potential solution to reduce interactions between protected species and commercial fishing operations is engineering fishing gear that is more selective.

Bycatch has been identified as a problem in the United States through various legislative actions (e.g., MSA, ESA, MMPA), and substantial effort to reduce bycatch in commercial fisheries has been made over the last 20 years. However, most of the management and conservation measures have included time/area fishing closures, reductions in target quota, size-limits, fishing effort, and prohibition of specific fishing gear or fishing techniques (Harrington *et al*., 2005). Recently, some progress has been made in modifying commercial fishing gear and practices (e.g., turtle excluder devices and circle hooks) as a method to reduce bycatch of protected species, but additional research in this field is essential so fishery managers can improve how they manage protected resources while still achieving, on a continuing basis, the optimum yield for commercial fisheries (MSFCA, 1996). In many ways, this is a difficult and even impossible task for fishery managers given the stringent (i.e., jeopardy, potential biological removal, and zero mortality rate goal) requirements of the ESA and MMPA. Adding to the issue is that commercial fisheries continue to evolve, grow, and emerge (Levesque, 2010), so fishery management problems constantly change.

Under Section 118 of the MMPA, commercial fisheries are re-classified every year under the List of Fisheries process (Category I, II, and III; level of incidental mortality or serious injury of marine mammals), and additional species are classified as threatened or endangered under the ESA, such as the Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*). In 2012, the National Marine Fisheries Service (NMFS) issued (6 February 2012) a final determination to list five distinct population segments (DPSs) of Atlantic sturgeon as endangered under the ESA (FR, 2012a,b): Gulf of Maine, New York Bight, Chesapeake Bay, Carolina, and South Atlantic. Despite this protection status, and a complete moratorium on possession of Atlantic sturgeon, these anadromous species are still incidentally taken as bycatch in various commercial fisheries along the east coast of the United States, especially sink gillnet fisheries (Wirgin *et al*., 2015). Unfortunately, Atlantic sturgeon are particularly vulnerable to sink gillnets because they are a demersal species that feeds on benthic biota, such as polychaetes, crustaceans, and molluscs.

Given their anadromous life-history, Atlantic sturgeon are susceptible to numerous inshore commercial operations (Logan-Chesney, 2013; Dunton *et al*., 2014) along the east coast of the United States, including commercial sink gillnet operations in North Carolina. In North Carolina waters, monofilament sink gillnets are used to target a variety of finfish (e.g., southern flounder [*Paralichthys lethostigma*]), which poses a threat to Atlantic sturgeon (Armstrong, 1999). Available scientific information indicates that commercial fisheries targeting southern flounder routinely encounter Atlantic sturgeon (White & Armstrong, 2000; FR, 2012a, FR, 2012 b). Data on Atlantic sturgeon bycatch in North Carolina commercial fisheries is limited, but researchers have reported that Atlantic sturgeon mortality in gillnet fisheries within Albemarle and Pamlico Sounds is between 0 and 19%, and possibly higher (Armstrong, 1999; White & Armstrong, 2000). According to White & Armstrong (2000), a single commercial fisherman in the Albemarle Sound incidentally entangled 131 Atlantic sturgeon while targeting southern flounder with gillnet gear during 1998 through 2000. Updated Atlantic sturgeon fishery interaction information, potential fishing gear/engineering solutions, or modifications in fishing practices in the North Carolina southern flounder fishery are currently unavailable. As such, the overarching goal of this study was to evaluate whether modifications to gillnet gear could reduce

Atlantic surgeon interactions in the southern flounder fishery. The objectives were to evaluate the effectiveness of the modified fishing gear in reducing Atlantic sturgeon fishery interactions and maintaining southern flounder catch. The specific objectives were to (1) describe, examine, and compare the bycatch associated with using a modified (experimental) versus a traditional (control) gillnet; (2) examine, compare, and test for differences in the number and mean size (length and weight) of southern flounder between a modified (experimental) and a traditional (control) gillnet; (3) examine, compare, and test for differences in the number and mean size (length and weight) of Atlantic sturgeon between a modified (experimental) and a traditional (control) gillnet; and (4) examine the environmental conditions (water depth and temperature) associated with Atlantic sturgeon encounters.

MATERIAL AND METHODS

Study area

Based on historical fishing information, present commercial fishing effort for southern flounder, Atlantic sturgeon fishery interaction information, and recent discussions with state representatives and fishermen, we specifically conducted this study in Albemarle Sound, North Carolina (**Fig. 1**) near major rivers (Pasquotank, Perquimans, Chowan, Alligator, and Roanoke Rivers) to optimize the probability of encountering Atlantic sturgeon. We specifically selected this location because the largest Atlantic sturgeon commercial fishery once occurred in the Roanoke River, North Carolina (Kahnle *et al*., 1998), and Atlantic sturgeon continue to be incidentally encountered by commercial gillnet fishermen targeting southern flounder (Armstrong 1999; White & Armstrong, 2000; FR, 2012a,b).

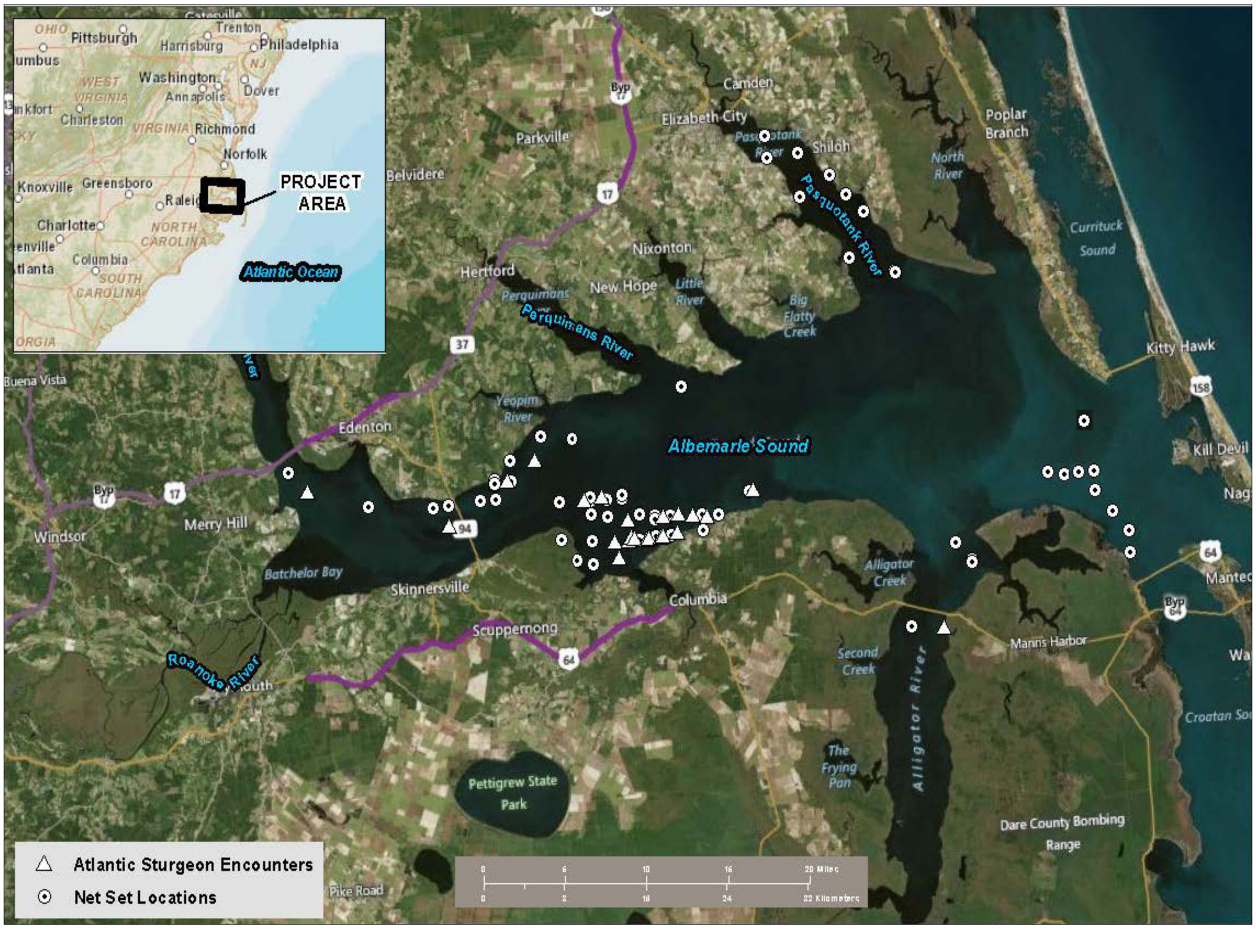

Figure 1. Map of the study area; Albemarle Sound, North Carolina (USA).

Experimental and control gear specifications

To standardize the gear, the net was constructed using traditional mesh size and lengths commonly used by commercial fishermen targeting southern flounder in Albemarle Sound (Armstrong, 1999; personal communication, Ms. Kathy Rawls, NCDENR; August 2012). It should be noted that the net and study were both designed prior to the release of revised commercial fishing regulations that prohibited the use of gillnets longer than 1,372 m (1,500) yards in Albemarle Sound.

To ensure the gillnet was constructed using a typical technique for the region, a local experienced commercial fishermen was hired to construct the monofilament gillnet. The monofilament gillnet was constructed with 30 equal length (91.4 m [100 yd]) panels or sections, and it was 2,743 m (3,000 yd) long. The configuration used an alternating pattern approach (15 control and 15 experimental sections). Each control section was 91.4 m long, and it was constructed with 14.6 cm (5.75 in; 0.177 mm [diameter]) stretched mesh webbing hung on a 49.3% ratio. The panels were 25 meshes deep with a fishing height of approximately 3.1 m (10 ft) (**Fig. 2**). The section had 0.91m (3 ft) lines sewn in every 9.1 m (32.8 ft) that connected the leadline to the top or float line (tie-downs); 6 meshes per tie. The float line was constructed with 0.79 cm (5/16 in) polypropylene braided line and 13.97 x 3.81 cm (5.5 x 1.5 in) floats were attached at the string ties every 9.1 m. The monofilament webbing was attached to the float line and leadline using #9 string ties every 41 or 43 cm (16-17 in). At the end of each section, a tie down was sewn into the webbing as a head rope, which prevented web tearing. The bottom line was constructed using a 9.1 kg (20 lb) per 91.4 m leadline.

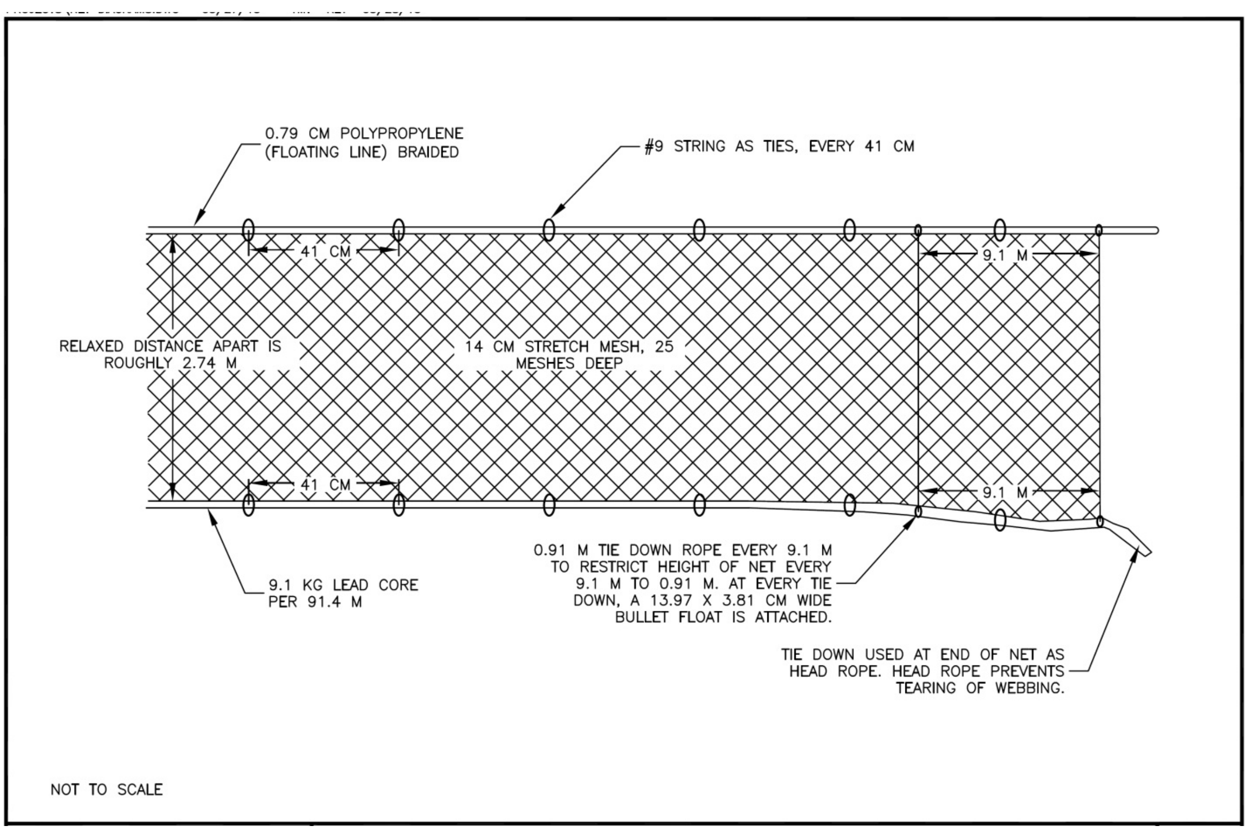

Figure 2. Control section gear specifications.

