DR. JASON KAHN (Orcid ID : 0000-0001-6426-9189)

Article type : Management Brief

Raised Footrope Gill Net Modification Significantly Reduces Sub-Adult Atlantic Sturgeon Bycatch

Christian Hager[1]*, Juan C. Levesque[2], R. Jason Dickey[3], Jason E. Kahn[4]

[1] Chesapeake Scientific, LLC
100 Sixpence Court
Williamsburg, VA 23185
[2] Environmental Resources Management, Highland Oaks II
10210 Highland Manor Drive, Suite 140
Tampa, Florida, 33610
[3] TRC Environmental, Inc.,
10 Maxwell Drive, Suite 200
Clifton Park, NY 12065
[4] National Marine Fisheries Service
1315 East West Highway
Silver Spring, MD 20910

*Corresponding author: Christian.hager@chesapeakescientific.org

[A] Abstract

Bycatch is a major problem in most commercial fisheries around the world and is among the biggest challenges for fisheries managers tasked with conserving, protecting, and sustaining marine resources. Bycatch of protected species is particularly problematic because even small levels of bycatch mortality can hinder conservation efforts. The federally protected Atlantic Sturgeon *Acipenser oxyrinchus oxyrinchus* is one such example. Unknown numbers of Atlantic Sturgeon are caught as bycatch in commercial gill net fisheries along the U.S. Atlantic Coast, with discard mortality rates as high as 51%. The Striped Bass *Morone saxatilis* sink gill net fishery in the James River in Virginia, a tributary to Chesapeake Bay, is the only inshore fishery in Virginia with mesh sizes (13.3 to 20.3 cm stretch mesh) large enough to have high levels of Atlantic Sturgeon bycatch. This study was conducted during the spring fishery and examined a modified gill net design, incorporating a raised footrope at the bottom of the net, creating an approximately one-meter space between the benthos and the net. The modified net was fished alongside conventional commercial gear to evaluate catch rates of Striped Bass and Atlantic Sturgeon in each gear. Our findings show that the experimental net significantly reduced bycatch of Atlantic Sturgeon (64.3%) and significantly increased landing of Striped Bass (45.6%). This gear should be considered as a management option for the spring Striped Bass fishery in Virginia and any fishery where sub-adult Atlantic Sturgeon are the primary bycatch. Additional research on seasonal Altantic Sturgeon orientation in the water column is needed before adopting the raised footrope design in the presence of adults on spawning runs.

[A] Introduction

Bycatch, whether recreational or commercial, is one of the greatest challenges for fisheries managers tasked with conserving, protecting, and sustaining marine resources (Read and Rosenberg 2002; Harrington et al. 2005). Substantial efforts to reduce bycatch in commercial fisheries have been made over the last 20 years by implementing time/area fishing closures, reductions in target quota, and size-limits (O'Keefe et al. 2014). More recently, progress has also been made in modifying commercial fishing gear (Harrington et al. 2005) such as the invention of turtle excluder devices (TEDs) in trawl fishing gear, the use of cull panels in pound nets (Hager 2000), and the promotion of circle hooks in commercial and recreational hook-and-line fisheries (Lewiston et al. 2004; Watson et al. 2005).

Bycatch of protected species is particularly problematic since these species often exhibit low reproductive rates and declining populations (Hall et al. 2000). Given the threats already facing protected species, even small levels of bycatch mortality can hinder conservation efforts (NMFS 2007). Protected anadromous species like Atlantic *Acipenser oxyrinchus oxyrinchus* and Shortnose *Acipenser brevirostrum* Sturgeon display similar seasonal migratory patterns as other economically important commercial anadromous species like Striped Bass *Morone saxatilis* and alosids. Consequently, protected species and commercial fisheries overlap in time and space and interactions between protected species and commercial gears results.

