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ARTICLE

Marine Distribution and Habitat Use of Atlantic Sturgeon in New York Lead to Fisheries Interactions and Bycatch

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Abstract

Population declines of Atlantic Sturgeon *Acipenser oxyrinchus oxyrinchus* prompted initial fisheries closures and an eventual endangered or threatened species listing across the U.S. portion of their range in 2012. Atlantic Sturgeon aggregations and migration routes along the coast of Long Island overlap with commercial fishing activities that may lead to incidental take in nondirected fisheries. Thus, understanding the distribution and movement of Atlantic Sturgeon in relation to commercial fisheries can help management agencies determine impacts and develop bycatch mitigation measures. Stratified random sampling and targeted bottom trawl surveys were used to identify the temporal and spatial use of marine habitat in New York waters. The majority of survey captures were restricted to depths of less than 15 m and known aggregation areas. During the aggregation periods (May, June, September, and October) in known aggregation areas, catches were an order of magnitude higher than in other areas and months of the year. Northeast Fisheries Observer Program bycatch data from 1989 to 2013 was analyzed for the New York region and suggested that bycatch occurs within two main gear types: otter bottom trawls and sink gill nets. Trawling bycatch contained primarily subadult Atlantic Sturgeon and is highest during the Summer Flounder *Paralichthys dentatus* fishery in New York State waters. Trawling overlaps spatially and temporally with identified Atlantic Sturgeon aggregation areas, while bycatch in gill nets targeted adult fish farther offshore in federal waters. Bycatch in these fisheries may be a regional threat to recovery, and spatial and temporal closures, gear modifications, or other bycatch reduction techniques are suggested to protect aggregating and migrating fish.

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For Atlantic Sturgeon *Acipenser oxyrinchus oxyrinchus*, a long history of commercial exploitation led to a century of population declines and a recent listing of the New York Bight (NYB) population as endangered (USOFR 2012). In the late 19th century, New York coastal gill-net fisheries targeted adults for caviar and flesh and juveniles for flesh (Murawski and Pacheco 1977; Smith and Clugston 1997). The New York fishery experienced peak landings of 231,000 kg in 1898, but quantities had declined to 30,000 kg by 1901 (Murawski and Pacheco 1977). This "boom and bust" pattern in fisheries landings was also experienced by other Atlantic Sturgeon populations as local fisheries collapsed throughout the eastern United States (Smith and Clugston 1997). In the mid-1970s a resurgent Atlantic Sturgeon fishery developed with southeastern stocks initially representing 80% of the landings, a proportion that persisted through the early 1980s (Smith and Clugston 1997). During the late 1980s until the closure of the fishery in 1996, the fishery overwhelmingly focused in the NYB (Smith and Clugston 1997; Kahnle et al. 2007). Increased fishing mortality from 1977 to 1995 was coincident with an 80% decline in the Hudson River population (Peterson et al. 2000). In order to protect the remaining Atlantic Sturgeon, a 40-year moratorium was enacted in 1998 (ASMFC 1998), followed by a National Oceanic and Atmospheric Administration (NOAA) listing as an endangered species in 2012. The Hudson River stock remains the largest Atlantic Sturgeon population, although still considered at risk of extinction (ASSRT 2007), with an estimated 870 spawning individuals, of which 270 are female (Kahnle et al. 2007).

Assessing the current health of Hudson River Atlantic Sturgeon has been problematic. Surveys that target different areas and life history stages indicate opposing abundance trends. In the Hudson River, surveys that target premigrant juveniles have shown an increasing population trend since the 1990s, while marine-based surveys targeting migrants have continued to show declining numbers (Kahnle et al. 2007). Marine-based surveys continue to show low abundance estimates of mature adults, raising the concern that an increase in premigrant juveniles is not resulting in an increased abundance of late juvenile and adult Atlantic Sturgeon (ASMFC 2007). At the current estimated population abundance, levels of bycatch mortality greater than 6% in the marine environment could hinder recovery (Boreman 1997; ASMFC 2007; Kahnle et al. 2007). Atlantic Sturgeon are particularly vulnerable to incidental bycatch in coastal fisheries. Mortality during marine migrations may explain why surveys show no increase in the abundance of older individuals (Stein et al. 2004a).

Understanding Atlantic Sturgeon use of marine habitat, where the majority of their life cycle is spent, is required for the development of effective habitat-related Endangered Species Act rules or area-based management solutions (Nemeth 2005). A relatively large amount of research has been conducted on the freshwater habitat use of Atlantic Sturgeon; however, there is a paucity of information characterizing marine habitat use. Available marine research suggests that Atlantic Sturgeon occur in shallow inshore areas of the continental shelf and form marine aggregations near the mouths of river systems (Stein et al. 2004a, 2004b; Laney et al. 2007; Dunton et al. 2010; Erickson et al. 2011). Along the coast of Long Island, New York, fisheries and other anthropogenic stressors commonly co-occur in locations identified as Atlantic Sturgeon aggregation sites and migration pathways, potentially causing an increased risk of bycatch mortality or other negative interactions (Dunton et al. 2010). Indeed, bycatch documented along the eastern seaboard (Stein et al. 2004a) and recent anecdotal information reported to the New York Department of Environmental Conservation suggest that Atlantic Sturgeon are caught in commercial trawl and gill-net fisheries along the coast of Long Island (K. A. McKown, unpublished data).

The objectives of this study were to describe Atlantic Sturgeon habitat use along the coast of Long Island and assess the potential for fisheries interactions and bycatch mortality. Specifically, we provide spatial distribution and abundance estimates from a 3-year trawl survey conducted in the coastal waters of New York and commercial bycatch and fishery interactions are examined using data collected by the Northeast Fisheries Observer Program (Karp et al. 2011). Additionally, targeted trawling was employed to measure the potential impacts of fisheries directed on aggregation areas.

METHODS

Sampling was conducted utilizing a depth-stratified random design based on 10-m depth intervals using the inshore strata and depth zones designed for the Northeast Fisheries Science Center's inshore trawl survey (Sosebee and Cadrin 2006). Strata 1, 2, 12, 13, and 14 were truncated to exclusively New York waters (Figure 1). Cruises consisted of two different surveys, the New York young-of-the-year Bluefish *Pomatomus saltatrix* survey and the New York ocean trawl survey for Atlantic Sturgeon that occurs throughout the year. A full description of the surveys can be found in Dunton et al. (2010). To briefly summarize, surveys used a three-to-one two-seam trawl (headrope 25 m, footrope 30.5 m) with forward netting beginning at 12-cm mesh and tapering down to 8-cm stretched mesh lined with a 6.0-mm-mesh cod end. Surveys were conducted with the RV *Seawolf* and included the waters inshore of 30 m from the easternmost point of Long Island to the entrance of New York Harbor. Tows were standardized to 20 min duration and 3–3.5 knots. Not all depth strata were sampled each survey.