The experimental sections were each 91.4 m long and constructed of 14.6 cm (5.75 in; 0.177 mm [diameter]) stretch mesh hung on a 50% ratio. The panels were 15 meshes deep with a fishing height between 0.3 (1 ft) and 0.91 m (3 ft) (**Fig. 3**); the net's profile and amount of material was approximately 75% less than the control. The tie-down lines were 41 cm long and sewn in every 9.1 m. Unlike the control sections, the top line of the experiment sections was replaced with another leadline (i.e., double leadline) to reduce the net's profile; no floats were used on the top line. Hog rings instead of string ties were used every 0.91 m (3 ft) on one of the top lead lines. The top and bottom line of the experimental section was constructed using a 9.1 kg per 91.4 m leadline. The monofilament webbing was hung through the lead core lines on the top and bottom rather than hung onto the net. One side was pinned every 9.1 m and the other side was allowed to free float on the opposite lead core line. Unlike a typical vertical wall

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construction (i.e., control), the experimental section webbing was a mushroom or half-moon shape, which reduced the height of the net. This design was based on the premise that reducing the height (75% reduction in comparison to the control) or profile of the net would reduce interactions with Atlantic sturgeon.

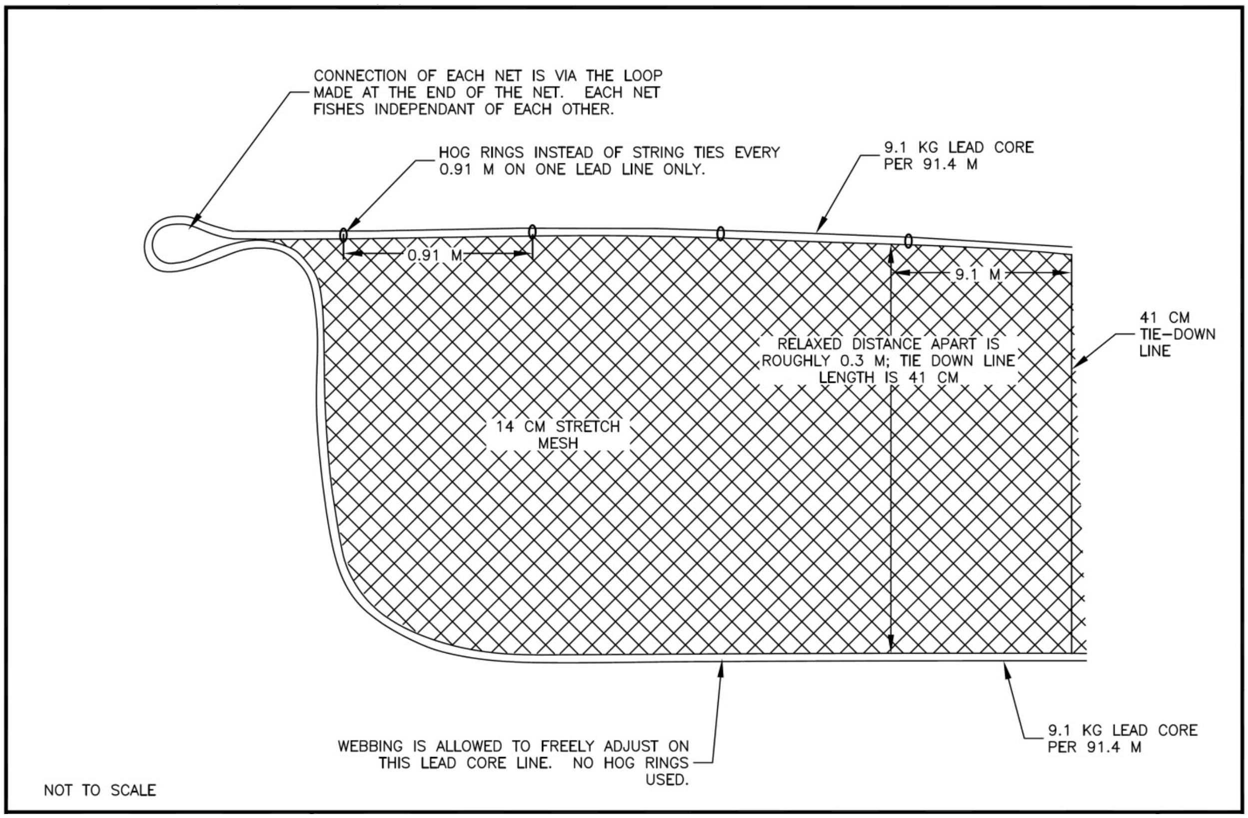

Figure 3. Experimental section gear specifications. It should be noted that the monofilament webbing in the experimental section did not hang in the water in a typical mode (i.e., vertical wall), it was more like a half moon or mushroom shape.

Field procedures

Mimicking Albemarle Sound commercial fishermen that target southern flounder, the gillnet was mainly set around sunset and retrieved around sunrise. However, a few daytime sets were conducted, but southern flounder catch rates were lower than nighttime sets so most of the fishing effort occurred at night (i.e., overnight sets). The net soak duration varied with fishing success and weather conditions, but it averaged almost 12 hours per set. The net was generally deployed parallel to shore, but the direction was somewhat contingent upon the wind, current, and tide conditions. Every time the net was deployed, the first panel was alternated between the control and experimental section to reduce any potential gear bias associated with distance from shore. The net was secured to the bottom using 6.8 kg (15 lb) Danforth anchors attached to each end of the net for the duration of the set.

Experimental study design

To optimize sample size and enable rigorous statistical evaluations of Atlantic sturgeon and target catch, field trials were conducted during August through October (2014). Fishing effort and techniques closely mimicked the commercial fishery to reduce any potential sampling bias. In North Carolina, commercial landings of southern flounder usually peak in September and October (NMFS, 2014); therefore, we primarily conducted focused our fishing effort during this period. However, because commercial fishermen sometimes target southern flounder during spring, a few sets were conducted during April, 2014.

Sample size (i.e., number of sets) was estimated using historical Atlantic sturgeon fishery interaction rates and standard power analyses procedures. To detect various corresponding reductions (control vs experiment) in Atlantic sturgeon retention rates (50–80%), we used the McNemar Test ($\alpha = 0.05$ level); power curves were generated to estimate the number of sets based on net length. Power curves were based on the mean annual Atlantic sturgeon catch rate (0.03 sturgeon/914 m of net/24 hr soak) in Pamlico and Albemarle Sounds (NCDMF Observer Program [2001–2009] and White and Armstrong [1998–2000]). Applying this approach, the number of sets necessary to detect an 80% reduction in Atlantic sturgeon interaction rate was 70.

A matched pair design consisting of alternating experimental and control panels was employed and gear was randomly set within specific areas based on elevated historic Atlantic sturgeon interaction rates and discussions with local commercial southern flounder fishermen. The matched pair design helped ensure that both net types had the same probability of encountering Atlantic sturgeon and target species (i.e., southern flounder). Every time the net was set, the first panel deployed was alternated between the control and experimental. It should be noted that we used adaptive setting procedures by considering Atlantic sturgeon and southern flounder daily catches. For instance, gear was always set in ideal southern flounder and historical Atlantic sturgeon fishing grounds. Similar to standard commercial fishing techniques, the fishing location was altered if the catch was low. In general, fishing grounds were selected based on the environmental conditions (water temperature, depth, and current), discussions with local fishermen, and southern flounder fishing experience. Using adaptive procedures also helped to ensure that an adequate sample size was obtained to allow for statistical inferences about the efficiency of the modified gear in terms of reducing Atlantic sturgeon bycatch and retaining target catch; it also helped with reducing any potential Atlantic sturgeon encounter sampling bias.

Field data

The time, wind speed, wind direction, water depth, water temperature, and geographic coordinates (latitude/longitude) were recorded at the start and end of each set and haul. Catch (fish and crabs) was sorted, identified, and a representative sample was measured to the nearest millimeter in total length (TL). The corresponding net type (control and experimental) and panel section was recorded for the catch. Southern flounder and Atlantic sturgeon were weighed to the nearest kilogram and measured to the nearest millimeter in fork length (FL) and TL. Atlantic sturgeon were carefully handled and released as quickly as possible at the site of capture. Other incidental bycatch were measured and released as quickly as possible. Protected birds and sea turtles were immediately removed from the net and released. Raw data were recorded on standardized data sheets and later reviewed for quality assurance by the field team lead, the Principle Investigator, and the data entry assistant. Data sheets were scanned, and then entered into Microsoft Excel®.

Statistical analyses

Total count, percent occurrence, and percent total catch were calculated for each taxa. More detailed descriptive analysis was conducted for southern flounder and Atlantic sturgeon. Distributions of catch were plotted by gear (control vs experimental) and species to assure that the most appropriate predictive models were used for analysis. All distributions were evaluated in terms of the best fit model: poison, negative binomial, zero inflated negative binomial, or a zero-inflated poison. If the criterion of normality was met, a one factor analysis of variance (ANOVA) or a paired *t*-test was used to compare the catch, catch-per-unit-effort (CPUE), and size (length and weight) with respect to total catch, target catch (i.e., southern flounder), and Atlantic sturgeon. However, if the data did not satisfy the criteria for normality or it could not be transformed (logarithm, square root, or arcsine square root), then non-parametric procedures (Kruskal-Wallis, Wilcoxon signed-rank, and Mann-Whitney tests) were applied to evaluate the data. Catch-per-unit-effort was calculated in two ways: 1) by the number of individuals per set, and 2) the by the number of individuals per one hour soak duration. Soak duration was defined as the elapsed time between the beginning of the set and haul; set time was the time the first section of the net was initially anchored. A Kolmogorov-Smirnov (KS) Goodness-to-Fit test was used to compare the distributions of Atlantic sturgeon and summer flounder (length and weight) by net type. The KS test was performed by computing the maximum distance between the cumulative distributions of the two samples. The Chi-square Goodness-of-Fit test was used to examine the representativeness of the sample for various categorical variables (e.g., water depth and water temperature) assumed to have uniform distribution. The Chi-square test was used to test the null hypothesis that the frequency of observed Atlantic sturgeon encounters was equal to the frequency of expected Atlantic sturgeon encounters. The Chi-square test was applied following the guidelines of Koehler and Larntz (1980); k classes > 3 (Zar, 1999). Firth regression was used to examine and evaluate probability of observing a positive catch of Atlantic sturgeon based upon a vector of covariates (net type, month, and water depth); firth regression is used to estimate parameter with small number of observations. All analyses were conducted using Microsoft Excel® and Statgraphics Centurion XVI® Version 16.1. Statistical significance was defined as $p < 0.05$.