The Atlantic Sturgeon inhabits major rivers, estuaries, and nearshore habitats along the Atlantic Coast of North America from Newfoundland, Canada to the St. Johns River, Florida (NMFS 2007). Atlantic Sturgeon are listed as threatened and endangered in five distinct population segments in all United States waters under the Endangered Species Act. Sharing a similar range as Atlantic Sturgeon, Striped Bass are found along the Atlantic Coast from Canada to Florida. Striped Bass smaller than 69 cm remain resident in rivers and estuaries while adults are seasonally present when returning to spawn early each spring. Atlantic Sturgeon reportedly spawn in the spring from the Delaware River north and in the fall from the Chesapeake Bay south but sub-adults return to estuaries and rivers during the spring and fall in mixed aggregations of individuals from multiple populations (Bartron et al. 2007) at the same time.

Virginia supports three Striped Bass sink gill net fisheries, where nets are anchored and they target individuals lower in the water column (VAC 20-252-140). Smaller Striped Bass provide a local population targeted during a fall fishery in rivers near the saltwater interface, however, while these fish are smaller they make up the majority of the weight landed each year because of restrictions in place during the spring (NEFSC 2019). In some years, a fall-winter fishery may occur in the lower bay based upon the availability of coastal migrants returning south (NEFSC

2019). The spring Striped Bass commercial fishery targets adults undertaking their spring spawning migration in the bay, estuaries and rivers. Virginia Marine Resources Commission has begun monitoring Atlantic Sturgeon bycatch rates in these fisheries, but no estimate is currently available.

Gear modification investigations to limit bycatch of Atlantic Sturgeon have ranged from the use of experimental nets (Fox et al. 2013; Pingguo and Jones 2013) to incorporating electropositive metals for behavioral deterrence (Bouyoucos et al. 2014). Musick and Hager (2007) found that increasing twine size, augmenting the hanging ratio, and removing tie-downs all significantly reduced the retention rate of captive Atlantic Sturgeon under controlled/captive conditions. Although these results show promise, confounding factors such as seasonal migratory behavior, long-range migrations across geopolitical boundaries, and potential effects of gear modification on other protected marine species underscore the need for additional field experimentation.

There are limited gear modifications available to protect Atlantic Sturgeon and as such bycatch in the Striped Bass commercial fishery remains a threat to the species. The purpose of this study was to engineer a gill net modification that builds upon years of fishery-based data and previous gear alteration experiments to reduce Atlantic Sturgeon interactions in the Striped Bass sink gill net fishery. This study compares experimental gill nets to control nets to understand both bycatch rates and target catch rates.

[A] Methods

[C] *Study Area and Design.* – Gill nets were set in Burwell Bay and Cobham Bay, in the lower James River, Virginia (Figure 1**)**. This area is the lower 50 km of the James River and is mesohaline to euhaline. This location was the focus of past Atlantic Sturgeon research efforts and current Striped Bass commercial fishing effort (Musick and Hager 2007; Hager 2011). Historic Atlantic Sturgeon bycatch rate in Striped Bass gill nets from spring 2005-2009 was 0.09 Sturgeon/914 m of net/24 hr soak (Hager, Chesapeake Scientific, unpublished). Using a McNemar Test at the $\alpha = 0.05$ level, power curves suggest 45 paired net sets would be necessary to achieve a 90% confidence level. Forty-one sets were completed in 2014 and another five were conducted in 2015. The split-year approach was caused by temporary delays resulting from an incidental Atlantic Sturgeon mortality during April 2014.

[C] *Experimental gear specifications.* – Experimental and control gill nets were paired for each stretch mesh size; each 183 m section contained a 91.5 m control panel and 91.5 m experimental panel. The full deployed gill net measured 1,280 m and comprised seven 183 m sections. The sections were 13.3 cm, 14 cm, 15.2 cm, 16.5 cm, 17.8 cm, and 20.3 cm stretched mesh. Mesh of 15.2 cm is the most commonly used and therefore two sections in the full deployed gill net were that size. The control panel of each pair was constructed in a traditional fashion so that monofilament webbing was tied directly to the lead line enabling the net to fish the benthos. The experimental panel was rigged with a raised foot rope connected to the lead line with drop lines (#12 osprey rope) spaced approximately 1.5 m apart. This design provided a distance of 106.6 cm of mesh-free passage between the monofilament webbing and the benthos (Figure 2**)**. Although the monofilament webbing in the control nets was consistent with conventional gill nets used by commercial fishermen within the Striped Bass fishery, an additional float line was attached 1.1 m above the top line where the webbing was attached to ensure that tension and vertical presentation between experimental and control net sections was consistent. Both the control and experimental nets utilized 34 kg per 1,969 m lead line and matching pairs of net configurations were always fished together in the same location.