In addition to stratified random sampling, directed research tows specifically targeting Atlantic Sturgeon aggregations occurred opportunistically in April, May, and June, and in October, November, and December of 2007–2013, largely in strata 12 and 13. Tow duration was reduced to 5–15 min during targeted sampling of aggregations in order to be in

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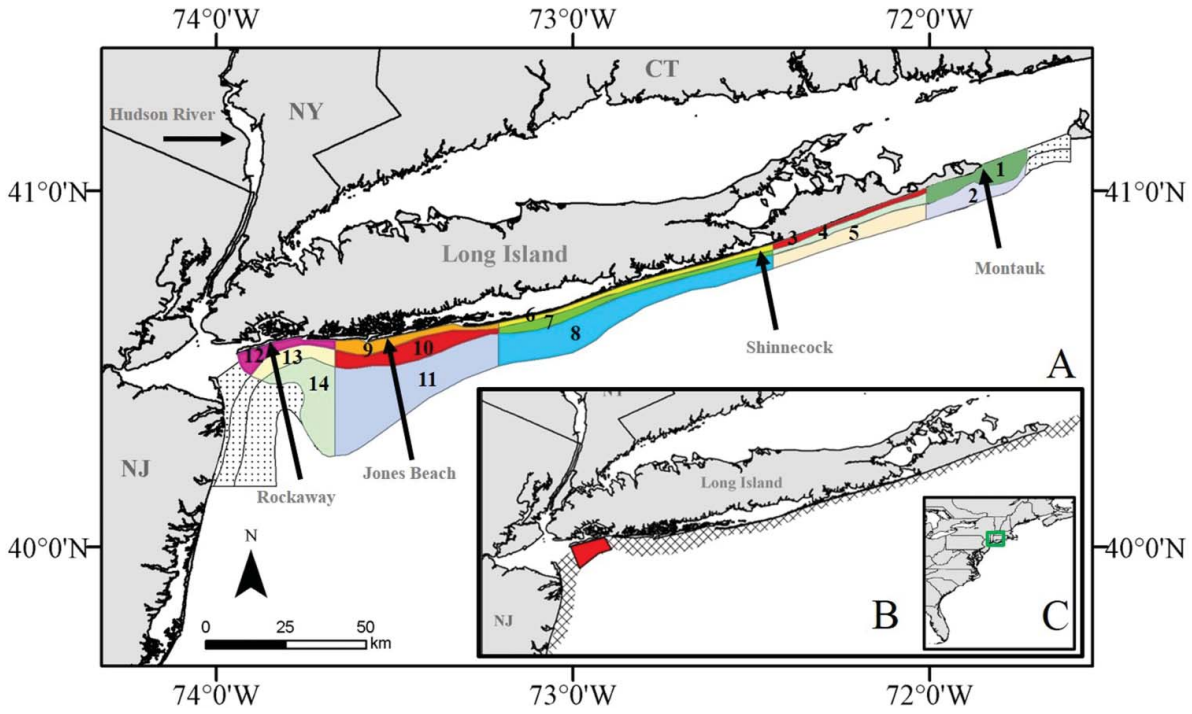


FIGURE 1. Map of the study site **(A)** showing strata used in the stratified random trawl survey along the south shore of Long Island. Strata 1, 2, 12, 13, and 14 were truncated from the Northeast Fisheries Science Center's inshore trawl survey to include New York waters only (dotted areas represent full strata). Targeted sampling was restricted to strata 12 and 13. Strata 12, 9, 6, and 3 have a depth of 0–10 m, strata 13, 10, 7, 4, and 1 have a depth 10–20 m, and strata 14, 11, 8, 5, and 2 have a depth of 20–30 m. Locations important to this study are noted. The inset maps show **(B)** the Atlantic Sturgeon aggregation area (red area) and their migration corridors (hatched) and **(C)** the regional location of the study site. The state abbreviations are as follows: NY = New York, CT = Connecticut, and NJ = New Jersey.

compliance with the Endangered Species Permit 16422 issued to Stony Brook University.

All Atlantic Sturgeon captured were measured to the nearest centimeter (fork and total length), weighed (kg) using a platform scale, and examined for prior tags. If no tags were detected, the Atlantic Sturgeon were double-tagged with an external United States Fish and Wildlife Service (USFWS) carlin or dart tag and an internally implanted 125- or 134.2-kHz passive integrated transponder (PIT). External tags, supplied by the USFWS, had reporting information printed directly on the tag to enable fisherman and the general public to report information on encountered Atlantic Sturgeon. Internally implanted PIT tags are long-term tags utilized by the scientific community to identify individuals. All Atlantic Sturgeon captured after April 2012 were collected under Endangered Species Permit 16422 issued to Stony Brook University.

Spatial distribution of catch.—Atlantic Sturgeon captures were mapped using ArcGIS 9.2 (ESRI; Redlands, California). Map base layers were obtained from the United States Geological Survey Coastal and Marine Geology Program GIS catalog. Atlantic Sturgeon captures were plotted using graduated symbols in the following categories: 1, 2, 3, 4, 6, and 10 Atlantic Sturgeon per tow.

Catch per unit effort.—Catch per unit effort (CPUE) was calculated as fish per minute to allow comparison of the varying tow times during targeted trawling. The CPUEs for the random trawl survey were weighted, taking into account the stratified design using the modified equation from Perry and Smith (1994) and Dunton et al. (2010):

$$\text{Weighted CPUE} = \frac{W_h}{n_h}\frac{y_{hi}}{y_{st}},$$

where W_h = the proportion of the survey area in stratum h; n_h = the number of tows in stratum h; y_{hi} = the CPUE (number of fish per minute) in tow i and stratum h; and y_{st} = the stratified mean abundance (CPUE × W_h).

Targeted sampling CPUE was not weighted due to its nonstratified design. The CPUE estimates were compared using 95% confidence intervals for random versus targeted sampling, western Long Island versus central-east Long Island, and peak versus nonpeak periods, using bootstrap resampling (n = 10,000). Confidence intervals were bias-corrected using the methods described by Efron (1987).

Fishery interactions.—Patterns in fishery interactions and regional bycatch of Atlantic Sturgeon off Long Island were

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examined using two methods: (1) collecting data on Atlantic Sturgeon tagged in this study and reported as bycatch from commercial fisheries using the external USFWS dart or carlin tags and (2) examining data collected by the Northeast Fisheries Observer Program (NEFOP) from 1989 to 2013. The NEFOP collects catch and species data, including geographic location and gear information, for each tow as well as biological data for bycatch species of interest, including number caught, length, weight, and condition (dead, alive, injured). There are some caveats to the observer data, including annual variability and relatively low coverage (Warden and Orphanides 2008). Additionally, only vessels with state and federal permits have observers through NEFOP, and no observer data were recorded for vessels that held only state permits. The NEFOP data for catch and total length was examined for all gear types for vessels originating from New York and New Jersey ports for the Northwest Atlantic Fisheries Organization's statistical areas 611, 612, and 613. Statistical area 611 included trips confined to marine waters south of Long Island in the Atlantic Ocean and excluded trips in Long Island Sound, Block Island Sound, and Gardiners Bay. Trips and bycatch were summarized by state, gear type, and season. Analysis of variance (ANOVA) was used to compare the size distributions of Atlantic Sturgeon captured in gill-net and trawl fisheries.

RESULTS

Stratified Random Survey

A total of 149 Atlantic Sturgeon were captured in 10,380 min ($n = 519$ tows) of stratified random trawling (Table 1). Atlantic Sturgeon distributions varied by strata throughout the season (Figure 2; Table 1). The weighted survey average CPUE was 0.023 sturgeon/min (SD, 0.159), with the highest average weighted CPUE in May, followed by October, November, September, and June (Table 1). The lowest weighted CPUEs were observed in January, followed by March and August (Table 1), with no fish captured in April. The CPUE was highest along western Long Island in strata 12, 9, and 10 (Table 1; Figure 2). Few Atlantic Sturgeon were captured off eastern Long Island (<8%). No Atlantic Sturgeon were captured at depths of 20–30 m (strata 2, 5, 8, 11, and 14) (Table 1; Figure 2).

Targeted Survey

Targeted trawling along western Long Island during spring and fall captured an additional 825 Atlantic Sturgeon in 4,144 min ($n = 312$ bottom tows) for a mean CPUE of 0.226 sturgeon/min (SD, 0.470) (Table 2). The highest CPUEs were

TABLE 1. Weighted CPUE ± SD (sturgeon/min) of Atlantic Sturgeon by month and stratum for random trawl surveys in 2005–2007.

