Population dynamics of juvenile Atlantic Sturgeon, *Acipenser oxyrinchus oxyrinchus,* within the Northwest Atlantic Ocean

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Abstract of the Dissertation

Population dynamics of juvenile Atlantic Sturgeon, *Acipenser oxyrinchus oxyrinchus,* within the Northwest Atlantic Ocean

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The Atlantic sturgeon, *Acipenser oxyrinchus*, an anadromous long-lived fish has experienced substantial population declines leading to its recent listing under the Endangered Species Act. While this fish occupies and requires both riverine and marine habitats, a lack of knowledge regarding marine distribution/habitat use is hindering conservation measures directed at restoring depleted populations. Currently, concerns exist that Atlantic sturgeon populations are being hindered by incidental captures along their migrations routes within the near shore coastal fisheries. In order to best manage human activities in a way that populations may recover fully, it is necessary to understand the association between Atlantic sturgeon and their marine habitat. To address this data gap, I analyzed fishery independent bottom trawl data and classified marine habitat preference for shallow migratory pathways as well as identified large coastal aggregation areas. Using genetic and non-lethal aging techniques I was able to evaluate the population demographics of these coastal aggregations to determine they largely consist of immature juveniles belonging to the Hudson River population. Furthermore, to better understand the temporal and spatial patterns of their movements and aggregations, I acoustically tagged a large number of animals (n=429) and established a large telemetry array within the New York Bight. Results indicate repeated and consistent yearly spatial and temporal movements and habitat use. Through acoustic telemetry data, I was able to evaluate management alternatives by estimating population proportions that can be protected under a number of spatial and temporal closure scenarios. Protection under the most conservative and restrictive scenarios indicates substantial closure windows would be required to protect sturgeon migrating through this area. This study provides a substantial increase in our knowledge of Atlantic sturgeon in the marine habitat and has delineated the aggregatory behavior, population structure, habitat use, and fine scale marine migrations of this species, which have been previously unknown, and should provide management agencies with necessary data to inform decisions to increase conservation efforts for this protected species.

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List of Abbreviations

CTDEEP – Connecticut Department of Energy and Environmental Protection

DPS – Distinct Population Segment

gDNA – genomic DNA

gMSA – Genetic mixed stock analysis

LIS – Long Island Sound

MAB – Mid-Atlantic Bight

mtDNA – mitochondrial DNA

NYDEC – New York Department of Environmental Conservation

NJDEP – New Jersey Department of Environmental Protection

NOAA – National Oceanic and Atmospheric Administration

NYB – New York Bight

ROM – Rate of movement

VBGF – von Bertalanffy growth function

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Publications

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Introduction

Diadromous fish species have suffered major declines in abundance during the past century through a variety of factors such as overfishing, ecosystem degradation and habitat fragmentation (Hall et al., 2010). One challenge of managing anadromous fish is that they face threats during both the freshwater and marine stages of their life cycle. Although river-based threats primarily affect a single spawning stock due to natal homing, localized marine threats have the potential to affect many stocks due to mixing during the oceanic phase of their life-cycle (Crozier et al., 2004). For many species, recovery and conservation efforts are often hindered by gaps in the knowledge of critical life stages occurring in both marine and freshwater habitats. In particular, the anadromous Atlantic sturgeon, *Acipenser oxyrinchus* that occurs along the eastern seaboard of the United States is in critical need of conservation (Gross et. al., 2002) due to previous unsuccessful recovery efforts. During the past century, Atlantic sturgeon have experienced a severe population decline with the majority of stocks extirpated (Van Eenennaam et al., 1996; Waldman et al., 1996a; Bain, 1997; Savoy and Pacileo, 2003; Secor, 2002). Despite this decline the Hudson River maintains one of largest populations of Atlantic sturgeon in the U.S. and is in need of conservation for survival of the species.

The primary cause of Atlantic sturgeon's decline was a commercial fishery that occurred approximately from 1870-1920 (Smith and Clugston, 1997) with peak harvest occurring in 1890 (ASMFC, 1998). By 1901, Atlantic sturgeon fisheries collapsed along the east coast (Secor, 2002). The species ease of capture during aggregation periods supported a brief fishery in the 1990's based primarily on the depleted Hudson River population (Waldman et al., 1996; Bain et al., 2000). In 1998, a 40 year moratorium was implemented in an effort to allow the stock to recover (ASSRT, 2007). Atlantic sturgeon were also placed on the National Marine Fisheries

Service's (NMFS) species of concern list in 1998 and the National Oceanic and Atmospheric Administration (NOAA) listed 5 distinct population segments as threatened (Gulf of Maine) or endangered (New York Bight, Chesapeake Bay, Carolina, South Atlantic) under the United States Endangered Species Act in 2013 ((77 FR 5880, 77 FR5914).

The Atlantic sturgeon population located in the Hudson River continues to decline at alarming rates (ASSRT, 2007). This has occurred despite stable or slightly improved juvenile abundance within the river (Kahnle et al., 2007). One contributing factor to declining Atlantic sturgeon populations is the incidental capture of immature juveniles in non-target marine fisheries (Stein et al., 2004a; Collins et al., 1996). Previously, there was an estimated observed bycatch of 1,500 fish per year in the marine environment based on fishery dependent data (Stein et al., 2004a). This occurs primarily in gill and drift net fisheries in which direct mortality occurs (Stein et al., 2004). While there have been few observed direct mortalities associated with trawling (Stein et al., 2004a; ASMFC, 2007), sturgeon may die days or weeks later due to related stress and injuries from capture (Stein et al., 2004a) making discard mortality rates from trawl fisheries difficult to estimate. While these deaths are not recorded, evidence of this can be frequently found as sturgeon carcasses commonly wash up on beaches in NY (K. Dunton, unpublished). Recent estimates of Atlantic sturgeon bycatch in trawl fisheries range from 2,000-7,000 fish per year (ASMFC, 2007) with mortality likely ranging from 0.02-0.176 (ASMFC, 2007). Because of their life history characteristics (long-lived, late maturing, non-annual spawning), Atlantic sturgeon populations can only withstand very low levels of anthropogenic mortality (ASSRT, 2007). ASSRT (2007) concluded that, while there was considerable uncertainty in estimates of mortality from fisheries, the current level of bycatch is likely hindering recovery of the Hudson River population and depressing smaller sturgeon populations elsewhere.

Although Atlantic sturgeon spend most of their lives within saltwater, there is an overall lack of information regarding their oceanic habitat use and its importance for conservation of the species. Here I postulate the recovery of Atlantic sturgeon is dependent on linking current science and management to develop protective measures for marine migrant juveniles. This requires estimation of temporal and spatial behavior and the ecological drivers associated with habitat selection during the juvenile stage of Atlantic sturgeon. The proposed research will address gaps in the understanding of the species demographics, population vital rates and habitat selection providing an ecological foundation for conservation measures.

Firstly, I identified local patterns in Atlantic sturgeon marine habitat use off the south shore of Long Island through analyses of random-stratified as well as targeted trawling surveys. I then expand on this work to describe their abundance, distribution, and habitat preferences within the Northwest Atlantic Ocean by analyzing 5 fishery independent trawl surveys. Secondly, I assessed the population structure through genetic analysis to estimate the proportion of individuals from the 5 DPS units that were captured in NY waters. Thirdly, the age structure and growth rate of the species was estimated by analysis of fin spines.   Fourthly, I analyzed habitat use and movement patterns of aggregations in the Mid-Atlantic Bight utilizing acoustic telemetry. Fifthly, I combined results from surveys, genetics, age and growth estimates and acoustic telemetry to both evaluate the current status of Atlantic sturgeon 15 years after a moratorium was enacted and I proposed temporal and spatial closures to extend protection of the species to the marine environment.

Chapter 1

Marine distribution and habitat-use of Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) in the New York Bight leads to fisheries interactions and bycatch.

Abstract

New York marine waters supported a lucrative Atlantic sturgeon fishery at the turn of the 20th century and again in the 1990s. Population declines lead to fisheries closures in 1996 and listing of the New York Bight Distinct Population Segment as endangered in 2012. Despite population declines, aggregations of Atlantic sturgeon can still be found along the nearshore of Long Island. Overlap with commercial fishing activities in either aggregation areas or along migration routes may lead to incidental take in non-directed fisheries. To determine impacts and mitigation measures for bycatch, management agencies need information on the distribution and movement of Atlantic sturgeon in relation to the behavior of fisheries. Random stratified and targeted bottom trawl surveys were used to identify temporal and spatial use of the marine habitat in New York waters. The majority of survey captures were restricted to depths less than 15 m and occupied known aggregation areas. During the aggregation periods (May, June, September and October), and in known aggregation areas, catches were an order of magnitude higher compared to other areas and months of the year. In order to determine the fishery sources of bycatch the Northeast Fisheries Observer Program catch data was analyzed for statistical areas 611, 612, and 613 from 1989-2013. Observer data suggested trawling bycatch is concentrated in the summer flounder fishery within aggregation areas and focused on juveniles, while gillnets targeted older fish during migrations. Bycatch in these fisheries may be a regional threat to the recovery and spatial/temporal closures, gear modifications or other bycatch reduction techniques are suggested to protect aggregating and migrating fish.

Introduction

Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) have a long history of commercial exploitation, which combined with other factors, has led to a century of population decline and the recent endangered listing of the New York Bight population (Federal Register 2012). Initially, near-shore gillnet fisheries targeted adults for caviar/flesh and juveniles for flesh (Smith and Clugston 1997) along the south shore of Long Island, NY from Bluepoint to Montauk Point around 1896 (Murawski and Pacheo 1977). The NY fishery experienced peak landings of 231,000 kg in 1898 but then declined to 30,000 kg in 1901 (Murawski and Pacheo 1977). This "boom and bust" pattern in fisheries landings was also experienced by other Atlantic sturgeon populations as local fishery collapses propagated throughout the eastern United States (Smith and Clugston 1997). In the mid-1970s a resurgent Atlantic sturgeon fishery occurred with southeastern stocks initially representing 80% of total landings through the early 1980s (Smith and Clugston 1997). A shift occurred from the late 1980s until the closure of the fishery in 1996 with the fishery focused primarily within the New York Bight with the states of NY and NJ accounting for 93% of landings (Smith and Clugston 1997; Kahnle et al. 2007). Fishing mortality from 1977-1995 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 National Oceanic and Atmospheric Administration (NOAA) Endangered Species Act action 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).

The improvement of pre-migrant Hudson River juvenile abundance since the mid 90's has not been followed by an increase of the spawning population and, conversely, marine-based surveys have indicated declining numbers (Kahnle et al. 2007). The low numbers of mature adults has led to concern by the Atlantic States Marine Fisheries Commission that Atlantic sturgeon recovery is being hindered by losses during marine migrations (ASMFC 2007). Because Atlantic sturgeon are long-lived, late maturing, and intermittent spawners, their life history means that even limited mortality could hinder recovery through the loss of reproductive potential (Boreman 1997). Atlantic sturgeon have been shown to be particularly vulnerable to incidental bycatch in many fisheries along the coast and this adds a chronic source of mortality (Stein et al. 2004a). At current population levels, Atlantic sturgeon populations can only sustain very low levels of mortality (<4%) and it is possible incidental bycatch is hindering the Hudson River population (ASMFC 2007).

Understanding habitat use in the marine environment, where the majority of Atlantic sturgeon's life cycle is spent, will be required for development of effective habitat-related ESA rules or area-based management solutions (Nemeth 2005). Although work on the freshwater component of Atlantic sturgeon migrations has identified habitat-use in many river systems; information from the marine environment is lacking. Fisheries-dependent (Stein et al., 2004a, 2004b) and independent (Laney et al. 2007; Dunton et al. 2010; Erickson et al. 2011) data indicate that most Atlantic sturgeon inhabit shallow inshore areas of the continental shelf with the caveat that extent and timing of sampling plays a critical role in interpretation of observed Atlantic sturgeon distributions (Dunton et al. 2010). Still, marine aggregation areas used by Atlantic sturgeon have been identified, including locations off the New York Coast (Stein et al. 2004a, 2004b; Dunton et al. 2010; Erickson et al. 2011). Along the coast of Long Island, New

York, fisheries and other anthropogenic stressors commonly occur in Atlantic sturgeon aggregation locations and migration pathways potentially causing increased risk of additional mortality.

Anecdotal information reported to the New York Department of Environmental Conservation indicate Atlantic sturgeon experience bycatch in commercial trawl and gillnet fisheries along the coast of Long Island, NY (Kim McKown unpublished data). The Northeast Fisheries Observer Program (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 this data including annual variability in coverage levels and coverage is relatively low (Warden and Orphanides 2008). However, the observer program provides information on the occurrence of Atlantic sturgeon captured in various fisheries and represents the best available information for identifying the fisheries and time and areas where bycatch is occurring (Karp et al. 2011).

The objective of this study is to describe Atlantic sturgeon habitat use off the coast of Long Island, New York, and potential for fisheries interactions and bycatch mortality. Specifically, we provide spatial distribution and abundance estimates from a 3-year trawl survey conducted in near shore waters of New York and commercial bycatch and fishery interactions are examined using data collected by the NEFOP. Additionally, we report results of targeted trawling of aggregation areas to measure the potential impacts of harvesting in habitat commonly occupied by the species.

Methods

Random sampling was conducted with the R/V Seawolf along the southern coast of Long Island, NY from 2005-2008 within water depths of 8-30 meters. Sampling was conducted utilizing a depth-stratified random design based on 10 m depth intervals, using inshore strata and depth zones designed for the Northeast Fisheries Center inshore trawl survey initiated in August 1972 (Sosebee and Cadrin 2006). Stratum 1, 2, 12, 13, and 14 were truncated to sample in NY waters only (Figure 1.1). Cruises consisted of two different surveys, the New York young-of-the-year bluefish survey and the New York Ocean trawl survey for Atlantic Sturgeon and occurred 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 tapering down to 8 cm stretched mesh lined with a 6.0 mm mesh codend. Surveys encompassed the waters inshore of 30 m from the eastern most point of Long Island to the entrance of N.Y. Harbor. Tows were standardized using a 20 min duration and a tow speed of 3-3.5 knots. Not all depth stratum were sampled each trip.

In addition to random stratified sampling, directed research tows specifically targeting Atlantic sturgeon occurred opportunistically in April, May, June, and May, October, November and December in 2007-2013 largely within strata 12 and 13, where abundance appeared to be higher, using the same vessel and gear. Tow duration was not standardized and was dependent on the number of Atlantic sturgeon within the area in order to be in compliance with Endangered Species Permit #16422 issued to Stony Brook University and of short duration, typically ranging from 5-15 minutes.

All Atlantic sturgeon captured were measured to the nearest cm (fork and total length), weighed (kg) using a platform scale, and examined for prior tags. If no tags were detected, sturgeon were tagged with two types of tags; an external United States Fish and Wildlife Service (USFWS) Carlin or dart tag and a internally implanted 125 or 134.2 kHz passive integrated transponder (PIT) tag. External tags, supplied by USFWS, had reporting information printed directly on the tag and were mainly used to enable fisherman and general public to report information on encountered sturgeon while internally implanted PIT tags, are long term tags utilized by the scientific community and required specialized equipment to detect unique individuals. All Atlantic sturgeon captured post April 2012 were collected under National Marine Fisheries Endangered Species Permit #16422 issued to Stony Brook University.

Spatial distribution of catch

Atlantic sturgeon captures will be mapped using ESRI® ArcGIS™ v.9.2 (ESRI; Redlands, CA). Map base layers were obtained from the United States Geological Survey Coastal and Marine Geology Program GIS catalogue. Atlantic sturgeon captures were plotted using graduated symbols in the following categories: 1, 2, 3-4, 5-10, 11-14, and >15 Atlantic sturgeon per tow.

Catch per unit effort

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

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

Where W_h = the proportion of the survey 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

y_{st} = the stratified mean abundance

Target sampling CPUE was not weighted due to the non-stratified design. CPUE estimates were compared using 95% confidence intervals for random vs. targeted, Western Long Island vs. Central-East Long Island, and peak vs. nonpeak periods, using bootstrap resampling (n = 10,000). Confidence intervals were bias-corrected using methods described by Efron (1987).

Fishery interactions

Patterns in fishery interactions and regional bycatch of Atlantic sturgeon within the Atlantic Ocean off of Long Island NY were examined using two methods: 1) Atlantic sturgeon tagged in this study and reported as bycatch using the external USFWS dart/carlin tags; and 2) examining data collected by the Northeast Fisheries Observer Program (NEFOP) from 1989-2013. During this time period, only vessels with State and Federal permits could have had observer coverage, and there was no observer coverage recorded for vessels that held only state permits. NEFOP data for catch and total length was examined for all gear types for vessels originating from NY and NJ ports for the Northwest Atlantic Fisheries Organization's statistical areas 611, 612, and 613. Statistical area 611 included trips confined to the 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 gillnet and trawl fisheries.

Results

Random stratified survey

A total of 149 Atlantic sturgeon were captured in 10,380 minutes of random stratified trawling (n=519 tows) (Table 1.1). Atlantic sturgeon distributions varied by strata monthly throughout the season (Figure 1.2; Table 1.1). The weighted survey average CPUE was 0.023 fish/minute ± 0.159 s.d. with the highest average weighted CPUE in May (0.058 fish/minute ± 0.407 s.d.) followed by October (0.034 fish/minute ± 0.085 s.d.), November (0.030 fish/minute ± 0.127 s.d.), September (0.0020 fish/minute ± 0.085 s.d.), and June (0.016 fish/minute ± 0.004 s.d.) (Table 1.1). Lowest weighted CPUE's were observed in January (0.008 fish/minute ± 0.03 s.d.), March (0.009 fish/minute ± 0.031 s.d.) followed by and August (0.015 fish/minute ± 0.083 s.d.) (Table 1.1). No fish were captured in April. December, February and, July were the only months not sampled. Inter-annual variation in monthly CPUE also occurred (Table 1.1). CPUE was highest in Western Long Island; stratum 12 (0.101 fish/minute ± 0.426 s.d.), followed by stratum 9 (0.059 fish/minute ± 0.130 s.d.) and 10 (0.040 fish/minute ± 0.151 s.d.) (Table 1.1; Figure 1.2). Few sturgeon were captured off Eastern Long Island (8%) and no sturgeon were cap captured in 10-20m depth strata (1 and 4) or any of the 20-30 m depth strata (2, 5, 8, 11 and 14) (Table 1.1; Figure 1.2).

Targeted survey

Targeting trawling occurred along western Long Island during spring and fall capturing an additional 825 sturgeon in 4,144 minutes (n=312 bottom trawls) for a mean CPUE of 0.226 fish/minute ± 0.470 s.d. (Table 1.2). The highest CPUE was observed during May 2011 where

82 fish were captured in 61 minutes of trawling for average trip CPUE of 1.533 fish/minute ± 1.301 s.d. and May 2007 where 141 sturgeon were captured in 164 minutes (n=8 trawls) for a trip CPUE of 0.848 fish/minute ± 0.493 s.d. (Table 1.2). The highest observed individual tow CPUE's was 3.8 fish per minute (May 2011) and 3.25 fish per minute (May 2012). Two targeted trawling trips yielded no sturgeon captured (December 2010, October 2012).

Bootstrap values

Bootstrap analysis was conducted for random vs. targeted, Western Long Island vs. Central-East Long Island and specific time periods (Peak: May, June, September and October vs. Nonpeak: November, January, March and April) (Figure 1.3; Table 1.3). Targeted trawling values were an order of magnitude higher than the weighted CPUE of random trawling with a bootstrap mean CPUE of 0.226 fish/minute ± 0.027 s.d. vs. 0.0227 fish/minute ± 0.0068 s.d. for random trawling. Significantly higher catches were found to occur in Western Long Island 0.048 ± 0.016 s.d, during peak months (Figure 1.3; Table 1.3).

Biological and tag release, capture, and recapture

A combined total of 974 Atlantic sturgeon were tagged through random and targeted efforts. Sturgeon ranged in size from 64 – 195 cm fork length with a mean of 101 ± 19.8 s.d. cm fork length (Figure 1.4). A total of 40 Atlantic sturgeon were recaptured and reported by various user groups in different locations (Table 1.4; Table 1.5). A total of 18 fish were re-captured during random and targeted sampling during our surveys (Atlantic Ocean), 1 within various scientific surveys in Virginia (James River), 3 by CTDEEP (1 within Long Island Sound, 2 within the CT River), 2 in the Atlantic Ocean (DSU and NEAMAP) 1 within the North Carolina Striped Bass Winter Cruise (Atlantic Ocean), and 1 in the Hudson River (Table 1.4).

Days at large ranged from 0.3 - 929 days while estimated distances from original tagging locations for these fish ranged from 1-542 km (Table 1.4).

Fishery interactions

Tagging data

Of the 40 fish tagged and recaptured, 10 were reported by commercial trawl fisheries; 2 in commercial gillnet fisheries and 1 fish in recreational non target hook-and-line fisheries (Figure 1.5; Table 1.5). Trawl fisheries targeting flounder (*Pseudopleuronectes americanus* or *Paralichthys dentatus*) accounted for 50% (n = 6) of the commercial recaptures, with the other reported recaptures occurring in trawl fisheries targeting horseshoe crab (*Limulus polyphemus*), (n=1), lingcod/squid (*Urophycis chuss/Doryteuthis pealeii*) (n=1); and skate spp. (genus *Leucoraja*) (n=2) and gillnet fisheries targeting monkfish (*Lophius americanus*) (n=1) and dogfish spp. (genus *Squalus* or *Mustelus*) (n=1) (Table 1.5). For commercial recaptures, estimated distance from original tagging sites ranged from 1-293 km while days at large for these fish ranged from 26-245 (Figure 1.5; Table 1.5). Commercial recaptures of Atlantic sturgeon tagged in NY were largely concentrated in 2 regions; off of Highlands, NJ and Jones Beach, NY (Figure 1.5).

Observer data

Northeast Fisheries Observer Program (NEFOP) observed trips demonstrated that captures in gillnets occurred more frequently off the coast of NJ while captures during bottom trawling were more frequent off the coast of NY (Figure 1.6). Within statistical areas 611, 612, and 613 there were 24,674 observed trips for all gear types and a total of 413 sturgeon were observed as bycatch off the south shore of Long Island from 1989 – 2013 (Table 1.6; Figure 1.6). Bycatch occurred in the fixed/anchor sink gillnet (n = 200; CPUE = 0.04 fish per observed trip), otter bottom trawl twin/fish (n = 182; CPUE = 0.03 fish per observed trip), drift-sink gillnet (n = 19; CPUE = 0.02 fish per observed trip), drift-floating gillnet (n = 6; CPUE < 0.01 fish per observed trip), and twin otter bottom trawl (n = 6; CPUE = 0.50 fish per observed trip)(Table 1.6; Figure 1.6). Sturgeon were not observed in anchored floating gillnets (n = 4), hydraulic clam dredges (n = 988), sea scallop dredges (n = 11,363), bottom longlines (n = 2), fish trap/pot (n = 15), lobster pots/traps (n = 28), scallop bottom trawls (n = 651), midwater otter trawls (n = 20), midwater paired otter trawls (n = 21), and troll lines (n = 6). Size distributions of sturgeon captured within gillnets (128 cm fl ± 28.47 s.d.) were significantly larger than otter trawls (120 cm fl ± 36.044 s.d.) (ANOVA p = 0.012) (Figure 1.7). Of the 413 observed sturgeon bycatch events in the NYB, direct mortality was highest in gillnets with 58.22% captured sturgeon released alive, 38.22% dead within gear and 3.56% with unknown status while trawls observed 94.15% released alive, 3.72% dead within gear and 2.13% having unknown status.

The distribution of otter bottom trawls were coast-wide but largely concentrated within the state limits of NY (Figure 1.6). Fisheries provided observers on trips targeting 30 different types of species, but Atlantic sturgeon were captured in only 13 of these. The summer flounder (*Paralichthys dentatus*) fishery represented 73 percent of total sturgeon bycatch within trawls (Figure 1.8). Bycatch was heavily concentrated along western Long Island. Much of the bycatch appeared to be a result of the high effort in the summer flounder fishery by vessels landing catch in NJ (Figure 1.6). Atlantic sturgeon captures varied seasonally; with peak catches in April (0.07 fish/observed tow), May (0.04 fish/observed tow), June (0.04 fish/observed tow), and September (0.04 fish/observed tow). Low bycatch was observed in February (0.01 fish/observed tow), July (0.02 fish/observed tow), October (0.01 fish/observed tow) and November (0.01 fish/observed tow). No bycatch was observed in January, March, August, and December. Bycatch within trawls was also depth dependent with 90% of all sturgeon captured in water of less than 20m in depth (Figure 1.9).

Distribution of gill nets largely occurred off the coast of NJ in area 612 (Figure 1.6). Gillnet fisheries occurring off of Long Island were focused within three regions; Jones Beach, Shinnecock Bay, and Montauk, NY. No gillnets were observed in western Long Island. Highest observed sturgeon captures were November, April, December, and May (0.11, 0.09, 0.08 and 0.071 fish per observed set) with intermediate catches observed in June, August, and October (0.04, 0.04, 0.03 fish per observed set). Lowest observed bycatch occurred in January, February, March, July (0.02, 0.01, 0.02, 0.01 fish per observed set).   Bycatch of Atlantic sturgeon was observed to occur in all 9 target species categories with 62% occurring in the Monkfish fishery largely in federal waters of area 612 (Figure 1.8). No trends in sturgeon captures by depth (Figure 1.9).

Discussion

Shallow marine distributions during migrations and the formation of aggregations are placing Atlantic sturgeon at risk of bycatch in New York Bight trawl and gillnet fisheries. Research survey and commercial fishery observer data suggest that interactions between Atlantic sturgeon and fisheries are most likely to occur between April to June and October to November, as fish make seasonal migrations to northern summer and southern winter habitat, respectively. Gillnets appear to intercept primarily migrating adults, while trawls encounter juveniles during aggregation behavior around the mouth of the Hudson River. While the behavior and distribution of these fish currently puts them at risk for interactions with fisheries the nature of these factors also presents an opportunity for managers. Because the seasonal aggregations and migratory behavior appear to be predictable and depth limited during migrations, fisheries interactions may be mitigated through gear changes (Glass 2000) or spatial management (Armstrong et al. 2013; Dunton 2014).

Targeted and random fishery independent bottom trawling provides evidence that Atlantic sturgeon aggregate in large numbers both in federal and non-federal waters outside of the Hudson River in NY. This area is identified as one of the aggregation areas along the Eastern US Coast for both sub-adults (Dunton et al. 2010) and adults (Erickson et al. 2011). These fishery independent surveys suggest Atlantic sturgeon aggregations were restricted to shallow depths (Strata 12, 9, 6, 3) in New York waters following a seasonal pattern with peak abundance during June and October. Dunton et al. (2010) also found that sub-adult Atlantic sturgeon had a significant habitat preference for shallow depths (<20 m) within this region. The aggregation area located in the Rockaway region accounted for the majority of all sturgeon captured and when this area was targeted CPUE's reached a maximum of 61 times the average of random surveys. Large capture events generally occurred within the aggregation area with the largest tows capturing 3.2-3.8 sturgeon per minute.

These findings were corroborated by the Northeast Fisheries Observer Program (NEFOP), for trawl fisheries, and bycatch reported in Stein *et al.* (2004). The Rockaway aggregation area experienced the highest bycatch rate from otter trawling during months of peak sturgeon abundance. This bycatch along western Long Island was primarily the result of the summer flounder fishery (73%) operating out of New Jersey. During the period of our research (2005-2013) 83% of our tag returns reported by commercial fishermen came from otter trawling with all but one occurring in the NYB. Coast-wide estimates of all recaptured tagged Atlantic sturgeon (USFWS Atlantic sturgeon database) ranged between 8% - 14% for trawl fisheries, while sturgeon recaptures occurring in the NJ-NY coastal sub-region increase to 30% (S. Eyler[1] pers. comm.; Eyler et al. 2009). Trawling appears to represent a bigger threat to Atlantic sturgeon recovery within the NYB region than any other location.