RESULTS

Sampling effort and environmental conditions

A total of 70 sets (1,050 match pairs) were conducted between April and October (2014) throughout Albemarle Sound Sound; many sets were associated with major rivers (**Fig. 1**). Nine sets were completed during 2–13 April, 2014, and another 61 sets were completed between 31 August and 20 October, 2014. In total, 192.02 km (210,000 yd) of net was set over a 75 day period. The majority of the fishing effort occurred in September (n = 46 or 66%). In April, the water temperature was between 10.6 and 15.4°C (51–59.8°F) and the water depth was between 2.4 and 6.4 m (8–21 ft). The wind direction was generally north/ northeast, and the mean wind speed was 4.4 m/s (8.6 knts). In late-summer through fall (31 August–20 October), the water temperature ranged from 18.5 to 28.9°C (65.3–84°F). As expected, the water temperature decreased with time (**Fig. 4**).

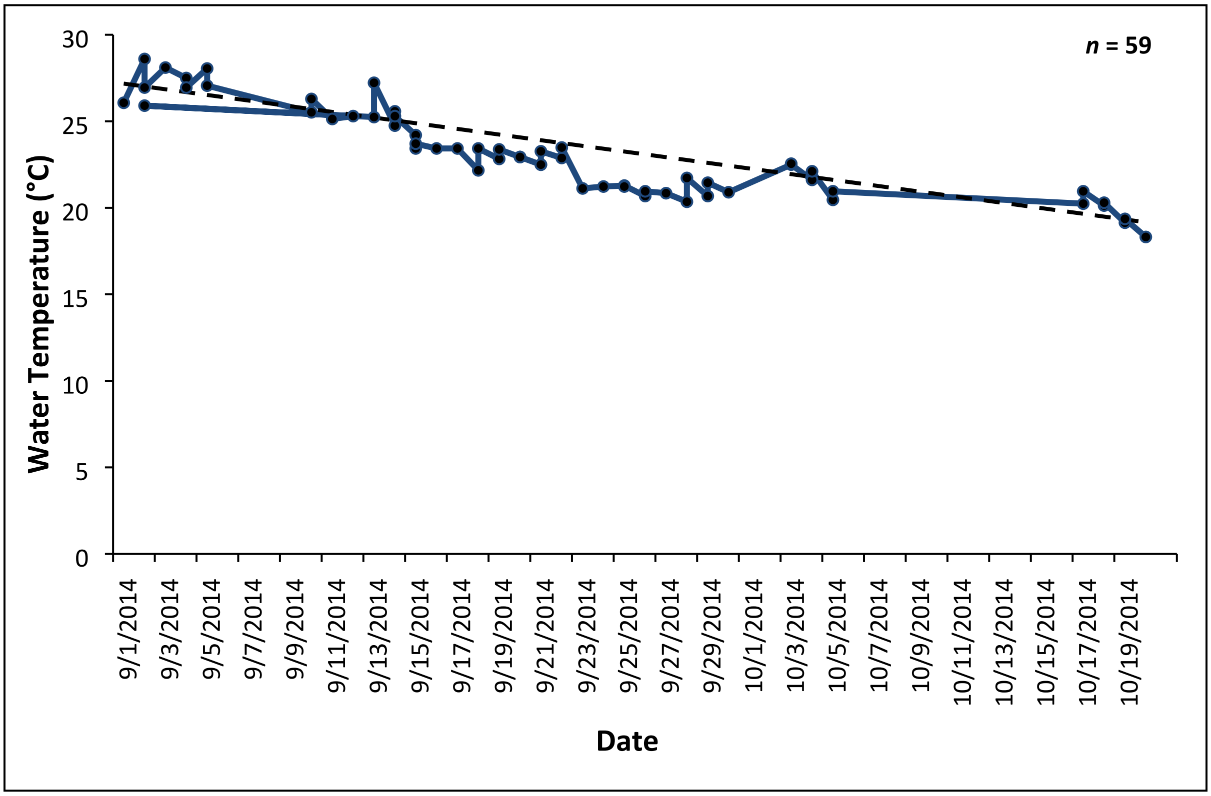

Figure 4. Water temperature in Albemarle Sound Sound, North Carolina during 1 September through 19 October 2014.

The water depth varied between 0.7 and 7.0 m (2.4–23 ft) with a mean of 13.5 m. The wind direction varied somewhat from week to week, but most of the days it was from the northeast direction (*n* = 31 or 44%). The wind speed ranged between 0 and 12.9 m/s (0–25 knts) with a mean of 5.7 m/s (11.1 knts). In general, it took about an hour to set the net and between 2 and 12 hours to retrieve the net, which depended on the catch and other circumstances. The net soak time duration ranged from 11 hours 45 minutes to 31 hours 6 minutes with a mean of 23 hours 5 minutes. The net soak time duration was dependent upon the weather and other circumstances, such as net tangles and the time it took to remove the catch from the net.

Bycatch

A total of 8,234 individuals representing 28 species were encountered in Albemarle Sound from April to October, 2014. The catch consisted of 3,775 fish representing 23 species, 4,303 blue crabs (*Callinectes sapidus*), 35 rays (stingray [*Dasyatis* sp] and butterfly ray [*Symnura micrura*]), 3 double-crested cormorant (*Phalacrocorax auritus*), and 2 Kemp's Ridley (*Lepidochelys kempii*) sea turtles. The control sections entangled 27 different species, while the experimental sections entangled 20 different species. The most numerically dominant fish were Atlantic menhaden (*Brevoortia tyrannus*) (n = 2,046 or 54%), southern flounder (n = 1,310 or 35%), longnose gar (*Lepisosteus osseus*) (n = 129 or 3%), and white catfish (*Ameiurus catus*) (n = 122 or 3%) (**Fig. 5**). Overall, 66% (n = 2,506) and 34% (n = 1,269) individual fish were entangled in the control and experimental sections, respectively. Atlantic menhaden (n = 1,307 or 64%), longnose gar (n = 70 or 54%), white catfish (n = 71 or 58%), and blue crabs (n = 2,653 or 62%) were entangled primarily in the control sections. The control sections ($\mu = 5.6$, $\sigma_x = 24.05$) entangled significantly more fish than the experimental sections ($\mu = 3.2$, $\sigma_x = 13.17$) at the 95% confidence level ($t\ (922) = 6.06$; $p < 0.05$).

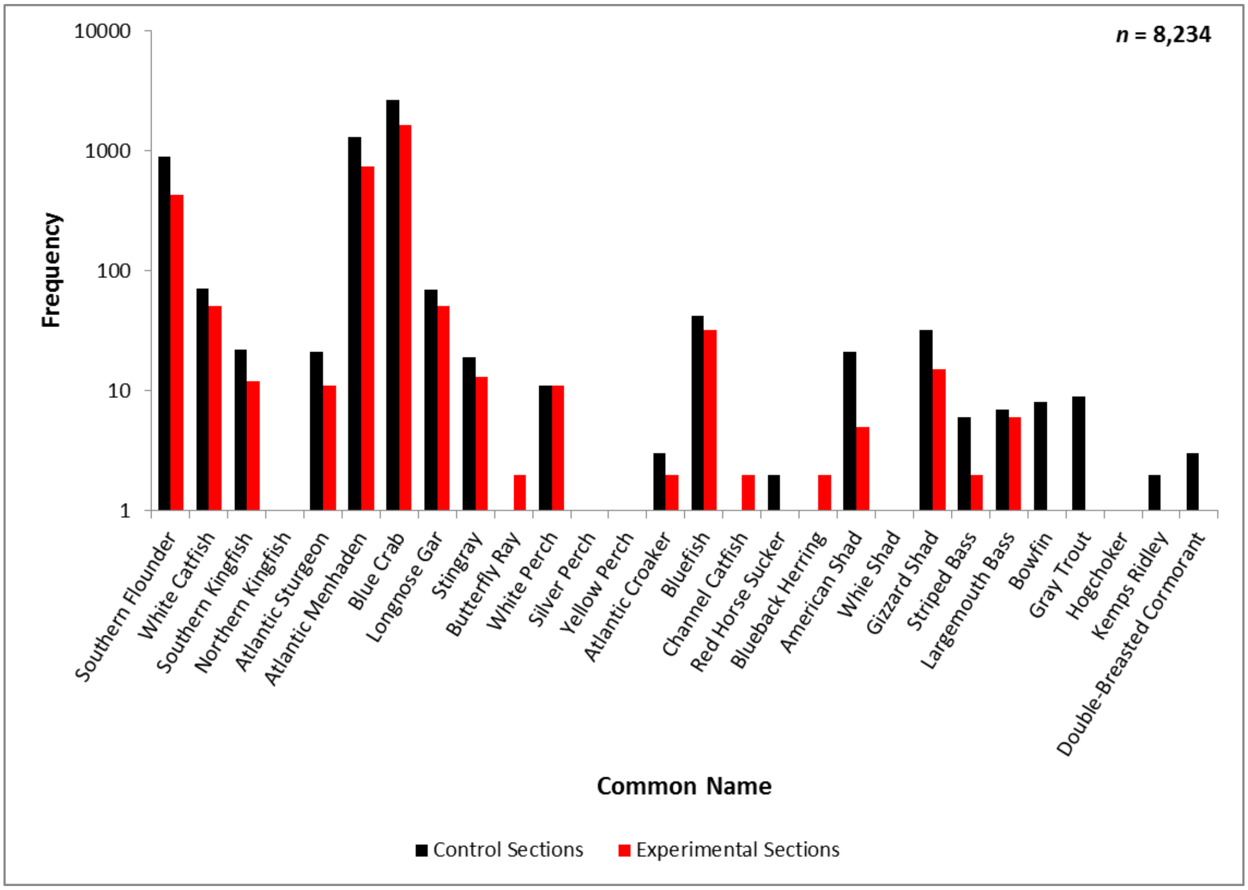

Figure 5. Total number of individuals collected by net type in Albemarle Sound, North Carolina from April to October, 2014. Silver perch, yellow perch, white shad, and hogchoker (*n* = 1 per species).

Target species

In total, 1,310 (845.5 kg) southern flounder were taken during April through October, 2014. Most (*n* = 1,199 or 92%) were collected from August to October, 2014. The total number of southern flounder taken ranged from 0 to 13 per set with a mean of 0.71 southern flounder per set. Monthly collections ranged from 21 southern flounder in August to 964 southern flounder in September (**Fig. 6**). The monthly mean number of southern flounder taken by set ranged from 0.35 in August to 3.11 in April with a mean of 1.21 southern flounder per set by month.

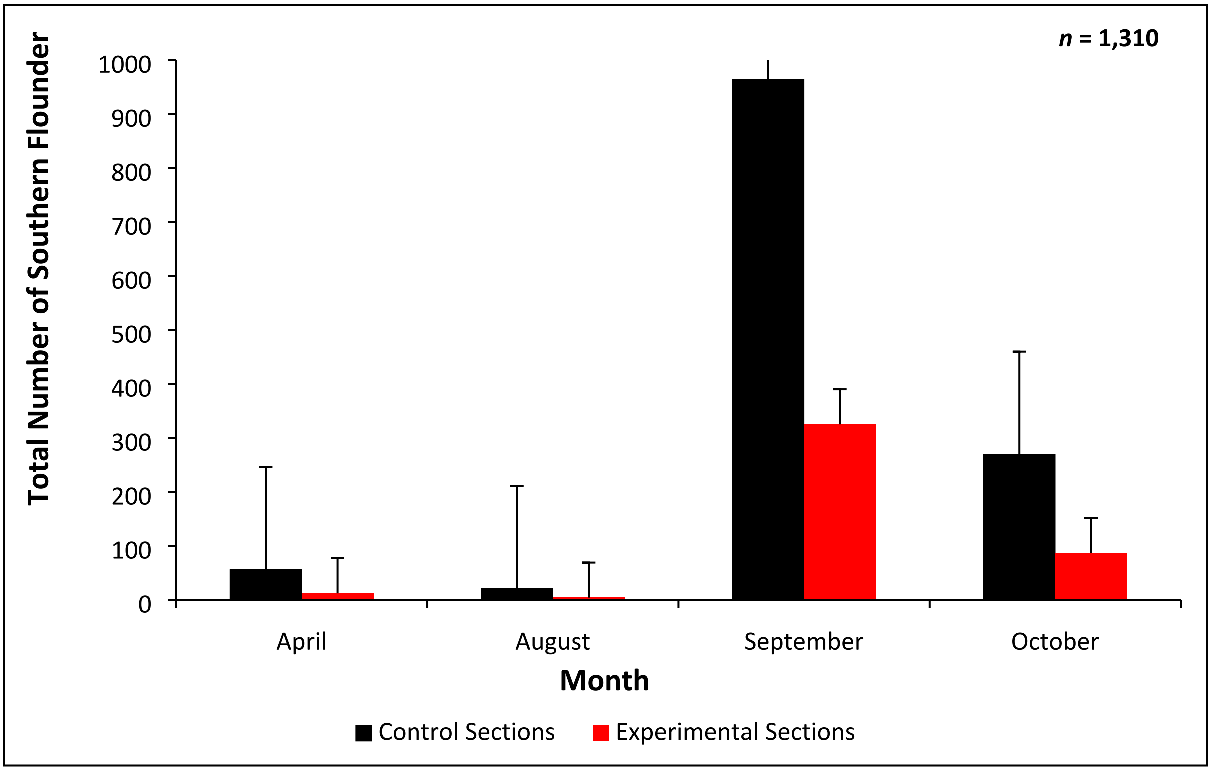

Figure 6. The total number of southern flounder collected by month and net type in Albemarle Sound, North Carolina from April to October, 2014.