Month, stratum, and average	2005	2006	2007	Average	Total sturgeon	Total minutes
January		0.005 ± 0.025	0.011 ± 0.046	0.008 ± 0.037	4	1,180
March		0.009 ± 0.031		0.009 ± 0.031	2	540
April		0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0	600
May	0.029 ± 0.058	0.003 ± 0.010	0.117 ± 0.594	0.058 ± 0.407	34	1,280
June	0.021 ± 0.062	0.010 ± 0.030	0.017 ± 0.024	0.016 ± 0.042	37	1,980
August	0.005 ± 0.024	0.027 ± 0.122		0.015 ± 0.083	5	900
September	0.000 ± 0.000	0.056 ± 0.165	0.019 ± 0.049	0.020 ± 0.090	21	1,620
October		0.034 ± 0.097	0.034 ± 0.070	0.034 ± 0.085	36	1,080
November	0.016 ± 0.086	0.044 ± 0.157		0.030 ± 0.127	10	1,200
1	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0	620
2	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0	400
3	0.036 ± 0.096	0.009 ± 0.025	0.002 ± 0.006	0.012 ± 0.048	11	1,000
4	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0	640
5	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0	400
6	0.010 ± 0.029	0.003 ± 0.008	0.003 ± 0.007	0.004 ± 0.015	9	1,440
7	0.007 ± 0.029	0.006 ± 0.026	0.000 ± 0.000	0.005 ± 0.025	2	880
8	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0	580
9	0.011 ± 0.039	0.118 ± 0.210	0.044 ± 0.070	0.059 ± 0.130	41	1,060
10	0.000 ± 0.000	0.083 ± 0.211	0.000 ± 0.000	0.040 ± 0.151	6	700
11	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0	540
12	0.036 ± 0.118	0.048 ± 0.115	0.187 ± 0.657	0.101 ± 0.426	78	1,200
13	0.000 ± 0.000	0.023 ± 0.053	0.000 ± 0.000	0.011 ± 0.037	2	520
14	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0	400
Yearly average	0.011 ± 0.054	0.022 ± 0.095	0.034 ± 0.252	0.023 ± 0.159	149	10,380

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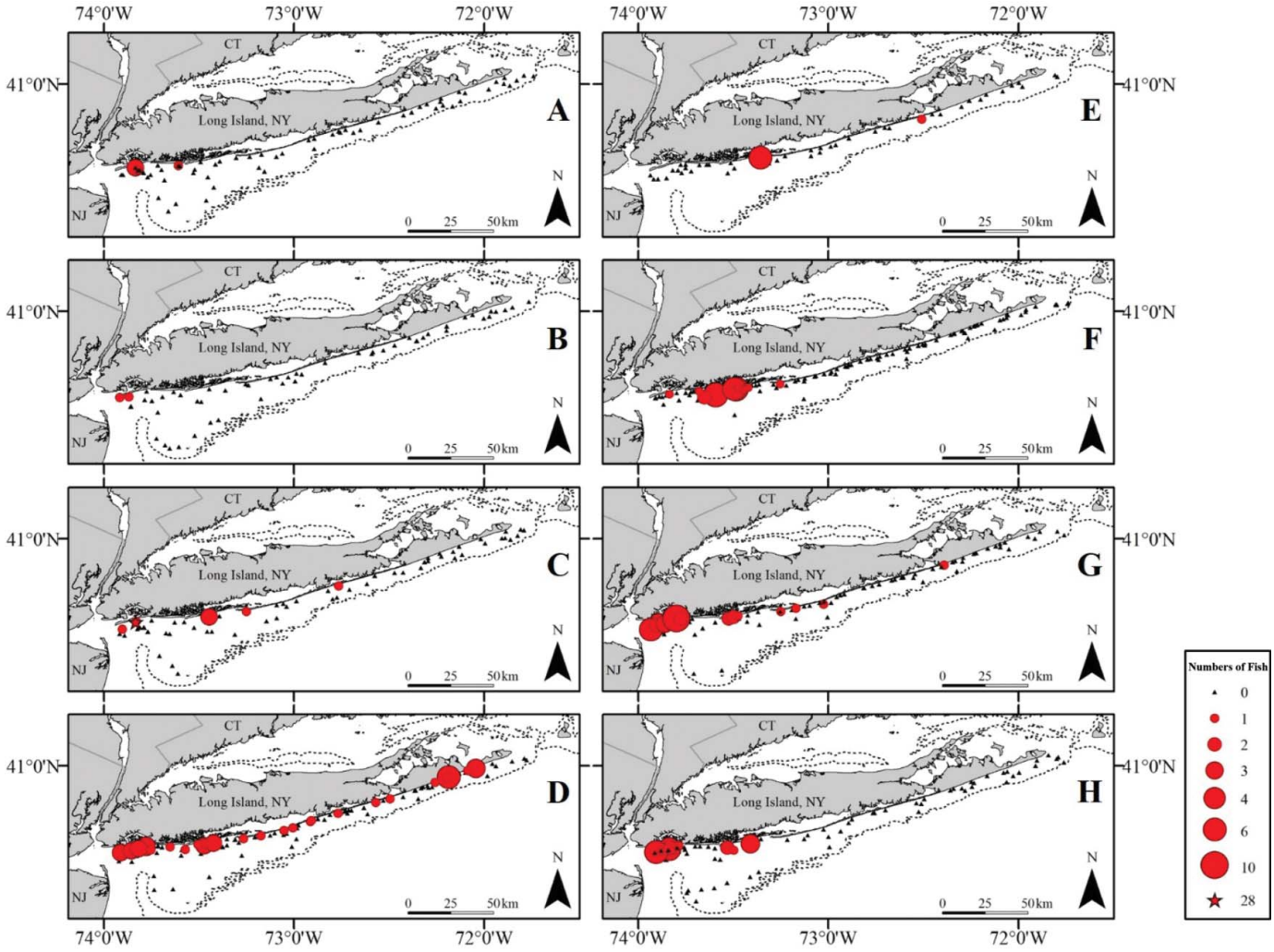


FIGURE 2. Abundance and distribution of Atlantic Sturgeon captured in random trawl surveys for **(A)** January, **(B)** April, **(C)** May, **(D)** June, **(E)** August, **(F)** September, **(G)** October, and **(H)** November. The dashed black line represents the 30-m depth contour (the farthest extent of the survey), and the black triangles represent the locations of tows in which no Atlantic Sturgeon were captured.

observed during May 2011, when 82 fish were captured in 61 min ($n = 8$ tows) of trawling for an average CPUE of 1.533 sturgeon/min (SD, 1.301), and May 2007, when 141 Atlantic Sturgeon were captured in 164 min ($n = 8$ trawls) for a trip CPUE of 0.848 sturgeon/min (SD, 0.493) (Table 2). The highest observed individual tow CPUEs were 3.8 sturgeon/min (May 2011) and 3.25 sturgeon/min (May 2012). Two targeted trawling trips yielded no Atlantic Sturgeon captured (December 2010, October 2012).

Bootstrap Values

Bootstrap resampling was conducted to compare random versus targeted sampling, western Long Island versus central-east Long Island locations, and specific time periods (May, June, September, and October versus November, January, March, and April) (Table 3). Targeted trawling had an order of magnitude higher weighted CPUE than did random trawling, with bootstrap-generated means of 0.226 sturgeon/min (SD, 0.027) and 0.023 sturgeon/min (SD, 0.007), respectively. Significantly higher catches occurred in western Long Island at 0.048 sturgeon/min (SD, 0.016) during the peak months (Table 3).

Fishery Interactions

Tagging data.—A combined total of 974 Atlantic Sturgeon were tagged through random and targeted efforts. Atlantic Sturgeon ranged in size from 64 to 195 cm fork length, with a mean of 101 cm fork length (SD, 19.8). A total of 13 tagged fish were captured in commercial and recreational fisheries: 10 were reported by commercial trawl fisheries, 2 in commercial gill-net fisheries, and 1 in recreational nontarget hook-and-line fisheries. All commercial recaptures were reported to the

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TABLE 2. Catch per unit effort ± SD (sturgeon/min) for Atlantic Sturgeon in targeted trawls for 2006–2013. Values were not weighted for targeted trawling.