Catches along the central Long Island coast occurred during the summer months while catches occurred off of western Long Island in June, October and November. Comparatively, few Atlantic sturgeon were captured on the east end of Long Island. While we found no evidence of aggregations of Atlantic sturgeon on the east end of Long Island that does not indicate a low risk for incidental take to occur as this region is an active commercial fishing area. Coast-wide, bycatch of Atlantic sturgeon occurs in a wide range of fisheries with the largest bycatch reported for gillnet (sink and drift) fisheries (Stein et al. 2004a; ASMFC 2007; Eyler et al. 2009). Sub-adults 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 gillnet and trawl fisheries. It is generally thought that trawl-related mortality is lower than gillnet fisheries; however, both are potentially significant sources of mortality. Trawling through aggregation areas during Atlantic sturgeon presence or gillnets set within the narrow migration corridor along the shoreline in depths <15 m during Atlantic sturgeon migrations could result in large bycatch and subsequent mortality. In response to high Atlantic sturgeon mortality associated with gillnets in the Monkfish fishery, industry have been experimenting with gear modifications and current evidence is building that these experimental nets can decrease Atlantic sturgeon bycatch, while limiting the impact on the catch of targeted species (Fox et al. 2013; Pingguo and Jones 2013). However, similar modifications to trawling

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[1] U.S. Fish & Wildlife Service, Maryland Fishery Resources Office, 177 Admiral Cochrane Dr., Annapolis, MD 21401

gear have not been developed and/or widely tested. The mortality rate for Atlantic sturgeon captured in commercial trawling is unknown; however, direct observations of dead 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. Dunton unpublished data; Tony Lomschumbo[2], Resource Management Dept. Breezy Point, Gateway National Recreation Area, personal commun. 2008).

Current estimates of Atlantic sturgeon bycatch in trawl fisheries range from 2,000-7,000 fish per year (ASMFC, 2007) with the highest likelihood that mortality ranges between 0.02-0.176 (ASMFC, 2007). Even though bycatch resulting in death is believed to be lower in gillnets compared to trawls, the potential for large catches in aggregation areas may lead to a significant impact on population mortality rates. An accurate estimate of total mortality of Atlantic sturgeon due to bycatch is not possible at this time, particularly due to an unknown post-release survival (Stein et al. 2004). Relatively few direct mortalities are observed from fish captured by otter trawl, with 94% of otter trawl captures observed by NEFOP being released alive. However, delayed effects of stress and injuries may occur weeks after initial capture (Davis 2002; Broahurst 2006). Beardsall et al. (2013) suggest that although sturgeon face physiological stress from capture in trawl gear, the minimum survival rates may be as high as 94% based on experimental trawls lasting 60 min and conducted in the Minas Basin, Canada. This estimate of survival confers with the NEFOP's observation of sturgeon being released alive. Still, multiple captures over the 7+ year juvenile marine stage, and then as adults in gillnet fisheries increases the likelihood of mortality associated with fisheries interactions.

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[2] Resource Management Department, Gateway National Recreation Area, 210 New York Avenue Staten Island, New York 10305

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). With average commercial tows in the NY region lasting between 60-180 minutes the potential of Atlantic sturgeon bycatch, and hence mortality, may be high if fisheries encounter a Atlantic sturgeon aggregation. The total number of Atlantic sturgeon captured in NEFOP observed tows was typically 1-4 animals although bycatch events as high as 60 individuals per tow have been reported to the USFWS (Table 1.5). A large catch of Atlantic sturgeon may increase mortality due to increases in handling time and injuries during capture. Even a 6% mortality rate would have a negative impact on recovering populations, as it is suggested that Atlantic sturgeon can sustain very low, <4%, rates of anthropogenic mortality (ASMFC 2007). A more in depth study of fishers handling practices once Atlantic sturgeon are on deck as well as interactions with catch size may be warranted to understand bycatch mortality and develop best-practices during fishing operations to increase survival rates.

The vulnerability of sturgeon aggregations to high levels of bycatch suggests that understanding causes of sturgeon movements could provide methods to predict location and timing of habitat-use needed for mitigation efforts. Unfortunately, the reasons why sturgeon aggregate are poorly understood and potential reasons have ranged from enhanced foraging areas to refuge locations for marine migrant sturgeon (Stein et al. 2004b). Some observed aggregations occurred during high abundance periods of the benthic polychaete, *Asabellides oculata,* and gammarid spp. *amphipods* (Dunton, Pers. obs.), which could serve as a vital food source for developing and migrating sturgeon. Genetic mixed-stock analysis has confirmed multiple populations or DPS’s are present in New York Bight aggregations (Dunton et al. 2012), although southern populations appear to be older (Dunton et al. Chapter 4). Sturgeon within this region are presumed to be transiting between over-summering habitat in Long Island Sound (Bain et al. 2000; Waldman et al. 2013) and winter habitat in the New York Bight and North Carolina to Virginia (Dunton et al. 2010; Laney et al. 2007). Conventional tag recaptures indicated repeat use of this area. The high potential for sturgeon bycatch in trawling fisheries in the waters off of Long Island emphasizes the need to development bycatch reduction measures. The majority of states in the region already offer Atlantic sturgeon de facto protection of bycatch by limiting or excluding trawling in state waters (Dunton et al. 2010); however, NY limits trawling only within 1.5 mile arc of coastline around navigable inlets. Aggregation areas within the New York Bight, have been recommended as closed areas and essential marine habitat for sub-adults to mitigate fisheries impacts (Dunton et al. 2010). Given the nature of sturgeon habitat preference and movements it is recommended that NY state adopt similar restricted trawl zones as neighboring states to protect important Atlantic sturgeon aggregation areas (Table 1.7) or move to a less restrictive approach of 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 its impacts may not be evenly distributed across DPS's (Stein et al. 2004; Dunton et al. 2012), thus requiring continued research. Regardless, protection of these aggregation areas is vital since the abundance of sturgeon, relative to the total population size, may be very high for periods of the year.

The ultimate goal of Atlantic sturgeon management is to recover 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 and potential targeted harvest. If a fishery were to target aggregations high catch rates could be maintained in the short term, even though declines in the area occupied by the aggregation would likely go undetected (Frisk et al., 2011), and metrics derived from a commercial fishery would need to be used with great caution out of concerns of hyperstability of stock estimates (Erisman et al. 2001; Jaric and Gessner 2013). Currently, estimates suggest that Atlantic sturgeon cannot sustain even low levels of bycatch (ASSRT 2007; Jaric 2013) and modest fishing effort within aggregation areas would likely result in high levels of bycatch. Improved research coordination amongst State agencies towards development of management policies for activities such as dredging, sand mining, pipeline construction, development of wind farms and commercial fishing to limit interactions with this endangered fish are required. Elucidating marine habitat-use throughout the species range will be a necessary pre-requisite for effective management. In addition to protection in the Hudson River, the high incidence of bycatch and abundance of Atlantic sturgeon during the spring and fall off of western Long Island indicates the need for spatial and temporal closures of marine fisheries to reduce bycatch and allow population recovery. Further, with multiple endangered distinct population segments, occurring and impacted from bycatch in the New York Bight (Dunton et al. 2012), protecting aggregation areas off Long Island will have cascading impacts on other population of the species.

Table 1.1. Catch weighed CPUE (fish per minute) of Atlantic sturgeon by month and strata for random stratified survey; 2005-2007.

Month	**2005**	**2006**	**2007**	**Average**	**Total sturgeon**	**Total Tows**	**Total Minutes**
January		0.005 ± 0.025	0.011 ± 0.046	0.008 ± 0.037	4	59	1180
March		0.009 ± 0.031		0.009 ± 0.031	2	27	540
April		0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0	30	600
May	0.029 ± 0.058	0.003 ± 0.010	0.117 ± 0.594	0.058 ± 0.407	34	64	1280
June	0.021 ± 0.062	0.010 ± 0.030	0.017 ± 0.024	0.016 ± 0.042	37	99	1980
August	0.005 ± 0.024	0.027 ± 0.122		0.015 ± 0.083	5	45	900
September	0.000 ± 0.000	0.056 ± 0.165	0.019 ± 0.049	0.020 ± 0.090	21	81	1620
October		0.034 ± 0.097	0.034 ± 0.070	0.034 ± 0.085	36	54	1080
November	0.016 ± 0.086	0.044 ± 0.157		0.030 ± 0.127	10	60	1200
Average	0.011 ± 0.054	0.022 ± 0.095	0.034 ± 0.252	0.023 ± 0.159	149	519	10380

Stratum	2005	2006	2007	Average	Total sturgeon	Total Tows	Total Minutes
1	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0	31	620
2	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0	20	400
3	0.036 ± 0.096	0.009 ± 0.025	0.002 ± 0.006	0.012 ± 0.048	11	50	1000
4	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0	32	640
5	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0	20	400
6	0.010 ± 0.029	0.003 ± 0.008	0.003 ± 0.007	0.004 ± 0.015	9	72	1440
7	0.007 ± 0.029	0.006 ± 0.026	0.000 ± 0.000	0.005 ± 0.025	2	44	880
8	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0	29	580
9	0.011 ± 0.039	0.118 ± 0.210	0.044 ± 0.070	0.059 ± 0.130	41	53	1060
10	0.000 ± 0.000	0.083 ± 0.211	0.000 ± 0.000	0.040 ± 0.151	6	35	700
11	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0	27	540
12	0.036 ± 0.118	0.048 ± 0.115	0.187 ± 0.657	0.101 ± 0.426	78	60	1200
13	0.000 ± 0.000	0.023 ± 0.053	0.000 ± 0.000	0.011 ± 0.037	2	26	520
14	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0	20	400
Average	0.011 ± 0.054	0.022 ± 0.095	0.034 ± 0.252	0.023 ± 0.159	149	519	10380

Table 1.2. Unweighted CPUE and standard deviation of Atlantic sturgeon in targeted trawls 2006-2013

Year	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	1070
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	4144

Table 1.3. Bootstrap (n=10,000) results for determining differences among catch-per-unit (fish per minute) for random trawling vs. targeted trawling and periods of higher vs. lower abundance and region for the random stratified survey.

Random vs. Target		**Mean**	**±**	**S.D**	**Max**	**Bias corrected 95% C.I.**
	Random	0.023	±	0.007	0.060	0.013 − 0.041
	Target	0.226	±	0.027	0.339	0.178 − 0.281
Random Trawling						
Region	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	May-Jun-Sep-Oct	0.024	±	0.006	0.053	0.028 − 0.011
	Nov-Jan-Mar-Apr	0.005	±	0.002	0.013	0.009 − 0.002

Table 1.4. Capture and recapture information of Atlantic Sturgeon, (*Acipenser oxyrinchus*), tagged in New York and recaptured by state, federal, and academic agencies. Recapture agencies include School of Marine and Atmospheric Sciences (SoMAS), United States Fish and Wildlife Cooperative Tagging Cruise (USFWS CTC), Delaware State University (DSU), Virginia Institute of Marine Sciences (VIMS), Connecticut Department of Energy and Environmental Protection (CTDEEP), North East Area Monitoring and Assessment Program (NEAMAP), and New York Department of Environmental Conservation (NYDEC).

Capture date	**Recapture date**	**Recapture agency**	**Recapture state**	**Recapture waterbody**	**Days at large**	**Distance from tagging location (km)**
11/14/06	05/10/07	SoMAS	NY	Atlantic Ocean	177	5.3
06/06/07	06/07/07	SoMAS	NY	Atlantic Ocean	0.3	24.6
11/14/06	10/16/07	SoMAS	NY	Atlantic Ocean	336	1.5
05/10/07	11/16/07	SoMAS	NY	Atlantic Ocean	190	1.2
05/10/07	11/16/07	SoMAS	NY	Atlantic Ocean	190	3.4
11/16/07	01/16/08	USFWS CTC	NC	Atlantic Ocean	61	529.0
11/02/08	02/17/09	VIMS	VA	James River	107	542.0
05/11/07	08/03/09	CTDEEP	CT	Long Island Sound	815	228.0
11/16/07	09/29/09	CTDEEP	CT	Connecticut River	683	238.0
06/15/10	04/26/11	DSU	DE	Atlantic Ocean	315	248.0
01/19/06	05/09/11	NEAMAP	NJ	Atlantic Ocean	1936	124.8
05/19/10	05/24/11	SoMAS	NY	Atlantic Ocean	370	10.0
11/01/08	05/24/11	SoMAS	NY	Atlantic Ocean	934	6.9
11/01/08	11/08/11	SoMAS	NY	Atlantic Ocean	1102	6.9
10/31/11	11/09/11	SoMAS	NY	Atlantic Ocean	9	2.0
10/31/11	11/09/11	SoMAS	NY	Atlantic Ocean	9	2.4
05/24/11	11/09/11	SoMAS	NY	Atlantic Ocean	169	4.3
03/01/06	11/10/11	SoMAS	NY	Atlantic Ocean	2080	4.5
06/14/10	11/10/11	SoMAS	NY	Atlantic Ocean	514	4.8
10/31/11	05/03/12	SoMAS	NY	Atlantic Ocean	185	1.2
11/08/11	05/04/12	SoMAS	NY	Atlantic Ocean	178	1.5
05/19/10	05/03/12	SoMAS	NY	Atlantic Ocean	715	5.3
05/24/11	05/04/12	SoMAS	NY	Atlantic Ocean	346	5.4
05/04/12	10/02/12	CTDEEP	CT	Long Island Sound	151	229.3
05/04/12	06/07/12	NYDEC	NY	Hudson River	34	166.2
05/03/12	07/11/12	CTDEEP	CT	Connecticut River	69	242.3
05/06/13	05/07/13	SoMAS	NY	Atlantic Ocean	1	2.7

Table 1.5. Capture and recapture information of Atlantic Sturgeon, (*Acipenser oxyrinchus*), tagged in New York and recaptured in commercial and recreational fisheries. All commercial recaptures occurred in the Atlantic Ocean while the recreational recapture occurred in Rhode Island Sound.

FWS ID #	**Capture Date**	**Recapture Date**	**Recapture Waterbody**	**Recapture State**	**Days at large**	**Estimated distance from tagging location (km)**	**Fishery type**	**Capture Fishery**	**Fishery method**	**# of untagged Atlantic sturgeon captured**
355060022	06/08/2006	11/15/2006	Atlantic Ocean	MD	160	293	Commercial	Horseshoe Crab	Trawl	60
355060074	11/14/2006	01/03/2007	Atlantic Ocean	NJ	50	16	Commercial	Lingcod and Squid	Trawl	0
355060063	11/14/2006	12/20/2006	Atlantic Ocean	NJ	36	18	Commercial	Flounder	Trawl	2
355060028	08/11/2006	03/12/2007	Atlantic Ocean	NJ	213	57	Commercial	Flounder	Trawl	
355070282	11/16/2007	12/10/2007	Atlantic Ocean	NJ	24	22	Commercial	Winter Flounder	Trawl	2
355070191	06/08/2007	12/26/2007	Atlantic Ocean	NJ	201	48	Commercial	Flounder	Trawl	0
355060054	11/14/2006	09/18/2008	Atlantic Ocean	NJ	674	65	Commercial	Summer Flounder	Trawl	0
355110087	10/31/2011	6/19/2012	Atlantic Ocean	NY	232	30	Commercial	Summer Flounder	Trawl	1
355120026	5/4/2012	4/2/2013	Atlantic Ocean	NY	333	25	Commercial	Skate	Trawl	
355120032	5/4/2012	4/2/2013	Atlantic Ocean	NY	333	26	Commercial	Skate	Trawl	
355070035	05/10/2007	12/26/2007	Atlantic Ocean	NJ	230	17	Commercial	Monkfish	Anchored Gillnet	
355080026	11/02/2008	07/17/2009	Atlantic Ocean	NY	257	60	Commercial	Dogfish	Anchored Gillnet	30
355120013	5/4/2012	6/10/2012	Rhode Island Sound	RI	37	225	Recreational	Recreational	Hook and Line	

Table 1.6. Atlantic sturgeon bycatch (# individuals captured parenthesis) and number of observed trips, gear type, and target species within statistical areas 611 (modified, only tows south of LI and Block Island included), 612, and 613 along the south shore of Long Island. Only gear types that encountered Atlantic sturgeon are shown.

	NMFS Statistical Areas					
Gear type and Target Species	**611 (Modified)**	**612**	**613**	**Total Observed Trips**	**Total number of bycatch of Atlantic**	**CPUE of Atlantic sturgeon per**
GILL NET, DRIFT-FLOATING, FISH		**148 (6)**	**201**	**349**	**6**	**0.00**
BASS, STRIPED		10 (6)	16	26	**6**	0.04
BLUEFISH		130	176	306	**0**	0.00
BONITO, ATLANTIC			8	8	**0**	0.00
DOGFISH, SMOOTH			1	1	**0**	0.00
MENHADEN, ATLANTIC		8		8	**0**	0.00
GILL NET, DRIFT-SINK, FISH		**190 (17)**	**372 (2)**	**562**	**19**	**0.02**
BASS, STRIPED		22 (2)	113 (1)	135	**3**	0.02
BLUEFISH		112 (10)	223 (1)	335	**11**	0.01
BONITO, ATLANTIC			8	8	**0**	0.00
CROAKER, ATLANTIC			2	2	**0**	0.00
DOGFISH, SMOOTH		13 (5)		13	**5**	0.23
DOGFISH, SPINY		2		2	**0**	0.00
FLOUNDER, SUMMER (FLUKE)			18	18	**0**	0.00
MENHADEN, ATLANTIC		3		3	**0**	0.00
TUNA, LITTLE (FALSE ALBACORE)			2	2	**0**	0.00
WEAKFISH (SQUETEAGUE SEA TROUT)		38	6	44	**0**	0.00
GILL NET, FIXED OR ANCHORED,SINK, OTHER/NK SPECIES	**54 (3)**	**2437 (158)**	**1138 (39)**	**3629**	**200**	**0.04**
BASS, STRIPED	40 (2)	12	43 (1)	95	**3**	0.03
BLUEFISH		84 (11)	124	208	**11**	0.02
BONITO, ATLANTIC		2	4	6	**0**	0.00
BUTTERFISH		12		12	**0**	0.00
DOGFISH, NK		6		6	**0**	0.00
DOGFISH, SMOOTH		2 (1)		2	**1**	0.50
DOGFISH, SPINY		236 (4)	2	238	**4**	0.02
FISH, NK		16		16	**0**	0.00
FLOUNDER, SUMMER (FLUKE)	8 (1)		21 (9)	29	**10**	0.21
GROUNDFISH, NK		16 (1)		16	**1**	0.06
MACKEREL, ATLANTIC		4		4	**0**	0.00
MACKEREL, SPANISH		1	3	4	**0**	0.00
MENHADEN, ATLANTIC		10		10	**0**	0.00
MONKFISH (GOOSEFISH)	2	1923 (112)	882 (28)	2807	**140**	0.04
SKATE, NK	4		3	7	**0**	0.00
SKATE, WINTER (BIG)		23 (17)	24 (1)	47	**18**	0.23
WEAKFISH (SQUETEAGUE SEA TROUT)		90 (12)	32	122	**12**	0.03
TRAWL,OTTER,BOTTOM,FISH	**94 (2)**	**5234 (156)**	**1696 (24)**	**7024**	**182**	**0.03**
BASS, STRIPED			31 (4)	31	**4**	0.13
BLUEFISH		22 (1)		22	**1**	0.05
BUTTERFISH			9	9	**0**	0.00
CRAB, HORSESHOE		10		10	**0**	0.00
DOGFISH, SMOOTH		2		2	**0**	0.00
DOGFISH, SPINY		135	25	160	**0**	0.00
FISH, NK		46	212 (1)	258	**1**	0.00
FLOUNDER, NK		20	6	26	**0**	0.00
FLOUNDER, SAND DAB (WINDOWPANE)		2		2	**0**	0.00
FLOUNDER, SUMMER (FLUKE)	41 (2)	3118 (129)	296 (6)	3455	**137**	0.04
FLOUNDER, WINTER (BLACKBACK)	24	405 (11)	95	524	**11**	0.02
FLOUNDER, WITCH (GREY SOLE)		6		6	**0**	0.00
FLOUNDER, YELLOWTAIL		16	36	52	**0**	0.00
GROUNDFISH, NK		70	10	80	**0**	0.00
HAKE, RED (LING)		6 (1)		6	**1**	0.17
HAKE, SILVER (WHITING)	4	296 (3)	10	310	**3**	0.01
HERRING, ATLANTIC	1		12	13	**0**	0.00
MACKEREL, ATLANTIC		30	17	47	**0**	0.00
MONKFISH (GOOSEFISH)			2	2	**0**	0.00
SCALLOP, SEA		2	6	8	**0**	0.00
SCUP	14	11 (1)	130	155	**1**	0.01
SEA BASS, BLACK		14	4	18	**0**	0.00
SKATE, LITTLE	2	16 (1)		18	**1**	0.06
SKATE, NK		26	2	28	**0**	0.00
SKATE, WINTER (BIG)		88 (2)	2	90	**2**	0.02
SQUID, ATL LONG-FIN	7	736 (6)	666 (11)	1409	**17**	0.01
SQUID, NK	1	46	20	67	**0**	0.00
SQUID, SHORT-FIN		3	1	4	**0**	0.00
TAUTOG (BLACKFISH)		74 (1)		74	**1**	0.01
WEAKFISH (SQUETEAGUE SEA TROUT)		34	104 (2)	138	**2**	0.01
TRAWL,OTTER,BOTTOM,TWIN		**2 (2)**	**10 (4)**	**12**	**6**	**0.50**
SQUID, ATL LONG-FIN		2 (2)	10 (4)	12	**0**	0.50
Grand Total	160	16888	7626	24674	**413**	0.01

Table 1.7. Regional Bottom trawling spatial restrictions

State	Bottom Trawl Limits	Regulatory Code
Massachusetts	Spatial and temporal trawl closure areas to protect spawning fish	MASS. REGS. CODE tit. 322, § 3.04(2c)
New Hampshire	Complete ban on trawls in state waters	N.H. REV. STAT. ANN. § 211.49 (2004)
New Jersey	No trawling within 2 miles of coast (limited exception for shrimp trawls)	N.J. ADMIN. CODE tit. 7:25, § 18.14(b)
New York	1.5-2 mile arc seaward of inlets with Atlantic Ocean; various spatial restrictions within Atlantic Ocean, LIS, and inland bays	N.Y. ENV. LAW § 13-0341
Delaware	Bottom trawling prohibited in state waters, except for scientific purposes	DEL. CODE ANN.tit. 7
Maryland	Bottom trawling prohibited within 1 mile of coastal shore, or in Chesapeake Bay or bays behind the Atlantic barrier islands	MD. REGS. CODE tit. 08.02, § 05.03

Figure 1.1. Map and strata used in the random stratified trawl survey. Strata 1, 2, 12, 13, and 14 were truncated from Northeast Fisheries Science Center's (NEFSC) inshore trawl survey to include NY waters only (dotted areas represent full NEFSC strata). Targeted sampling was restricted to strata 12 and 13. Strata 12, 9, 6, and 3 are within the depth range on 0-10m, Strata 13, 10, 7, and 1 are within the depth range of 10-20m and, Strata 14, 11, 8, 5, and 2 are within the depth range of 20-30m.

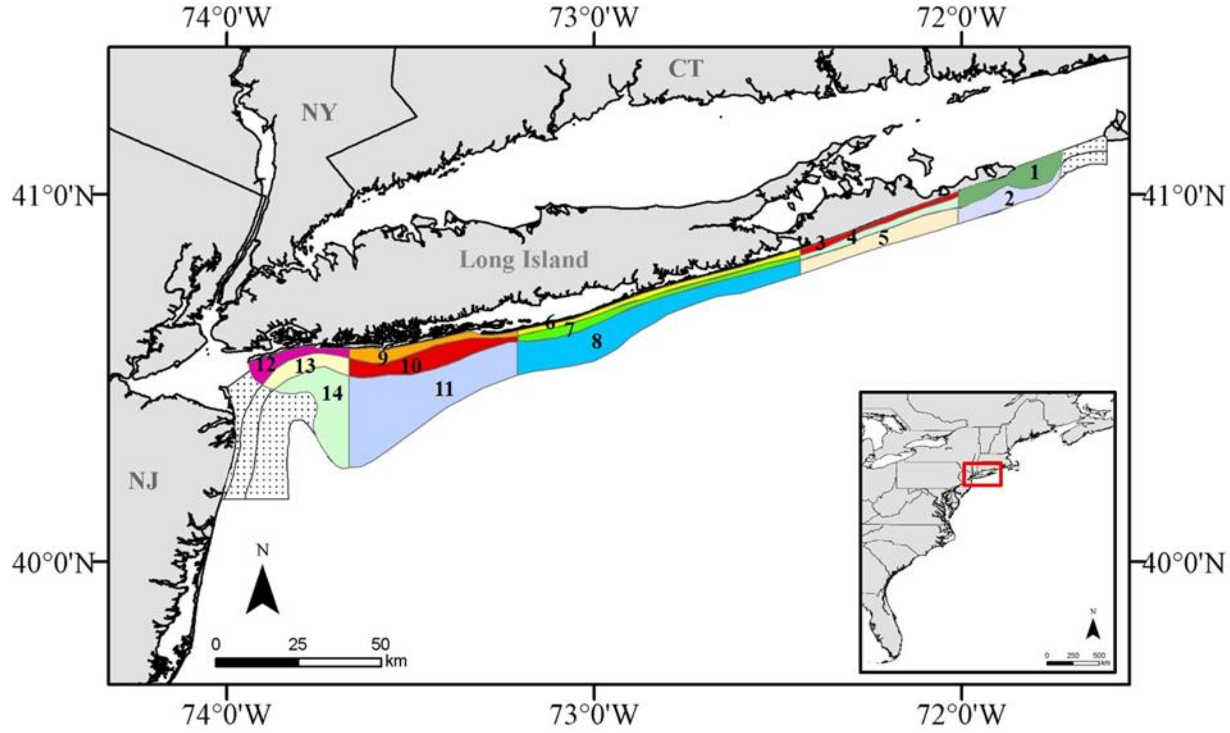


Figure 1.2. Atlantic sturgeon (*Acipenser oxyrinchus*) abundance and distribution captured in random trawl surveys for (A) January, (B) April, (C) May, (D) June, (E) August, (F) September, (G) October, and (H) November. Dashed black line represents 30 m depth contour (furthest extent of survey) and black triangles represents locations of tows where no Atlantic sturgeon were captured.