[C] *Field procedures.* – Soak durations followed Striped Bass commercial fishing regulations during the study period. Gill nets were typically deployed for regular 24-hour intervals. As the net was hauled, catch was sorted, identified, and measured. Striped Bass were measured to the nearest millimeter total length (TL) while all Atlantic Sturgeon were measured to the nearest millimeter fork length (FL) because the ends of the heterocercal tails were often damaged making fork length a more reliable metric for comparing sizes. Total count was recorded for all taxa by net type (control vs. experimental) and mesh size.

[C] *Statistical analyses.* – Statistical tools in this study were selected to quantitatively 1) compare catch of Striped Bass and Atlantic Sturgeon between experimental and control gill nets, and 2) assess whether gear type, mesh size, or week of the commercial fishing season affected commercial catch or bycatch occurrence. The week of fishery never had a significant correlation with bycatch and is not discussed further. Catches between experimental and control nets were compared using a t-test to compare Striped Bass abundance and size (Zar 2010). Correlations between mesh size and body length were made using a general linear model in R. The equation produced was:

$$TL = \beta_0 + \beta_1 x_1$$

This equation predicts total length of Striped Bass by relying on the regression coefficients ($\boldsymbol{\beta}$) and regression variables (x_1 = mesh size).

A zero inflated Poisson regression model was used to describe Atlantic Sturgeon abundance and size with respect to gear type (control vs experimental), mesh size, and timing (sample week). Soak time was standardized with an offset term in the regression and therefore was not included as an explanatory variable in the model.

The zero inflated Poisson regression considers two possible independent responses (Y) to sampling, the first that no sturgeon are captured and the second that their capture probability fits a Poisson distribution (Lambert 1992). These equations are written:

$$\frac{Y_i}{t} = 0 \text{ with probability } \pi + (1 - \pi)e^{-\lambda}$$

$$\frac{Y_i}{t} = k \text{ with probability } (1 - \pi)\frac{\lambda^{k_i} e^{-\lambda}}{k_i!}$$

In the above equations, $\frac{Y_i}{t}$ is the outcome with k being the probability of catching a sturgeon in 24 hours, while λ and π are the expected values and the probability of zeroes, respectively, within a Poisson distribution. The regression following these probability distributions can be written:

$$\Pr\left(\frac{Y_i}{t}\right) = \beta_0 + \beta_1 x_{1i}$$

Where Pr $(\frac{Y_i}{t})$ is the probability of Atlantic Sturgeon bycatch in a 24-hour period, β is the regression coefficient, and x is the regression variable. The distributional characteristics of the zero-inflated Poisson regression were evaluated and only gear modifications were included in the best fitting model as determined via the Akaike Information Criterion (AIC; Akiake 1973, 1974).

The zero inflated Poisson regression was performed in R (Zeileis et al. 2008). The best fitting model included only a comparison of control and experimental gear.

[A] Results

Forty-six gill net sets captured 10 species of fish and 1 bird species in the control gear and 11 species of fish and 1 bird species in the experimental nets (Table 1**)**. Nineteen Atlantic Sturgeon were caught as bycatch in this study and ranged in size from 635 to 1,422 mm FL. Generally, larger sturgeon were captured in larger mesh, but given the infrequency of bycatch, the trend was not significant. Fourteen Atlantic Sturgeon (74%) were captured in the control nets and five (26%) were collected in the experimental nets. The catch of Atlantic Sturgeon was significantly greater ($p = 0.0419$, df = 17) in control nets (0.48 per 914 m) than experimental (0.17 per 914 m).