Year and average	April	May	June	October	November	December	Average CPUE	Total sturgeon	Total minutes
2006					0.221 ± 0.170		0.221 ± 0.170	31	140
2007	0.017 ± 0.026	0.848 ± 0.493	0.020 ± 0.045		0.145 ± 0.441		0.256 ± 0.490	200	764
2008					0.041 ± 0.057		0.041 ± 0.057	14	340
2010		0.026 ± 0.032	0.043 ± 0.068			0.000 ± 0.000	0.026 ± 0.046	28	1,070
2011		1.533 ± 1.301		0.247 ± 0.487	0.428 ± 0.319		0.504 ± 0.721	272	642
2012		0.369 ± 0.560		0.000 ± 0.000			0.287 ± 0.516	196	645
2013		0.088 ± 0.106		0.418 ± 0.533			0.149 ± 0.271	84	543
Average	0.017 ± 0.026	0.291 ± 0.580	0.039 ± 0.064	0.215 ± 0.443	0.237 ± 0.344	0.000 ± 0.000	0.226 ± 0.470	825	4,144

TABLE 3. Bootstrap ($n = 10{,}000$) results for determining differences among CPUE (sturgeon/min) of Atlantic Sturgeon for random versus targeted trawling, for region, and for periods of higher versus lower abundance for the stratified random survey.

Comparisons	Factors	Mean ± SD	Max	Bias corrected 95% CI
Random and targeted trawling	Random	0.023 ± 0.007	0.060	0.013–0.041
	Target	0.226 ± 0.027	0.339	0.178–0.281
Region (random trawling)	West	0.048 ± 0.016	0.133	0.027–0.092
	Central	0.004 ± 0.001	0.010	0.001–0.007
	East	0.004 ± 0.001	0.010	0.001–0.007
Time (random trawling)	May-Jun-Sep-Oct	0.024 ± 0.006	0.053	0.011–0.028
	Nov-Jan-Mar-Apr	0.005 ± 0.002	0.013	0.002–0.009

USFWS directly by commercial fishermen with no observers on board. Trawl fisheries targeting Winter Flounder *Pseudopleuronectes americanus* or Summer Flounder *Paralichthys dentatus* accounted for 50% ($n = 6$) of the commercial recaptures, with other recaptures reported in trawl fisheries for Atlantic horseshoe crab *Limulus polyphemus* ($n = 1$), Red Hake *Urophycis chuss* or longfin inshore squid *Loligo pealeii* ($n = 1$), and skate *Leucoraja* spp. ($n = 2$) (Figure 3). Recaptures also occurred in gill-net fisheries targeting Goosefish *Lophius americanus* ($n = 1$) and dogfish (genus *Squalus* or *Mustelus*) ($n = 1$) (Figure 3). Commercial recaptures of Atlantic Sturgeon tagged in New York were largely concentrated in two regions: off of Highlands, New Jersey, and Jones Beach, New York (Figure 3).

Northeast Fisheries Observer Program data.—Captures in observed gill-net fishing trips occurred more frequently off the coast of New Jersey, while captures during bottom trawling trips were more frequent off the coast of New York (Figure 4). In the area studied, there were 24,674 observed trips for all gear types, and a total of 413 Atlantic Sturgeon were observed as bycatch off the south shore of Long Island from 1989 to 2013 (Dunton 2014; Figure 4). Bycatch of Atlantic Sturgeon occurred in the fixed or anchor sink gill net ($n = 200$ sturgeon; CPUE = 0.04 sturgeon/observed trip), otter bottom trawl fish ($n = 182$ sturgeon; CPUE = 0.03 sturgeon/observed trip), drift-sink gill net ($n = 19$ sturgeon; CPUE = 0.02 sturgeon/observed trip), drift-floating gill net ($n = 6$ sturgeon; CPUE < 0.01 sturgeon/observed trip), and twin otter bottom trawl ($n = 6$ sturgeon; CPUE = 0.50 sturgeon/observed trip) (Dunton 2014; Figure 4). Atlantic Sturgeon were not observed in anchored floating gill nets, hydraulic clam dredges, sea scallop dredges, bottom longlines, fish traps or pots, lobster pots or

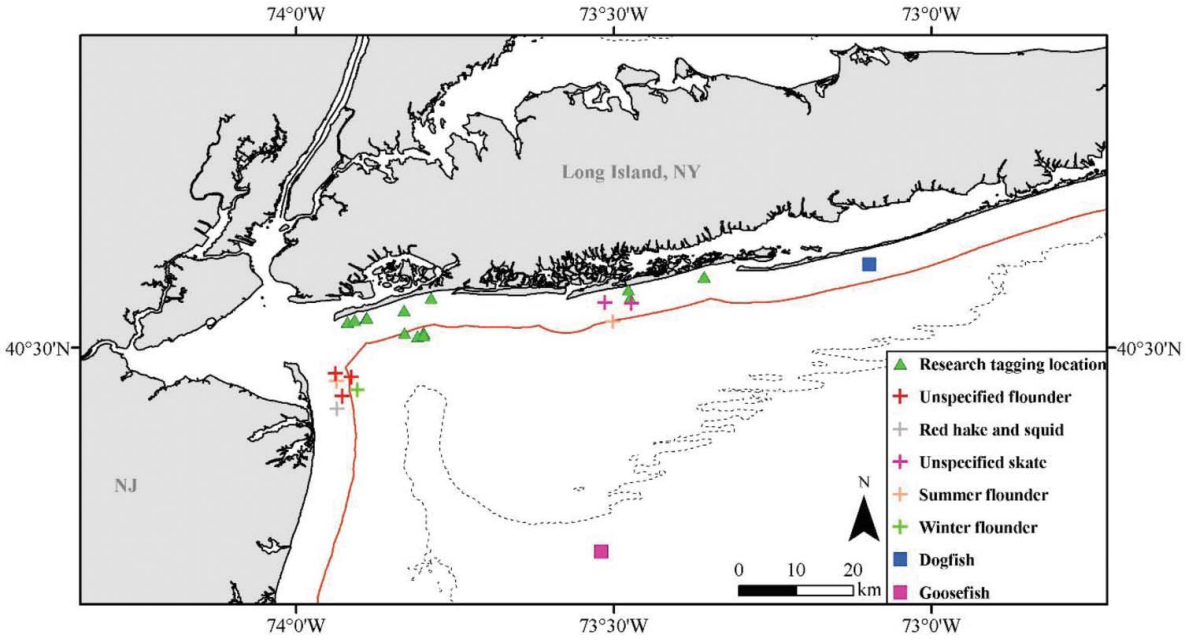


FIGURE 3. Atlantic Sturgeon captured and tagged in New York research trawls (green triangles) and recaptured in commercial fisheries for target species that used bottom trawls (crosses) and gill nets (squares). One commercial recapture off Maryland is not shown. The dashed black line represents the 30-m depth contour, and the red line indicates the Federal–State boundary (4.83 km).