The control and experimental sections entangled 67% (*n* = 883) and 33% (*n* = 427) individual southern flounder, respectively. Overall, the experimental sections entangled 51.6% (*n* = 456) less southern flounder than the control sections. The total number of southern flounder taken in the control sections ranged from 0 to 13 per set with a mean of 0.96 southern flounder per set. The total number of southern flounder taken in the experimental sections ranged 0 to 9 per set with a mean of 0.46 southern flounder per set. A paired *t*-test detected a statistical difference in the mean number of southern flounder taken by net type at the 95% confidence level (t (923) = 11.18; $p < 0.05$; **Fig. 7**).

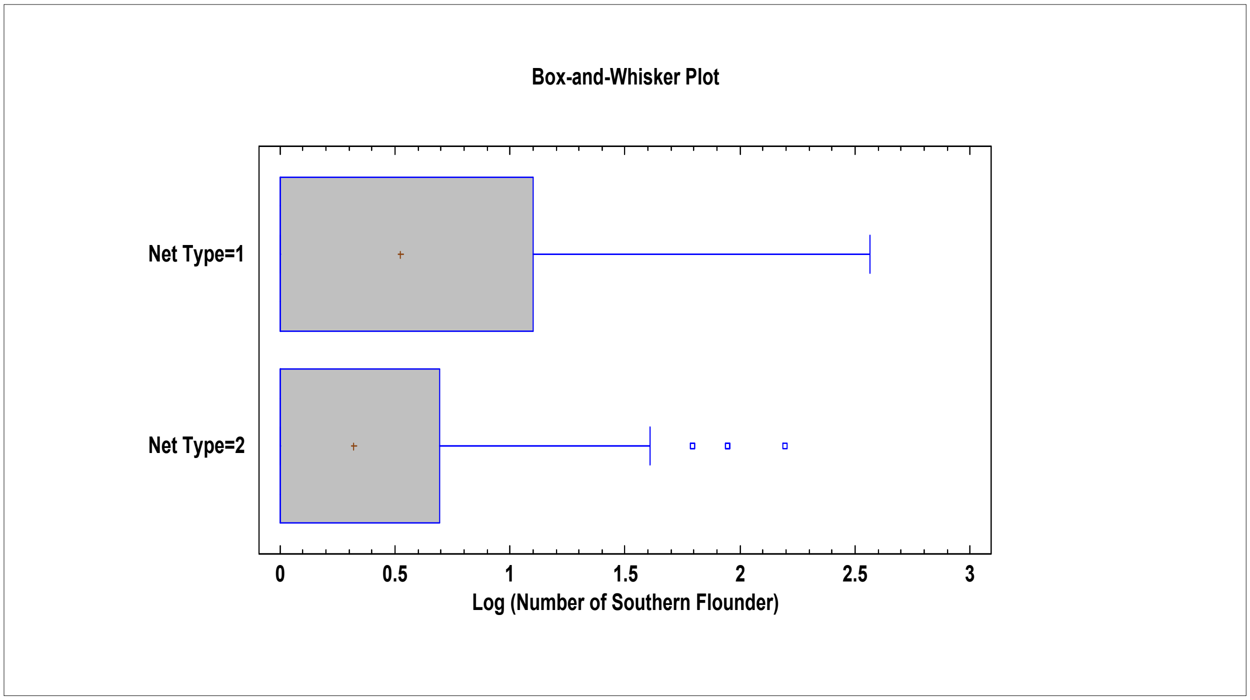

Figure 7. The log total number of southern flounder (*n* = 1,310) collected by net type in Albemarle Sound, North Carolina from April to October, 2014. Net type 1= control, Net type 2 = experimental.

The control sections entangled 0.32 southern flounder/1 m gillnet, whereas the experimental sections entangled 0.16 southern flounder/1 m gillnet. The monthly mean number of southern flounder taken in the control sections ranged from 0.57 in August to 4.89 southern flounder per set in April. The monthly mean number of southern flounder taken in the experimental sections ranged from 0.13 in August to 1.33 southern flounder per set in April. A linear regression showed that mean CPUE (i.e., number of southern flounder/set) increased from August to October; the highest CPUE occurred in September for both the control and experimental sections (**Fig. 8**). Southern flounder catches in April were excluded from these analyses since only nine sets were conducted in spring; incorporating these data would have skewed the results since most of the fishing effort was conducted during August through October.

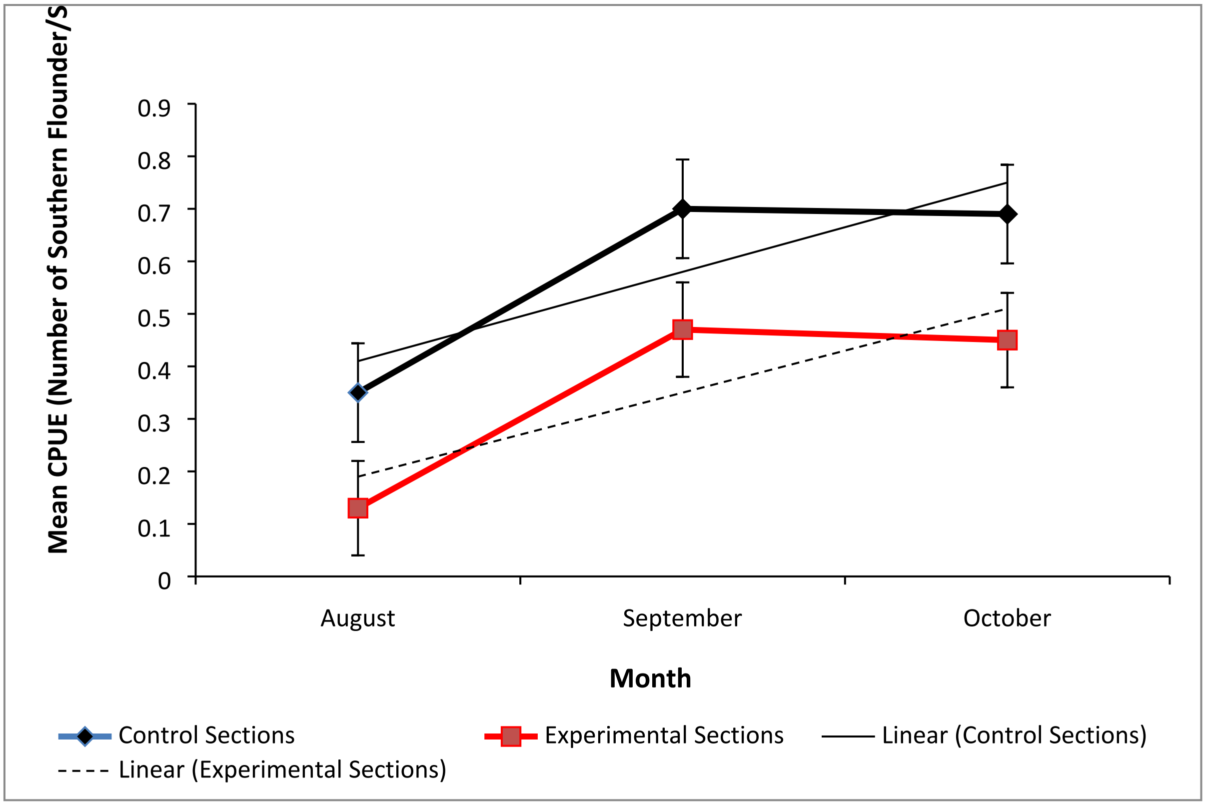

Figure 8. The mean CPUE (Number of southern flounder/Set) collected by month and net type in Albemarle Sound, North Carolina from April to October, 2014.

A paired *t*-test showed a statistically significant difference between the CPUE by net at the 95% confidence level (t (924) = 10.98; $p < 0.05$). The total weight of southern flounder collected in the control section was 559.6 kg (66%), and the experimental section collected 285.9 kg (34%), which was 273.7 kg (32%) less than the control sections (**Fig. 9**).

Southern flounder price varied from $2.00 in late-September, 2014 for medium size individuals to $3.25 per 0.45 kg (pound) in August, 2014 for large size individuals. On average, commercial fishermen received around $2.56 per 0.45 kg for southern flounder during April through October, 2014 in Albemarle Sound. Using the average price per 0.45 kg for southern flounder, the experimental sections entangled about $1,341 less than the control sections over the duration of the study.

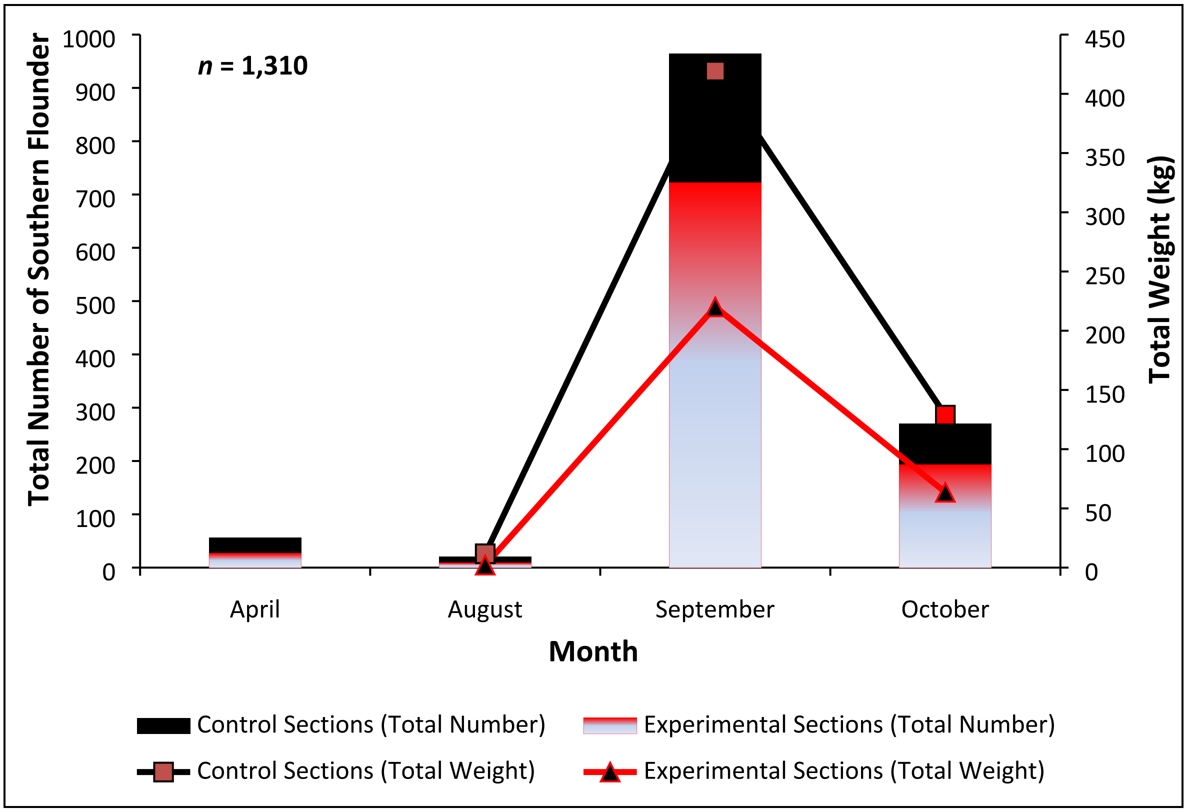

Figure 9. The total number and associated weight (kg) of southern flounder collected by month and net type in Albemarle Sound, North Carolina from April to October, 2014.