The experimental nets captured 45.5% more Striped Bass ($n = 481$ or 65%) than the control nets ($n = 262$ or 35%), significantly increasing target catch ($p < 0.001$, df = 37). The average length of Striped Bass taken in the control net sections was slightly larger (699.6 mm TL) than that landed in the experimental sections (683.6 mm TL), but this difference was not statistically significant (p = 0.164, df = 590). Total length (mm) of Striped Bass was significantly correlated ($p < 0.001$, null df = 587, residual df = 585) with the size of the gill net mesh, while the size of Striped Bass increased through the season with more captures in smaller meshes in March, transitioning to more catches in larger meshes by mid-April.

[A] Discussion

The results of this study indicate that the experimental gill net was successful at reducing Atlantic Sturgeon bycatch while increasing harvest of commercially valuable species. The raised footrope design works by taking advantage of different spatial orientation of Striped Bass and Atlantic Sturgeon within the lower James River during the spring. Aggregating sub-adult Atlantic Sturgeon are primarily benthically oriented (Musick and Hager 2007; Hager 2011), whereas adult Striped Bass are pelagic predators (Graves et al. 2009; Overton et al. 2009).

Atlantic Sturgeon are acutely susceptible to capture in gill nets (Collins et al. 1996; Armstrong and Hightower 2002; Stein et al. 2004; Laney et al. 2007; Grunwald et al. 2008) because they have sharp snouts that easily enter meshes of gill nets and once in the webbing, they are covered in five rows of scutes that reduce the likelihood of escape. There is no spatial or temporal separation between Striped Bass and Atlantic Sturgeon that would allow for interaction avoidance (Grantham et al. 2008; Harden and Williard 2012; O'Keefe et al. 2014; Ward et al. 2015), which leaves gear modification or fishery closure as the options to protect this endangered species. Many aspects of Atlantic Sturgeon ecology are not well understood and therefore there may not be a single gear modification that can address all fisheries bycatch at all times of the year.

In this study, over 90% of Atlantic Sturgeon were sub-adults, as described in Bain (1997), which were most often entangled near the lower section of the control net. The most abundant life stage of Atlantic sturgeon in February and March are sub-adults (Musick and Hager 2007; Hager 2011) and due to their spatial distribution, level of activity, water column orientation, and size relative to commercial Striped Bass mesh size, they are the most susceptible to traditional sink gill net gear. Adult Atlantic Sturgeon increase their presence in the James River when the river reaches approximately 19 °C usually in mid-April (Musick and Hager 2007). Striped Bass initiate spawning at temperatures between 9 and 12 °C and begin leaving the river around 22 °C (Setzler-Hamilton 1981). The spring fishery targets Striped Bass moving upriver, missing the influx of adult Atlantic Sturgeon. Adult sturgeon are further protected by restrictions on large mesh net along with Striped Bass size restrictions in April (VAC-20-252-140). In late summer, as adult Atlantic Sturgeon migrate upriver to the fall spawning grounds (Balazik et al. 2012; Hager et al. 2014; Kahn et al. 2019), there are no large mesh fisheries in the Chesapeake Bay. However, adult Atlantic Sturgeon outmigration in October coincides with resident Striped Bass moving out of fresh water habitats into lower river sections as they cool and become more productive (Coutant and Benson 1990; Hartman and Brandt 1995). The fall fishery that targets these Striped Bass overlaps with these adult sturgeon.

The gear modification proposed in this study reduces the chance of bycatching sub-adult Atlantic Sturgeon in the spring, but more work is needed to be sure these modifications are similarly protective of sturgeon in the fall. The fall Striped Bass commercial fishery employs roughly the same effort as the spring fishery (VMRC Mandatory Harvest Reporting Program Data) and therefore the risk of bycatch is likely roughly the same, only the fall may have a greater impact on adult Atlantic Sturgeon. A longer study that explores the effectiveness of the raised footrope design for all large mesh gill net fisheries in Virginia would allow managers to establish effective mitigation during each season. This study has identified a gear modification that benefits listed species and fishers, but more work is needed before bycatch in Virginia gill net fisheries can be reduced in every season.