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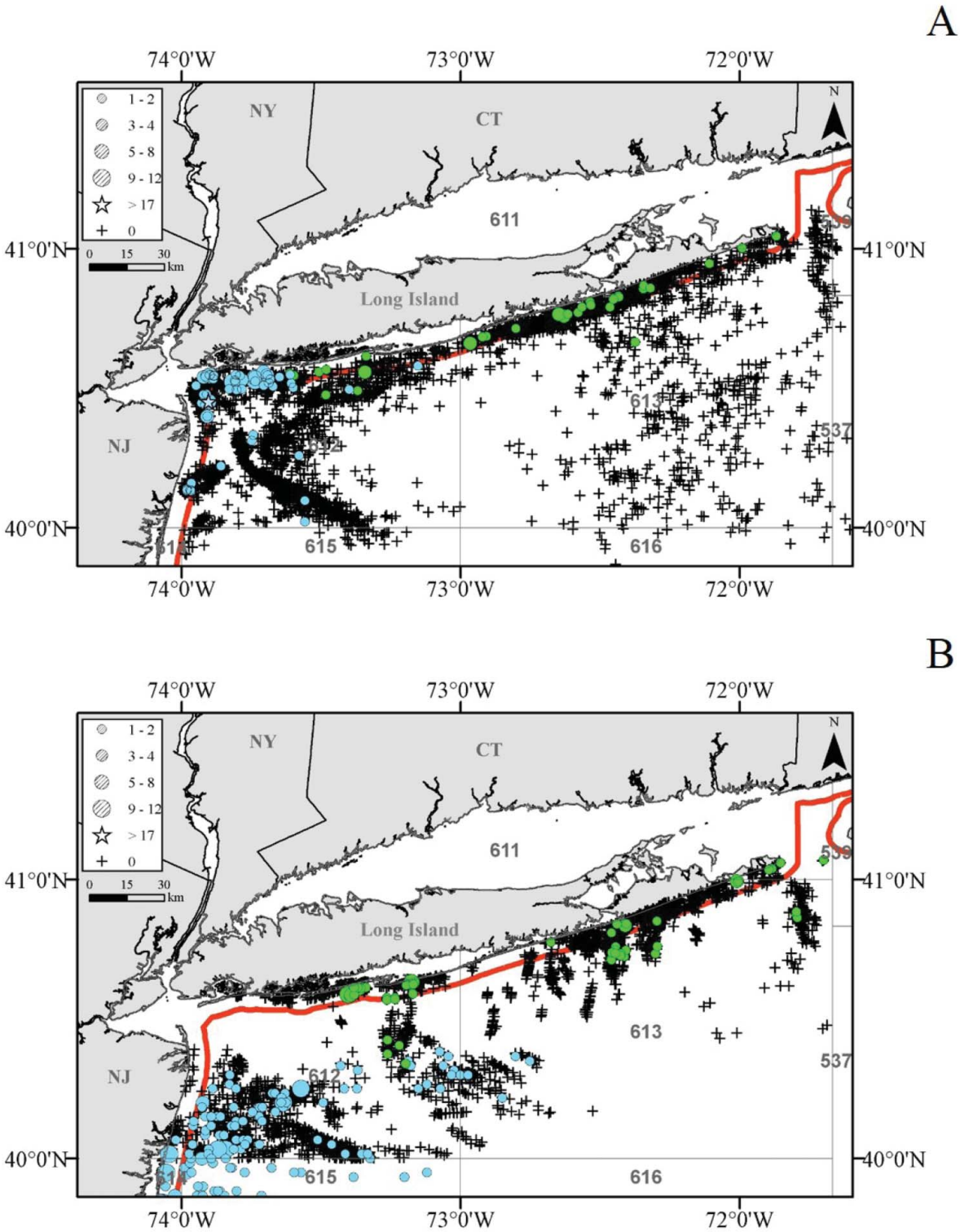


FIGURE 4. Atlantic Sturgeon bycatch observed by the Northeast Fisheries Observer Program from **(A)** bottom otter trawls (fish and twin) and **(B)** gill nets (floating sink-drift and sink fixed-anchored combined). Green circles represent bycatch from vessels that landed in New York ports and blue circles are from vessels that landed in New Jersey ports within statistical areas 611 (modified, only tows south of Long Island and Block Island are included), 612, and 613 (gray numbers and gray lines). The Federal–State boundary (4.83 km) is indicated by the red line.

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traps, scallop bottom trawls, midwater otter trawls, midwater paired otter trawls, and troll lines. For the two main gear types, gill nets and trawls, bycatch and observer coverage varied spatially and seasonally (Figure 5).

Atlantic Sturgeon captured in gill nets (all types combined) were significantly (ANOVA: $F_{1, 371} = 6.39$, $P = 0.012$) larger (mean length $\pm$ SD, 128 $\pm$ 29 cm FL) than those captured in otter trawls (120 $\pm$ 36 cm FL; Figure 6). Of the 413 observed Atlantic Sturgeon bycatch events in the NYB, direct mortality was highest in gill nets, with 58.22% of captured Atlantic Sturgeon released alive, 38.22% dead, and 3.56% with unknown status. Trawls released 94.15% alive, 3.72% dead, and 2.13% with unknown status.

While otter bottom trawls were distributed coastwide, 64% of the observed trawl bycatch occurred less than 4.83 km from shore within state waters (Figure 4; Figure 5). Observed fisheries targeted 30 different species, but Atlantic Sturgeon were captured in only 13 of these fisheries (fisheries for Summer Flounder, longfin inshore squid, Winter Flounder, Striped Bass *Morone saxatilis*, Winter Skate *Leucoraja ocellata*, Silver Hake *Merluccius bilinearis*, Weakfish *Cynoscion regalis*, Bluefish, Red Hake *Urophycis chuss*, Scup *Stenotomus chrysops*, Little Skate *Leucoraja erinacea*, Tautog *Tautoga onitis*, and one unidentified species). The Summer Flounder fishery generated 73% of Atlantic Sturgeon trawl bycatch (Figure 7A). Much of the observed bycatch was from vessels engaged in the Summer Flounder fishery landing catch in New Jersey (Figure 4). Atlantic Sturgeon captures and observer coverage varied seasonally (Figure 5), with peak catches in April (0.07 sturgeon/observed tow), May (0.04 sturgeon/observed tow), June (0.04 sturgeon/observed tow), and September (0.04 sturgeon/observed tow). Low bycatch was observed in February (0.01 sturgeon/observed tow), July (0.02 sturgeon/observed tow), October (0.01 sturgeon/observed tow), and November (0.01 sturgeon/observed tow). No bycatch was observed in January, March, August, and December. Bycatch in trawls was also depth dependent, with 90% of all Atlantic Sturgeon captured in water less than 20 m deep (Figure 8).

Gill nets were concentrated off the coast of New Jersey, with 30% of total observed bycatch occurring within state limits (Figure 4; Figure 5). Gill-net fisheries off Long Island were focused in three regions: Jones Beach, Shinnecock, and Montauk, New York (Figure 4; Figure 5). Atlantic Sturgeon captures and observer coverage varied seasonally (Figure 5). The highest observed Atlantic Sturgeon captures occurred in November, April, December, and May (0.11, 0.09, 0.08 and 0.07 sturgeon/observed set, respectively), with intermediate catches observed in June, August, and October (0.04, 0.04, and 0.03 sturgeon/observed set, respectively). The lowest observed bycatch occurred in January, February, March, July (0.02, 0.01, 0.02, and 0.01 sturgeon/observed set, respectively). Bycatch of Atlantic Sturgeon was observed to occur in all nine target-species categories (Goosefish, Summer Flounder, Striped Bass, Winter Skate, Weakfish, Bluefish, Spiny Dogfish *Squalus acanthias*, and an unknown), with 62% in the Goosefish gill-net fishery concentrated within area 612 in federal waters (Figures 4, 7B). No trends were seen in Atlantic Sturgeon captures by depth (Figure 8).

DISCUSSION

Shallow marine distributions during migration and the formation of aggregations are placing Atlantic Sturgeon at risk for bycatch in coastal trawl and gill-net fisheries based in New York and New Jersey. Research survey and commercial fishery observer data suggest that interactions between Atlantic Sturgeon and fisheries are most likely to occur during seasonal migrations along coastal New York during April to June and October to November. The highest bycatch of Atlantic Sturgeon was observed in the Summer Flounder bottom trawl fishery and the Goosefish gill-net fishery. Gill nets primarily appear to intercept migrating adult Atlantic Sturgeon, while trawls encounter juveniles during periods of aggregation around the mouth of the Hudson River. The seasonally predictable timing of migration and aggregation formation provides an opportunity to develop limited spatial and temporal management to reduce bycatch (Armstrong et al. 2013; Dunton 2014).