Southern flounder taken in the control section ranged from 0.2 to 8.3 kg with a mean of 1.08 kg. The total length ranged from 231 to 500 mm with a mean of 371.9 mm (n = 39). Southern flounder taken in the experimental section ranged from 0.2 to 4.0 kg with a mean of 0.95 kg. The total length ranged from 332 to 492 with a mean of 393.9 mm (n = 29). A t-test showed a there was a significant difference in mean total length by net type at the 95% confidence level (t (69) = -2.13; p = 0.03; **Fig. 10**). In addition, a KS test detected there was a significant difference in the length distribution of southern flounder by net type (D = 1.88; p = 0.002).

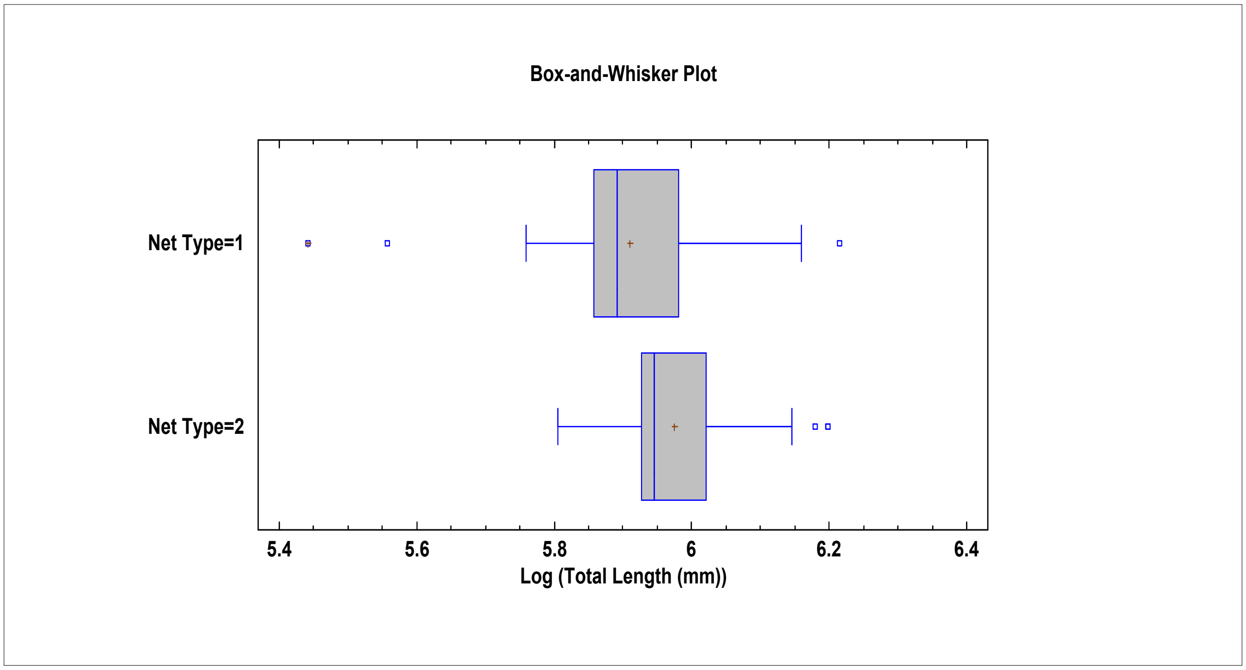

Figure 10. Mean log total length (mm) of southern flounder collected by net type in Albemarle Sound, North Carolina from April to October, 2014. Net type 1= control, Net type 2 = experimental.

A *t*-test did not show a significant difference in mean weight by net type at the 95% confidence level (t (819) = 0.72; p = 0.47). However, a KS test did detect a statistical difference in the weight distribution of southern flounder by net type (D = 3.09; $p < 0.05$). As expected, total catch and weight peaked in September for both the control and experimental sections (**Fig. 11**).

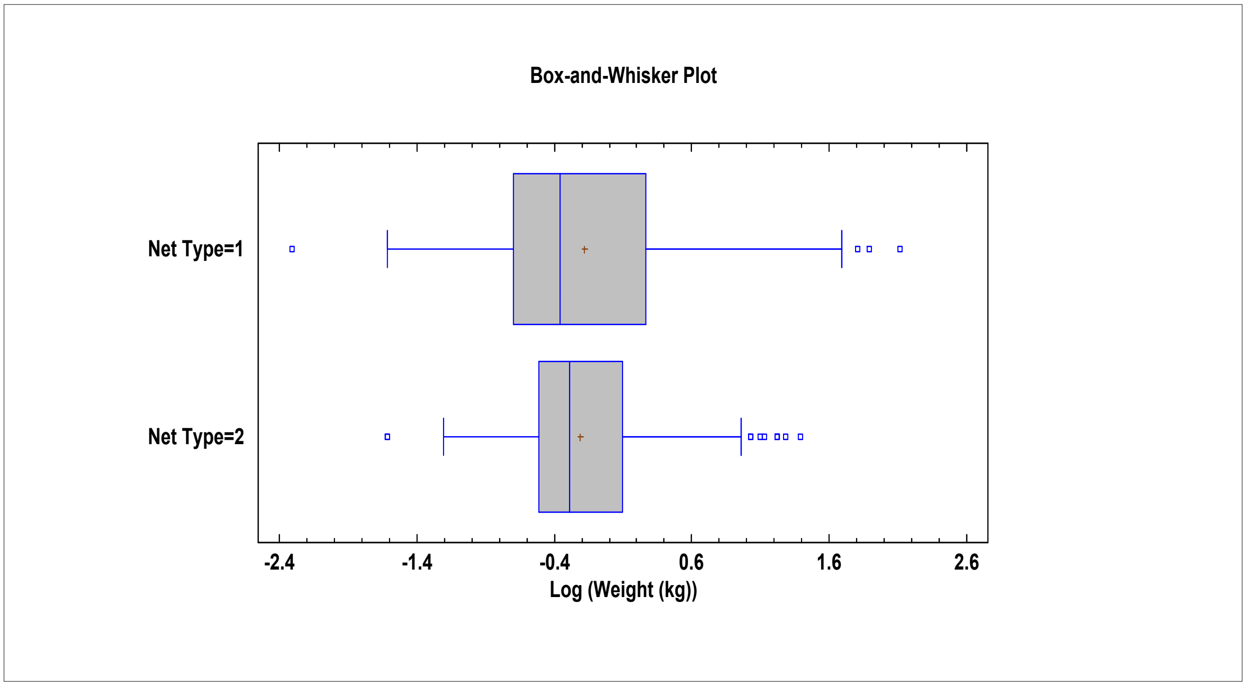

Figure 11. Mean log weight (kg) of southern flounder collected by net type in Albemarle Sound, North Carolina from April to October, 2014. Net type 1= control, Net type 2 = experimental.

Protected species, Atlantic sturgeon

A total of 37 individuals representing three protected species (Atlantic sturgeon [*n* = 32], double-crested cormorant [*n* = 3], and Kemp's ridley sea turtle [*n* = 2]) were incidentally entangled during the study; all protected species were released alive. No mortalities of Atlantic sturgeon (*n* = 32) were documented in either the control or experimental sections. It should be noted that two of the Atlantic sturgeon had external T-bar tags at the base of the left dorsal fin musculature (#49364 and #48022; **Table 1**).

Table 1. Atlantic sturgeon encounters in Albemarle Sound, North Carolina from April to October, 2014. Net type is defined as control (C) and experimental (E) sections.

Date	Set	Net	Net Type (C or E)	Latitude	Longitude	Total Length (mm)	Weight (Kg)	Tag #
4/4/2014	4	1	C	36 00.299	76 22. 440	510		
4/4/2014	4	1	C	36 00. 299	76 22. 440	632		
4/4/2014	4	1	C	36 00. 299	76 22. 440	759		
4/4/2014	4	1	C	36 00. 299	76 22. 440	815		
4/11/2014	7	1	C			530	0.8	
4/11/2014	7	1	C			760	2.7	
4/12/2014	8	1	C	35 59. 345	76 17. 195	825	3	
9/3/2014	14	7	C	35 59. 299	76 15. 443	747	2.1	
9/3/2014	15	17	C	35 58. 139	76 19. 908	680	1.4	49364
9/5/2014	17	29	C	35 58. 622	76 19. 501	685	1.5	
9/5/2014	18	3	C	35 59. 227	76 19. 958	765	1.4	
9/6/2014	19	17	C	35 58. 207	76 20. 736	636	0.4	
9/10/2014	20	15	C	35 58. 177	76 18. 518	648	1.6	
9/10/2014	21	14	C	35 57. 720	76 20. 198	691	1.4	
9/13/2014	25	8	C	35 58. 489	76 19. 064	913	4.9	
9/13/2014	25	18	C	35 58. 441	76 18. 479	725	1.8	
9/13/2014	25	20	C	35 58. 432	76 18. 268	784	2	
9/14/2014	27	8	C	36 01. 478	76 40. 816	864	3.2	
9/14/2014	27	8	C	36 01. 465	76 40. 825	915	3	
9/15/2014	32	14	C	35 59. 160	76 14. 621	788	2.4	
9/16/2014	33	5	C	36 00. 484	76 11. 340	858	3.4	
9/19/2014	37	15	C	35 59. 619	76 31. 306	725	1.8	
9/25/2014	48	30	C	36 01. 609	76 27. 502	733	2.7	
4/13/2014	9	2	E	35 59. 569	76 16. 258	640	1	
9/3/2014	14	30	E	35 59. 299	76 15. 443	840	2.9	48022
9/4/2014	16	30	E	35 58. 962	76 16. 462	599	1.2	
9/10/2014	20	16	E	35 58. 177	76 18. 518	841	2.8	
9/11/2014	22	7	E	36 02. 403	76 25. 993	570	1	
9/13/2014	25	22	E	35 58. 418	76 18. 157			
9/13/2014	25	28	E	35 58. 480	76 17. 789	850	2.8	
9/15/2014	31	13	E	35 58. 625	76 17. 315	682	1.1	
9/24/2014	47	27	E	35 53. 301	75 59. 230	744	1.9	

Seventy-two percent (n = 23) of Atlantic sturgeon were incidentally encountered in the control sections, but only 28% (n = 9) Atlantic sturgeon were incidentally encountered in the experimental sections. Overall, the experimental sections encountered 60.9% (n = 14) less Atlantic sturgeon than the control sections. A Wilcoxon signed-rank test indicated the medium Atlantic sturgeon encounter scores was lower in the experimental sections than the control sections at the 95% confidence level ($Z = 2.06$; $p = 0.04$). Moreover, a Chi-square test showed a significant difference in the standard deviation of Atlantic sturgeon encounters between net type (χ^2 [1, 32] = 45.8; $p < 0.05$). Applying the McNemar test indicated 70 sets were necessary to detect a corresponding 80% reduction in Atlantic sturgeon encounters between the two nets at an alpha of 0.05 and beta of 0.2 (80% power). Based on this power analysis, results showed the difference was significantly between the two nets ($p < 0.05$; power >80%).

Overall, the length-frequency distribution of Atlantic sturgeon encountered ranged from 510 to 915 mm TL with a mean of 734 mm TL (**Fig. 12**). The total length of Atlantic sturgeon encountered in the control sections ranged from 510 to 915 mm with a mean of 738.6 mm. The corresponding weight ranged from 0.4 to 4.9 kg with a mean of 2.2 kg. The total length of Atlantic sturgeon encountered in the experimental sections ranged from 570 to 850 mm with a mean of 720.8 mm. The corresponding weight ranged from 1.0 to 2.9 kg with a mean of 1.8 kg. A Wilcoxon signed-rank test indicated the medium Atlantic sturgeon length scores was lower in the experimental sections than the control sections at the 95% confidence level ($Z = 82.0$; p = 0.67; **Fig.13**). Moreover, a KS test did not detect a statistical difference in the size distribution of Atlantic sturgeon by net type at the 95% confidence level ($\chi^2 = 0.58$; $p = 0.89$). A Wilcoxon signed-rank test indicated the medium Atlantic sturgeon weight scores was lower in the experimental sections than the control sections at the 95% confidence level ($Z = 59.0$; $p = 0.38$;

Fig.14). A KS test did not detect a statistical difference in the weight distribution of Atlantic sturgeon by net type at the 95% confidence level ($\chi^2 = 0.39$; $p = 0.35$).