[A] Acknowledgements

We thank D. Orner, G. Thatcher, and the NMFS Office of Protected Resources who were instrumental in the execution of this grant. We gladly acknowledge the fishermen Herman Hogge and Dennis Liknes who provided essential work to help the crew at Chesapeake Scientific L.L.C. complete the field work safely and efficiently. A special acknowledgement goes out to Bobby Weagley the wise fishermen with whom Dr. Hager developed the idea of raised foot ropes for Sturgeon bycatch reduction. In addition, we thank Dr. D. Durbin from Cardno and A. Smith from ERM for their management support and guidance. A special thanks to J. Busalacchi and B. Wanner from Cardno who provided GIS assistance and background literature review, respectively. This work was primarily supported by funding from NMFS through the Bycatch Reduction Engineering Program (NA13NMF4720279). Field sampling was carried out under the auspices of NMFS's ESA Section 7 consultation process. Manuscript preparation and submission was facilitated by Noelle H. Mathies.

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Figure 1. Map of the study area: the lower James River, Virginia, United States.

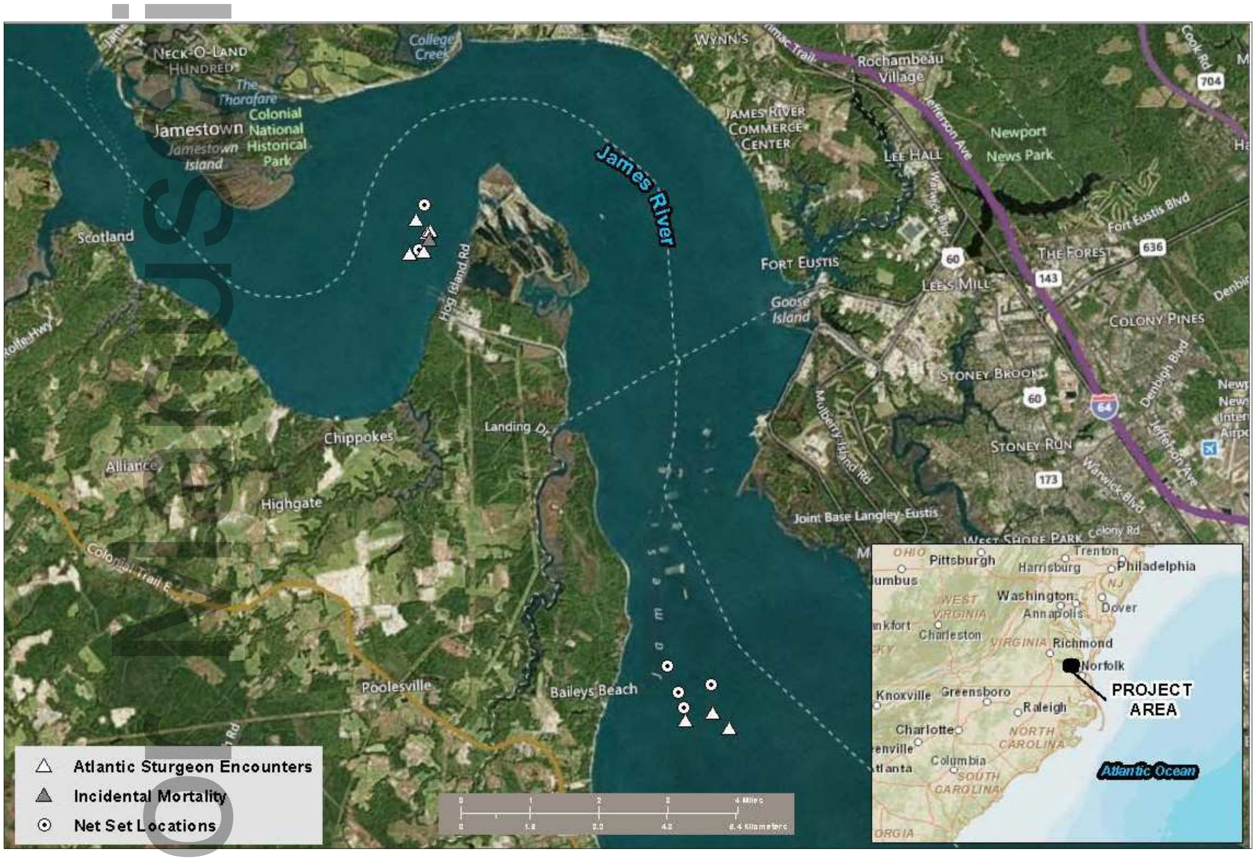

Figure 2. Illustrations of control net (left) and experimental gill net gear (right) with benthic passage. Shaded blue sections are approximately 1 m^2 areas that do not contain webbing.