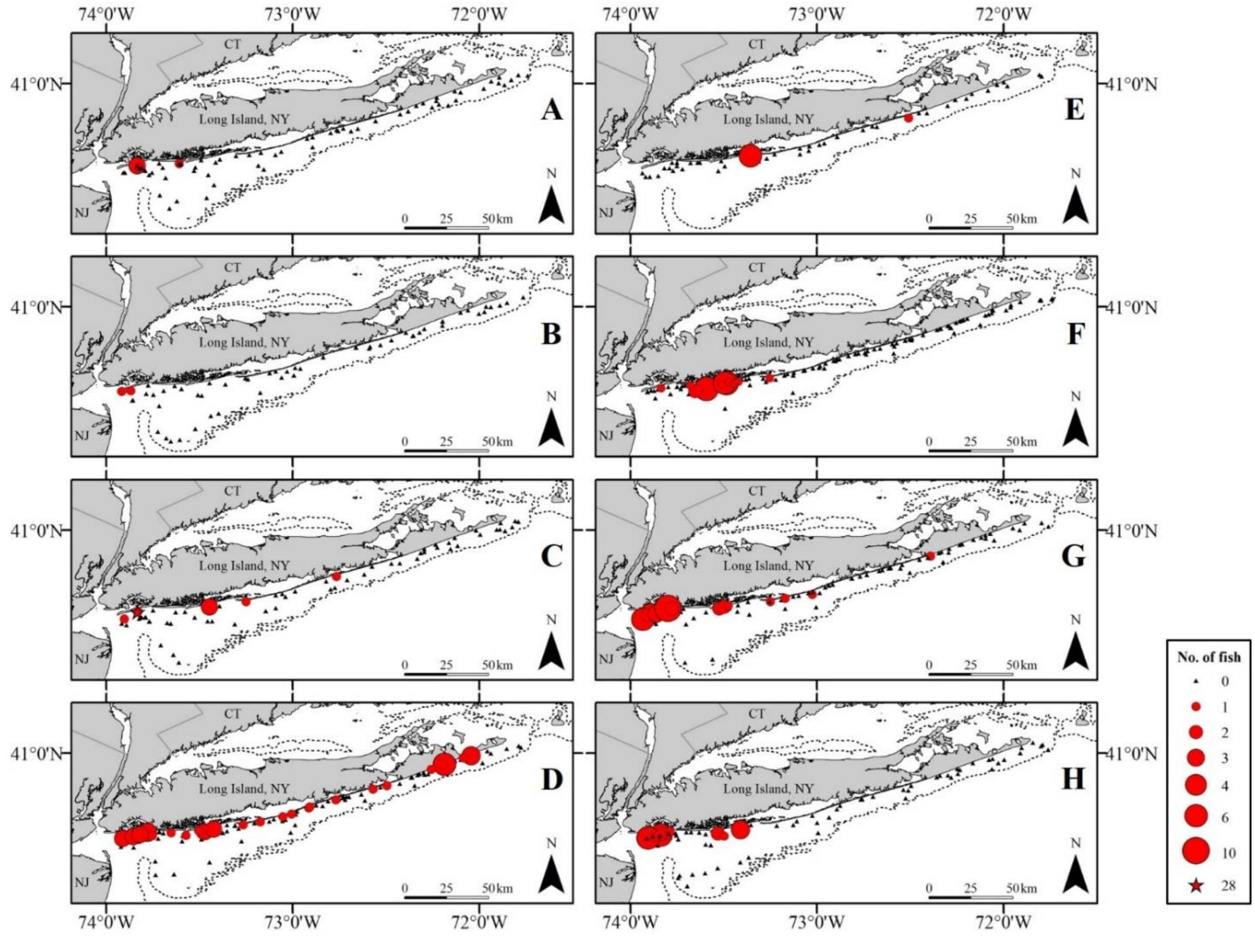


Figure 1.3. Bootstrap (n=10,000) results for determining differences among catch-per-unit (fish per minute) for (A) periods of higher vs. lower abundance (B) western Long Island vs. Eastern Long Island and (C) random trawling vs. targeted trawling

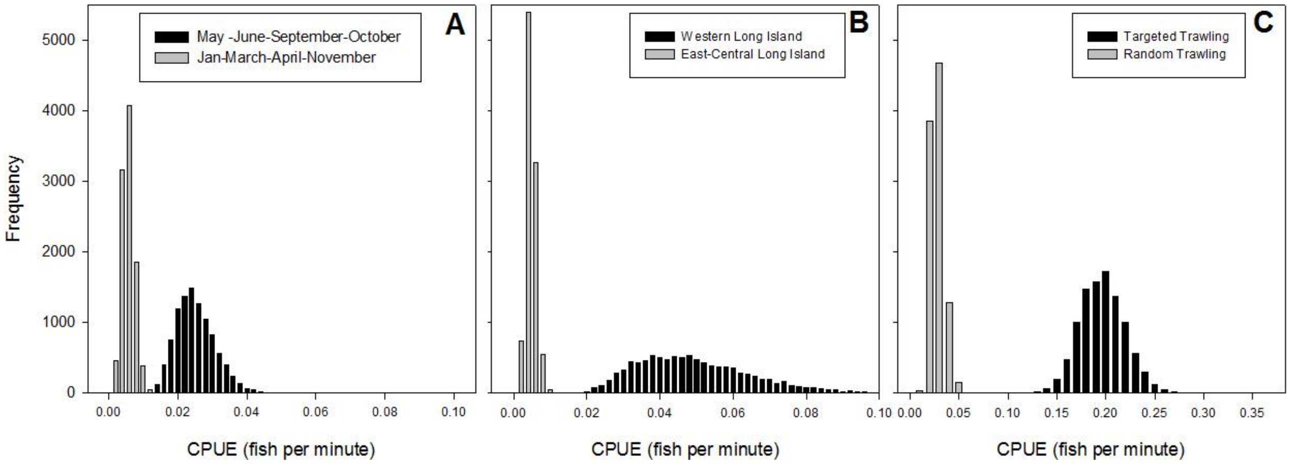


Figure 1.4. Length Frequency distribution of Atlantic sturgeon captured in random and targeted trawls (combine) off the coast of New York during research otter trawling

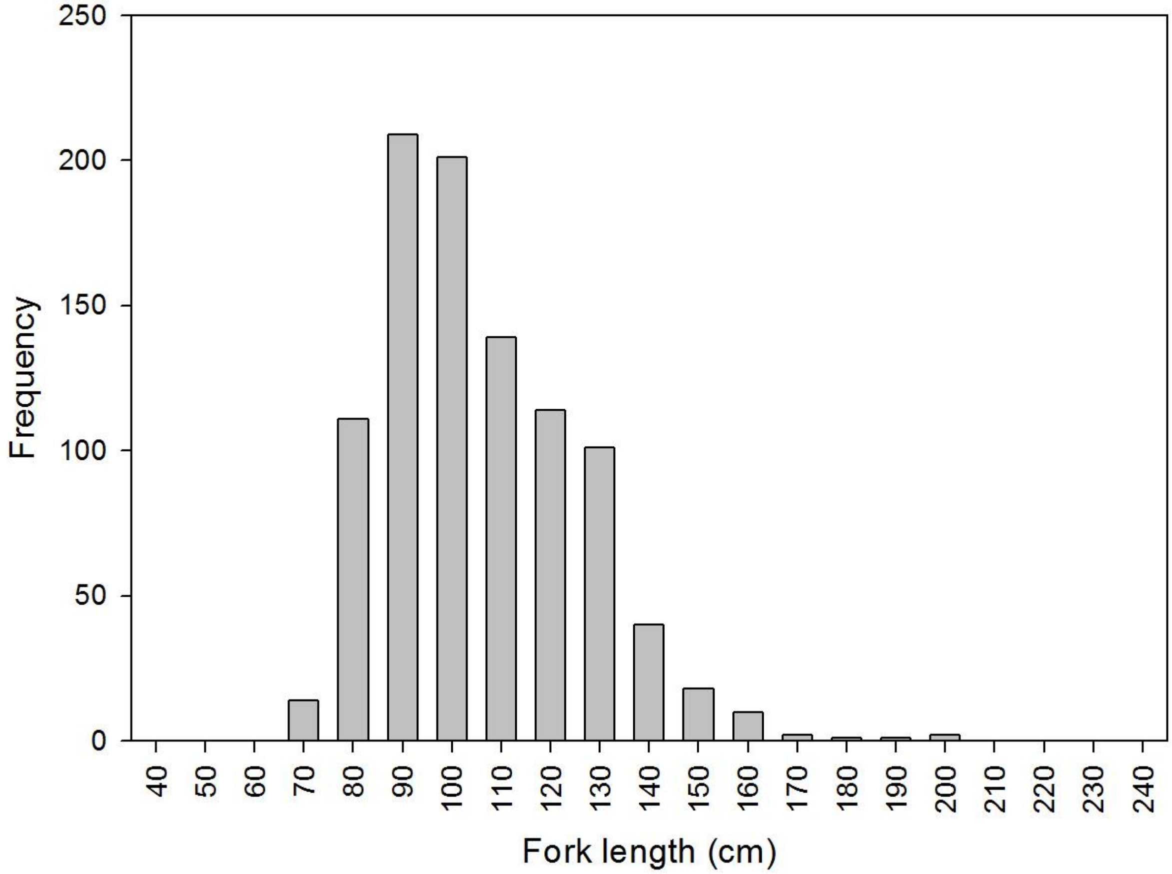


Figure 1.5. Captured and tagged Atlantic sturgeon within New York research trawls (red cross) and recaptured within commercial fisheries; bottom trawls (black cross) and gillnet (green cross). One commercial recapture off MD is not shown. Dashed black line represents the 30m depth contour.

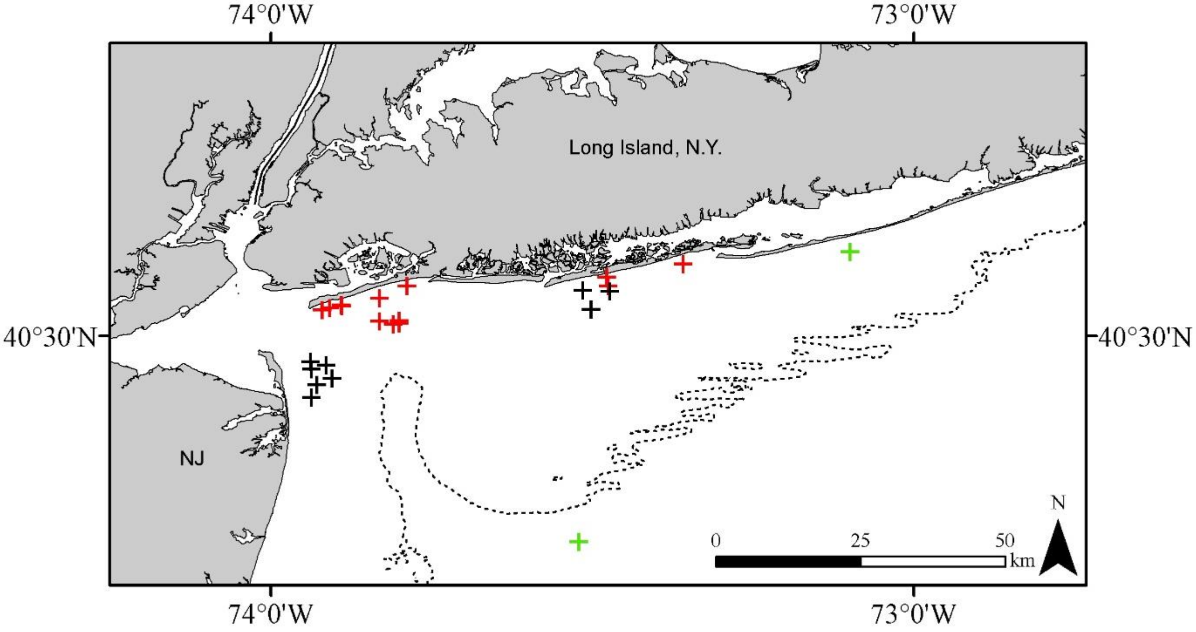


Figure 1.6. (A) Atlantic sturgeon bycatch from bottom otter trawls (fish and twin) and (B) gillnets (floating sink/drift and sink fixed/anchored combined). Green represents bycatch from vessels that landed within NY ports and blue is from vessels that landed in NJ ports within statistical areas 611 (modified, only tows south of LI and Block Island included), 612, and 613 (grey numbers and grey lines). Federal/state boundary (2 miles) is indicated by the red line.

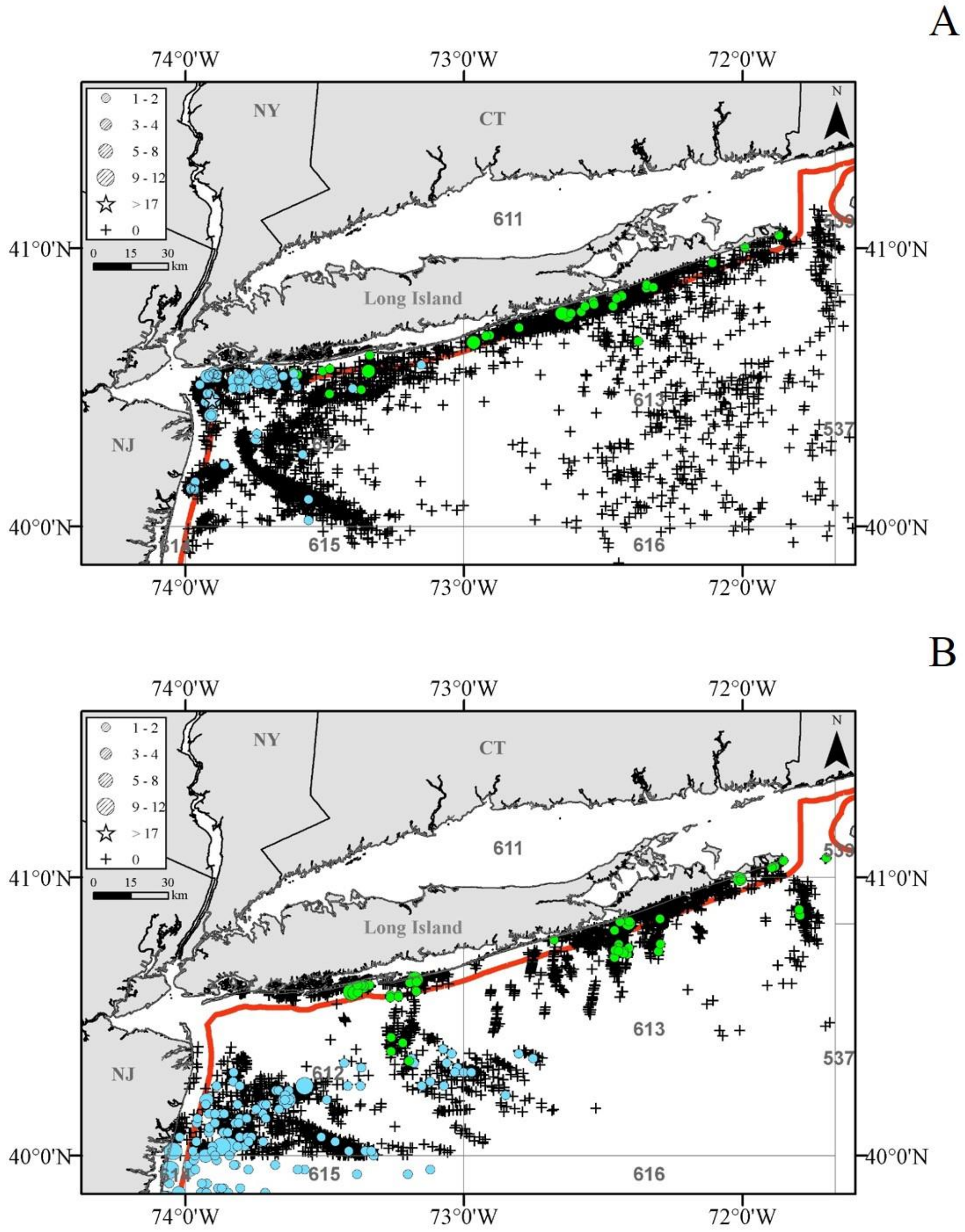


Figure 1.7. Size distribution of Atlantic sturgeon bycatch within bottom otter trawl, twin and fish, (black) and gill net, all types, (grey) fisheries.

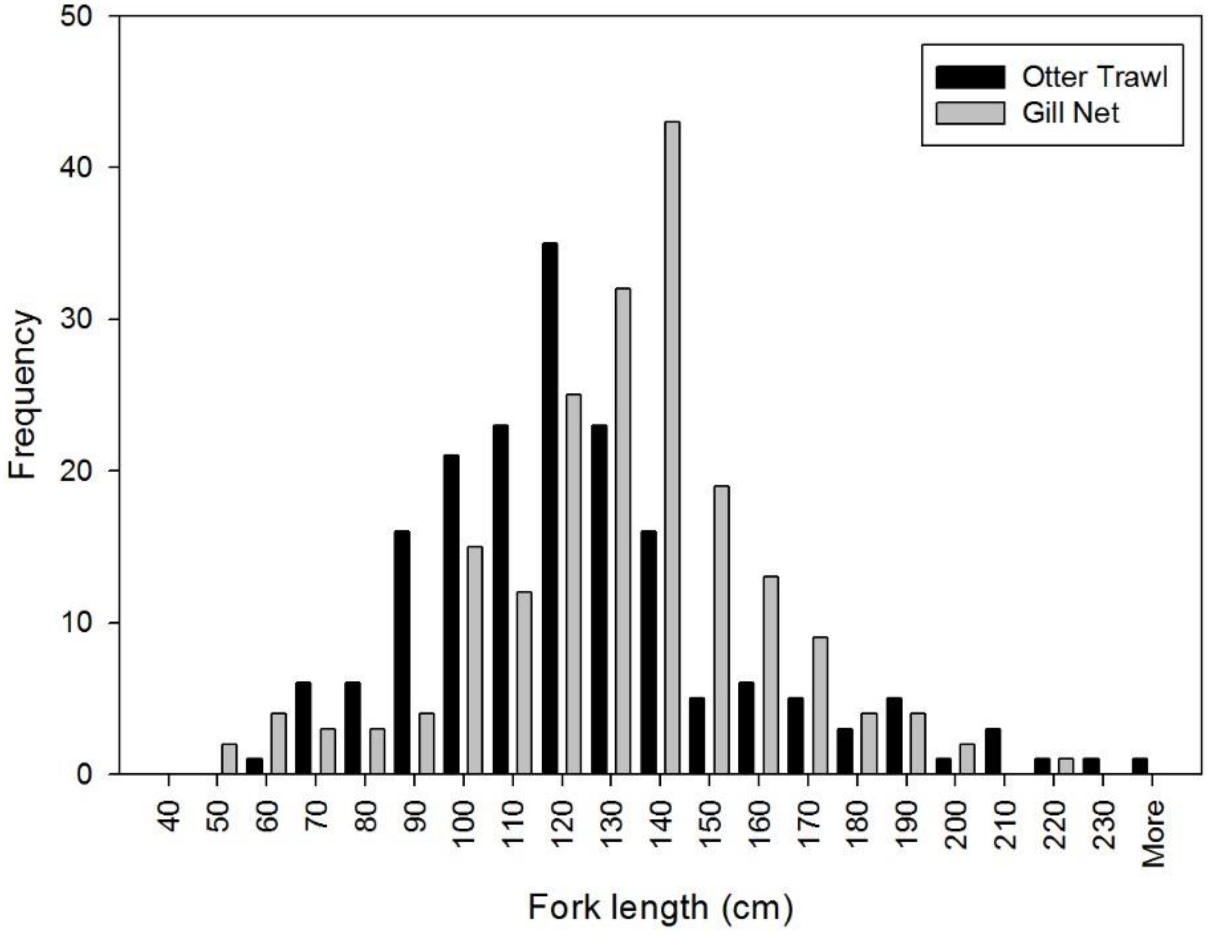


Figure 1.8. Proportion of Atlantic sturgeon bycatch by target fish species for (A) bottom and twin otter trawls (fish only) and (B) gillnets (all types). Exact proportions of Atlantic sturgeon bycatch is within the legend.

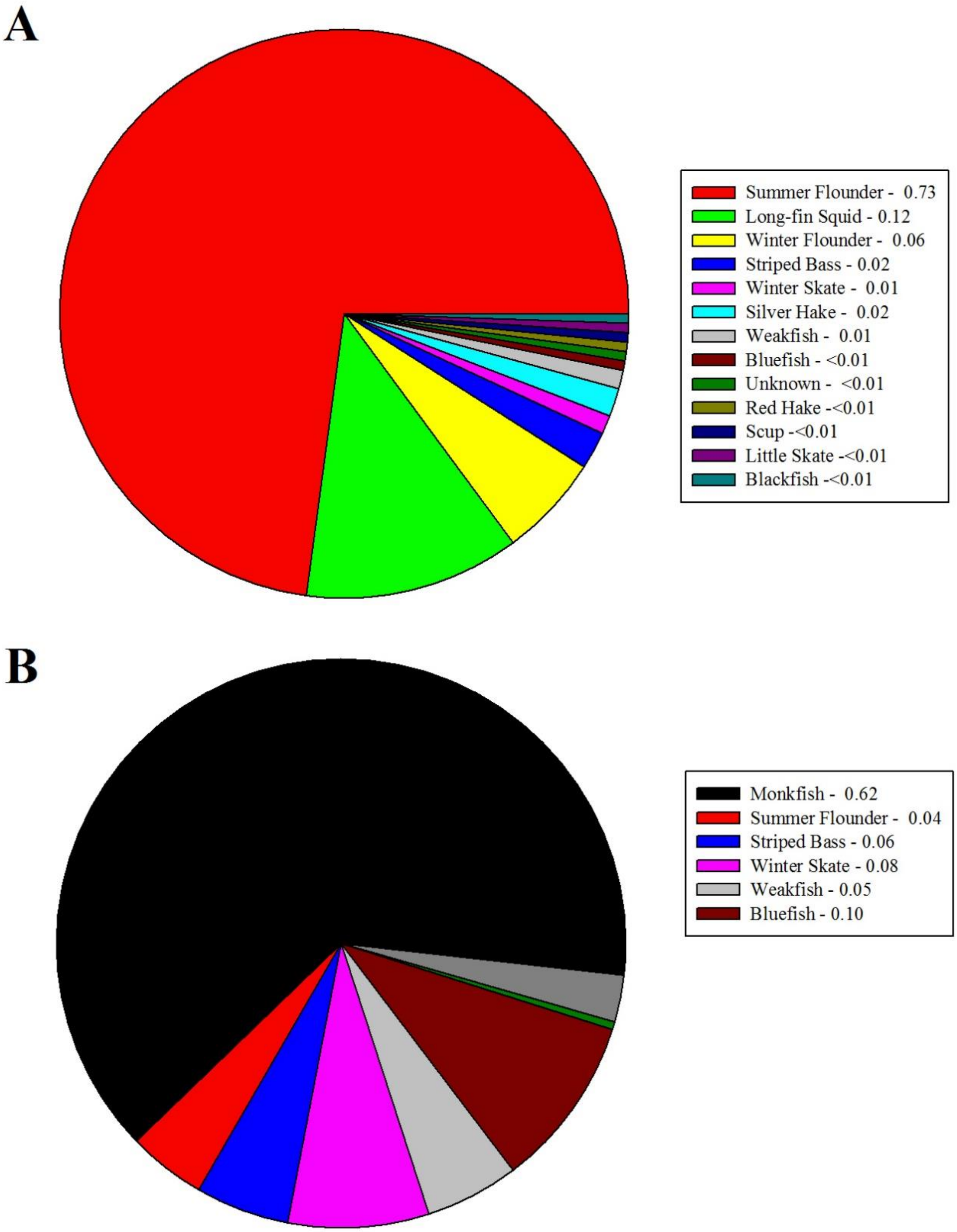
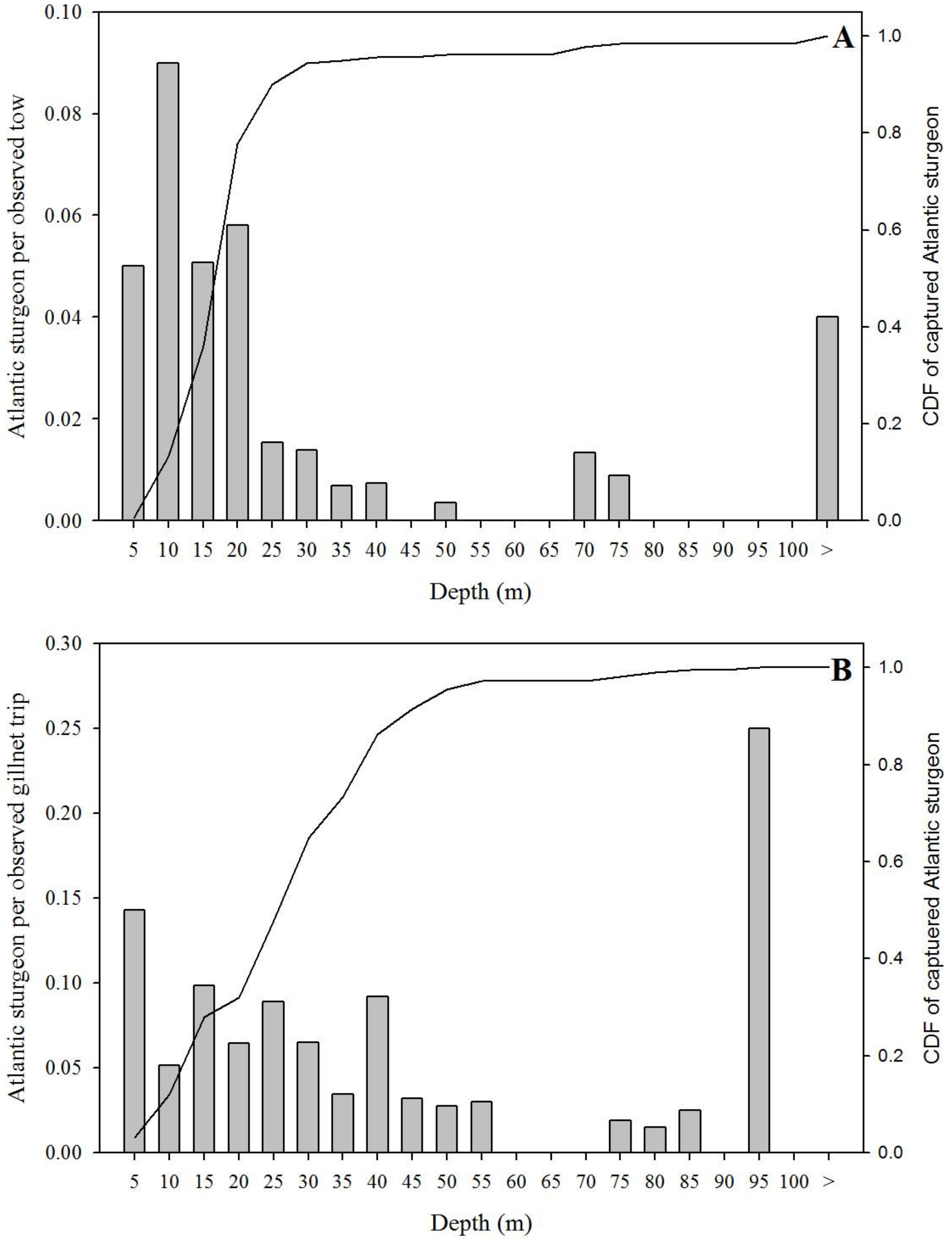


Figure 1.9. Observed Atlantic sturgeon bycatch (grey bars; primary y-axis) and cumulative distribution function (black line; secondary y-axis) of captured Atlantic sturgeon within commercial fisheries by depth for (a) bottom otter trawls (fish and twin) and (b) gillnets (all types combined).



Chapter 2

Abundance and distribution of Atlantic sturgeon (*Acipenser oxyrinchus*) within the Northwest Atlantic Ocean: spatial and habitat analyses of five fishery-independent surveys

Abstract

A lack of knowledge regarding oceanic habitat use of juvenile marine migrant Atlantic sturgeon (*Acipenser oxyrinchus*) is hindering conservation measures directed at restoring severely depleted populations. Identifying the spatial distribution of Atlantic sturgeon is necessary to identify critical habitat and appropriate management actions. We used five fishery-independent surveys to assess habitat use and movement of Atlantic sturgeon during their marine life stage. The size distribution ranged from 56-269 cm total length with a mean of 108 cm. Ninety-eight percent of all Atlantic sturgeon were smaller than 197 cm indicating that the majority were immature. The pattern of habitat use revealed concentration areas and potential migration pathways used for northerly summer and southerly winter migrations. Atlantic sturgeon, were largely confined to water depths less than 20 m with aggregations which tended to occur at the mouths of large bays (Chesapeake and Delaware bays) or estuaries (Hudson and Kennebec rivers) during the fall and spring, and dispersed throughout the Mid-Atlantic Bight during the winter. In most surveys, depth, temperature, and salinity were significantly related to the distribution of Atlantic sturgeon. Knowledge of their habitat and movements can be used to devise spatially-based conservation plans to minimize bycatch and enhance population recovery.

Introduction

The Atlantic sturgeon (*Acipenser oxyrinchus*) is a long-lived, anadromous fish with a historic range from Hamilton Inlet on the coast of Labrador to the Saint Johns River in Florida (Smith and Clugston, 1997). A major commercial fishery once existed throughout the historic range with peak estimated U.S. landings of 3.3 million kg in 1890 (Smith and Clugston, 1997). Unable to support such intensive fishing, Atlantic sturgeon populations collapsed throughout the eastern seaboard by 1901 (Secor et al., 2002). During the late 1900s, there was a brief reemergence of the Atlantic sturgeon fishery in New York and New Jersey (Kahnle et al., 2007) with peak landings of 125,000 kg in the late 1980s (Waldman et al., 1996; Bain et al., 2000). In 1990 the Atlantic States Marine Fisheries Commission (ASMFC 1990) developed a fishery management plan for the conservation and restoration of Atlantic sturgeon, which aimed to restore population levels that supported harvests at 10% of the historical peak landings (ASMFC 1990). With a continued decline in the population, a 1998 ASMFC amendment instituted a 40 year moratorium in order to protect 20 year-classes of spawning females (ASMFC 1998). Currently, Atlantic sturgeon have recently been federally listed in 2012 for protection under the Unites States Endangered Species Act (Federal Register 77 FR 5880, 77 FR 5914).