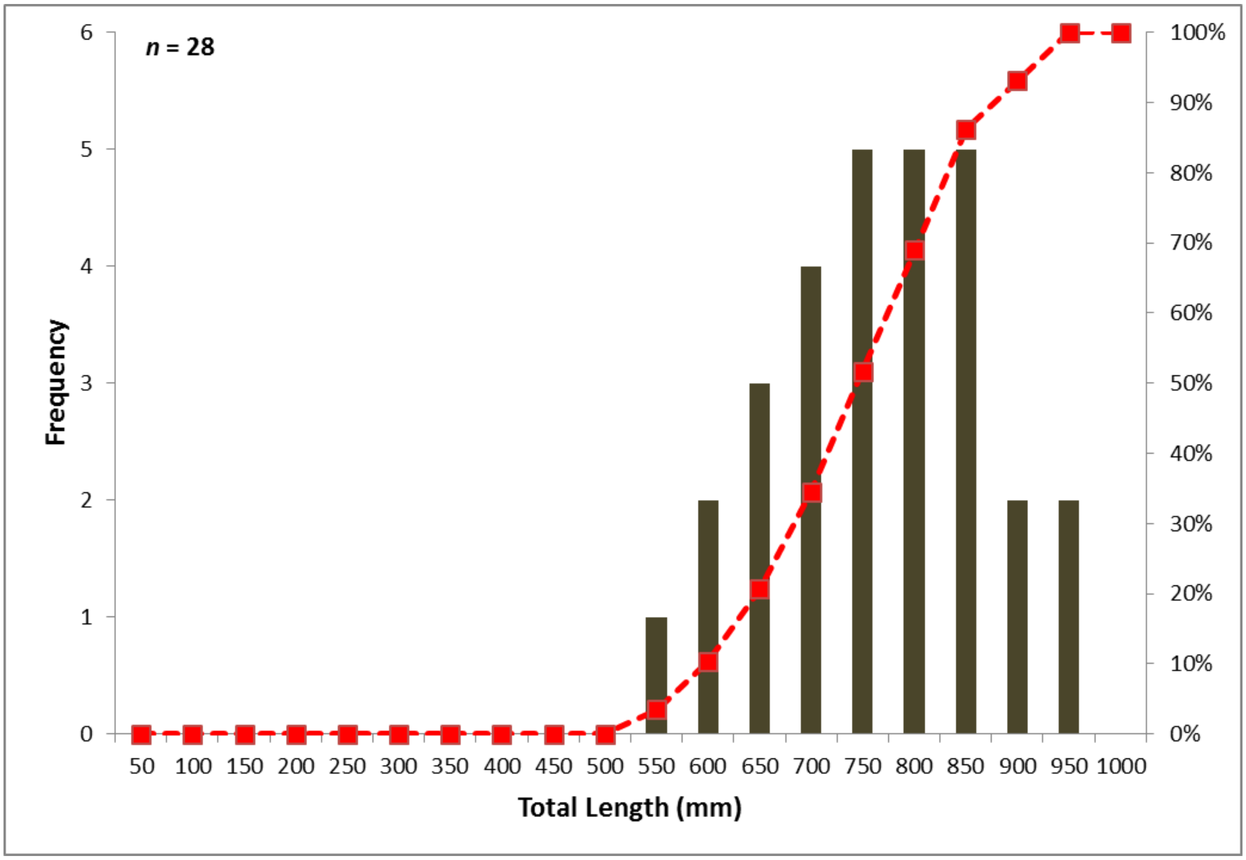

Figure 12. Length-frequency distribution of Atlantic sturgeon encountered in Albemarle Sound, North Carolina from April to October, 2014.

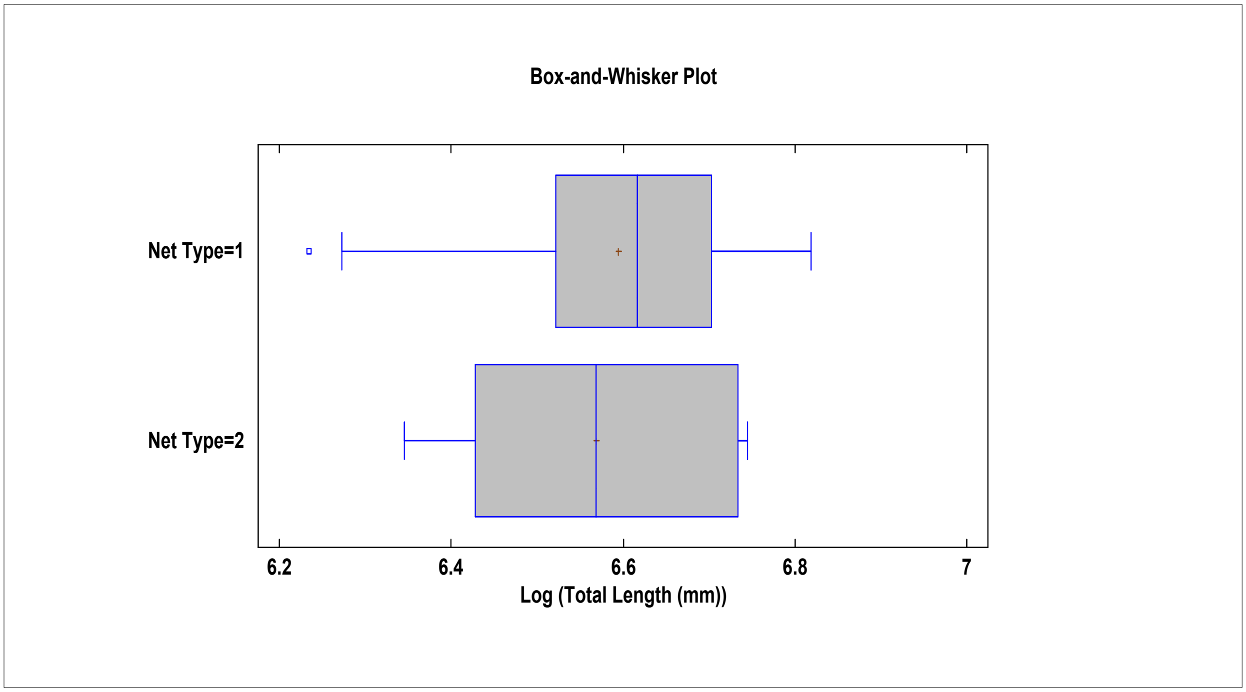

Figure 13. Mean log total length (mm) of Atlantic sturgeon incidentally encountered by net type in Albemarle Sound, North Carolina from April to October, 2014. Net type 1= control, Net type 2 = experimental.

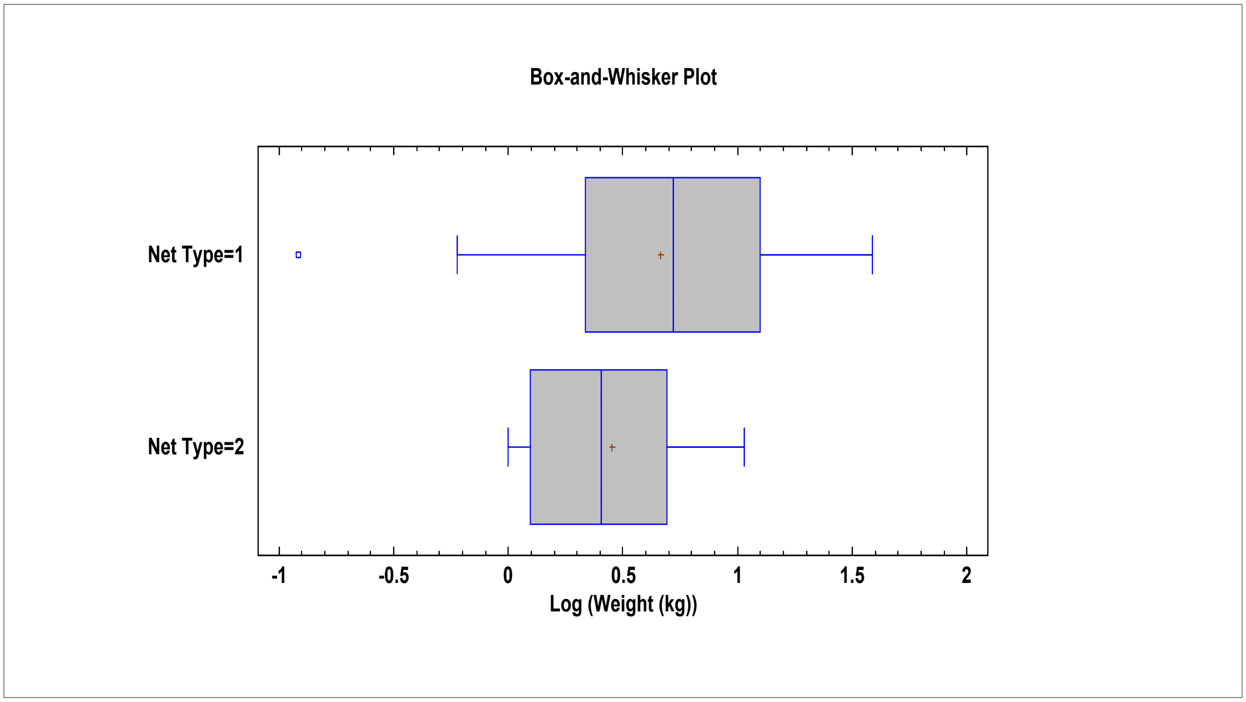

Figure 14. Mean log weight (kg) of Atlantic sturgeon incidentally encountered by net type in Albemarle Sound, North Carolina from April to October, 2014. Net type 1= control, Net type 2 = experimental.

In terms of net location (Net Sections/Pair Number 1–30), Atlantic sturgeon were incidentally entangled throughout the net, but most were entangled in the first section ($n = 7$ or 22%) followed by net section 8 ($n = 3$ or 14%) and the last (30) section ($n = 3$ or 14%). Thirty-one percent ($n = 10$) of the Atlantic sturgeon were incidentally entangled in either the beginning or end sections of the net (**Fig. 15**). Despite this apparent difference, a Kruskal-Wallis test did not detect a significant difference in the ranks among the number of Atlantic sturgeon encountered by net section ($H = 24.9$; $p = 0.68$).

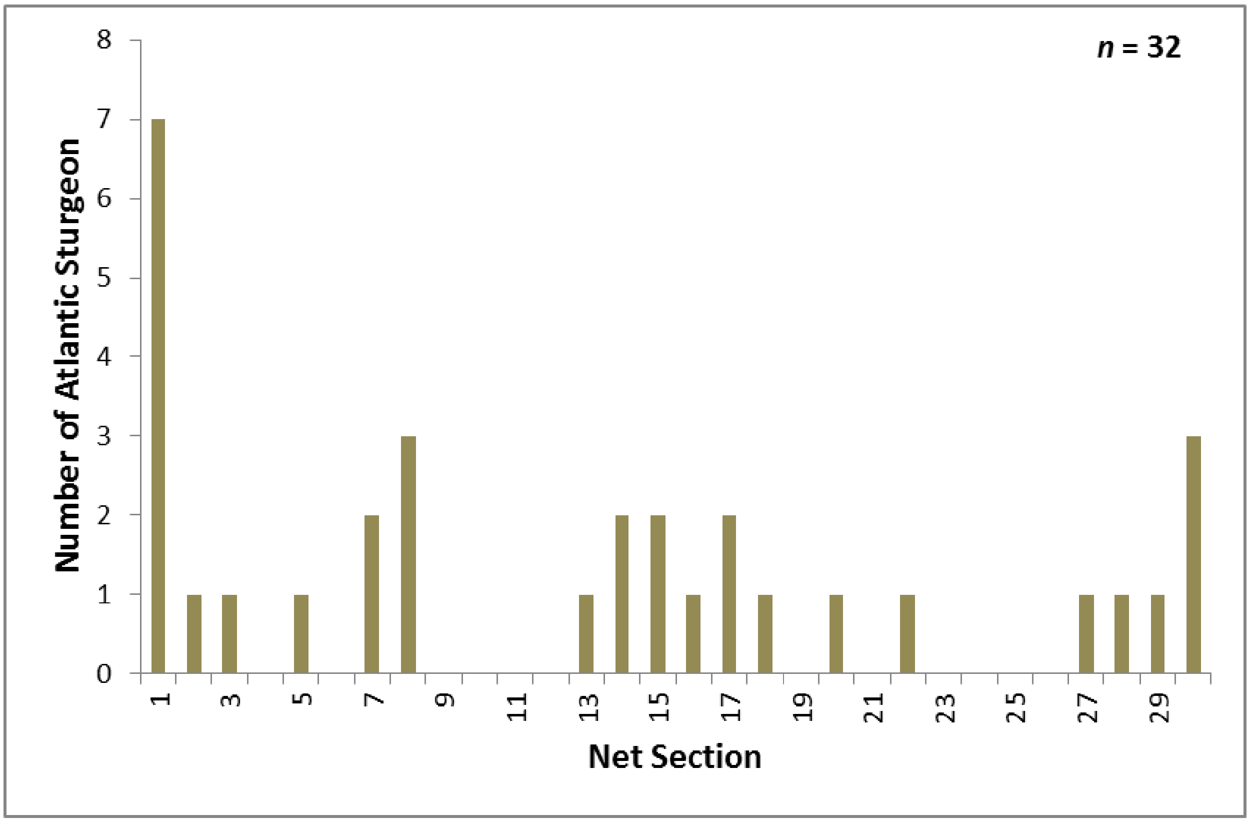

Figure 15. Total number of Atlantic sturgeon encountered by net section (pair number) in Albemarle Sound, North Carolina from April to October, 2014.