Atlantic Sturgeon occur in large numbers in the federal and state waters outside of the Hudson River, one of the previously identified aggregation areas along the East Coast for both subadult (Dunton et al. 2010) and adult Atlantic Sturgeon (Erickson et al. 2011). Atlantic Sturgeon aggregations (Dunton et al. 2010; Erickson et al. 2011) were generally restricted to shallow depths (<20 m) in New York waters, following a seasonal pattern with peak abundance during the spring and fall. Dunton et al. (2010) also found that subadult Atlantic Sturgeon had a significant habitat preference for shallow depths (<20 m) in the region. The aggregation area located in the Rockaway region accounted for the majority of Atlantic Sturgeon captured. When this area was specifically targeted, CPUE rose to a maximum of 61 times the average of random surveys, reaching around 3.8 sturgeon/min.

The Rockaway aggregation area experienced the highest bycatch from otter trawling during months of peak Atlantic Sturgeon abundance. Bycatch was primarily the result of the Summer Flounder fishery (73% of the total trawl bycatch) operating out of New Jersey. Commercial trawlers also reported 83% of tag returns from commercial fisheries in the Rockaway area, with all but one capture occurring in the NYB. Coastwide estimates of all recaptured tagged Atlantic Sturgeon within the USA (including all participating researchers and reports to the USFWS Atlantic Sturgeon database) ranged between 8% and 14% for trawl fisheries. When reported bycatch in the USFWS database for the New Jersey–New York coastal subregion was examined separately, bycatch increased to 30% (S. Eyler, USFWS Maryland Fishery Resources Office, personal communication; Eyler et al. 2009).

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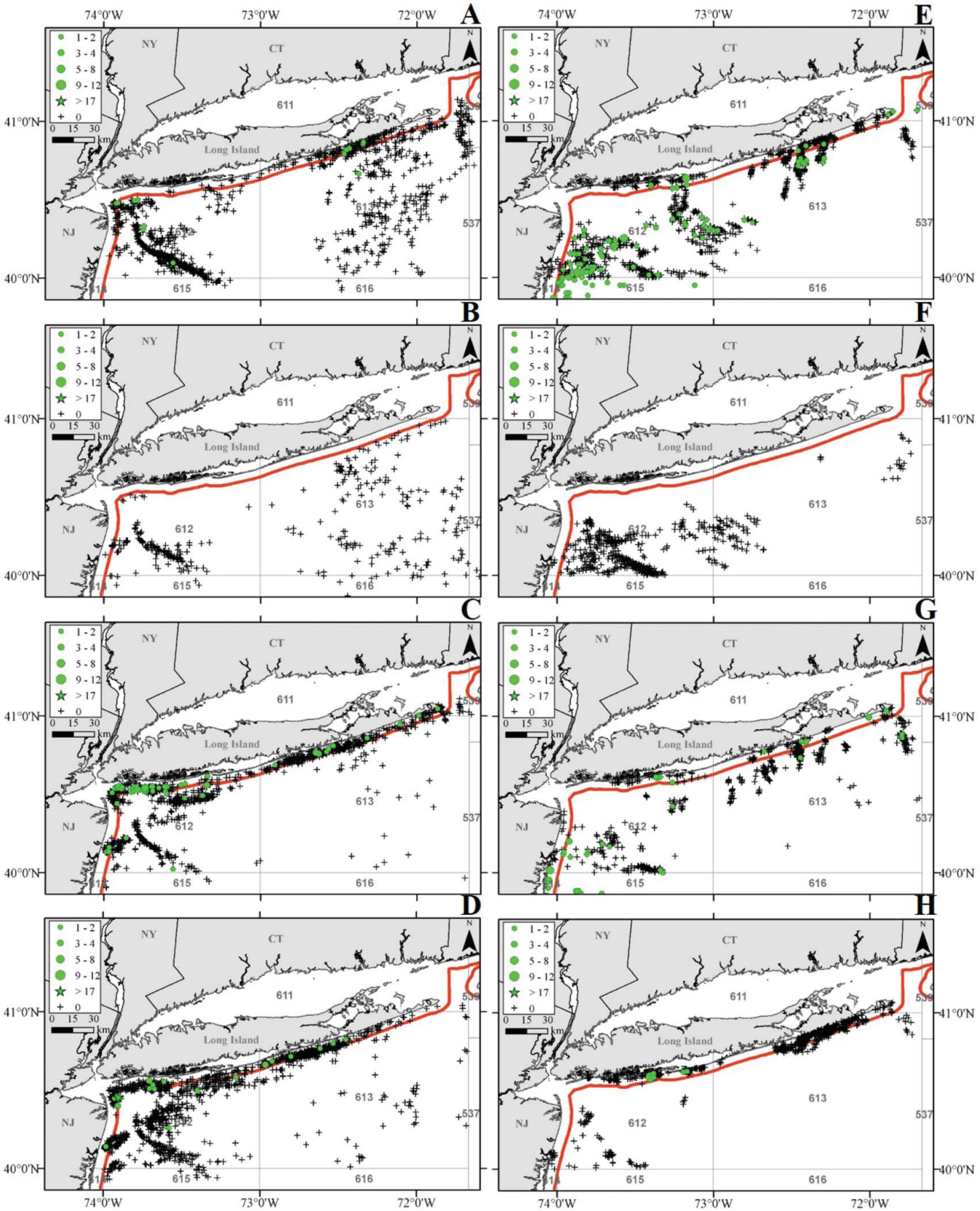


FIGURE 5. Commercial bycatch of Atlantic Sturgeon observed by the Northeast Fisheries Observer Program by season for otter trawls in (A) fall, (B) winter, (C) spring, and (D) summer and for gill nets in (E) fall, (F) winter, (G) spring, and (H) summer. The Federal–State boundary (4.83 km) is indicated by the red line.

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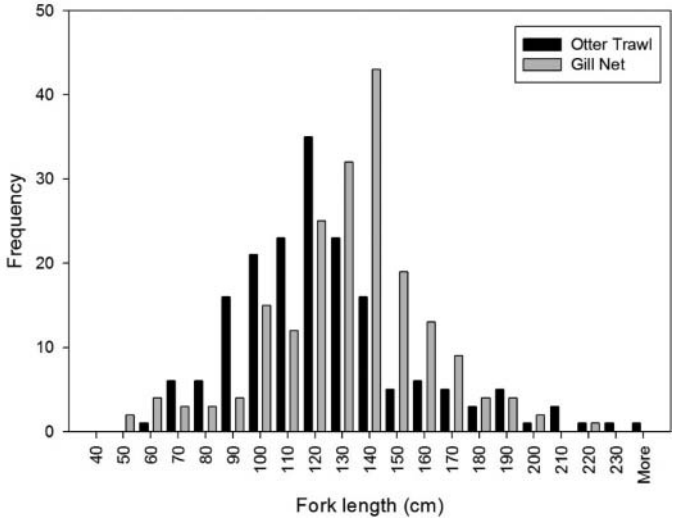


FIGURE 6. Size distribution of Atlantic Sturgeon captured as bycatch in commercial fisheries that use bottom otter trawls (twin and fish) and gill nets (all types). This information was recorded through the Northeast Fisheries Observer Program.

Based on tag reporting and analysis of NEFOP data, trawling within the NYB region appears to represent a bigger threat to Atlantic Sturgeon recovery compared to other locations.