Atlantic sturgeon utilize river, estuarine, coastal, and oceanic environments at different life stages but spend the majority of their lives in saltwater (Smith and Clugston, 1997). However, information on oceanic habitat use is lacking beyond evidence of broad-scale marine migrations and exchange among river systems based on tag recaptures (Dovel and Berggren, 1983) and commercial fisheries bycatch data (Stein et al., 2004a, 2004b). Fisheries-dependent data suggest, that most Atlantic sturgeon are present in shallow inshore areas of the continental shelf (Stein et al., 2004a, 2004b). More recently, some long-term fishery-independent data showed that juvenile Atlantic sturgeon utilize the inshore waters of North Carolina during the winter months (Laney et al., 2007). Additionally, there are a handful of reported cases of Atlantic sturgeon captured in deeper offshore areas (Timoshkin, 1967; Collins and Smith, 1997; Stein et al., 2004a, 2004b). Still, more information is needed to guide management towards the best mechanisms to protect the remaining Atlantic sturgeon.

One contributing factor to the continued decline of Atlantic sturgeon populations is incidental capture of juveniles in non-target marine fisheries (Collins et al., 1996; Stein et al., 2004a). Most of the current bycatch mortality occurs in gill and drift net fisheries (Stein et al., 2004a; ASSRT 2007). Discard mortality from trawl fisheries is hard to estimate because few direct mortalities are observed. Mortality however may be very high due to delayed effects on captured individuals (Davis, 2002; Broadhurst et al., 2006). Because Atlantic sturgeon do not reach maturity until 12-14 years of age and reproductive output increases later in life (Van Eenennaam and Doroshov, 1998), reducing mortality on juveniles is key to restoring depleted populations (Boreman, 1997).

In order to adequately protect both juvenile and adult Atlantic sturgeon, marine spatial distribution patterns must be identified such that essential habitat may be protected. In this paper we use data from five different oceanic fishery-independent surveys to reveal seasonal distribution, abundance, and habitat use of Atlantic sturgeon along the Northwest Atlantic continental shelf from Cape Hatteras, NC to the Gulf of Maine (GOM) (Figure 2.1).

Methods

We analyzed data from five fishery-independent surveys conducted by the following agencies trawl surveys: 1) National Marine Fisheries Service (NMFS); 2) New Jersey

Department of Environmental Protection (NJDEP); 3) Maine Department of Marine Resources and the New Hampshire Fish and Game Department (ME-NH); 4), Massachusetts Division of Marine Fisheries (MADMF); and 5) New York Bottom Trawl Survey (NYBTS) (Figure 2. 1). Catch per unit effort (CPUE) was calculated (number of fish per tow) for each survey and depth (m). Depth (m), temperature (°C) and salinity (ppt) data were obtained from the NMFS, NJDEP, and NYBTS databases to estimate environmental preferences. For all surveys except MADMF, depth is calculated as the average between the maximum and minimum values. Depth values used in the MADMF analysis is the depth at which the tow started. For all surveys, tows were analyzed for each season, which are defined as winter (21 Dec – 20 Mar), spring (21 Mar – 20 Jun), summer (21 Jun – 20 Sept), and fall (21 Sep – 20 Dec). Specifics of each survey are discussed in detail below.

Since male and female Atlantic sturgeon mature at different size ranges (Van Eenennaam and Doroshov, 1998) and we could not distinguish between gender, we applied the female size at maturation for all individuals. Female maturation is reached at a total length of 197 cm (Van Eenennaam and Doroshov, 1998).

NMFS bottom trawl survey

These surveys were conducted primarily by the research vessels Albatross IV and Delaware II and used a Yankee 36 bottom trawl with a 1.27 cm mesh liner, towed for 30 min at 3.79 knots. Sampling was conducted during the day and night (Sosebee and Cadrin, 2006). A total of 300-400 trawls were executed each season from the Gulf of Maine (GOM) to just south of Cape Hatteras, NC (Figure 2.1). The NMFS fall survey began sampling in 1963 and primarily sampled the waters of southern New England and the Gulf of Maine before expanding to include inshore stations in 1973. The NMFS survey further expanded to include spring samples in 1973.

We also used some additional NMFS surveys that were conducted during the winters of 1964-66, 1972, 1978, 1981, and 1992-2007, and summers of 1977-1981 and 1993-1995.

NJDEP finfish survey

The NJDEP survey began in 1988 and is conducted five times per year in April, June, August, October, and January. A total of 186 tows are conducted each year (39 stations per trip for spring-fall months and 30 stations per trip for winter months). Sampling occurred from NY Harbor to the entrance of Delaware Bay, DE, from 8-30 m depth (Figure 2.1). The survey utilized a depth stratified random sampling design with a minimum of 10 tows completed per depth interval (0-10 m, 10-20 m, and 20-30 m). The survey was conducted with a three-to-one two-seam trawl (headrope 25 m, footrope 30.5 m) with 12-cm stretched mesh forward netting that is tapered down to 8-cm stretched mesh rear netting lined with a 6.4-mm mesh codend liner. Tows were conducted at a speed of 3-3.5 knots for an duration of 20 min during daylight hours.

ME-NH inshore bottom trawl survey

This survey began in fall of 2000 and primarily sampled the inshore waters of Maine and New Hampshire covering a depth range of 9-150 m and distance up to 19.3 km offshore (In accordance with the 12 mile territorial limit) (Figure 2.1). A total of 115 trawls were attempted in the fall and spring, with 100 stations selected based on a depth-stratified, random sampling design and 15 with fixed location stations. The survey used a 57-70 modified shrimp trawl (head rope 17.37 m, footrope 21.34 m) with 5.08-cm stretched mesh and 2.54-cm stretched mesh liner in the codend. Tows were conducted for 20 min at 2.2-2.3 knots during daylight hours.

MADMF bottom trawl survey

Conducted during the spring and fall from 1978-2007, this bottom trawl survey encompassed the Massachusetts inshore waters up to 5.6 km from the boundaries of New Hampshire and Rhode Island (Figure 2.1). A ¾ size North Atlantic two seam otter trawl (head rope 11.9 m, footrope 15.5 m) with a 6.4-mm lined codend was towed at 2.5 knots for 20 min during daylight hours. The survey sampled 100 stations per year selected using a depth-stratified, random sampling design.

NY bottom trawl surveys

The NY surveys consisted of two surveys, the New York young-of-the-year bluefish survey and the NY trawl survey for sub-adult Atlantic sturgeon. The sampling area encompassed the waters inshore of a depth of 30 m, with the practical inshore limit of 8-10 m from Montauk Point to the entrance of NY Harbor (Figure 2.1). The survey utilized a depth-stratified sampling design with strata based on the depth intervals 0-10 m, 10-20 m, and 20-30 m. Tows were randomly selected using a random number generator and conducted for a duration of 20 min at a tow speed of 3-3.5 knots during daylight hours. The net was a three to one two-seam trawl (headrope 25 m, footrope 30.5 m) with forward netting comprised of 12-cm stretched mesh tapering down to the rear netting of 8-cm stretched mesh lined with a 6.0-mm mesh liner within the codend. Since the surveys utilized the same gear, they were combined for the purpose of this analysis. Further differences between the two surveys are described below.

NY young-of-the-year bluefish survey sampling was initially restricted to the 10 and 20 m depth stratum where 10 tows per depth strata were completed for a total of 20 tows per cruise. Sampling took place from June-October in 2005 and August-September in 2006. The survey was confined to the 10 m depth strata in September, October, and November of 2007 with 25, 24, and 27 tows completed, respectively.

NY trawl survey for sub-adult Atlantic sturgeon conducted a total of 10 cruises from October 2005-June 2007 with 30 tows per cruise distributed within the 10, 20, and 30 m depth stratums. Sampling months included October, November, January, April, May, and June. A total of 10 tows were completed for each depth. In June 2007, 36 tows were confined to the 10 m depth stratum.

Spatial analysis

Atlantic sturgeon captures were mapped using ESRI® ArcGIS™ v.9.2 (ESRI; Redlands, CA). Map base layers were obtained from the United States Geological Survey Coastal and Marine Geology Program GIS catalogue. Atlantic sturgeon captures were plotted using graduated symbols in the following categories; 1, 2, 3-4, 5-10, 11-14, and >15 Atlantic sturgeon per tow.

Habitat preferences

We estimated the habitat preference of Atlantic sturgeon using the catch-weighted methods of Perry and Smith (1994) for correcting bias that arises in stratified surveys where sampling effort differs between strata. The method compares a catch-weighted cumulative distribution of available (all habitat sampled) and occupied (habitat where Atlantic sturgeon were captured) habitat and utilizes a randomization routine to estimate whether the species' occupied habitat is significantly different from available habitat. Habitat variables analyzed included temperature, dissolved oxygen, and salinity.

The cumulative distribution function (cdf) of the environmental variable was calculated with the following function:

(1) $$f(t) = \sum_h \sum_i \frac{W_h}{n_h} I(x_{hi})$$

where W_h = the proportion of the survey in stratum h

n_h = is the number of tows in stratum h,

x_{hi} = is the habitat variable in tow i and stratum h and I is an indicator function where:

(2) $$I(x_{hi}) = \begin{cases} 1, & if\ x_{hi} \le t \\ 0, & otherwise \end{cases}$$

The following function relates the catch weighted cdf with the habitat variable:

(3) $$g(t) = \sum\sum \frac{W_h}{n_h} \frac{y_{hi}}{\bar{y}_{st}} I(x_{hi})$$

where y_{hi} = the number of fish captured in tow i in stratum h

y_{st} = is the stratified mean abundance. The strength of the association is measured by the difference between the available and occupied cdf:

(4) $$\max\left|g(t) - f(t)\right| = \max\left|\sum_h \sum_i \frac{W_h}{n_h} \left(\frac{y_{hi} - \bar{y}_{st}}{\bar{y}_{st}}\right)(x_{hi})\right|$$

Significance is determined by randomizing for 1000 trials the pairings of x_{hi} and $(W_h/n_h)(y_{hi} - \bar{y}_{st})/\bar{y}_{st}$) then dividing the number of trials that are greater than the test statistic by the total number of trials.

Results

The NYBTS had the highest CPUE (0.291 fish/tow), followed by the NJDEP Finfish Survey (0.072 fish/tow), ME-NH Inshore Bottom Trawl Survey (0.024 fish/tow), NMFS Bottom Trawl Survey (0.004 fish/tow), and the MADMF Bottom Trawl Survey (<0.001fish per tow) where only one Atlantic sturgeon has ever been captured (Table 2.1, Figure 2.2). The details of the CPUE by depth (Figure 2.3) and seasonal distribution and abundance (Figure 2.4–2.7) for each survey are reported in detail below. Total length of Atlantic sturgeon captured within the surveys ranged from 56–269 cm, with a mean of 108 cm (Table 2.2, Figure 2.8).

NMFS bottom trawl survey

A total of 107 Atlantic sturgeon were captured in 27,420 bottom trawls (Table 2.1). The depth distribution of completed tows ranged from 5-542 m deep, with a peak of 5214 tows occurring between 20-40 m (Figure 2.3A). CPUE of Atlantic sturgeon was highest for the 10-m depth stratum (0.0273/tow) and decreased with each depth interval (Figure 2.3A). A total of 71.30% of the Atlantic sturgeon were captured in 20 m or less and no individuals were captured in water deeper than 30 m (Figure 2.3A). Atlantic sturgeon were captured during all seasons but were most abundant during the spring, with an average CPUE of 0.006 fish/tow followed by winter (0.005 fish/tow), fall (0.002 fish/tow), and summer (0.001 fish/tow) (Table 2.1).

In the spring, 70.59% of Atlantic sturgeon were captured in Virginia (VA) and NC waters and 23.53% were captured in NY and NJ. One Atlantic sturgeon was captured south of Cape Hatteras and as well as one captured offshore of Northern MA. During winter months captures were evenly distributed from NJ to NC. A total of 42.30% (11 fish) of fall captures occurred off Long Island, NY, while 30.76% (eight fish) occurred in the mouth of Delaware Bay, Delaware (DE). In addition three fish were captured in NJ, one fish south of Cape Hatteras, and one fish near Cape Cod, MA. Only one Atlantic sturgeon was captured during this survey in the summer months, which occurred in NY waters off of Long Island.

NJDEP finfish survey

A total of 261 Atlantic sturgeon were captured within 3617 bottom trawls from 1988-2007 (Table 2.1) at all depths sampled (Figure 2.3B). Tow distribution of the survey ranged from 5-30 m with a majority of the tows occurring within the 10-25 m range (Figure 2.3B). CPUE was highest for the 10-15 m depth range (0.134 fish/tow) and lowest for 20-30 m (0.005 fish/tow) (Figure 2.3B). A total of 94.78% of all captures occurred in depths less than 20 m (Figure 2.3B). CPUE was highest for the winter months (0.124 fish/tow) followed by fall (0.096 fish/tow) and spring (0.079 fish/tow) (Table 2.1). No Atlantic sturgeon were captured during the summer months (Table 2.1). During the winter, 74 Atlantic sturgeon were captured with 90.54% occurring off northern NJ and 79.73% occurring within a small area outside Sandy Hook, NJ. Three fish were captured at 0-20 m depth outside of Delaware Bay, DE. During the fall season 74 Atlantic sturgeon were captured with 92% occurring north of Little Egg Inlet, NJ. Of the total Atlantic sturgeon captured, 64% (48 fish) were captured off northern NJ. Captures within the spring occurred along the entire coast with Sandy Hook, NJ, accounting for 44.2% of spring captures.

ME-NH inshore bottom trawl survey

A total of 38 Atlantic sturgeon were captured in a total of 1601 bottom trawls from 2001-2006 (Table 2.1). Sampling depths ranged from 10-200 m, with three defined peaks in sampling effort at 30 m, 65 m, and 90 m (Figure 2.3C). All Atlantic sturgeon were captured between 15-90 m depth (Figure 2.3C) with 36 Atlantic sturgeon being captured near the Kennebec estuarine complex (Figure 2.9A). Two additional Atlantic sturgeon were captured south of the Kennebec River closer to the Saco River.

MADMF bottom trawl survey

Only one Atlantic sturgeon was captured in a total of 5563 bottom trawls (Table 2.1). Sampling depths ranged from 4-86 m, with a peak in sampling effort at a depth of 20 m (Figure 2.3D). The only Atlantic sturgeon captured was during the spring at a depth of 41 m.

NYBTS

A total of 149 Atlantic sturgeon were captured in 512 random stratified tows (Table 2.1). Sampling depths ranged from 5-35 m with a peak in sampling effort at a depth of 15 m (Figure 2.3E). Atlantic sturgeon were captured within all months sampled; however, no Atlantic sturgeon were captured deeper than 20 m. A total of 85% of all Atlantic sturgeon were captured between 5-10 m with a mean CPUE of 1.34 (Figure 2.3E). CPUE was highest during the fall (0.35 fish/tow) followed by spring (0.33 fish/tow) and summer (0.26 fish/tow) and was lowest during the winter (0.07 fish/tow) (Table 2.1). Of the 149 Atlantic sturgeon captured, 51% occurred off the western coast of Long Island, 30% were captured off central Long Island, and only one was captured off the east end of Long Island. During the spring, Atlantic sturgeon were captured along on the entire coast of Long Island, NY, but 57% occurred off of Western Long Island, specifically Rockaway, NY. The Rockaway region was also an important area during the fall, accounting for 70% of the catches occurring within this region. Twenty-six Atlantic sturgeon were captured in the summer months with 99% occurring in western-central Long Island, NY, and only one along the east end of Long Island. During the winter, all Atlantic sturgeon were captured off the western end of Long Island.

Habitat preferences

Hydrographic variables and distributions of Atlantic sturgeon were compared only for the NMFS Bottom Trawl Survey, NJDEP Finfish Survey, and NYBTS for the spring and fall seasons because these contained sufficient Atlantic sturgeon capture data to perform the analyses. The habitat occupied by Atlantic sturgeon was significantly different than available depths in the NMFS survey and NYBTS for both the spring and fall surveys and the NJDEP spring survey (Tables 2.3 and 2.4). Atlantic sturgeon occupied significantly different temperatures compared to available habitat in the NYBTS spring and NMFS fall survey as well as significantly different salinities in the NMFS fall and spring surveys and NJDEP spring survey (Table 2.3). Survey-specific cumulative distribution functions for available and occupied depth, salinity, and temperature are shown in Figure 2.10 while median values and 95% confidence intervals are listed in Table 2.4. Where significant differences occurred, Atlantic sturgeon were always found in shallower water than potentially available habitat (Table 2.4, Figure 2.10). Occupied salinities were less than the available salinities in all surveys, although only the NMFS fall and spring survey and NJDEP spring survey had significant differences (Table 2.4, Figure 2.10). In two circumstances the occupied temperature was significantly warmer than available temperatures, while the other seasons and surveys showed no trend (Table 2.4, Figure 2.10).

Discussion

A majority of the Atlantic sturgeon captured along the continental shelf from ME to NC were juveniles aggregating in specific locations around the mouths of estuarine complexes and along narrow dispersal corridors in shallow water (<20 m) from Cape Hatteras (NC) to the southern tip of Long Island (NY). The highest catches occurred within the NY Bight in water 10-15 m deep, particularly during the spring and fall, with few captured north of MA. Little work has been done to describe the marine habitat distribution and habitat preference of Atlantic sturgeon, but similar coast-wide, shallow (with respect to regional bathymetry) marine distributions have also been shown for green sturgeon, *Acipenser medirostris,* (Erickson and Hightower, 2007) and Gulf sturgeon, *Acipenser oxyrinchus desotoi* (Edwards et al., 2007; Ross et al., 2009). These results are also consistent with Atlantic sturgeon bycatch data (Stein et al., 2004a, 2004b). Our comprehensive analysis of a coast-wide collection of surveys identified the area between the NY Bight to VA as a region of overwintering habitat for juvenile Atlantic sturgeon. This agrees with Laney et al. (2007), who found the coastal waters off NC and VA to be important overwintering habitat for Atlantic sturgeon. Atlantic sturgeon that originated from the Hudson River represented 43.5% of those in the NC overwintering habitat (Laney et al., 2007) agreeing Dovel and Berggren's (1983) tagging data that demonstrated southerly movement of Atlantic sturgeon from the Hudson River. In addition to Laney et al. (2007), there have been further reports of Atlantic sturgeon in marine waters off the coast of South Carolina during winter months (Collins and Smith, 1997). The identification of the NY Bight as an important overwintering area has not been widely reported, therefore determining the genetic makeup of these fish would add important information on Atlantic sturgeon demographics and movements.

Atlantic sturgeon had a coast-wide distribution during the spring and fall, with southerly and centrally located distributions during the winter and summer, respectively. These results corroborate tagging data that suggests Atlantic sturgeon undergo large-scale southerly fall migrations and northerly spring migrations (Dovel and Berggren, 1983). Catches varied by season, but were greatest during the fall and spring months. Because of the strong seasonal component of Atlantic sturgeon movements, the timing of surveys to have important consequences on observed patterns.

The interaction of Atlantic sturgeon behavior and temporal and spatial variability amongst surveys

Some of the variation in distribution and abundance of Atlantic sturgeon can be explained by temporal and spatial differences in sampling effort. Stein et al. (2004a) reported that MA ports have one of the highest cumulative catches of Atlantic sturgeon. This contrasts with the MADMF bottom trawl survey, which captured virtually no Atlantic sturgeon. The discrepancy between reports of Atlantic sturgeon in MA waters likely comes from the timing of sampling. Stein et al. (2004a) showed the highest bycatch rates in June and November for bottom trawl fisheries, while the MADMF survey took place during May and September. Any aggregations and dispersal within MA marine waters may occur at limited enough spatial and temporal scales to be missed by the survey. The absence of Atlantic sturgeon during the MADMF survey does, however, suggest lower abundance within this area during comparable time frames since Atlantic sturgeon are captured at relatively high rates by other surveys occurring during this period. More work should be done to monitor Atlantic sturgeon habitat within other months not typically sampled by the MADMF survey, because it is possible that Atlantic sturgeon are present in higher concentrations during months that are not routinely sampled.

The NMFS survey missed critical areas for Atlantic sturgeon because they do not sample inshore close enough in certain regions. Such areas include important overwintering habitat identified within this study in NY waters and by Laney et al. (2007) in VA and NC, in addition to critical habitat within the GOM. The ME-NH inshore bottom trawl survey was used to identify the Kennebec estuarine complex as an important concentration area for Atlantic sturgeon within the GOM region because of their shallower sampling efforts. Additional surveys such as the Northeast Fisheries Sciences Center (NEFSC) industry-based Surveys for cod (*Gadus morhua*) and yellowtail (*Limanda ferruginea)* which also sample inshore, have also captured Atlantic sturgeon between the Saco and Kennebec rivers in fall, winter, and spring (Figure 2.9A; W. Kramer, personal communication[3]). Stein et al. (2004a, 2004b) also showed that Atlantic sturgeon are captured as bycatch within this region in sink gillnets. The depth distribution of Atlantic sturgeon within the GOM was deeper than the other coast-wide captures, but similar to those reported for green sturgeon (Erickson and Hightower, 2007) in that both species occupied shallow depth distributions relative to the bathymetric characteristics of the region. There has not been sufficient inshore trawling conducted during the winter and summer to validate whether this is important year-round habitat.

Despite the NMFS survey covering the entire continental shelf, no fish were captured deeper than 30 m. However, Atlantic sturgeon of unknown size have been captured in deeper water (>100 m) on the continental shelf as bycatch in gillnet fisheries (Stein et al. 2004b; ASMFC 2007). Additionally, there have only been two recorded trawl captures of an Atlantic sturgeon on the continental shelf; one mature Atlantic sturgeon (225 cm) was captured in the Hudson canyon in water 110 m deep off NY and NJ while another was captured in Wilmington Canyon , 113 km southeast of Atlantic City, NJ (Timoshkin, 1967). The lack of trawl-caught fish on the continental shelf may be a result of either a gap in timing of Atlantic sturgeon migrations on or off the shelf, a function of gear selectivity towards smaller fish, or simply a scarcity of Atlantic sturgeon. Either a substantial increase in trawl survey effort or the use of

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[3] Kramer, William. 2009. NOAA Fisheries Service, Ecosystems Survey Branch. 166 Water St., Woodshole, MA 02543.

different gears, such as gillnets, may be required in order to capture Atlantic sturgeon along the shelf.

Essential fish habitat

The Magnuson-Stevens Fishery Conservation and Management Act requires identification of Essential Fish Habitat (EFH), defined as waters or substrate used for spawning, breeding, feeding or growth to maturity, in order to minimize adverse effects and to promote conservation and enhancement of such habitat for particular species. Unfortunately, EFH can only be defined for federally managed species and does not include species such as Atlantic sturgeon which is managed by regional fishery management councils. Now, Atlantic sturgeon is a currently listed under the US Endangered Species Act, and the identification of critical habitat necessary to recover the species will be required. The identification of critical habitat for listed species is mandatory and is defined as all areas essential to the conservation of the species. Without EFH or critical habitat designation, habitat degradation and incidental mortality within critical areas will continue to be maintained and hinder population recovery.

Our analysis of habitat preferences indicated that depth was the primary environmental characteristic defining the Atlantic sturgeon distribution. Thus, essential habitat of juvenile, marine migrant Atlantic sturgeon can broadly be defined as coastal waters <20 m depth, and concentrated in areas adjacent to estuaries such as the Hudson River-NY Bight, Delaware Bay, Chesapeake Bay, Cape Hatteras and Kennebec River. This narrow band of shallow water appears to represent an important habitat corridor and potential migration path. There are likely additional hotspots along the migration corridor, but greater temporal and spatial sampling effort is required to identify them. Other authors have reported concentrations of Atlantic sturgeon in Long Island Sound (Bain et al., 2000; Savoy and Pacileo, 2003) and NC (Laney et al., 2007), while Stein et al. (2004a) reported several concentrations of Atlantic sturgeon in Massachusetts Bay, RI, NJ, and DE. However, the analysis by Stein et al. (2004a) used bycatch data where captures were lowest during the summer months while the fishing rates were highest. This indicates that biases imposed by changing fishing effort may be influencing observed distributions.

The reason(s) for aggregations of Atlantic sturgeon migrants are not understood, nor are their movements to and from aggregation areas. Concentrations identified by Stein et al. (2004b) led the authors to suggest that temperature, bathymetry, geomorphic formations, food habits, and the sampling gear type used may contribute to observed movements and aggregation of Atlantic sturgeon. Complex circulation patterns are also a potential reason for observed concentrations of Atlantic sturgeon (Wilk and Silverman, 1979; Savoy and Pacileo, 2003). Haiten et al. (2002) found that Atlantic sturgeon, concentrated within the St. Lawrence estuary, had large numbers of nematodes and oligochaetes within their stomachs, suggesting that these habitats are feeding areas. Known seasonal migrations often involve energetic demands related to food availability, environmental factors and reproductive activity (Roff, 2002). Because the majority of captures are juveniles, reproductive activity is not a likely cause for movement, although traits that have an evolutionary background are difficult to discern since life-history stages are often linked through long term fitness (Taborsky, 2006). We hypothesize that migrations are depth restricted and aggregations are related to food availability while seasonal cues, temperature in particular, drive movement.

Current and future management of Atlantic sturgeon

Current knowledge suggests that the majority of Atlantic sturgeon populations have been extirpated and that the Hudson River stock is one of the largest remaining populations (Waldman et al., 1996; Van Eenennaam et al., 1998; Savoy and Pacileo, 2002; Secor et al., 2002). Three fishery management tools commonly used to help restore depleted populations include implementing minimum size limits, temporary closures of the fishery, and designation of marine reserves (Nowlis, 2000). Atlantic sturgeon management has included minimum size limits since the early 1990's, followed directly by a 40 year complete closure of the fishery beginning in 1998. Currently, after 10 years of the fishery closure, recruitment within the Hudson River still remains at historic lows (Kahnle et al., 2007).

Since previous Atlantic sturgeon management has not resulted in significant improvements to populations, recovery efforts should now focus on establishing marine reserves or implementing area closures to protect essential habitat and to reduce fishing mortality on juveniles (Collins et al., 2000). Specifically, Sandy Hook (NJ), Rockaway (NY), and Kennebec (ME), which are hotspots of Atlantic sturgeon captures as identified by this study, should be protected. Although sturgeon are not as abundant in the Kennebec region in ME as in NY and NJ waters, it represents a unique localized hotspot. This is of particular importance because Atlantic sturgeon captured in ME river systems have been shown to represent a separate discrete population segment (Grunwald et al., 2008). The genetic origins of the Atlantic sturgeon captured within marine waters of ME are unknown, although they are likely to originate from multiple stocks. Due to the proximity of ME river systems it is probable that the majority of these Atlantic sturgeon are part of this discrete population segment. If our recommended habitat protection were to occur, he total amount of closed area within these locations would be relatively small totaling 85.47 km^2 within NJ (Figure 2.9A), 106.19 km^2 within NY (Figure 2.9A), and 209.79 km^2 within ME (Figure 2.9B). In addition, although Atlantic sturgeon are highly migratory, primary juvenile habitat and migrations are limited to narrow corridors in waters less than 20 m deep. The presence of Atlantic sturgeon in such a narrow band of water should allow for an effective seasonal or permanent closure to gillnet and trawl fisheries. By focusing immediate efforts on the protection of these hotspots and corridor pathways, bycatch mortality will be reduced effectively through protection of habitat. Further efforts should also seek to protect important areas within other systems in order to conserve the several discrete population segments defined by ASSRT[3] and Grunwald et al. (2008) to promote genetic diversity among Atlantic sturgeon populations.