The total number of Atlantic sturgeon encounters ranged from 0 in August and October to 24 in September. Despite the limited fishing effort in April, there were 7 Atlantic sturgeon encounters in the control sections and 1 encounter in the experimental sections (**Fig. 16**). In

September, there were 16 and 8 encounters in the control and experimental sections, respectively.

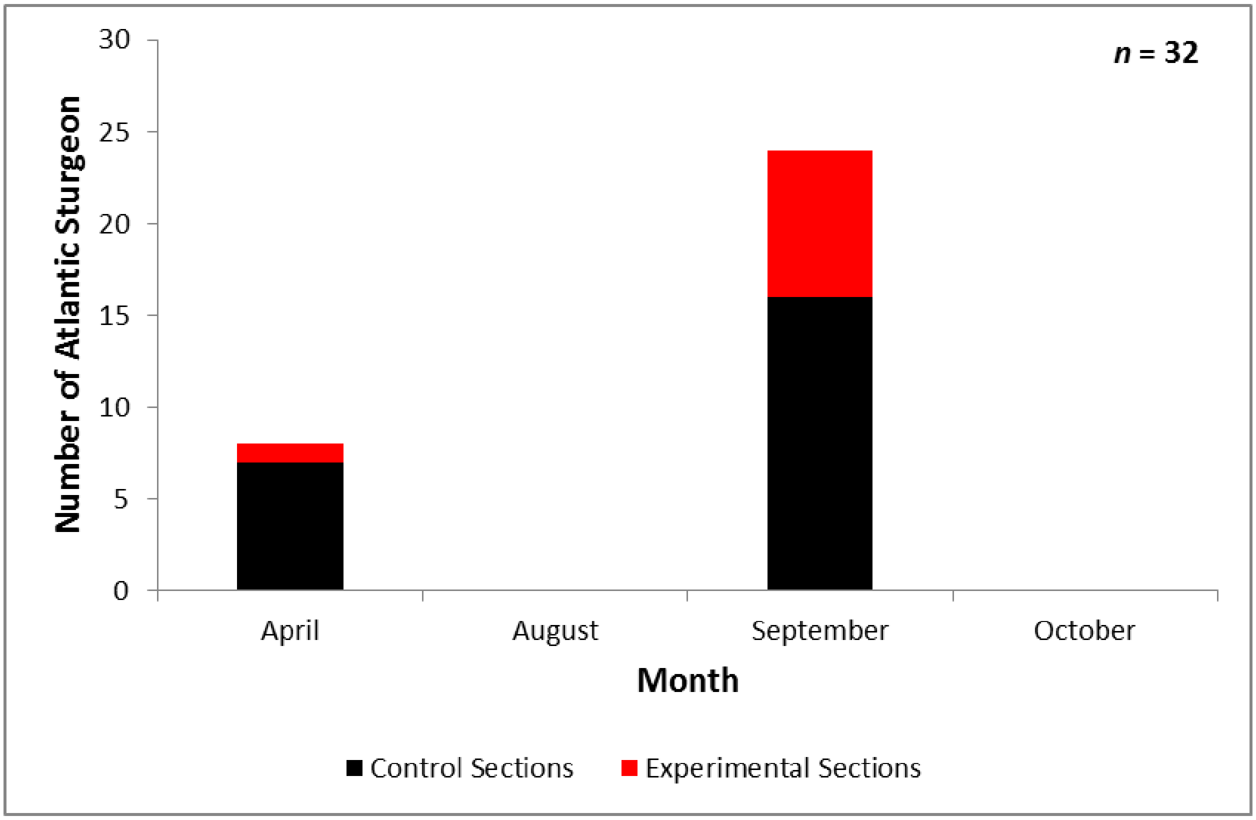

Figure 16. Number of Atlantic sturgeon incidentally encountered by net type and month in Albemarle Sound, North Carolina from April to October, 2014.

More Atlantic sturgeon were encountered in deeper than shallower waters. Seventy-five percent (n = 24) of the Atlantic sturgeon encounters occurred at water depths between 4.6 and 6.1 m. A Chi-square test revealed a statistical significant discrepancy between the observed and expected counts of the number of Atlantic sturgeon encountered by depth range (χ^2 [3, 32] = 25.2; $p < 0.05$). The number of Atlantic sturgeon encounters was positively associated with mean water depth. The association between the number of Atlantic sturgeon and mean water depth was explained by polynomial regression (**Fig. 17**). Also, more Atlantic sturgeon (n = 13 or 41%) were encountered in warmer (26–30°C) than colder water temperatures. A Chi-square test found a significant discrepancy between the observed and expected counts of the number of Atlantic sturgeon encountered by water temperature range (χ^2 [3, 32] = 8.4; p = 0.04). Despite these outcomes, a firth regression test did not find a significant interaction effect between the number of Atlantic sturgeon encounters and net type, month, or water depth. The best model fit did suggest that month and depth were significant predictors of a positive outcome for Atlantic sturgeon encounters.

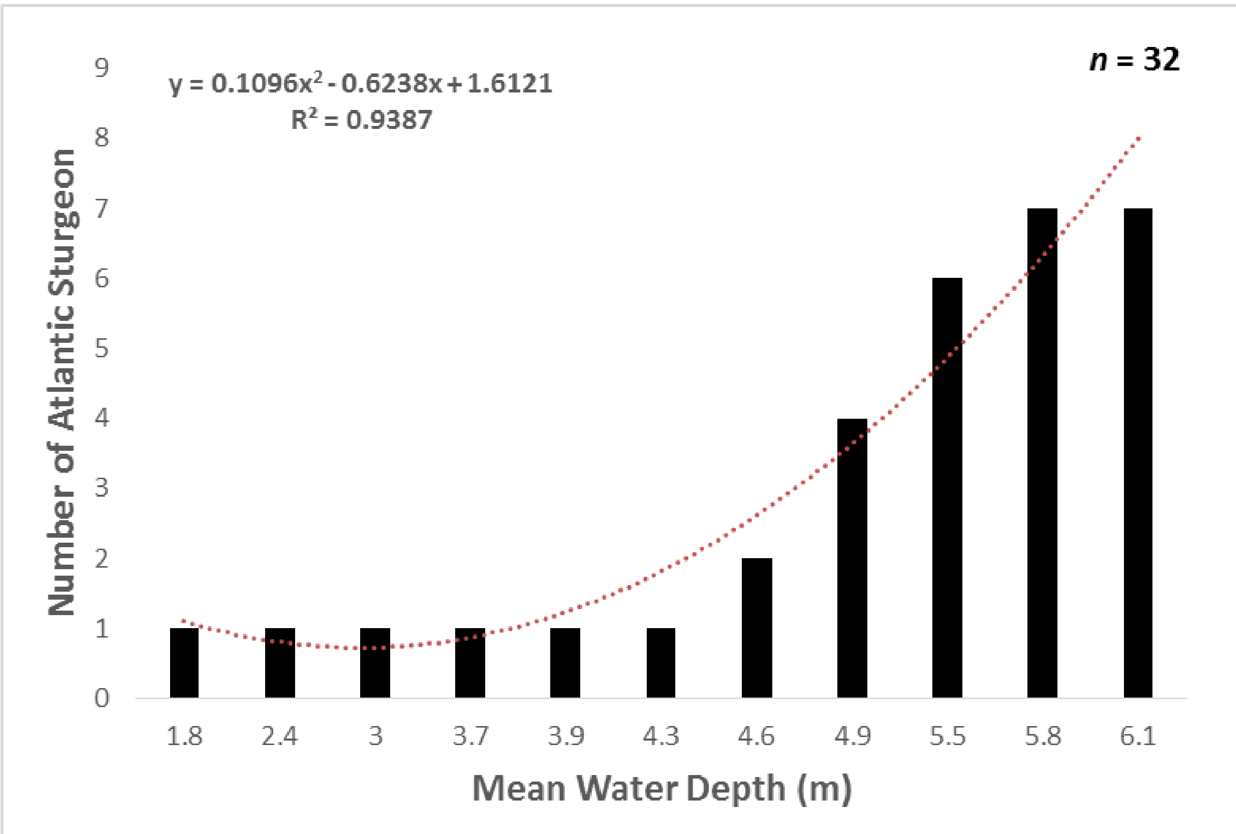

Figure 17. Number of Atlantic sturgeon incidentally encountered by mean water depth (m) in Albemarle Sound, North Carolina from April to October, 2014. The dash line depicts the polynomial regression.

DISCUSSION

Bycatch is major issue concerning fishery managers around the world, especially for those charged with preserving and recovering protected species. In the United States, one of the primary concerns is the incidental capture of protected species in commercial fishing operations, especially long-lived species such as Atlantic sturgeon. Although Atlantic sturgeon are protected under the ESA, updated fishery interaction information is unavailable for most commercial fisheries that incidentally encounter the species (FWC, 2011). Unfortunately, only limited research has specifically focused on finding potential solutions to the Atlantic surgeon/fishery interaction problem in the United States. Most studies to date have focused on understanding the life-history, movements, habitat preferences, and population dynamics of Atlantic sturgeon (e.g., Breece *et al*., 2013). Discovering a potential resolution to the fishery interaction problem is currently pressing, especially since fishery managers are debating the continued authorization of sustainable commercial fishing activities, specifically those that interact with protected species (e.g., marine mammals, sea turtles, and Atlantic sturgeon). Given this pressing conservation and economic need, we conducted the first bycatch reduction study to evaluate modifications in commercial fishing gillnet gear to reduce interactions between Atlantic sturgeon and the southern flounder fishery in Albemarle Sound, North Carolina.

Protected species; Atlantic sturgeon

The results of this study indicate that our modified gill net design is a plausible solution to the Atlantic sturgeon/southern flounder fishery interaction problem in Albemarle Sound, North Carolina. Designing a monofilament gillnet with a reduced profile and associated webbing (75% less) led to a significant reduction in the number of Atlantic sturgeon encounters. The experimental sections also did not entangle any sea turtles or double-breasted cormorants; unlike the control sections. Regrettably, the gear encounters for sea turtles [n = 2] and double-breasted cormorants [n = 3]) were too low to allow for any conclusive inferences. Reducing the profile of the net did not lead to any potential negative changes in the catch distribution of Atlantic sturgeon. The experimental sections incidentally encountered similar mean size, corresponding weight, and frequency distribution (length and weight) of Atlantic sturgeon as the control sections. Overall, Atlantic sturgeon encountered in this study were slightly larger than those reported by Armstrong (1999), which was somewhat expected given the selectivity characteristics of gillnets. Using NCDMF data (1990–1995), Armstrong (1999) reported that the number of Atlantic sturgeon encounters deceased with mesh size, but mean fork length increased with mesh size. Interestingly, the Atlantic sturgeon encountered in this study were much larger than those reported by Armstrong (1999) for the larger stretch mesh sizes (14–17.8 cm). It is unclear to us why the individuals we encountered were larger than those previously reported, but it was probably related to the small sample size (n = 32) or limited number of sets. Despite the observed mean length for Atlantic sturgeon being inconsistent with previous studies, the control and experimental sections incidentally captured Atlantic sturgeon with a similar size distribution. The net modifications tested during this study were not expected to influence the Atlantic sturgeon size distribution, but this is a relevant finding because potential changes in Atlantic sturgeon length could have inadvertently harmed vulnerable size classes (< 130 cm; minimum size-at-maturity [Van Eenennaam *et al*., 1996]). The incidental capture of juvenile Atlantic surgeon threatens recovery of the population (Stein *et al*. 2004). Though post-release mortality information is unavailable for Atlantic sturgeon, it is possible that smaller individuals incidentally taken in gillnet gear have a greater risk of mortality than larger individuals.