Coastwide bycatch of Atlantic Sturgeon occurs in a wide range of fisheries, with the largest bycatch reported for gill-net (sink and drift) fisheries (Stein et al. 2004a; ASMFC 2007; Eyler et al. 2009). Subadults and adults are presumed to have similar seasonal migration patterns (Bain et al. 2000; Stein et al. 2004a; Erickson et al. 2011; Dunton et al. 2012) that place them in the path of both gill-net and trawl fisheries. Trawls passing through aggregation areas when Atlantic Sturgeon are present could result in large bycatch, as could gill nets set in the narrow migration corridor along the shoreline in depths < 15 m during Atlantic Sturgeon migrations. In response to high Atlantic Sturgeon mortality associated with gill nets in the Goosefish fishery, the fishing industry has been experimenting with gear modifications. Currently, evidence suggests that these experimental nets can decrease Atlantic Sturgeon bycatch (Fox et al. 2013; Pingguo and Jones 2013). However, similar modifications to trawling gear have not been developed or widely tested. The mortality rate for Atlantic Sturgeon captured in commercial trawling is unknown; however, direct observations of deceased juvenile Atlantic Sturgeon are frequently made on beaches close to the Rockaway aggregation region during the spring and fall and adjacent to coastal areas that experience high-frequency bottom trawling (K. J. Dunton, unpublished data; T. Lomschumbo, Gateway National Recreation Area, personal communication). Although these observations suggest that mortality is occurring in local commercial trawl fisheries, the exact cause of mortality for these fish is unknown.

While bycatch-related mortality is believed to be lower in trawls than in gill nets, the potential for large catches in aggregation areas and repetitive habitat use may lead to a significant impact on the recovering population. An accurate estimate of population mortality of Atlantic Sturgeon due to bycatch is not possible at this time because of unknown postrelease survival (Stein et al. 2004a). Relatively little direct mortality is observed for fish captured by otter trawls, with 94% of otter trawl captures observed by NEFOP being released alive. However, the delayed effects of stress and injuries may occur for weeks after the initial capture (Davis 2002; Broadhurst et al. 2006). Beardsall et al. (2013) showed that 60-min experimental trawls are a moderate stressor leading to survival rates of around 94% for acoustically tagged fish tracked for an average of 56 d in the Minas Basin, Canada. However, the small sample size ($n = 34$) and the short duration for some tracked fish (3 d), limit inference to coastwide fisheries, particularly in more southerly (warmer) regions. The estimate of postrelease survival by Beardsall et al. (2013) coupled with NEFOP observations of captured Atlantic Sturgeon released alive, indicates that fisheries mortality is certainly higher when postrelease mortality is considered for trawls. Further, multiple possibilities for capture during the 7 year (or longer) juvenile marine stage and as adults in gill-net fisheries increase the cumulative likelihood of mortality associated with fishery interactions.

Many factors, such as catch size, species composition, water and air temperatures, tow duration, and handling time, are likely to influence survival (Beardsall et al. 2013). Tow durations in commercial fisheries in the New York region last between 60 and 180 min (NEFOP). The total number of Atlantic Sturgeon captured in NEFOP-observed tows was typically 1 to 4 animals, although bycatch events as high as 60 individuals have been reported to the USFWS (Dunton 2014). A large catch of Atlantic Sturgeon may increase mortality due to increased handling time and injuries during capture. Since a 6% mortality rate would put recovering populations at risk (ASMFC 2007), a detailed study of handling practices once Atlantic Sturgeon are on deck is warranted, as well as how handling practices are influenced by the total catch size. Understanding bycatch mortality is essential to developing best-practices during fishing operations, thereby increasing survival rates.

The high potential for Atlantic Sturgeon bycatch in trawl fisheries that overlap aggregation areas in coastal Long Island emphasizes the need for bycatch reduction measures. Most states in the region offer Atlantic Sturgeon de facto protection from bycatch by limiting or excluding trawling in state waters (Dunton et al. 2010); however, New York limits trawling only within a 2.41-km arc of coastline around navigable inlets. The NEFOP data shows that 64% of Atlantic Sturgeon bycatch in otter trawling occurs in state waters. A majority of incidents occur in known aggregation areas along western Long Island. Aggregation areas in the NYB have been recommended as closed areas and essential marine habitat for subadults in order to mitigate fisheries impacts (Dunton et al. 2010; Dunton 2014). Given the nature of Atlantic Sturgeon habitat preference and movements, New York state could adopt restricted

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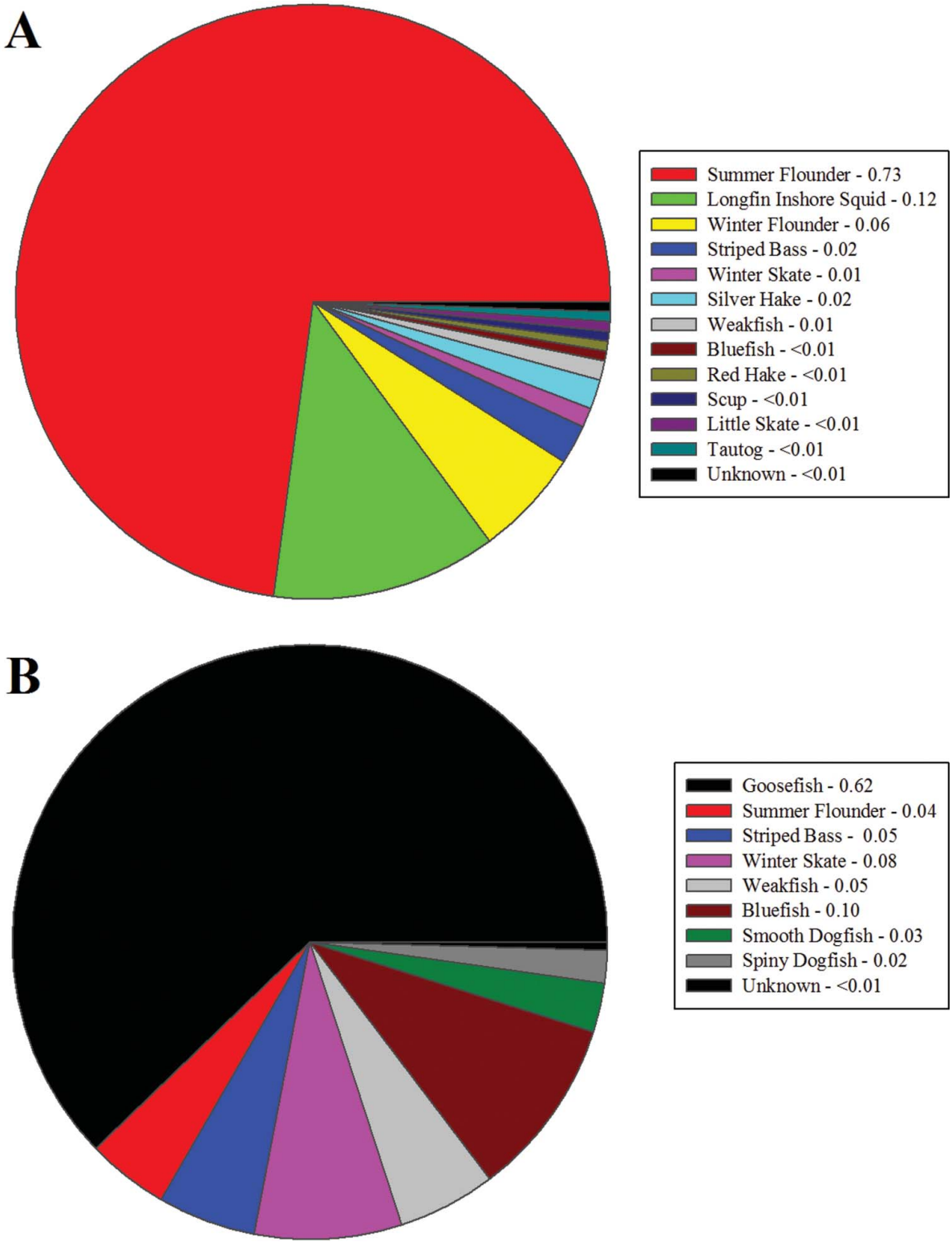


FIGURE 7. Proportion of Atlantic Sturgeon bycatch observed through the Northeast Fisheries Observer Program organized by commercial target fish species for **(A)** bottom and twin otter trawls (fish only) and **(B)** gill nets (all types). The proportion of Atlantic Sturgeon bycatch by target species is shown as the numbers in the legend.