Effective plans could be developed that minimize the extent and length of closures by understanding the time periods of localized aggregations and movements among them, which are concentrated within narrow corridors. Some states, such as NJ (3.22 km limit), MD (1.61 km limit), and DE (no trawling) already have state limits for inshore trawling which limit fishery interactions with Atlantic sturgeon while other states such as NY have no such measures. Any spatial closures require proper enforcement and substantial community-level support for successful implementation (Sumaila et al., 2000). While broad-scale patterns are becoming clearer, work is required to understand the finer scale movements of Atlantic sturgeon such that any spatial management plans could be minimized while still achieving adequate protection. Current plans toward understanding finer scale movements are aided by cooperative efforts such as the Atlantic Cooperative Telemetry (ACT) network, which is a large scale collaborative telemetry network comprised of ~30 groups from Maine to South Carolina (Dwayne Fox[4] and Tom Savoy[5] personal communication). Such coordinated efforts are steps in the right direction

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for species conservation. Once fine-scale movements are understood, in particular with regards to aggregation areas, management will be better informed as to limit interactions between fisheries and the near-endangered Atlantic sturgeon while minimizing economic impacts. Improving estimates of fishery bycatch mortality would be of enormous value, in particular if it included a spatial perspective. Regardless of the outcome of current consideration of Atlantic sturgeon for listing under the endangered species act, a coordinated effort amongst academic, federal, state, and local institutions will be required to conserve this ancient species.

Table 2.1. Summary of the surveys effort and Atlantic sturgeon (*Acipenser oxyrinchus*) captures for the New York bottom trawl survey (NYBTS), New Jersey Department of Environmental Protection (NJDEP) finfish survey, National Marine Fisheries Service (NMFS) bottom trawl survey, Maine Department of Marine Resources and New Hampshire Fish and Game (ME-NH) inshore trawl survey, and Massachusetts Division of Marine Fisheries (MADMF) bottom trawl survey. Seasons are defined as winter (21 Dec – 20 Mar), spring (21 Mar – 20 Jun), summer (21 Jun – 20 Sep), and fall (21 Sep – 20 Dec).

Survey	**Time period**	**Total # of trawls completed**	**Total # of Atlantic sturgeon captured**	**Catch per unit effort**
NYBTS	**2005-2007**	**512**	**149**	**0.291**
	Fall	132	46	0.348
	Winter	59	4	0.068
	Spring	219	73	0.333
	Summer	102	26	0.255
NJDEP	**1988-2007**	**3617**	**261**	**0.072**
	Fall	769	74	0.096
	Winter	599	74	0.124
	Spring	1439	113	0.079
	Summer	810	0	0.000
NMFS	**1973-2007**	**27,420**	**107**	**0.004**
	Fall	11,919	26	0.002
	Winter	2563	12	0.005
	Spring	11,395	68	0.006
	Summer	1543	1	0.001
ME-NH	**2000-2006**	**1601**	**38**	**0.024**
	Fall	773	31	0.040
	Spring	828	7	0.008
MADMF	**1978-2007**	**5563**	**1**	**>0.001**
	Spring	2874	1	>0.001
	Fall	2689	0	>0.001

Table 2.2. Mean, standard deviation, and range of total length (cm) of Atlantic sturgeon (*Acipenser oxyrinchus*) captured in the New York bottom trawl survey (NYBTS), New Jersey Department of Environmental Protection (NJDEP) finfish survey, National Marine Fisheries Service (NMFS) bottom trawl survey, Maine Department of Marine Resources and New Hampshire Fish and Game (ME-NH) inshore trawl survey, and Massachusetts Division of Marine Fisheries (MADMF) bottom trawl survey. Length information includes all recorded lengths over the duration of the entire time frame of the above surveys.

Survey	Mean total length ± standard deviation (cm)	Range (cm)
NYBTS	112.01 ± 27.75	72 - 215
NJDEP	103.89 ± 32.13	52 - 248
NMFS	113.87 ± 40.18	51 - 269
ME-NH	115.4 ± 19.39	76 - 152
MADMF	78 ± 0	---------

Table 2.3. *P*-values of habitat preference analysis. The strength of the association is measured by the difference between the available and occupied cumulative distribution functions. Significance is determined by randomizing for 1000 trials the pairings of x_{ih} and $(W_h/n_h)(y_{hi} - \bar{y}_{st})/\bar{y}_{st}$ then dividing the number of trials that are greater than the test statistic by the total number of trials.

Season	Survey	Depth	Temperature	Salinity
Fall	NMFS	<0.005	<0.005	<0.005
Fall	NJDEP	0.129	0.173	0.273
Fall	NYBTS	<0.005	0.518	0.530
Spring	NMFS	<0.005	0.355	0.001
Spring	NJDEP	<0.005	0.173	<0.005
Spring	NYBTS	<0.005	0.001	0.084

Table 2.4. Median and 95% confidence intervals for available and occupied habitat of Atlantic sturgeon (*Acipenser oxyrinchus*) for depth, temperature, and salinity for the fall and spring National Marine Fisheries Service bottom trawl survey (NMFS), New Jersey Department of Environmental Protection finfish survey (NJDEP), and New York Bottom Trawl Survey (NYBTS) where “habitat” represents available habitat and “sturgeon” represents occupied habitat.

Season	Parameter	Survey	Median	95% confidence interval
Fall	Depth (m)	NMFS Habitat	76.0	15.5-260.5
		NMFS Sturgeon	18.0	10.0-25.0
		NJ Habitat	19.0	8.0-27.0
		NJ Sturgeon	16.0	7.0-22.0
		NY Habitat	23.8	9.5-30.3
		NY Sturgeon	10.7	9.0-17.0
	Temperature (°C)	NMFS Habitat	10.6	5.9-22.5
		NMFS Sturgeon	18.9	13.3-23.3
		NJ Habitat	15.8	12.3-18.6
		NJ Sturgeon	14.8	13.3-17.6
		NY Habitat	15.3	13.5-19.3
		NY Sturgeon	16.8	13.6-19.9
	Salinity (ppt)	NMFS Habitat	33.1	31.0-35.4
		NMFS Sturgeon	31.6	29.3-32.0
		NJ Habitat	32.0	29.6-33.5
		NJ Sturgeon	31.5	29.5-33.1
		NY Habitat	31.4	30.1-32.9
		NY Sturgeon	31.3	29.4-31.8
Spring	Depth (m)	NMFS Habitat	76.0	16.0-259.0
		NMFS Sturgeon	18.0	8.0-27.0
		NJ Habitat	19.0	7.5-27.0
		NJ Sturgeon	12.0	7.0-18.0
		NY Habitat	22.4	9.9-29.7
		NY Sturgeon	9.9	9.9-13.9
	Temperature (°C)	NMFS Habitat	6.0	3.4-12.5
		NMFS Sturgeon	6.4	3.2-15.0
		NJ Habitat	9.1	4.9-18.8
		NJ Sturgeon	11.0	5.7-19.0
		NY Habitat	9.4	5.1-14.6
		NY Sturgeon	11.1	5.7-13.9
	Salinity (ppt)	NMFS Habitat	33.2	31.4-35.4
		NMFS Sturgeon	32.0	27.0-32.8
		NJ Habitat	32.0	30.0-34.0
		NJ Sturgeon	30.0	28.8-35.0
		NY Habitat	31.6	30.2-33.1
		NY Sturgeon	30.9	29.9-32.3

Figure 2.1. Coverage area of the Maine-New Hampshire Inshore Bottom Trawl Survey (ME-NH), Massachusetts Division of Marine Fisheries Bottom Trawl Survey (MADMF), New York Bottom Trawl Survey (NYBTS), New Jersey Department of Environmental Protection Finfish Survey (NJDEP), and the National Marine Fisheries Service Bottom Trawl Surveys (NMFS). NMFS coverage area is represented by horizontal stripes while all other surveys are represented by shades of grey.

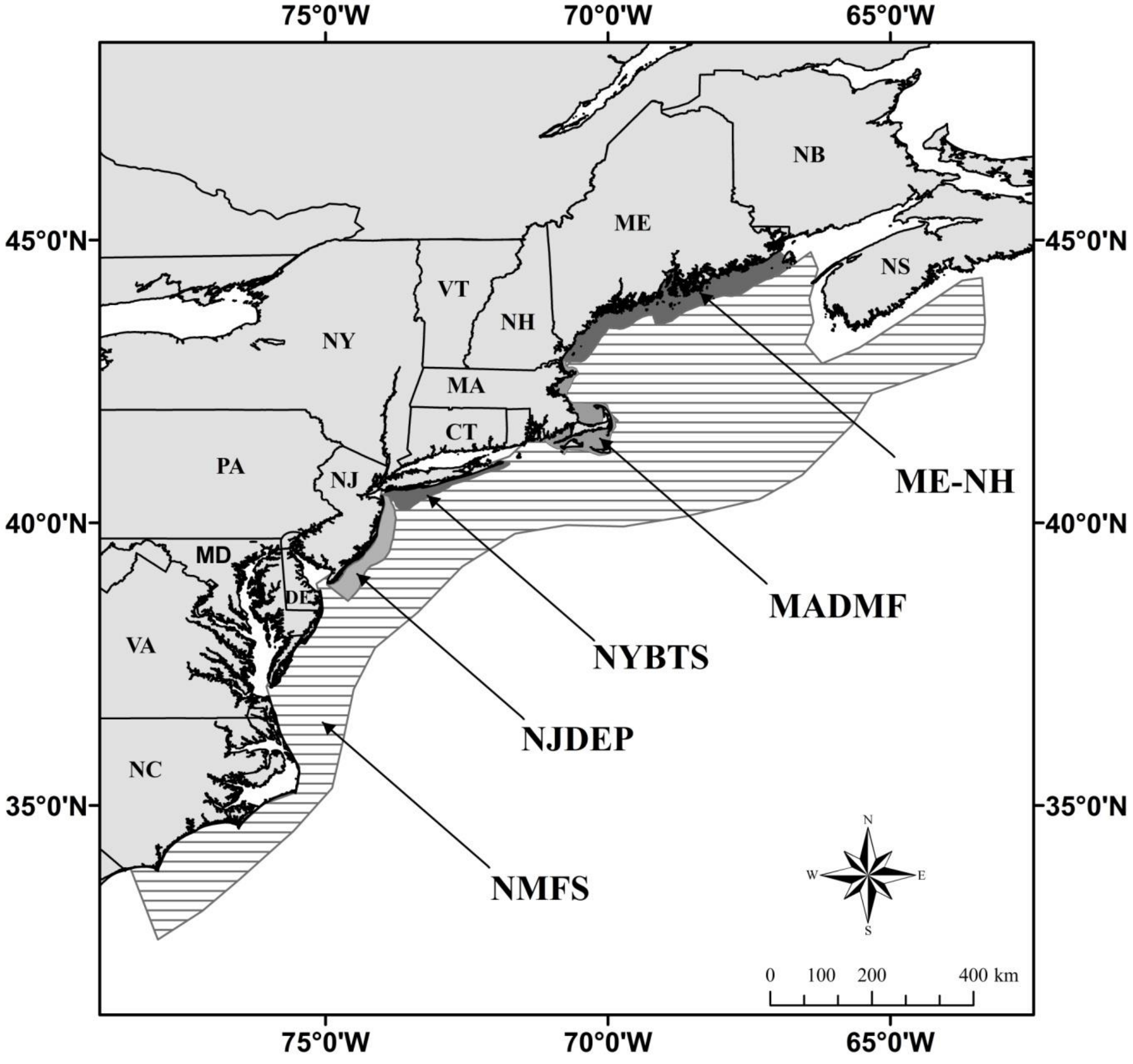


Figure 2.2. Catch per unit effort (CPUE) of Atlantic sturgeon (*Acipenser oxyrinchus*) for the New York Bottom Trawl Survey (NYBTS), New Jersey Department of Environmental Protection Finfish Survey (NJDEP), Maine-New Hampshire Inshore Bottom Trawl Survey (ME-NH), National Marine Fisheries Service Bottom Trawl Surveys (NMFS), and Massachusetts Division of Marine Fisheries Bottom Trawl Survey (MADMF).

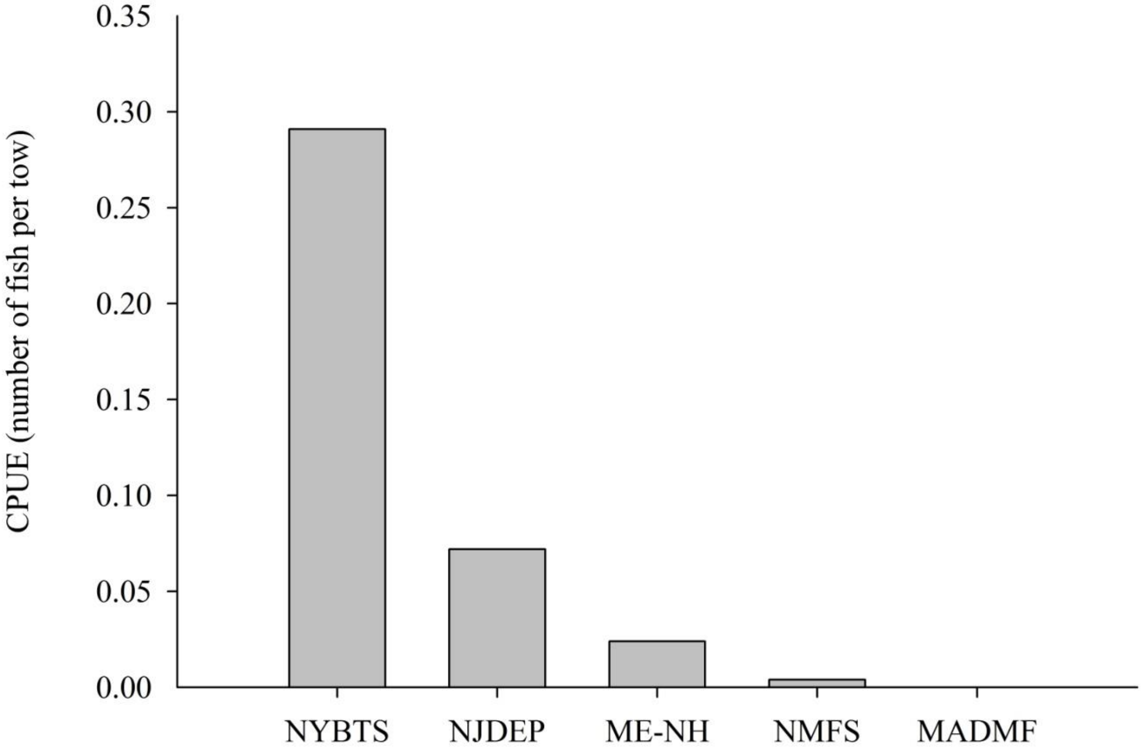


Figure 2.3. Catch per unit effort (CPUE) of Atlantic sturgeon (*Acipenser oxyrinchus*) and frequency of tows conducted by depth for the (A) National Marine Fisheries Service Bottom Trawl Surveys (NMFS), (B) Maine-New Hampshire Inshore Bottom Trawl Survey (ME-NH), (C) New Jersey Department of Environmental Protection Finfish Survey (NJDEP), (D) New York Bottom Trawl Survey (NYBTS), and (E) Massachusetts Division of Marine Fisheries Bottom Trawl Survey (MADMF).

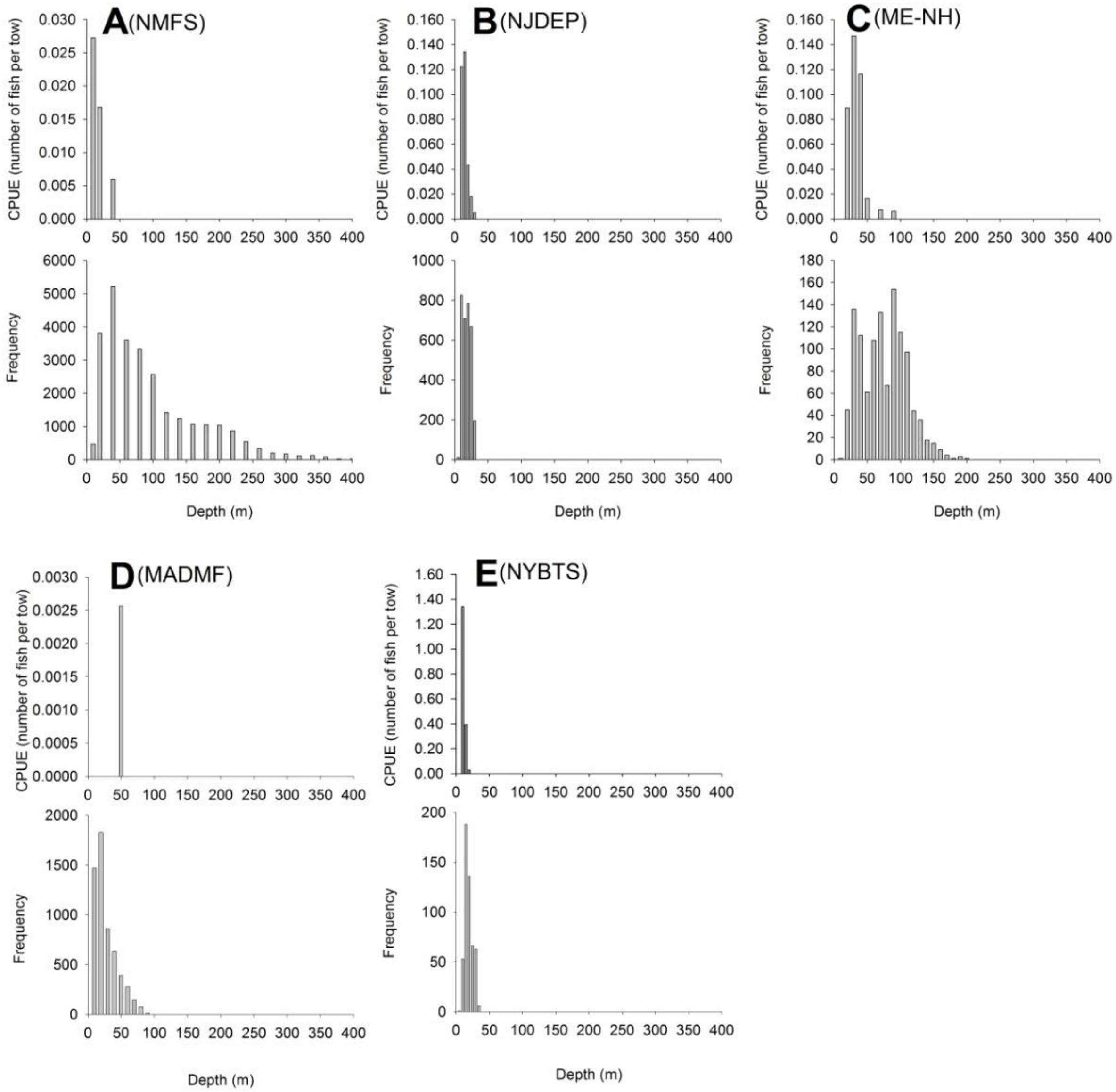


Figure 2.4. Atlantic sturgeon (*Acipenser oxyrinchus*) captures from all surveys during spring months. Circle size corresponds to total number of Atlantic sturgeon captured at a given location (insert A). Locations of all tows can be seen in insert B.

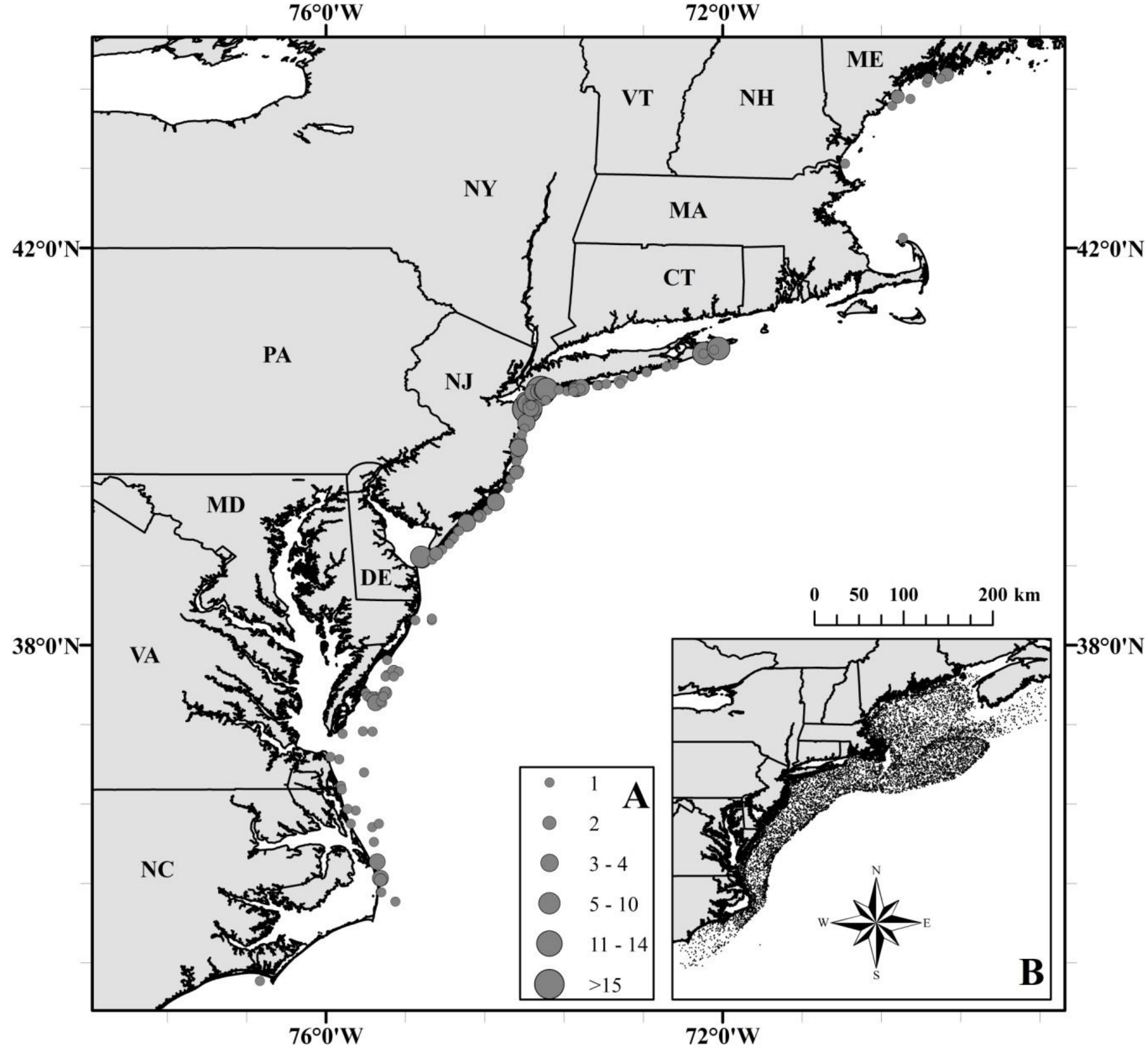


Figure 2.5. Atlantic sturgeon (*Acipenser oxyrinchus*) captures from all surveys during winter months. Circle size corresponds to total number of Atlantic sturgeon captured at a given location (insert A). Locations of all tows can be seen in insert B.

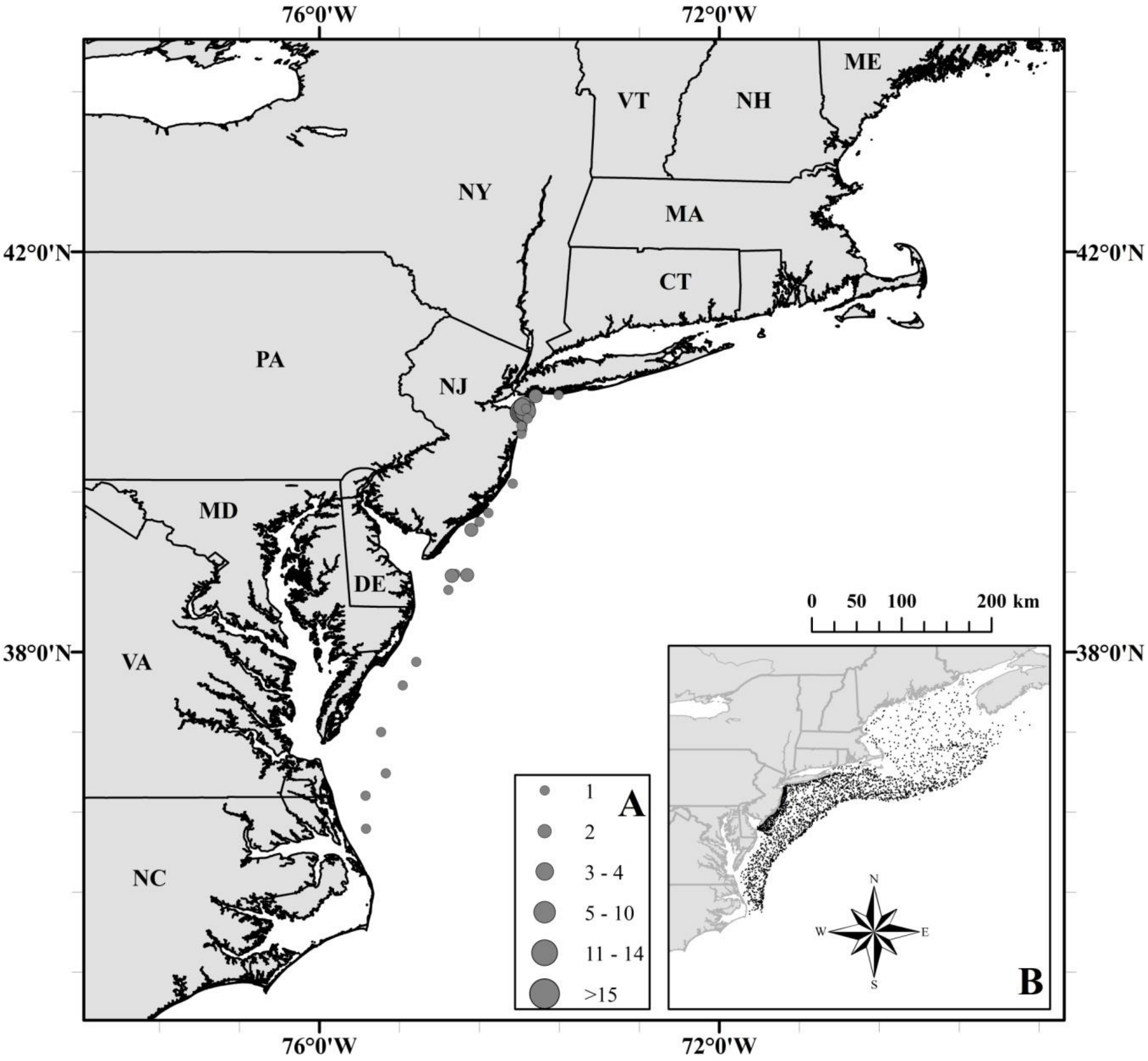


Figure 2.6. Atlantic sturgeon (*Acipenser oxyrinchus*) captures from all surveys during fall months. Circle size corresponds to total number of Atlantic sturgeon captured at a given location (insert A). Locations of all tows can be seen in insert B.