Fishing effort and subsequent Atlantic sturgeon encounters primarily occurred in September. Actually, after 30 September, 2014, we did not encounter any Atlantic sturgeon. It is difficult to guess why no Atlantic sturgeon were encountered after September, but it could have been related to changes in the environmental conditions and/or Atlantic sturgeon movement patterns. Armstrong (1999) hinted that Atlantic sturgeon may aggregate or increase swimming activity in Albemarle Sound during certain periods (spring and fall), so it's conceivable that the Atlantic sturgeon had simply moved to a different section in the sound. It's also probable that Atlantic sturgeon have limited preferred habitat within Albemarle Sound (Armstrong, 1999), which decreases the likelihood of random encounters. To reduce any potential effort bias, we attempted to set the gear in ideal Atlantic sturgeon and southern flounder habitat by evaluating daily catch and discussing fishing success with local cooperative commercial fishermen. We used this approach because it is well documented that fishing success can potentially bias results in research studies focused on gear modification solutions. For instance, He and Jones (2013) reported significant differences in catch rates for Atlantic sturgeon between the two fishing vessels they used in their study. The researchers were able to consider this effect in their statistical analyses, but it should be noted that fishing tactics can bias results, especially if the gear is set in a different method, area, or time.

In many ways, the experimental panels out-performed previously tested gillnet designs in terms of reducing Atlantic sturgeon fishery interactions even though the nets used by other researchers were specifically designed for different fisheries (i.e., monkfish [*Lophius americanus*]). In earlier research, gillnet modifications designed to reduce Atlantic sturgeon fishery interactions resulted in conflicting and mixed outcomes given the low statistical power, relatively high mortality rates for Atlantic sturgeon and other protected species, and reduced target catch (Fox *et al*., 2011). Building upon previous research, Fox *et al*. (2012) found that modifications to gillnet gear could provide a potential solution to Atlantic sturgeon interactions with large mesh sink gillnet fisheries in the mid-Atlantic and Northeast regions of the United States. Although the results were statistically insignificant, the research showed that bycatch of Atlantic sturgeon could be reduced and landings of target species (monkfish and winter skate

[*Leucoraja ocellata*]) could be maintained using low profile tie-down gillnets. Fox *et al*. (2012) also found that incorporating specific tie-down configurations was important for maintaining target catch and reducing Atlantic sturgeon encounters in the monkfish fishery. In 2013, Fox *et al*., once again decreased the profile of the net and compared it to the standard monkfish net, but were unable to achieve statistically significant reductions in Atlantic sturgeon catch. The experimental net did however catch similar numbers of monkfish and winter skate. Of note, Fox *et al*. (2013) found that most of the entangled Atlantic sturgeon were located in the upper half of the net, suggesting that a lower profile design might reduce more fishery interactions. He and Jones (2013) also discovered that a low profile gillnet reduced Atlantic sturgeon bycatch in the monkfish fishery in Virginia and Maryland; although, the experimental nets caught significantly less monkfish (i.e., target species).

Given the findings from this present study and others, it appears that reducing the gillnet profile, regardless of the fishery, has a beneficial significant impact on reducing the number of Atlantic sturgeon encounters. Unlike previous studies, our study was able to achieve sufficient statistical power to demonstrate a reduction in Atlantic sturgeon encounters. More importantly, the gear modifications in this study did not result in any observed mortalities of Atlantic sturgeon even though the experimental net had much greater mean soak times than previous studies (Fox *et al*., 2011; Fox *et al*., 2013; He and Jones, 2013); soak time has been correlated with Atlantic sturgeon mortalities (Fox *et al*., 2013). According to He and Jones (2013), every sturgeon encountered in the gear with soak times greater than 24 hours was dead. Fortunately, no mortalities occurred in Albemarle Sound during this study. Indeed, every Atlantic sturgeon encountered was in good condition despite warm water temperatures (> 25°C) for many of the encounters (n = 16). Maybe the Atlantic sturgeon encountered the net shortly before haul back?

Overall, this present study was able to achieve more conclusive results than previous studies due to the larger sample size (*n* = 70), the fact that the study was conducted independently rather than relying on various commercial fishing vessels, and the alternating panel design (control and experimental sections) of the trial net; as opposed to using more than one net (e.g., He and Jones, 2013). In our opinion, all of these factors helped reduce potential sampling and gear bias. More importantly, the gear was specifically set in locations that were ideal for Atlantic sturgeon and southern flounder, underscoring the notion that fishing success can have on statistical inference and subsequent conclusions about the data.

Southern flounder catch

The goal of gear modifications is not only to reduce interactions between protected species and commercial fisheries, but to maintain catch rates of specific target species. In North Carolina, southern flounder is an economically valuable commercial species, thus any proposed gear modifications should have little to no significant impact on the target catch. Despite the positive outcome for reducing the number of Atlantic sturgeon encounters, the modified gear did entangle less southern flounder (numbers and corresponding weight) than the control sections. The experimental sections entangled 52% less number of individuals corresponding to a 32% loss in total weight of southern flounder than the control sections. Although statistically insignificant, the experimental sections entangled slightly larger individuals than the control sections, and the length and weight-frequency distributions were relatively different than the control sections. This is a common observation since changes in catch (mean size) are expected as gillnets are known to be selective in terms of number and size of individuals. He and Jones (2013) reported that modifications to gillnet gear yielded fewer monkfish smaller than 75 cm compared to the control net, but they did not detect a difference in monkfish larger than 75 cm. Fox *et al*. (2013)

indicated they too entangled slightly smaller (statistically insignificant) monkfish in their modified gillnets.

Overall, reducing the profile of the gillnet had a relatively negative economic impact on overall southern flounder catch. We acknowledge that commercial fishermen often operate at marginal profit levels, but considering the alternative options (e.g., permanently closing the fishery), the 32% loss in southern flounder catch (total weight) is relative in terms gross revenue, especially in comparison to other expenses, such as fluctuations fuel prices. The reduction in target catch in our study mimicked previous bycatch reduction studies that also modified the profile of the gear to reduce Atlantic sturgeon fishery interactions (Fox *et al*., 2011; He and Jones, 2013). Though this study cannot be compared to other studies given the fishery (southern flounder) and geographic location, the reduction in target catch was slightly higher than previously reported for other fisheries and target catch. Nevertheless, it appears that reducing the profile of the net tends to decrease landing in the target catch regardless of the fishery. He and Jones (2013) found that changing the gear's profile (number of meshes and tie-down length and spacing), decreased the primary target species (monkfish) by 16.1%; but it had little effect on the secondary target species (winter skate). Fox *et al*. (2013) also reported lower (4.5%) numbers of monkfish (target species) in their modified gear.

Modifying commercial fishing gear is challenging since many marine organisms have similar preferred habitat, and aggregate or display similar movement patterns. Making modifications in fishing gear can either have no change in catch or it can alter catches of more than one species. Modifications in fishing gear or fishing practices can even have detrimental impacts to certain species. Fox *et al*. (2011) found that removing tie-downs did not have any impact on reducing Atlantic sturgeon encounters, but it did significantly reduce target catch (monkfish) landings and caused a number of unacceptable marine mammal mortalities. Despite our findings demonstrating that reducing the profile significantly (statistically) decreased southern flounder landings, we believe this reduction is economically insignificant compared to other possible alternatives for reducing Atlantic sturgeon encounters.

Bycatch

The modified gear tested in this study was also successful at reducing bycatch. The total number of individuals entangled in the experimental sections was significantly lower than the control sections, which is encouraging given that bycatch is a concern to both commercial fishermen and fishery managers. In terms of biodiversity, the experimental sections entangled fewer species than the control sections. In general, both sections of net captured similar primary species, but there were some differences among a few species. The butterfly ray (G*ymnura micrura*), blueback herring (*Alosa aestivalis*), and channel catfish (*Ictalurus punctatus*) were only captured in the experimental sections, while the red horse sucker (*Moxostoma carinatum*) was only captured in the control sections. Currently, the blueback herring is a species of concern, so this could be an issue for fishermen and managers in the future. Nonetheless, only one individual was entangled. Overall, species composition was similar between the two sections, which corresponded with previous studies (He and Jones, 2013). Given the net design and the experimental approach (alternating sections), a difference in overall species composition was not expected. Modifying the gillnet had a positive effect on reducing bycatch and little to no effect on the entanglement of additional species, including protected species (endangered, threatened, or species of concern).

Gear characteristics

As previously discussed, the modified gear was successful at reducing Atlantic sturgeon fishery interactions, while maintaining relative catch rates of southern flounder. Despite these optimistic outcomes, the gear does have some limitations in terms of its "fishability" for commercial fishermen. We define the term "fishability" as the way the fishing gear responds to the environmental conditions (i.e., winds, waves, and currents), which is very important to commercial fishermen because it effects catchability in terms of corresponding economics. As expected, commercial fishermen are interested in catchability (i.e., optimizing catch while reducing fishing effort), but one of their other main concerns is gear maintenance and associated costs. Often one of the drawbacks of using new gear or technology is often its upkeep. To mimic the fishery, the gear was set under the same environmental conditions as local fishermen, which caused various issues (gear twists) that were related to incumbent weather (i.e. frontal storms). We noticed the experimental sections were often prone to twisting during high winds, currents, and waves. For example, on one occasion, after an overnight storm, the field crew had to untwist 732 m (800 yd) of net, which not only took longer to retrieve, but also increased the potential risk to Atlantic sturgeon encounters since the net was in the water longer. Although the field crew was able to untwist much of the webbing, net repairs were occasionally required, which extended the haul back time. The other issue we noticed was that the modified gear was more fragile than the traditional gear in terms of its durability. By the end of the study, much of the monofilament webbing used in the construction of the experimental sections needed to be replaced. Replacement of webbing translates to additional costs that would be a concern to commercial fishermen. In contrast, the monofilament webbing in the control was in much better shape.

Developing innovative fishing gear solutions requires refinement not only in terms of increasing target catch and decreasing bycatch, but reducing general gear maintenance and associated costs. In our opinion, the following refinements could increase the gear's catchability (southern flounder landings) and fishability (lower gear upkeep time and costs): (1) adding an anchor every 457 m (500 yd) to minimize twisting; adding more anchors would secure the net to the bottom better; and (2) increasing the amount of drop back from 2 to 6 m in the experimental section webbing; increasing the amount of drop back should reduce the number of twists and increase southern flounder catch. We believe increasing the drop back in the experimental section webbing would reduce the tension between the top and bottom line causing the webbing to loosen, which would thereby entangle more southern flounder.

CONCLUSION

Protected species interactions in commercial fisheries are major problem in the United States, especially Atlantic sturgeon fishery interactions. As evident in this study, engineering solutions are possible for reducing fishery interactions, but modifications need to be fishery and location specific. Our study proved that reducing the profile and amount of webbing material (75% less) in the water can reduce the number of interaction between Atlantic sturgeon and the southern flounder fishery in North Carolina, but further refinement is necessary in terms of gear specifics. Additional gear refining is necessary before commercial fishermen will support changing their traditional gear and tactics, especially if the transition to modified gear requires more maintenance. We primarily conducted the study in September to coincide with peak southern flounder fishing effort, but based on our limited fishing effort (n = 9) and associated catch (Atlantic sturgeon and southern flounder) in April, we recommend addition sets be conducted in the spring to further validate our results. In summary, our finding are encouraging for Atlantic sturgeon conservation and maintaining sustainable commercial fisheries in Albemarle Sound, North Carolina.

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