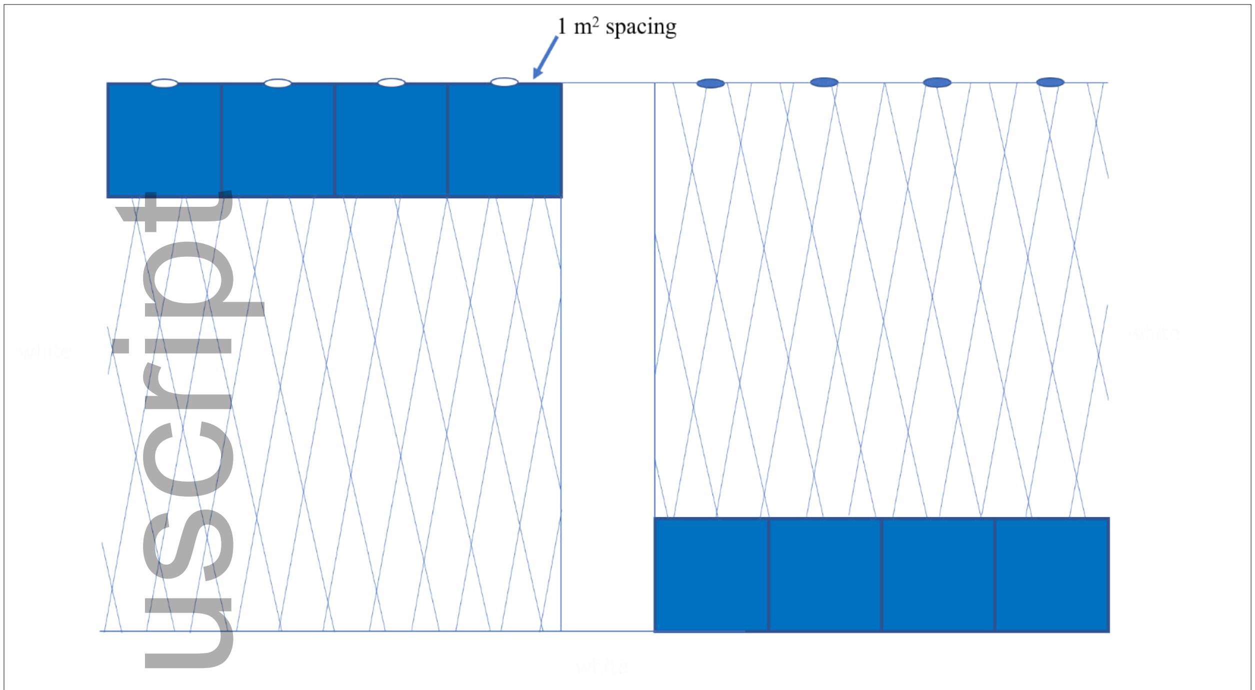

Table 1. Species composition captured in traditional sink and experimental gill nets in the mesohaline section of the James River, Virginia during spring 2014 and spring 2015.

Common Name	Scientific Name	Control	Experimental
Atlantic Sturgeon	*Acipenser oxyrhynchus oxyrhynchus*	14	5
Striped Bass	*Morone saxitilis*	263	484
Blue Catfish	*Ictalurus furcatus*	856	1288
Menhaden	*Brevoortia tyrannus*	3157	1844
Common Carp	*Cyprinus carpio*	198	484
Gizzard Shad	*Dorosoma cepedianum*	40	24
White Perch	*Morone americana*	5	1
Flathead Catfish	*Pylodictis olivaris*	4	2
American Shad	*Alosa sapidissima*	0	3
Red Drum	*Sciaenops ocellatus*	0	2
White Catfish	*Ameiurus catus*	1	0
Summer Flounder	*Paralichthys dentatus*	0	1

Common Name	Scientific Name	Control	Experimental
Common Loon	*Gavia immer*	3	3

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