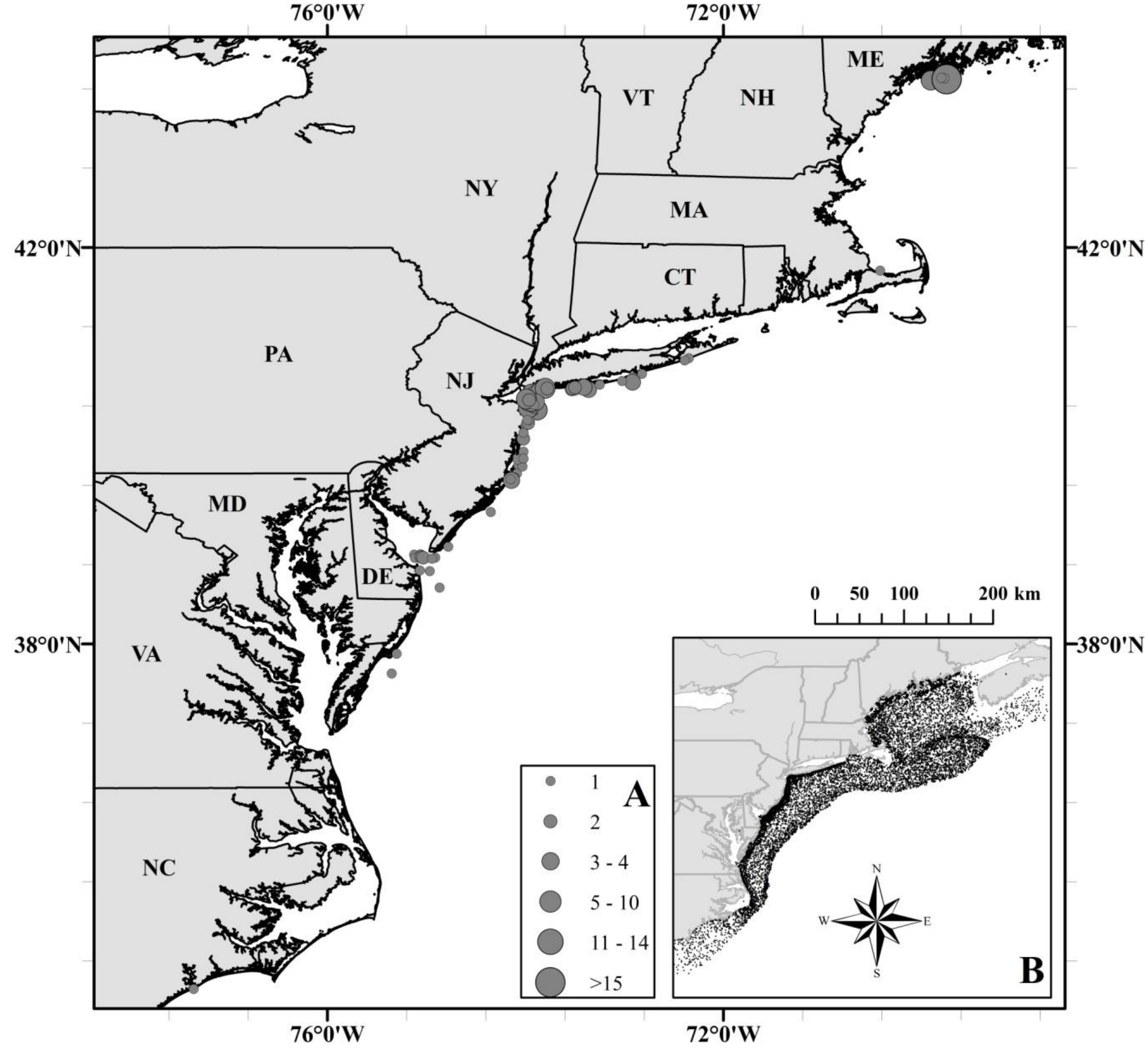


Figure 2.7. Atlantic sturgeon (*Acipenser oxyrinchus*) captures from all surveys during summer months. Circle size corresponds to total number of Atlantic sturgeon captured at a given location (insert A). Locations of all tows can be seen in insert B.

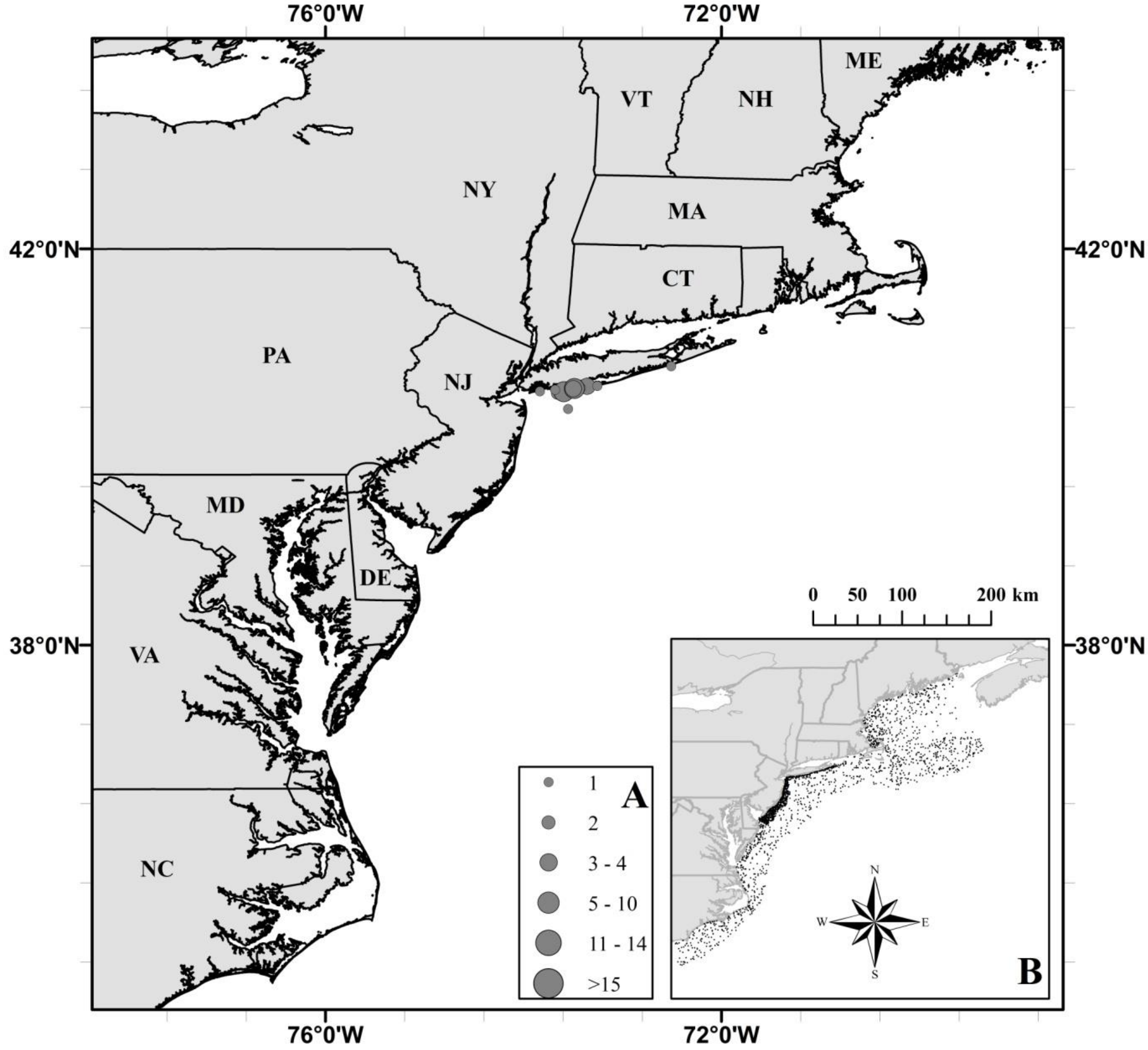


Figure 2.8. Total length distribution of Atlantic sturgeon (*Acipenser oxyrinchus*) captured within all surveys combined over the duration of the above surveys.

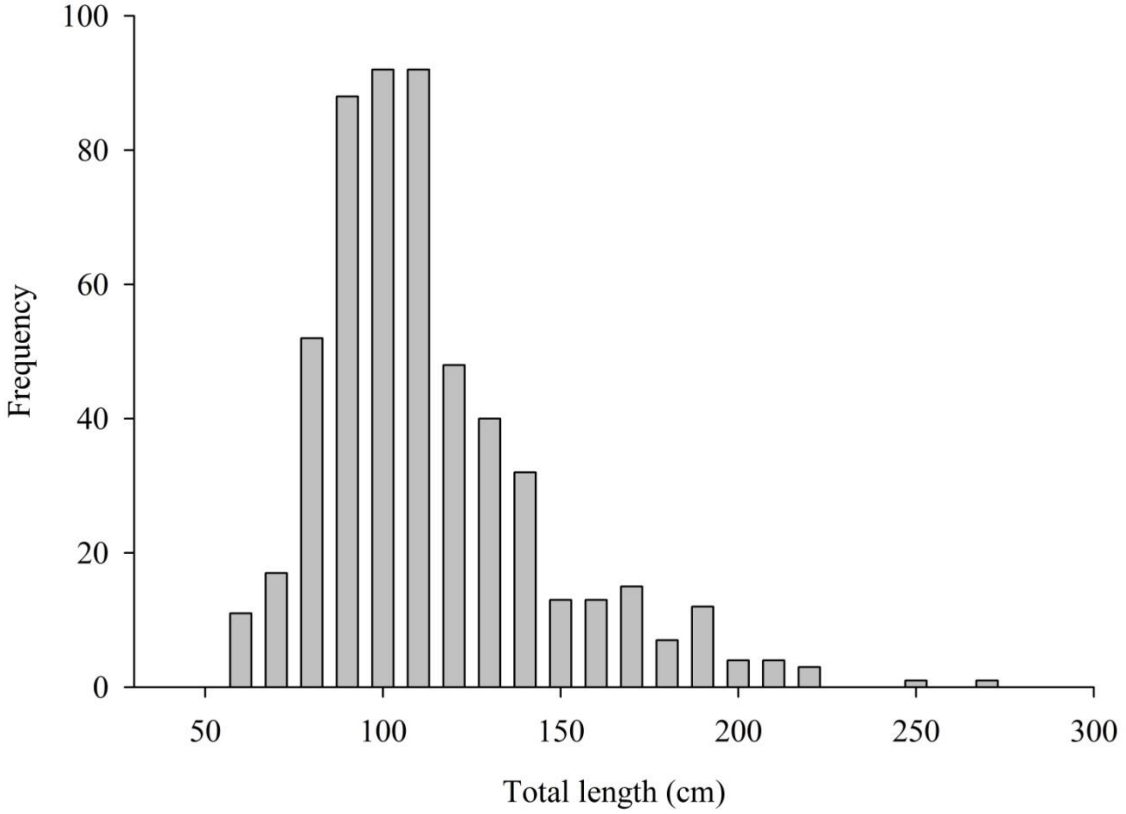


Figure 2.9. Detailed view of Atlantic sturgeon (*Acipenser oxyrinchus*) captures and recommended areas of habitat protection for (a) within the Gulf of Maine; the Maine-New Hampshire bottom trawl surveys (grey) and during the Northeast Fisheries Science Center Industry- industry-based surveys for cod (*Gadus morhua*) and yellowtail (*Limanda ferruginea*) (black). (B) Sandy Hook, NJ and Rockaway NY; includes all captures from the National Marine Fisheries Service bottom trawl survey, New Jersey Department of Environmental Protection Finfish Survey, and New York Bottom Trawl Survey. Dotted lines in both panels represent suggested closed areas.

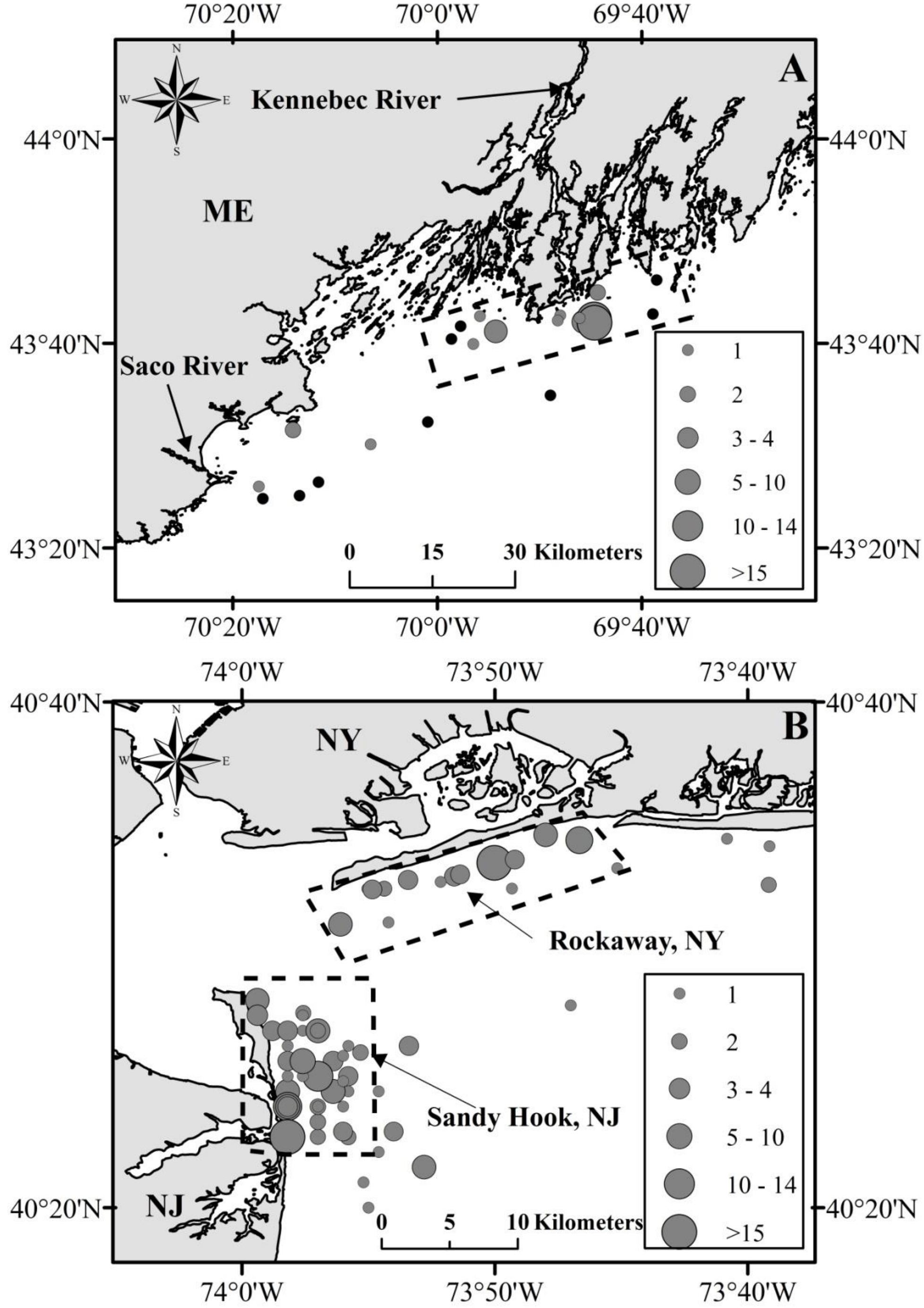
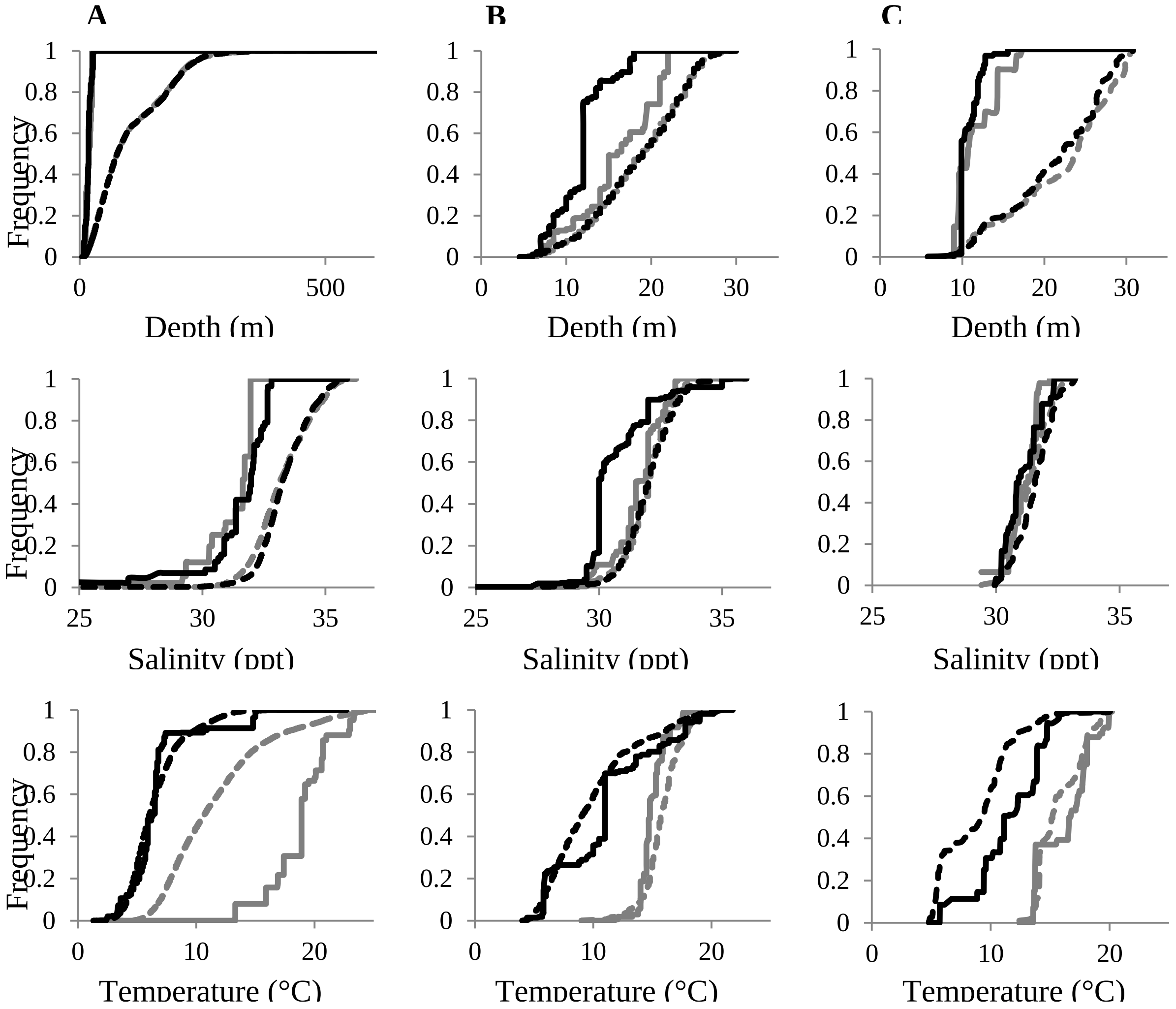


Figure 2.10. Cumulative distribution functions for available and occupied habitat of Atlantic sturgeon (*Acipenser oxyrinchus*) in the fall and spring surveys for (A) National Marine Fisheries Service Bottom Trawl Surveys (NMFS), (B) New Jersey Department of Environmental Protection Finfish Survey (NJDEP), and (C) New York Bottom Trawl Survey (NYBTS) for depth (m), salinity (ppt), and temperature (°C). Solid lines indicate habitat occupied by *A. oxyrinchus* (fall = grey and spring = black) while dashed lines indicate available habitat (fall = grey dashed, spring = black dashed). Note difference in scale in figure.



Chapter 3

Genetic mixed-stock analysis of Atlantic sturgeon *Acipenser oxyrinchus oxyrinchus* in a heavily exploited marine habitat indicates the need for routine genetic monitoring

Abstract

The recovery of the recently listed endangered, anadromous Atlantic sturgeon, *Acipenser oxyrinchus oxyrinchus* (Mitchell 1815), is threatened by incidental mortality in marine fisheries. Although a previous genetic mixed-stock analysis (gMSA) conducted in the early 1990s showed that marine-captured New York Bight Atlantic sturgeon almost exclusively originated from the Hudson River, fish from southern U.S. rivers were well represented within this contemporary sample (n = 364 fish), at least during the fall. Widely distributed spawning stocks are therefore exposed to heavy fishing activity and habitat degradation in this relatively small area, illustrating the need for spatial management across multiple management jurisdictions and routine gMSA to account for temporal change.

Introduction

One challenge of managing anadromous fishes is that they face threats during both the freshwater and marine stages of their life cycle. Although river-based threats primarily affect a single spawning stock due to natal homing, localized marine threats have the potential to affect many stocks due to mixing during this phase of the life cycle (Crozier et al., 2004). Genetic mixed-stock analysis (gMSA) is frequently used to estimate the relative contribution of discrete spawning stocks to fishes under threat in a specific marine location. It is much less common for gMSA to be employed repeatedly over time in order to track how the contribution of different spawning stocks to fishes in a marine area changes (Gauthier-Ouellet et al., 2009). A marked difference in the composition of two collections of Atlantic sturgeon, *Acipenser oxyrinchus oxyrinchus* (Mitchell 1815), from the New York Bight (NYB) that were made 15 years apart is demonstrated. Changes in the stock composition between fall and spring seasons are also demonstrated. These temporal differences highlight the need to establish a time series of gMSA estimates for marine catches of exploited anadromous fishes. The composition of the sampling also has immediate implications for the management of this threatened species.

Atlantic sturgeon is a large, long-lived and late maturing anadromous fish found along the western Atlantic Ocean from the Gulf of St Lawrence to northern Florida (Smith & Clugston, 1997). A directed fishery for this species was developed in 1870 to supply an emerging caviar market (Smith & Clugston, 1997), producing record landings in 1890 that resulted in a fishery collapse in just over a decade (Smith & Clugston, 1997; Secor & Waldman, 1999). During the late 1980s, there was a brief reemergence of the Atlantic sturgeon fishery in New York and New Jersey (Waldman et al., 1996a; Bain et al., 2000; Kahnle et al., 2007). In 1990, the Atlantic States Marine Fisheries Commission (ASMFC) developed a fishery management plan outlining conservation and restoration measures to achieve population levels that support harvests at 10% of the historical peak landings (ASMFC, 1990). Despite this, continued population declines led to a 40 year moratorium to protect 20 year classes of female fish in 1998 (ASMFC, 1998) before being federally listed for protection under the Unites States Endangered Species Act in 2012 (Federal Register 77 FR 5880, 77 FR 5914).

Acipenserids are particularly vulnerable to anthropogenic stressors given their complex life cycle and low intrinsic rates of population increase (Pikitch et al.,2005). Genetic studies suggest that adult Atlantic sturgeon return to spawn in their natal river (Ong et al., 1996; Waldman et al., 1996a, b; Wirgin et al., 2000, 2002, 2007; King et al., 2001; Grunwald et al., 2008; Peterson et al., 2008), which means that overfishing or habitat degradation within rivers can cause rapid, localized and lasting stock collapse. Analyses of mitochondrial DNA (mtDNA) sequences from early juveniles and spawning adults in 12 river systems along the east coast of North America indicate strong population structure with almost all riverine populations being genetically distinct [mean FST values 0.242 (Grunwald et al., 2008)] confirming natal homing by spawning adults and early natal site-fidelity among juveniles (Wirgin et al., 2000, 2007; Grunwald et al., 2008). Incorporating both mitochondrial and nuclear marker data, the Atlantic Sturgeon Status Review Team (ASSRT, 2007) recommended that Atlantic sturgeon be managed as five distinct population segments (DPS) : (1) Gulf of Maine (Penobscot, Kennebec, Androscoggin, Sheepscot, Saco and Merrimack Rivers), (2) New York Bight (Taunton, Connecticut, Hudson and Delaware Rivers), (3) Chesapeake Bay (James, York, Rappahannock, Potomac, Susquehanna and Nanticoke Rivers), (4) Carolina [Albemarle (Roanoke River) and Pamilico Sound (Neuse and Tar Rivers), Cape Fear River, Santee-Cooper River and Winyah Bay (Waccamaw, Great Pee Dee, Black and Sampit Rivers)] and the (5) South Atlantic [ACE Basin (Ashepoo, Combahee and Edisto Rivers) Savannah, Ogeechee, Altamaha, Satilla, St Mary's and St John's Rivers]. In 2012, the National Oceanic and Atmospheric Administration (NOAA) listed these 5 DPS's as threatened (Gulf of Maine) or endangered (New York Bight, Chesapeake Bay, Carolina and South Atlantic) under the United States Endangered Species Act (Federal Register 77 FR 5914, 77 FR 5880).

Considerable research and management attention has been focused on Atlantic sturgeon in rivers, while very little work has been done on the juvenile marine migrant life stage. This requires rectification for at least two reasons: (1) this stage is vagile and encounters a wide variety of threats in the ocean (Dovel & Berggren, 1983) and (2) elasticity indices of acipenserids indicate that mortality of juveniles has a disproportionately large effect on population dynamics (Gross et al., 2002). Atlantic sturgeon by-catch in marine trawl fisheries is estimated at 2000–7000 fish per year (ASMFC, 2007), equivalent to the mortality imposed by directed fisheries during the 1990s (ASMFC, 1998). Although direct mortality of by-catch Atlantic sturgeon from trawls is rarely observed, mortality may be high due to delayed effects on individuals (Davis, 2002; Broadhurst et al., 2006). Because Atlantic sturgeon can only withstand very low levels of anthropogenic sources of mortality (ASMFC, 2007), inshore trawling is now considered the most significant marine threat to population recovery (Collins et al., 1996; Stein et al., 2004). By following shallow (<20 m) migration corridors (Dunton et al., 2010), Atlantic sturgeon gain de facto protection in states that restrict inshore trawling such as Maryland (1.61 km limit), Delaware (no trawling), New Jersey (3.22 km limit) and parts of New York (various no trawl zones in marine waters). There are large areas, particularly in the NYB, where no such closures exist and this species remains vulnerable to by-catch mortality.

Atlantic sturgeon aggregation areas in the NYB, off the coasts of NY and NJ, exhibit the highest abundance of Atlantic sturgeon along the east coast of the U.S.A. and have been recommended as essential fish habitat, warranting either full time or seasonal closures (Dunton et al., 2010). One such seasonal marine aggregation has been observed at the mouth of the Hudson River in an area that is heavily trawled (Dunton et al., 2010). Most individuals within these aggregations are juvenile marine migrants (Dunton et al., 2010). gMSA using restriction fragment length polymorphism of mtDNA conducted in this area prior to the closure of the directed fishery (1993) revealed that aggregating fish were almost always spawned in the Hudson River (97.2%) with a small contribution from southern rivers (2.8%) (Waldman et al., 1996a). If this estimate is representative of the Atlantic sturgeon exposed to inshore trawling today, it means that by-catch in this area greatly affects the Hudson River spawning stock. If fish from other spawning stocks are now present in greater numbers in the NYB, it is essential to assess their exposure to this incidental fishing mortality. The present objective was to revisit the natal origins of fish captured in this area by using gMSA c. 10–15 years after the study conducted by Waldman et al. (1996a).

Methods

Small tissue clips of either the barbel or anal fin of Atlantic sturgeon were collected in 2005–2009 off the coasts of NY and NJ in the NYB during the NJ Department of Environmental Protection's Finfish and the NY Bottom Trawl Surveys (Figure 3.1). Detailed descriptions of the surveys can be found in Dunton et al. (2010). All tissue samples were immediately stored in 95% ethanol until DNA extraction. DNA was isolated from 15 to 25 mg of tissue using DNeasy Tissue Kit (Qiagen Inc.; www.qiagen.com). A 580 bp section of the mitochondrial control region (mtCR) was amplified using Atlantic sturgeon specific primers and amplification protocols previously identified by Wirgin et al. (2000). PCR products were purified by adding 0.25 μl of exonuclease I, 0.50 μl shrimp alkaline phosphatase and 2.0 μl 10× buffer to 50 μl of PCR product and incubated for 15 min at 37◦ C followed by 15 min at 80◦ C. Cleaned products were then sequenced in both the forward and reverse directions using the BigDye Terminator v3.1 Cycle Sequencing Kit (Applied Biosystems; www.appliedbiosystems.com). Sequencing reactions were precipitated with ethanol and 125 mM EDTA and run on an ABI 3730 capillary DNA analyzer. Final mtDNA sequences were assigned haplotypes by comparing the present results to previously identified mtDNA haplotypes that were collected from the five DPSs among other studies (Waldman et al., 1996a; Wirgin et al., 2000; Grunwald et al., 2008), using a known 205 bp region of the mtCR. Estimates of stock composition were made using a maximum likelihood approach implemented in the statistics program for analyzing mixtures, SPAM v. 3.7b (www.cfadfg.state.ak.us). Baseline haplotype frequencies for riverine spawning stocks for the gMSA were obtained from Grunwald et al. (2008) and Wirgin et al. (2000) (Genbank accession numbers: AF162716, AF162717, AF162719, EU726274, AF162721, AF162753, EU726275, AF162722, AF162723, AF162724, AF162725, EU726276, EU726277, EU726278, AF162726, AF162728, AF162729, AF162749, AF162732, AF162733, AF162734, AF162735, AF162736, AF162737, AF162738, AF162741, AF162743, AF162744, AF162745, AF162746, EU726279, AF162748 and AF162751). To demonstrate the accuracy of the gMSA based on the haplotype frequencies observed in these DPS units, a sample of 100 fish drawn exclusively from each DPS unit with 1000 resamplings was simulated in SPAM v.3.7b. The simulation option was then used to estimate the contribution of each of the DPS units to the sample. After the simulation exercise proved that the U.S. DPS units were highly identifiable, the contribution of each DPS unit to the 364 juvenile Atlantic sturgeon sampled was estimated. This was also carried out for the fall and spring seasons on their own (n = 150 and 181). The summer (n = 21) and winter (n = 12) months did not contain enough samples to conduct separate analyses. To evaluate bias and variance in sampling error, the findings were also expressed in terms of the contribution of the five different DPSs to the NYB samples by calculating 90% symmetric C.I. for the contribution of each DPS using bootstrap resampling (n = 1000) of the baseline (i.e. DPS) and mixture (i.e. NYB marine) samples. Significance ($P < 0.001$) of seasonal differences in contributions of DPSs was made using R × C test of independence with William’s correction for an R × C table.