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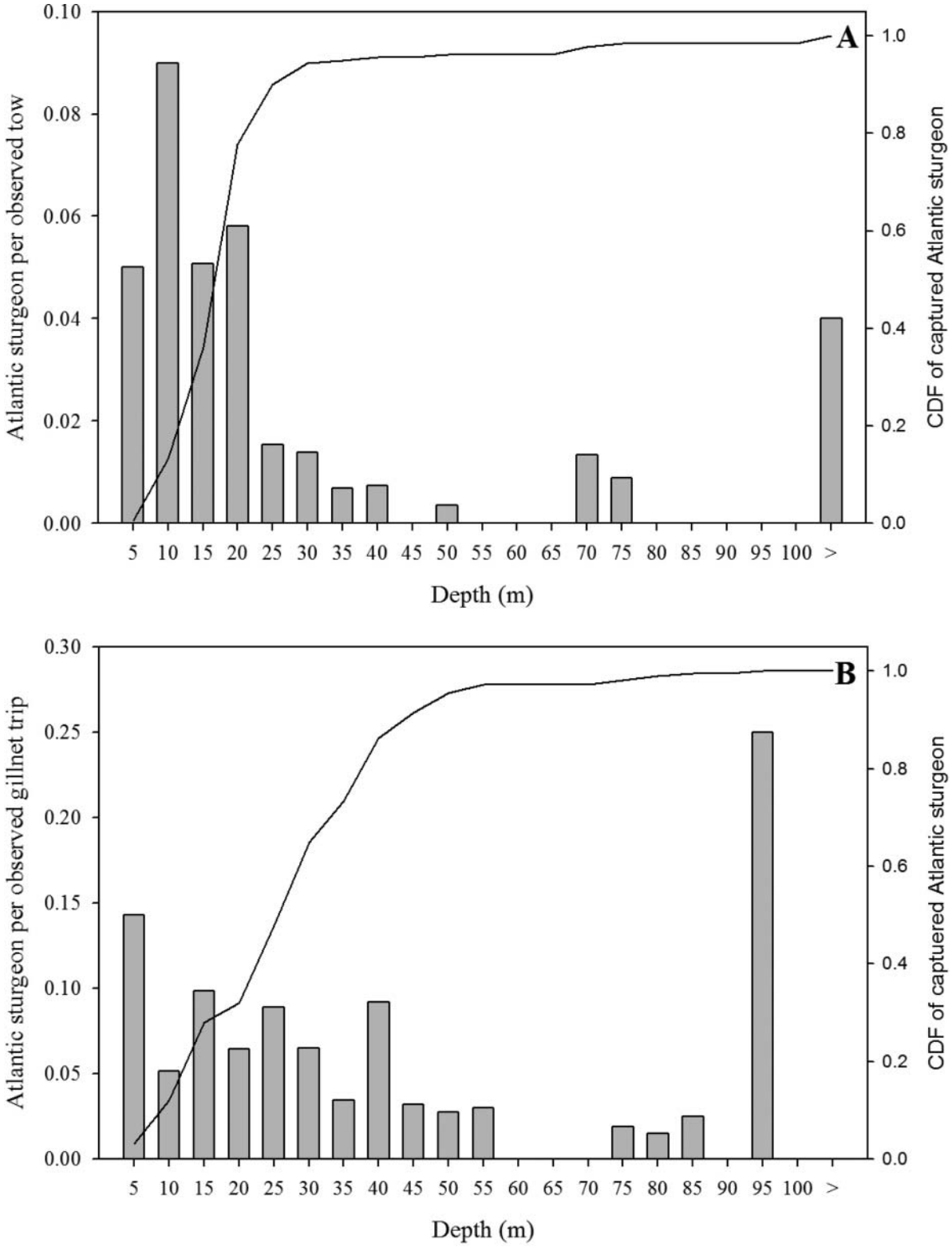


FIGURE 8. Observed Atlantic Sturgeon bycatch (gray bars; primary *y*-axis) and cumulative distribution function (CDF; black line; secondary *y*-axis) of captured Atlantic Sturgeon within commercial fisheries by depth for **(A)** bottom otter trawls (fish and twin) and **(B)** gill nets (all types combined).

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TABLE 4. Regional spatial restrictions for bottom trawling.

State	Bottom trawl limits	Regulatory code
Massachusetts	Spatial and temporal trawl closure areas to protect spawning fish	Code of Massachusetts Regulations, Title 322, section 8.09
New Hampshire	Complete ban on trawls in state waters	New Hampshire Revised Statutes Annotated, section 211.49
New Jersey	No trawling within 3.22 km of coast (limited exception for shrimp trawls)	New Jersey Administrative Code, Title 7:25, section 18.14(b)
New York	2.41–3.22-km arc seaward of inlets with Atlantic Ocean; various spatial restrictions within Atlantic Ocean, Long Island Sound, and inland bays	New York Environmental Law, section 13-0341
Delaware	Bottom trawling prohibited in state waters, except for scientific purposes	Delaware Code Annotated, Title 7, section 927
Maryland	Bottom trawling prohibited within 1.61 km of coastal shore or in Chesapeake Bay or bays behind the Atlantic barrier islands	Code of Maryland Regulations, Title 08.02, section 05.03

trawl zones similar to those of neighboring states to protect important Atlantic Sturgeon aggregation areas (Table 4) or employ less restrictive spatial and temporal closures to protect migrating fish (Dunton et al. 2010). Bycatch of Atlantic Sturgeon continues to be a chronic source of mortality, and the fact that impacts may not be evenly distributed across distinct population segments (Stein et al. 2004a; Dunton et al. 2012) supports the need for ongoing research. Regardless, protecting aggregation areas is vital. Since they may contain a large proportion of the population(s) during the spring and fall, sufficient levels of bycatch during those periods may impede recovery (ASSRT 2007; Jaric and Gessner 2013).

The ultimate goal of Atlantic Sturgeon management is to rebuild the population to a level that can sustain harvest (ASMFC 1998). In order to do so, threats to recovery, such as incidental take in fisheries, must be considered and addressed. Our results provide information that can be used for understanding the future impacts of bycatch as well as the potential targeted harvest of Atlantic Sturgeon. If a future fishery targeted Atlantic Sturgeon aggregations, high catch rates could be maintained in the short term, even though declines within the aggregation area would likely go undetected (Frisk et al. 2011). Metrics derived from commercial fisheries would need to be used with great caution out of concerns about hyperstability in stock estimates (Erisman et al. 2011; Jaric and Gessner 2013). Potential impacts can come from dredging, sand mining, pipeline construction, and wind farm development, as well as from commercial fishing. The improved coordination of research and planning among state agencies is required to develop integrated policies for managing all impacts to this endangered fish. Determining marine habitat use throughout the species range will be essential for effective management. In addition to protection in the Hudson River, concentrations of Atlantic Sturgeon, combined with the high incidence of bycatch during the spring and fall off western Long Island, indicate the need for spatial and temporal marine fisheries closures to reduce bycatch and allow population recovery. Because several distinct and endangered population segments are inadvertently caught in the NYB (Dunton et al. 2012), protecting aggregation areas off Long Island will impact the recovery of significant segments of the Atlantic Sturgeon population.

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