Results

A total of 364 Atlantic sturgeon mtDNA samples were collected and analyzed from 2005-2009 along the coasts of New York and New Jersey (Table 3.1; Figure 3.1). Captured individuals consisted largely of sub-adults ranging in total length (L_T) from 54 to 215 cm, mean 107 cm (Figure 3.2). Overall, the haplotype distribution observed among fish sampled in the NYB is incompatible with these fish, nearly exclusively originating from the NYB-DPS, which is in contrast to the sample analyzed by Waldman et al. (1996a). A total of 16 unique, previously identified (Wirgin et al., 2000; Grunwald et al., 2008), mtCR haplotypes were identified in the NYB collection (Table 3.2). Haplotype B (the common endemic Hudson River haplotype, 42%) and haplotype A (the ubiquitous haplotype, 25%) occurred in the highest frequencies while all other haplotypes, all from populations south of the NYB, each occurred at much lower levels (<5%).

In general, a population is considered highly identifiable based on gMSA when a simulated sample consisting of a 100% contribution from that population is estimated by the analysis to contribute >90% (Anderson et al., 2008). The null hypothesis for the present study was that the fish sampled from the NYB were almost entirely spawned from NYB-DPS units, as found by Waldman et al. (1996a). Thus, the critical question was: Is the NYB-DPS highly identifiable? In the simulated sample consisting of 100% NYB-DPS fish, the estimated contribution was 89.1%, which is near the highly identifiable cut-off (Table 3.3(a)). Upon closer examination, almost all of the assignment error consisted of misassigning NYB-DPS fish to Canadian rivers, which is probably due to the ubiquity of the widespread haplotype A in this region. Few NYB-DPS were misassigned to any of the southern populations and the overall accuracy of the simulation increased to 90.9% when the Canadian populations were excluded

(Table 3.3(b)). It was therefore concluded that the NYB-DPS unit was highly identifiable, especially relative to all of the other U.S. DPS units which allowed a gMSA to be conducted.

gMSA analysis estimated that a majority of the Atlantic sturgeon captured originated from the Hudson River (NY) (70.33%) followed by the Albemarle Sound (NC) (14.38%), James River (VA) (4.91%), Ogeechee River (GA) (3.55%), Savannah River (GA) (3.51%) and Delaware River (DE) (3.32%) (Table 3.4 and Figure 3.3). Significant differences in the relative frequency of spawning stocks were found between the spring and fall seasons ($\chi 2 = 18.47$, d.f. = 11,$P < 0.001$) with a higher per cent of fish originating from the Hudson River (NY) in the spring (78.69%) than in the fall (62.94%) (Table 3.5 and Figure 3.3). Population estimates and bootstrap values for DPSs reveal that fish from the NYB-DPS contribute most to the Atlantic sturgeon captured within the NYB (73.65%), followed by fish from Carolina DPS (14.38%), South Atlantic DPS (7.06%) and Chesapeake Bay DPS (4.91%) (Table 3.5). Mean estimates of 1000 bootstrap resampling yielded similar results with the exception of the appearance of an extremely small contribution (<0.006%) of the Canadian and Maine spawning stock to account for a small fraction of the ubiquitous haplotype A (Table 3.5).

Discussion

The gMSA indicates that the majority (70.33%) of Atlantic sturgeon captured within the NYB originated from the NYB-DPS (probably the Hudson River) with a significant, but small, increase in the percentage of fish from that DPS present in the spring (78.69%) compared to the fall (62.94%) (Table 3.4 and Figure 3.3). A much larger contribution of southern stocks (26.35%) (Carolina > South Atlantic > Chesapeake) in the NYB (Table 3.5 and Figure 3.3) was found in this study than by Waldman et al. (1996a), who sampled NYB fisheries in 1993–1994.

The findings of Waldman et al. (1996a) may differ from the present study because they primarily sampled during the spring (n = 90) with few samples obtained in the fall (n = 22). That study also included larger individuals and adults ranging from 136to 207 cm LT, in contrast to the present study that included primarily juveniles (87.67%) ranging from 54 to 215 cm LT (mean 107 cm) with 89% <136 cm. Under this scenario, Waldman et al. (1996a) may have primarily sampled Hudson-derived adults on their way to the river to spawn. The discrepancy between studies could also indicate a decline in the Hudson River spawning stock, an increase in the size of the southern river spawning stocks or both. Most populations had suffered major overfishing when Waldman et al. (1996a) obtained samples from the NYB fishery. At that time the NYB region accounted for 93% of total commercial landings (Smith & Clugston, 1997; Kahnle et al., 2007) indicating that the Hudson River population was probably the largest at the time, although fisheries dependent data can contain significant spatio-temporal biases. As a result of intense fishing prior to the moratorium, the Hudson River population declined by c. 80% from 1977 to 1995 (Peterson et al., 2000). While there have been slight signs of improvement in abundance of Hudson River pre-migrant juveniles since the mid-1990s, recruitment still remains at historic lows (Kahnle et al., 2007). Although not captured within this study, some Atlantic sturgeon populations, such as the Altamaha River, are in the beginning stages of recovery (Peterson et al., 2008). Thus, the proportion of fish from DPSs aggregating in the NY region will vary depending on the abundance of each stock. Given the possible variation between seasons and years, the present study indicates that regular monitoring of the regional genetic composition of Atlantic sturgeon in marine habitats is needed to track the species recovery and to assess the risks posed by localized marine threats to different spawning stocks. This is probably true for many, if not all, anadromous fishes that are captured in marine fisheries.

Currently NOAA is managing Atlantic sturgeon as five DPS areas (Federal Register 77 FR 5914, 77 FR 5880). This fairly rigid division of genetic structure, based on the freshwater portion of the species life history, does not translate into marine habitat where substantial mixing occurs and local factors far removed from natal rivers can affect populations. Further, improvements or protection in freshwater habitat may not achieve restoration targets while marine juveniles experience by-catch mortality in distant jurisdictions. There is an immediate need to limit by-catch of Atlantic sturgeon in near-shore waters where aggregations commonly form (Dunton et al., 2010). Regular gMSA of incidental catches in marine fisheries is a crucial component of efforts to measure the effect of marine threats to Atlantic sturgeon recovery as fisheries by-catch mortality within the marine environment far removed from the spawning stock of origin may have a significant, yet unrecognized, effect on individual DPSs recovery efforts. The present results also indicate that heavy inshore trawling in the NYB is a potential source of incidental by-catch mortality for fish spawned in rivers from the Hudson River to as far south as the Savannah River. Removing or minimizing this localized threat, perhaps by establishing closed areas similar to neighboring states, is therefore likely to benefit this proposed threatened or endangered species across a large fraction of its range.

Table 3.1. Total number of Atlantic sturgeon genetic samples analyzed by year and season.

Season	2005	2006	2007	2008	2009	Total
Spring	0	7	165	7	2	181
Summer	4	4	0	13	0	21
Fall	0	51	76	20	3	150
Winter	0	0	4	2	6	12
Total	4	62	245	42	11	364

Table 3.2. Observed haplotype distribution from *Acipenser oxyrinchus oxyrinchus* within the New York Bight. Haplotypes were previously identified by Grunwald et al. (2008) and Wirgin et al. (2000) (Genbank Accession numbers: AF162716, AF162717, AF162719, EU726274, AF162721, AF162753, EU726275, AF162722, AF162723, AF162724, AF162725, EU726276, EU726277, EU726278, AF162726, AF162728, AF162729, AF162749, AF162732, AF162733, AF162734, AF162735, AF162736, AF162737, AF162738, AF162741, AF162743, AF162744, AF162745, AF162746, EU726279, AF162748, AF162751).

	Observed Haplotypes																
Season	A	A3	A5	B	B1	B2	C	C3	C4	C5	D	D2	N1	O	P7	S1	Total
Spring	47	2	1	92	2	6	5	0	5	7	2	4	5	2	0	1	181
Fall	39	1	1	51	3	7	8	1	6	8	5	8	6	2	1	3	150
Winter	1	1	0	6	0	0	0	0	2	2	0	0	0	0	0	0	12
Summer	5	0	0	4	0	0	0	1	2	0	2	2	1	2	1	1	21
Total	92	4	2	153	5	13	13	2	15	17	9	14	12	6	2	5	364

Table 3.3. SPAM v. 3.7b (www.cfadfg.state.ak.us) simulation results of a sample of 100 *Acipenser oxyrinchus oxyrinchus* drawn exclusively from Gulf of Maine (GOM) with (a) Canada (GOM–CAN) and (b) without Canada (GOM), New York Bight (NYB), Chesapeake Bay (CHE), Carolina (CAR) and South Atlantic (SOU) distinct population segments (DPS) with 1000 resamplings. Actual mean ± s.d. values are shown for each DPS unit. Bold values indicate the simulation-estimated contribution when the sample is drawn exclusively from the specified source DPS

(a) With Canada	GOM/CAN (100%)	NYB (100%)	CHE (100%)	CAR (100%)	SOU (100%)
GOM/CAN (actual)	**0.9965 ± 0.0113**	0.0490 ± 0.0587	0.0317 ± 0.0479	0.0903 ± 0.1057	0.0624 ± 0.0636
NYB (actual)	0.0000 ± 0.0000	**0.8912 ± 0.0719**	0.0000 ± 0.0000	0.0002 ± 0.0019	0.0000 ± 0.0000
CHE (actual)	0.0000 ± 0.0000	0.0309 ± 0.0339	**0.9519 ± 0.5920**	0.0102 ± 0.339	0.0230 ± 0.0334
CAR (actual)	0.0001 ± 0.0003	0.0010 ± 0.0096	0.0161 ± 0.0405	**0.8738 ± 0.1161**	0.0035 ± 0.0119
SOU (actual)	0.0002 ± 0.0005	0.0194 ± 0.0325	0.0002 ± 0.0008	0.0117 ± 0.0203	**0.8982 ± 0.0716**

(b) Without Canada	GOM (100%)	NYB (100%)	CHE (100%)	CAR (100%)	SOU (100%)
GOM (actual)	**0.9871 ± 0.0345**	0.0247 ± 0.0452	0.0156 ± 0.0356	0.0404 ± 0.0756	0.0199 ± 0.0431
NYB (actual)	0.0000 ± 0.0002	**0.9088 ± 0.0665**	0.0000 ± 0.0001	0.0004 ± 0.0058	0.0000 ± 0.0000
CHE (actual)	0.0000 ± 0.0000	0.0303 ± 0.0340	**0.9583 ± 0.0581**	0.0095 ± 0.0328	0.0218 ± 0.0324
CAR (actual)	0.0005 ± 0.0009	0.0023 ± 0.0132	0.0249 ± 0.0498	**0.9243 ± 0.0891**	0.0049 ± 0.0149
SOU (actual)	0.0016 ± 0.0134	0.0255 ± 0.0402	0.0012 ± 0.0086	0.142 ± 0.0284	**0.9403 ± 0.0563**

Table 3.4. Estimates (mean ± s.d.) of stock composition of *Acipenser oxyrinchus oxyrinchus* using a maximum likelihood approach implemented in the statistics program for analyzing mixtures, SPAM v. 3.7 (www.cfadfg.state.ak.us) for total samples collected (*n* = 364), fall (*n* = 150) and spring (*n* = 181)

	Total	Fall	Spring
Population	Mean ± S.E.	Mean ± S.E.	Mean ± S.E.
Saint Lawrence	0.0000 ± 0.0000	0.0000 ± 0.0000	0.0000 ± 0.0000
Saint John	0.0000 ± 0.0000	0.0000 ± 0.0000	0.0000 ± 0.0000
Kennebec	0.0000 ± 0.0000	0.0000 ± 0.0000	0.0000 ± 0.0000
Hudson	0.7033 ± 0.0327	0.6294 ± 0.0516	0.7869 ± 0.0477
Delaware	0.0332 ± 0.0230	0.0336 ± 0.0329	0.0441 ± 0.0422
James	0.0491 ± 0.0180	0.0768 ± 0.0316	0.0464 ± 0.0242
Albemarle	0.1438 ± 0.0266	0.1899 ± 0.0447	0.0893 ± 0.0338
Edisto	0.0000 ± 0.0000	0.0000 ± 0.0000	0.0000 ± 0.0000
Combahee	0.0000 ± 0.0000	0.0000 ± 0.0000	0.0000 ± 0.0000
Savannah	0.0351 ± 0.0167	0.0412 ± 0.0278	0.0000 ± 0.0000
Ogeechee	0.0355 ± 0.0157	0.0291 ± 0.0252	0.0332 ± 0.0157
Altamaha	0.0000 ± 0.0000	0.0000 ± 0.0000	0.0000 ± 0.0000

Table 3.5. Estimates (mean ± s.e.) of stock composition of *Acipenser oxyrinchus oxyrinchus* using a maximum likelihood approach implemented in the statistics program for analyzing mixtures SPAM v. 3.7 (www.cfadfg.state.ak.us) for total samples collected (*n* = 364), fall (*n* = 150) and spring (*n* = 181) based on distinct population segments

		Expected		Bootstrap values	
	DPS Unit	Mean ± S.E.	90% C.I.	Mean ± S.E.	90% C.I.
Total	Gulf of Maine/Canada	0.0000 ± 0.0000	0.0000	0.0055 ± 0.0168	0.0000 - 0.0434
	NY Bight	0.7365 ± 0.0298	0.6880 - 0.7850	0.7287 ± 0.0417	0.6561 - 0.7969
	Chesapeake Bay	0.0491 ± 0.0180	0.0200 - 0.0790	0.0483 ± 0.0238	0.0037 - 0.0873
	Carolina	0.1438 ± 0.0266	0.1000 - 0.1880	0.1263 ± 0.0432	0.0414 - 0.1886
	South Atlantic	0.0706 ± 0.0170	0.0430 - 0.0990	0.0749 ± 0.0257	0.0405 - 0.1212
Spring	Gulf of Maine/Canada	0.0000 ± 0.0000	0.0000	0.0154 ± 0.0289	0.0000 - 0.0840
	NY Bight	0.8310 ± 0.0383	0.7680 - 0.8940	0.8149 ± 0.0502	0.7295 - 0.8911
	Chesapeake Bay	0.0464 ± 0.0242	0.0070 - 0.0860	0.0443 ± 0.0258	0.0002 - 0.0887
	Carolina	0.0893 ± 0.0338	0.0340 - 0.1450	0.0731 ± 0.0417	0.0000 - 0.1420
	South Atlantic	0.0332 ± 0.0157	0.0070 - 0.0590	0.0418 ± 0.0235	0.0103 - 0.0905
Fall	Gulf of Maine/Canada	0.0000 ± 0.0000	0.0000	0.008 ± 0.0235	0.0000 - 0.0570
	NY Bight	0.6630 ± 0.0489	0.5830 - 0.7430	0.6518 ± 0.0589	0.5533 - 0.7447
	Chesapeake Bay	0.0768 ± 0.0316	0.0250 - 0.1290	0.0783 ± 0.0362	0.0151 - 0.1357
	Carolina	0.1899 ± 0.0447	0.1160 - 0.2630	0.1659 ± 0.0634	0.0470 - 0.2648
	South Atlantic	0.0703 ± 0.0273	0.0250 - 0.1150	0.0745 ± 0.0358	0.0283 - 0.1408

Figure 3.1. Map of the total sampling areas of the New York Bight Trawl Survey (NYBTS; hatched area) and New Jersey Department of Environmental Protection survey (NJDEP; crossed area) and individual locations of where Atlantic sturgeon genetics samples were collected.

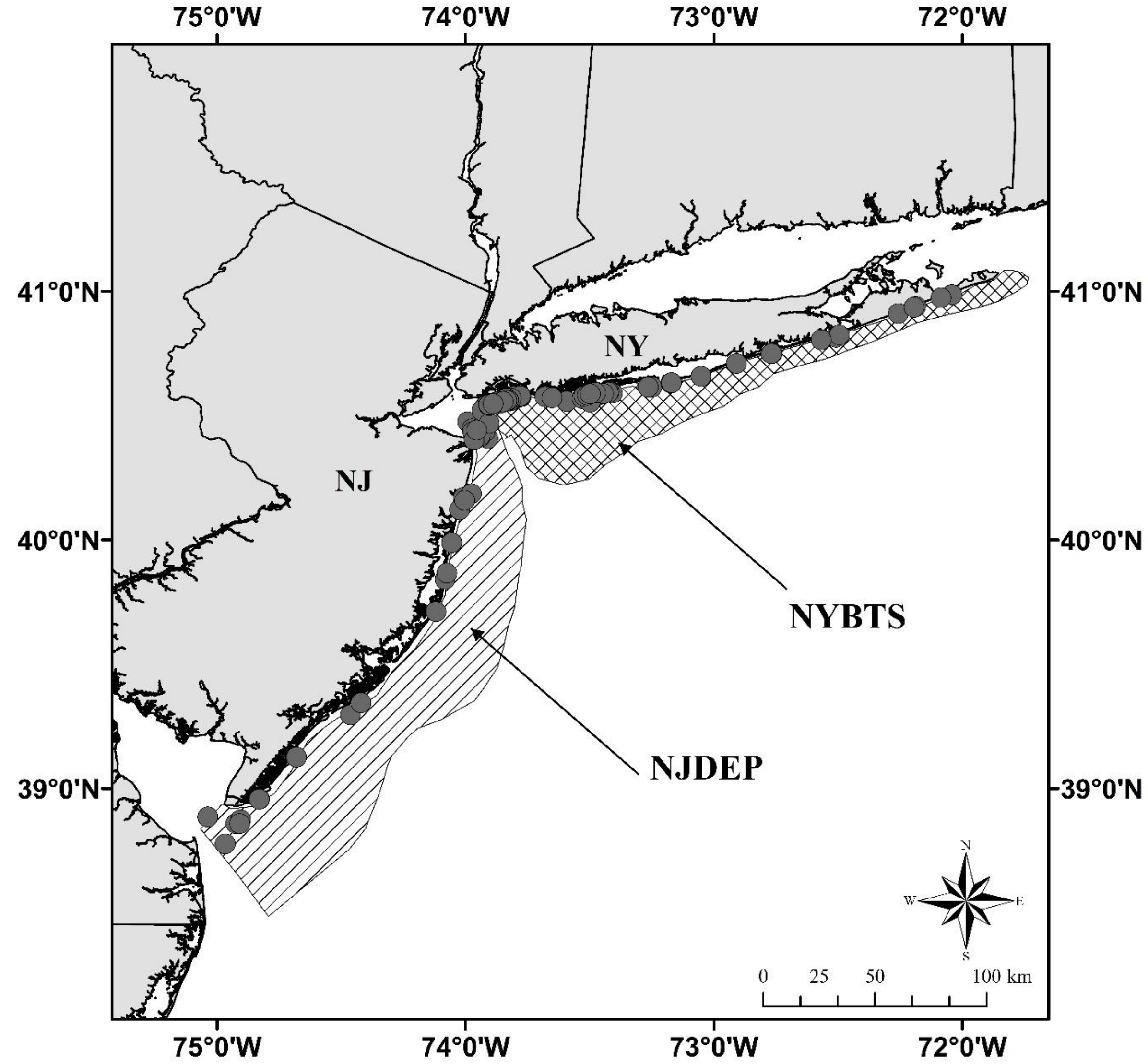


Figure 3.2. Size distribution (total length cm) of *Acipenser oxyrinchus oxyrinchus* (n=364) captured within the New York Bight in 2005-2009 during the New Jersey Department of Environmental Protection's Finfish survey and the New York Bottom Trawl Surveys and used for genetic analyses. Shaded box indicates size range of mature adults (Van Eenennaam and Doroshov 1998; Baine et al. 2000)

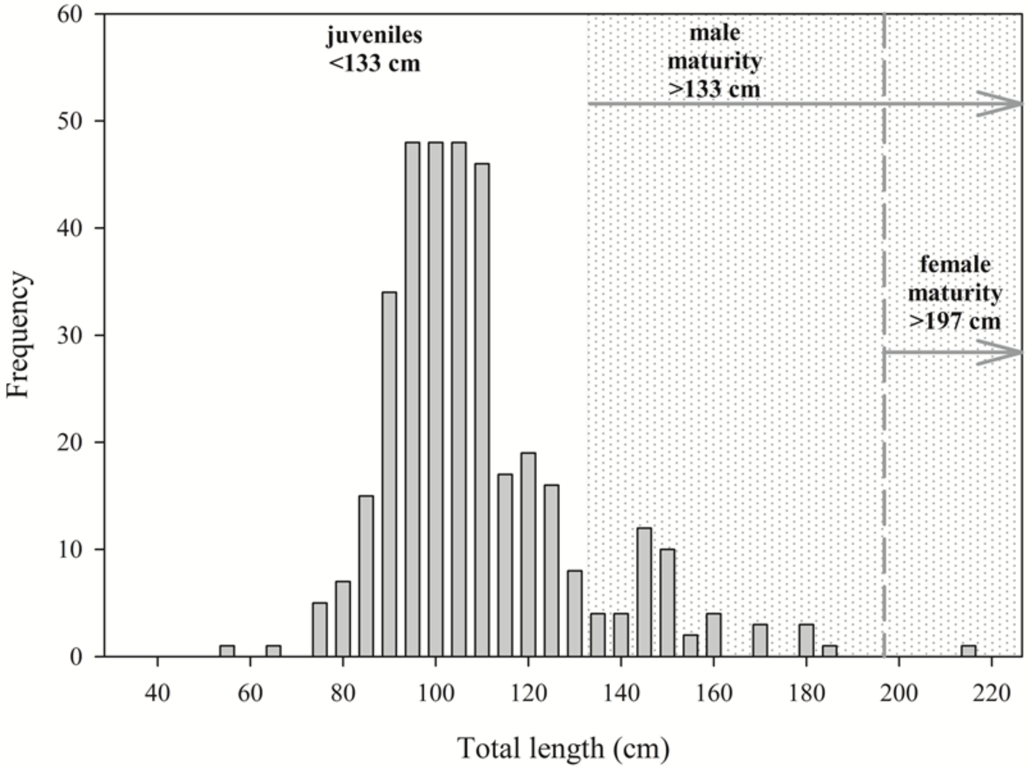
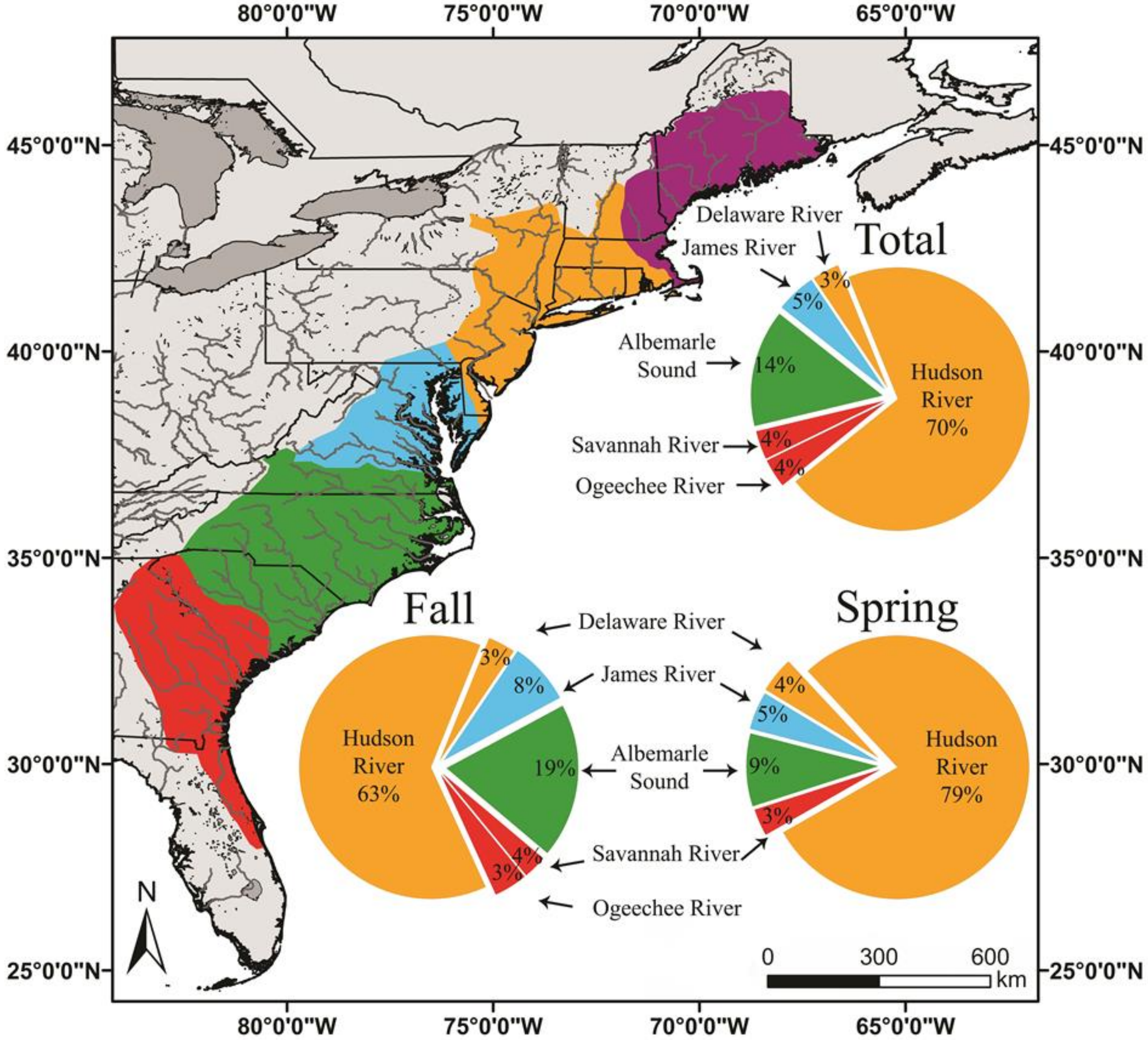


Figure 3.3. Map of the US showing the location of the five *Acipenser oxyrinchus oxyrinchus* distinct population segment (DPS) units: Gulf of Maine (purple), (2) New York Bight (orange), (3) Chesapeake Bay (blue), (4) Carolina (green), and the (5) South Atlantic (red) as defined from the Atlantic Sturgeon Status Review Team (2007). Pie charts show the contribution of each river and DPS unit (colors of DPS units identified above) to the individuals sampled in this study from the New York Bight for spring (n=181), fall (n=150), and overall (n=364).



Chapter 4

Development of age and growth relationships for Atlantic Sturgeon in the New York Bight: Implications for population dynamics and evaluation of a fisheries moratorium.

Abstract

Atlantic sturgeon (*Acipenser oxyrinchus*) is a long-lived fish species that experienced marked population declines which lead to a 1998 coast-wide fisheries moratorium. By 2012, 5 distinct population segments (DPS) were listed under the United States Endangered Species Act by the National Oceanic and Atmospheric Administration. Evaluating the success of management actions and development of fisheries models requires accurate age-determination and length-at-age estimates. Ages for the New York Bight DPS were compiled from multiple research labs and sources in the Hudson River and coastal NY, NJ and DE waters from 1975–2012. Importantly, this work includes additional juvenile marine stage sturgeon that have been generally lacking in past studies. Juveniles were sampled using bottom trawl surveys along the southern shore of Long Island NY and the coast of New Jersey from 2005–2012. Current age structure of Atlantic sturgeon estimated here ranged from 2–35 years with a mean of 8.9. However, most fish ranged from 6–10 years, with relatively few older than 16. von Bertalanffy growth functions produced the following parameters: L_∞ = 278.87, K= 0.057, $t0$ = -1.27, however datasets had poor agreement, potentially resulting from some combination of season, sex ratio, lab effects, gear type and more importantly life stage. Most of the datasets used in prior analysis did not include sexes, which combined with migration-related differences in age frequency and gear selectivity, produced limited age frequencies. Therefore, the information presented here provides the most comprehensive study of Atlantic sturgeon growth and will aid in the development of age-based population models to inform management decisions.

Introduction

Atlantic sturgeon (*Acipenser oxyrinchus*) have a complex migratory life history, remaining in natal rivers for a period of 1–6 years, then emigrating into the marine environment and into non-natal freshwater systems before returning to respective rivers of origin 10–20 years later to spawn (Dovel and Berggen 1983; Van Eenennam et al., 1996, 1998). The combination of slow life history (Musick 1999), late maturation and intermittent spawning, make them particularly susceptible to overfishing and other anthropogenic sources of mortality encountered during migrations (Boreman 1997). Habitat degradation and extensive overfishing in the late 19th century and during the 1970s contributed to low contemporary population sizes (Smith and Clugston 1997). Regional fisheries closures were introduced in 1995, followed by a coast-wide moratorium in 1998. In 2012, 5 distinct population segments (DPS) of Atlantic sturgeon (i.e. Gulf of Maine (GOM), New York Bight (NYB), Chesapeake Bay (CHE), Carolina (CAR), and South Atlantic (SOA)) were provided federal protection under the U.S. Endangered Species Act (Federal Register; 77 FR 5880, 77 FR5914). With populations at low levels and current mortality rates unknown, time horizons required for population recovery remain uncertain.

The largest contemporary US population of Atlantic sturgeon occurs in the Hudson River (Kahnle et al. 2007), which along with Delaware Bay comprises the extant populations of the NYB DPS. The NYB coastal zone ranges from Montauk Point, NY to Cape May, NJ and was historically important as the center of a remerging commercial fishery that ran from the 1980’s until the moratorium, presumably due largely to its proximity to the Hudson River and Delaware Bay populations (Smith and Clugston 1997; Kahnle et al. 2007). Despite small population sizes, aggregations of both adult and sub-adult sturgeon continue to occur in restricted areas outside the Hudson and Delaware Rivers during coast-wide migrations (Dunton et al. 2010; Erickson et al.

2011). Aggregations comprise a genetically mixed stock that is primarily composed of fish originating from the NYB DPS, with other DPS units detected in smaller numbers (Waldman et al. 1996; Dunton et al. 2012; O'Leary et al. 2014), and occur in areas that are exposed to active fisheries and dredging. Due to continued low population sizes, an assessment of anthropogenic activities requires field studies and modeling to estimate the population level impacts to determine whether the previous moratorium and current protection is sufficient to promote recovery. Success of the fisheries moratorium depends on future expansion of the adult spawning stock through accumulation of post-moratorium cohorts. Monitoring the response of the moratorium 14 years after its initiation requires ageing of individuals to determine if there is an accumulation of year-classes following initial protection (ASMFC 1998).

Because of age related differences in habitat use brought on by differential migration and sex-dependent age of first reproduction, population modeling would ideally include an age-based component. The von Bertalanffy growth function (VBGF) relates individual length to age using parameters for the x-intercept (t_0), a growth coefficient (K) and the asymptotic maximum length, L_∞. Apart from quantifying life history characteristics, unbiased estimates of VBGF parameters are essential for age-structured stock assessments (Johnston et al. 2005; Pardo et al. 2013). Age and growth of Atlantic sturgeon has been studied from research surveys (Dovel and Berggen 1983; Kehler 2007), commercial fisheries (Johnson et al. 2005) and by a combination of sampling techniques (Van Eenennam et al. 1996, 1998; Stevenson and Secor 1999; Balazik et al. 2010, 2012). Selectivity due to gear or timing of surveys relative to migration patterns means that all surveys will have inherently biased age-distributions informing estimates of VBGF parameters. Studies ageing Atlantic sturgeon from marine waters have focused on mixed stocks that were targeted by commercial fisheries prior to the 1998 moratorium (Van Eenennam et al.

1996; Stevenson and Secor, 1999; Johnson et al., 2005). The use of data collected from commercial fisheries may be biased and result in underestimation of L_∞ and overestimation of K, since minimum size restrictions at the time were likely selective towards fish with higher growth rates (Stevenson and Secor 1999; Johnston et al. 2005; Kahnle et al. 2007).

Focus of previous work on either early pre-migrant juveniles or adults within natal rivers, and limited at-sea sampling has left gaps in Atlantic sturgeon age estimates during important periods of their life history (Dovel and Berggen, 1983; Lazzari et al. 1986; Van Eenennam et al. 1996, 1998; Stevenson and Secor 1999); namely as marine juveniles (Dunton et al. 2010). Despite potential biases, studies have found growth differences between sexes and among DPS (Vladykov and Greeley 1963; Van Eenennam et al. 1998; Stevenson and Secor 1999; Table 4.1). Since age of maturity, longevity, and growth are influenced by both sex and latitude (Smith 1985), we may expect both geographic (DPS) and within-population (sexes) variation in the form of VBGF which could result in either larger or smaller size at age of DPS compared to NYB.

While fatal sampling is usually required for ageing, the ESA listing prevents research surveys from accruing mortalities. Fortunately, acipenserid ages have been estimated with otoliths, scutes, operculum, and pectoral fin-spines (Stevenson and Secor 1999), with the latter technique being non-lethal (Collins and Smith 1996). While analysis of pectoral fin-spines is not ideal for all species because of biased age estimation (Rien and Beamesderfer 1994; Paragamian and Beamesderfer 2003; Hurley et al. 2004), it has been validated for Atlantic sturgeon as an unbiased method for age determination in both juveniles and adults (Stevenson and Secor, 1999).

The objectives of this study were to 1) evaluate the current age structure of NYB DPS Atlantic sturgeon in the Atlantic Ocean through random and targeted fisheries-independent surveys, 2) create an updated estimate of VBGF parameters using newly collected data and those from past studies to include all life stages, 3) evaluate growth of NYB DPS of Atlantic sturgeon in relation to seasonal, spatial and genetic differences.

Methods

Current collections and age estimation

To examine the current age structure within NYB DPS, Atlantic sturgeon were sampled during bottom trawl surveys conducted by Stony Brook University, along the southern shore of Long Island NY, and by the New Jersey Department of Environmental Protection (NJDEP), along the coast of New Jersey, from 2005 – 2012 (Figure 4.1). Detailed descriptions of the surveys can be found in Dunton *et al.* 2010. Briefly, both trawl surveys utilized a three-to-one two-seam trawl with a 25 m headrope and a 30.5 m (NJDEP) and 30.6 m (Stony Brook) footrope. Nets consisted of 12 cm stretched mesh forward netting, tapering down to the rear netting of 8 cm stretched mesh, lined with 6.0 mm mesh. All bottom trawls conducted after 2009 from Stony Brook University had the 6.0 mm liner removed. The NJDEP survey occurred from Delaware Bay, DE to the NY Harbor Entrance, while the Stony Brook survey occurred from the NY Harbor entrance to Montauk Point, NY. Trawls were restricted to depths less than 30 m. All trawls conducted by the NJDEP were selected with a random stratified design, while those in NY included both random and targeted effort for Atlantic sturgeon and occurred during spring and fall (Chapter 1).

Once on board, all Atlantic sturgeon were measured to the nearest cm (total length and fork length) and weighed (kg). Samples for aging were collected using a non-lethal and non-deleterious technique that involved removing a small 1-2 cm section of the primary pectoral fin spine close to the point of articulation, using a pair of cutting pliers or a saw (Collins and Smith

1996; Stevenson and Secor 1999). Samples collected after April 2012 were collected under the National Marine Fisheries Endangered Species Permit #16422 issued to Stony Brook University. Fin spines were air dried and soft tissue was allowed to undergo microbial decay (Secor and Stevenson 1999). Any remaining tissue was removed through washings under warm water (Balazik *et al.* 2012). Spines were sectioned transversely from proximal to distal by cutting them directly with a Buhler Isomet low speed saw, equipped with two diamond wafering blades, with a spacer between the two blades, allowing for 2 simultaneous cuts. Two to four sections were taken from each fin spine sample with a range in thickness from 0.4 to 0.6 mm. Samples too small to be directly sectioned were embedded in a block of epoxy and then sectioned. All sectioned fin spines were briefly sanded and polished using lapping film (3M 266x series; 3 and 30 micron) and/or 1200 grit sand paper before being examined under 10X magnification with transmitted light (Nikon Eclipse 80i). In addition to reading directly under a microscope, all spines were photographed (Nikon DXM 1200c) and annuli were examined both visually and with ImageJ and ImagePro software. A single annulus is defined by both an opaque and translucent zone that could be distinctly and readily identified around the spine (Stevenson and Secor 1999)(Appendix 3). All age samples were read blindly a minimum of 2-3 times, with precision among readings estimated by the coefficient of variation as follows:

$$(1)\quad CV_j = 100 * \frac{\sqrt{\sum_{i=1}^{R} \frac{(X_{ij}-X_j)^2}{R-1}}}{X_j}$$

where CVj is the precision of the age estimate for the jth fish, X_{ij} is th i^{th} age estimate for the j^{th} fish, X_j is the mean estimate of the j^{th} fish, and R is the number of times a fish is aged (Campana 2001). Bias was evaluated using a subset of spines that were examined by a second reader and compared to a 1:1 line. Readers estimated ages with no prior knowledge of biological data, previous age estimates, or collection dates.

Additional and available age data for MAB Atlantic sturgeon

Age estimates were combined from this study and several other published (Dovel and Begrennan 1983; Kehler 2007; Stevenson and Secor 1999; Van Eenennam and Doroshov 1998) and unpublished studies (Hattela unpublished; Fisher unpublished). Collectively the data covered a wide range of size and life-stages (Table 4.2; Figure 4.2). All ages were estimated using fin spine sections, except those from Hatella (unpublished) that had known age and lengths as they were recaptures of hatchery-released fish (described in Mohler *et al.* 2012). Ages from Fisher were estimated through fin spines collected from directed sampling as well as observed mortalities of Atlantic sturgeon within the Delaware River and Delaware Bay systems. Based on the location and timing of sample collections consolidated within this study, these fish largely represent the NYB DPS and the influence of genetic effects on growth rates by different DPS units is likely negligible based on genetic evidence of fish collected. The timing of fish collection from NY/NJ coastal commercial fishery during the 90's (Stevenson and Secor 1999; Van Eenennam et al., 1996, 1998; Johnson et al. 2005) overlapped with a genetics study showing that 97.2% ± 6.8% S.D. of fish caught within the NYB were of NYB origin (Waldman et al. 1996). Collections of younger fish came directly from within the Hudson River (Dovel and Berggen, 1983; Kehler 2007; Hattela unpublished) or Delaware River (Fisher unpublished) and are assumed to be of NYB origin since they were under the documented age of emigration from natal rivers from 1-6 years of age (Dovel and Berggen, 1983).

Estimation of von Bertalanffy growth function parameters

To evaluate growth of Atlantic sturgeon within the NYB DPS, the von Bertalanffy growth function (VBGF) was estimated using age and length data. Model fitting was achieved with nonlinear least-squares analysis, using the nls() function in R (R Core Team, 2013). The VBGF takes the following form:

$$(2) \quad L_t = L_\infty \left(1 - e^{-K(t-t_0)}\right)$$

where L_t is length at age t, L_∞ is the asymptotic length, t is age, t_0 is the hypothetical age at zero length, and K is the growth coefficient. Sexes were combined in a single growth model since sex determination was not available in all studies and because there was considerable overlap in size-at-age between juvenile age classes. To assess how each dataset affected the overall model fit, we performed a series of bootstrap routines to examine the impact of each of the datasets on parameter estimates of the overall growth model. For each model, we first ran 10,000-replicate bootstraps and then additional bootstraps, each time removing one of the eight datasets. The analysis produced 95% confidence intervals for K, L_∞ t_o for each independent dataset and cumulatively for all of them. Because sources provided data of differing sample size, we also ran the above analyses keeping the size of pseudo-samples constant. The impact on overall results were negligible, therefore are not displayed here.

Effects of genetics

To evaluate the potential confounding effects of DPS origin on growth, a subset of aged Atlantic sturgeon were also evaluated against river of origin using nDNA. In addition to the age samples collected, small tissue clips from the anal fin were collected and immediately stored in 95% ethanol until DNA extraction. DNA was isolated from 25mg of tissue using DNeasy Tissue

Kit (Qiagen Inc., Valencia, CA, USA) (Dunton et al. 2012). nDNA was amplified and analyzed at 12 microsatellite loci at the USGS Leetown Science Center using methods previously described (King et al. 2001; Henderson-Arzapalo and King 2002). River of origin and DPS were assigned using baseline data described by Waldman et al. (2012).

Results

Current age structure within the NYB

A total of 742 (Stony Brook University Trawl n = 657; NJDEP, n = 85) captured Atlantic sturgeon had readable spines (Figure 4.3a). The total number of sturgeon captured, and hence spines read, varied each year from 12-316 (Figure 4.4). There were 21 estimated age classes with Atlantic sturgeon ages ranging from 2-35 years old with a mean of 8.89 years old (S.D.=3.027)(Appendix 4). Total length ranged from 54-248 cm; mean = 109.30 (S.D = 22.67) (Figure 4.2a).

Significant differences were found between NY (9.03 years) and NJ (7.76 years) ($p = 0.0003$; pairwise t-test with Bonferroni correction). Pairwise comparisons with Bonferroni correction showed significant seasonal variation ($p<0.0001$), with winter (5.97 yrs) significantly different than spring (8.89 yrs), summer (9.03 yrs), and fall (9.29 yrs). The majority of Atlantic sturgeon caught by Stony Brook University and NJDEP during nearshore NY Bight surveys (2005-2012) were immature sub-adults (84.7%) less than 12 years of age.

Precision of age estimates by different readers was determined for a subset of 64 samples. These results indicated a CV of 3.78% and an age bias plot showed no evidence of bias in the estimation between readers (paired t-test, $p = 0.469$). There was 62.5% exact age agreement, 28% within 1 year, 7% within 2, 1 fish having a discrepancy of 3 years indicating no systematic errors were found (Figure 4.5).

Growth curves

The number and range of estimated ages and sizes varied among studies and comprised a total of 2,774 samples collected and processed from the Hudson River, coastal NY, NJ and DE from 1975-2012 (Table 4.2; Figure 4.6). These data were used to estimate VBGF parameters for ages ranging from 0 – 43 years old and size from 16 – 277 cm TL (mean 114.35; S.D. = 48.69) (Figure 4.6). Pooled ages using the VBGF produced estimates L_∞ = 278.87, K= 0.057, t_0 = -1.28 (r^2=0.87) (Figure 4.6). 95% confidence intervals from bootstrap estimates of VBGF produced a range of 267.42 – 292.60 for L_∞, 0.052 – 0.062 for K and -1.45 – -1.11 for t_0 (Figure 4.8).

With the exception of the Stevenson and Secor (1999) data and the data from this study, removal of individual datasets resulted in L_∞ and K estimates that remained within the 95% C.I. for the combined data (Figure 4.7). t_0, however, was more sensitive to the removal of data (Figure 4.7). With the removal of data from Dunton, the overall L_∞, decreased, while K and t_0 increased; (L_∞ = 249.51 (95% C.I. 241.42 – 259.01), K= 0.07 (95% C.I. 0.071 – 0.082), t_0 = -0.71 (95% C.I. -0.86 – -0.55) (Figure 4.6). In contrast, removal of data from Secor increased L_∞ and decreased K and t_0 (L_∞ = 382.99 (95% C.I. 350.31– 448.19), K= 0.03 (95% C.I. 0.03 – 0.04), t_0 = -1.93 (95% C.I.-2.23 – -1.70) (Figure 4.7). The results are not completely unexpected as the age distribution is restricted to older fishes in Stevenson and Secor (1999) and juveniles in Dunton (Figure 4.2).

Age and genetic structure

Age collections from this study ranged between 73-86% NYB origin based on previous estimates by Dunton *et al*. 2012 that used mtDNA, and the current study using gDNA. Of the 742 aged sturgeon in this study, 203 fish had age and associated gDNA with DPS assignments available. A total of 86.21% were New York Bight (Hudson = 149, Delaware = 26), 7.39 %

Chesapeake Bay (James River = 15), 2.46% South Atlantic (Albemarle = 3, Ogeechee = 3; Savannah = 2), 2.46% Gulf of Maine (Kennebec = 3, St. John = 2), and 1.48% Carolina (Albemarle = 3) (Figure 4.9). Small sample sizes of other DPS units prevented any direct comparisons of growth rates among populations, although no fish younger than 8 years old were identified as non-NYB DPS fish.

Discussion

Complex long distance migrations, mixing of stocks, and changing habitat-use of Atlantic sturgeon makes representative sampling a challenge. The combined dataset provided a range of length sizes covering the full life cycle of Atlantic sturgeon. However, despite the nearly ideal representation of length groups, biases were observed in VBGF parameter estimates. The influence of sampling location and/or researcher effects impacted estimated growth parameters. Analysis of contemporary age composition shows the beginnings of the accumulation of spawning age fish in the population during the post-moratorium period. The moratorium appears to have had a positive effect, but increases of adult abundance should be confirmed on spawning grounds. The late maturity and intermittent spawning of Atlantic sturgeon mean that the time required for fish to achieve their maximum size and for populations to recover to stated management targets is uncertain and may take decades. Comparatively, shortnose sturgeon (*Acipenser brevirostrum*), which live 37+ yrs, mature earlier (3-8 years old), spawn more frequently than Atlantic sturgeon, and have overlapping habitat during freshwater and brackish stages, show signs of recovery 40 years after being listed as endangered (Baine et al. 2007; Woodland and Secor 2007). If Atlantic sturgeon follows the same trend as the riverine shortnose sturgeon, time horizons approaching a century should be anticipated based on overall life history differences.

The observed age distribution in the most recent marine surveys was biased towards juveniles (84.7%), resulting from either differential habitat use among life stages, reduced catchability of adults, or low numbers of adult fish. Recent genetic analyses suggest that Atlantic sturgeon populations have low effective number of breeders and show evidence of inbreeding (O'leary 2013), suggesting that low CPUE of adults may reflect a continuing legacy fisheries effect. The rarity of large fish reflects a common trend in the truncation of size frequencies by commercial fishing (Stevenson and Secor 1999; Johnston et al. 2005). The timing of moratoria initiated in 1996 for New York and coast-wide in 1998, means that the first cohort protected in the Hudson River would have reached maturity in 2010 and signs of recovery of adult age structure will take an uncertain amount of time given poorly understood survival rates. Early signs of improvement of NYB DPS adult spawner abundance could be observable in the next few years. However, there is concern that current bycatch within the marine environment and other sources of mortality continue to impede population recovery (ASRT 2009). Bycatch reported by Stein *et al.* (2004) demonstrates how commercial fishing can impact sturgeon populations, while Dunton *et al.* (2010) and Erickson *et al.* (2011) identified aggregation areas in the NYB that are susceptible to high levels of bycatch during migration periods.

Maturity schedules of Atlantic sturgeon are influenced by latitude with males and females maturing as early as 8 and 10 years within southern DPS's and greater than 22 years old in Canadian populations (Smith 1985). Males and females from the NYB DPS achieve maturity as early as 12 and 14 years, respectively (Van Eenennam et al. 1996, 1998). Sturgeon from non NYB DPS's began to show up within the NYB at 8 years old, with the closest DPS, Chesapeake, being most frequently identified. Sturgeon from the South Atlantic DPS were absent until about

10 years of age. Thus, most fish sampled were immature juveniles of the NYB DPS, while fish from the southern DPS were predominantly mature individuals given their higher age assignments and presumed early maturity schedule. The lack of other DPS's and dominance of NYB DPS fish at age classes less than 8 years old, suggests that young fish are migrating over shorter distances and therefore share different and more localized risks and threats relative to adults.

Growth estimates from combined datasets provided an improved statistical fit for the NYB population with a high overall model fit ($r^2 = 0.82$), and fairly narrow bootstrap-estimated 95% C.I.s for all parameters. The sequential removal of datasets from our bootstrap methods resulted in strong study effects on estimated values of K (mean 0.057, range 0.03 -0.08) and L_∞ (mean 278.87; range 249 – 382 cm TL). This phenomena can be seen with the exclusion of the contemporary NYB study consisting of juveniles (higher L_∞, lower K) and the Stevenson and Secor (1999) study that focused on larger individuals (lower $L_{\infty,}$ higher K). In general, previous studies that focused on juvenile stages produced faster growth rates leading to the overestimation of K. The growth models that used only juvenile data resulted in near linear growth functions (Balazik et al. 2012). The large effect of research focused on a single stage or area resulted in strong biases in estimated growth parameters and argues for large-scaled and coordinated ageing studies that represent all life stages and habitats of the species.

Peak fisheries for Atlantic sturgeon occurred from 1880-1890 and focused primarily on large females for caviar. Reports of that period provide a source of comparison for large females captured in the fishery. Ryder (1890) suggests that females averaged 244 cm TL and sometimes reached 305 cm, while males averaged 183-213 cm. Cobb (1899) reports females averaging 159 kg and males 30 kg and lengths of 305 cm were not uncommon. The oldest aged Atlantic sturgeon on record was 60 years and 233 cm FL taken in the St. Lawrence River, Canada (Magnin 1964), where population growth is slower than the NYB. The maximum size of Atlantic sturgeon has been proposed to be as large as 540 cm (Bigleow and Schroeder 1953; Smith 1985), with the largest reported observed specimens measuring 272 kg (Bigelow and Schroeder 1953) and 368 kg and a length of 426.72 cm reported for the northern DPS (Vladykov and Greely 1963). Our estimates of L_∞ are within the size range of sturgeon captured in the late 1880's and early 1900's, indicating reported parameters fall within the observed biological range of the species. The combined dataset model failed to reach estimated L_∞'s near maximum observed sizes, likely reflecting the lack of older specimens.

The historical, pre-1900 to early 1900, fishery led to the collapse of the population by targeting the largest reproductive females and was followed by a fishery governed by a minimum size limit that targeted the largest juveniles (post-1990). Such long-term selection for the largest individuals suggests evolutionary effects of selection are possible (Conover and Munch 2002). These fishing practices would have selected of early sexual maturation and smaller individuals, especially since populations were driven close to extirpation with the long-term and consistent removal of the largest fish. Similarly, minimum size limits likely led to the disproportionate selection on faster growing fish that are harvested at a younger age as they enter the fishery. Recently, O'leary et al. (2014) has shown a detectable amount of inbreeding occurring within the Delaware and Hudson River populations indicating that genetic effects of overfishing a century ago may still be prevalent in contemporary populations. While the evolutionary effects of fishing have the potential to be reversed over time, it may take several generations for this to occur (Conover et al. 2009).

Sex-dependent growth patterns in Atlantic sturgeon have been suggested as early as the 1890's (Ryder 1890; Cobb 1899) and have been supported by recent evidence showing that females grow slower but reach a larger maximum size than males (Van Eenennam 1998; Stevenson and Secor 1999). A latitudinal gradient in growth and maximum size likely exists for Atlantic sturgeon populations, with southern populations having a higher growth rate but obtaining a smaller maximum size (Smith 1985, Stevenson and Secor 1997; Johnson et al. 2005). Previous studies estimating the VBGF have identified a maximum length (L_∞) ranging from 184-315 and K from 0.3-0.14 for various populations (Table 4.1). Here the combined dataset, covering all life stages and sexes of the species, resulted in reasonable estimates of K 0.052 – 0.062 and L_∞ 267.42 – 292.60 providing a growth model that can be used for management of the NYB DPS. The L_∞ reported here was the largest value estimated in the US for combined sexes and matched sizes commonly captured in the historic fisheries. However, the considerable, known and unknown, demographic variation by sex, region, and genetic population suggests growth estimates for Atlantic sturgeon should be used with caution until research can address the full demographic complexity of the species.

Sixteen years have passed since enactment of the 1998 fishing moratorium and signs of population recovery should start to be observable within rivers as the first round of protected year-classes begins to spawn. Population monitoring (Sweka et al. 2007) and indices of early juvenile abundance are crucial for the detection of strong year-classes and can serve as early detection for recovery and success of protection (Woodland and Secor 2007). Since both annual spawning and recruitment success is highly variable and may even not occur during unfavorable conditions (Bemis and Kynard 1997), several strong year classes will be needed for rapid population growth and recovery (Woodland and Secor 2007). Although the link between early juvenile to sub-adult survival is unknown, continued sampling of the marine environment is needed to estimate how many are recruiting to this life stage. The next 20 years will present an opportunity to detect signs of population recovery and understand demographic shifts that may become apparent. If no improvement is apparent in juvenile or adult abundances, then attention will have to shift to a broader range of impacts and managers will have to work towards identifying sources of mortality through population modeling approaches. This information can in turn be used to develop rebuilding plans, and identify potential threats to recovery.

Table 4.1. Summary of VBGF parameters estimated from previous studies (Modified from Stevenson and Secor 1999). Sample sizes from Smith 1985 represent age classes and VBGF was calculated using mean size-at-age. Smith 1985, Van Eenennam et al. 1996, and Johnston et al. 2005 and Balazik et al. 2012 was converted from FL to TL using the regression TL = 1.10FL+5.02 (r^2=0.993)(See Appendix for FL-TL conversion)

Study	**Sample size**	**K**	**L∞ (cm)**	**Sex**	**Study area**
Magnin 1964	582	0.03	315	Combined	St. Lawerence
Smith1985	7	0.06	236	Combined	Kennebec, ME
[a]Stevenson and Secor 1999	634	0.08	225	Combined	Hudson River and NYB
	225	0.07	251	Female	
	301	0.25	180	Male	
[b]Van Eenennam et al. 1996	142	0.064	290	Female	Hudson River and NYB
	161	0.11	226	Male	Hudson River and NYB
[c]Johnston et al. 2005	303	0.144	197	Combined	NYB
	86	0.122	224	Female	
	79	0.147	203	Male	
Balazik et al. 2012	202	0.05-0.097	251	Combined	James River, VA
Smith 1985	24	0.12	242	Combined	Winyah Bay, SC
Smith 1985	17	0.14	184	Combined	Suwannee River, FL
This Study (includes [abc])	2774	0.06	279	Combined	NYB, Hudson River, Delaware Bay

Table 4.2. Summary of information from Atlantic sturgeon age samples used in the von Bertalanffy growth function.

Study	**Collection method**	**Sample years**	**Sample location**	**Sample size**	**Size range TL (cm)**	**Age range (yrs.)**
This study	Research trawl	2005-2012	Atlantic Ocean	742	54 - 258	2 - 35
Tom Kehler (2007)	Research gillnet	2003-2005	Hudson River	520	36 - 110	1 - 8
Stevenson and Secor (1999)	Commercial Fishery	1993-1995	Hudson River and Atlantic Ocean	490	43 - 277	1 - 34
Van Eenennam et al. (1996)	Commercial Fishery	1992 -1995	Hudson River and Atlantic Ocean	303	56 - 277	2 - 43
Johnston et al. (2005)	Commercial Fishery	1992-1994	Atlantic Ocean	303	97 - 219	5 - 26
Dovel and Berggren (1983)	Research trawl	1975-1978	Hudson River	124	16 - 239	0 - 29
Matt Fisher (unpublished)	Research gillnet; mortalities	2008 - 2011	Delaware Bay	59	24 - 255	0 - 31
Kathy Hattela (unpublished)	hatchery release	1994-2005	Various	238	40 - 200	2 - 17

Figure 4.1. Regional map of collection locations of contemporary pectoral fin spines for aging of Atlantic surgeon, *Acipenser oxyrinchus*. Samples were taken from 2005-2012 during New Jersey Department of Environmental Protection (dotted area) and the Stony Brook University (hatched area) bottom trawling surveys.

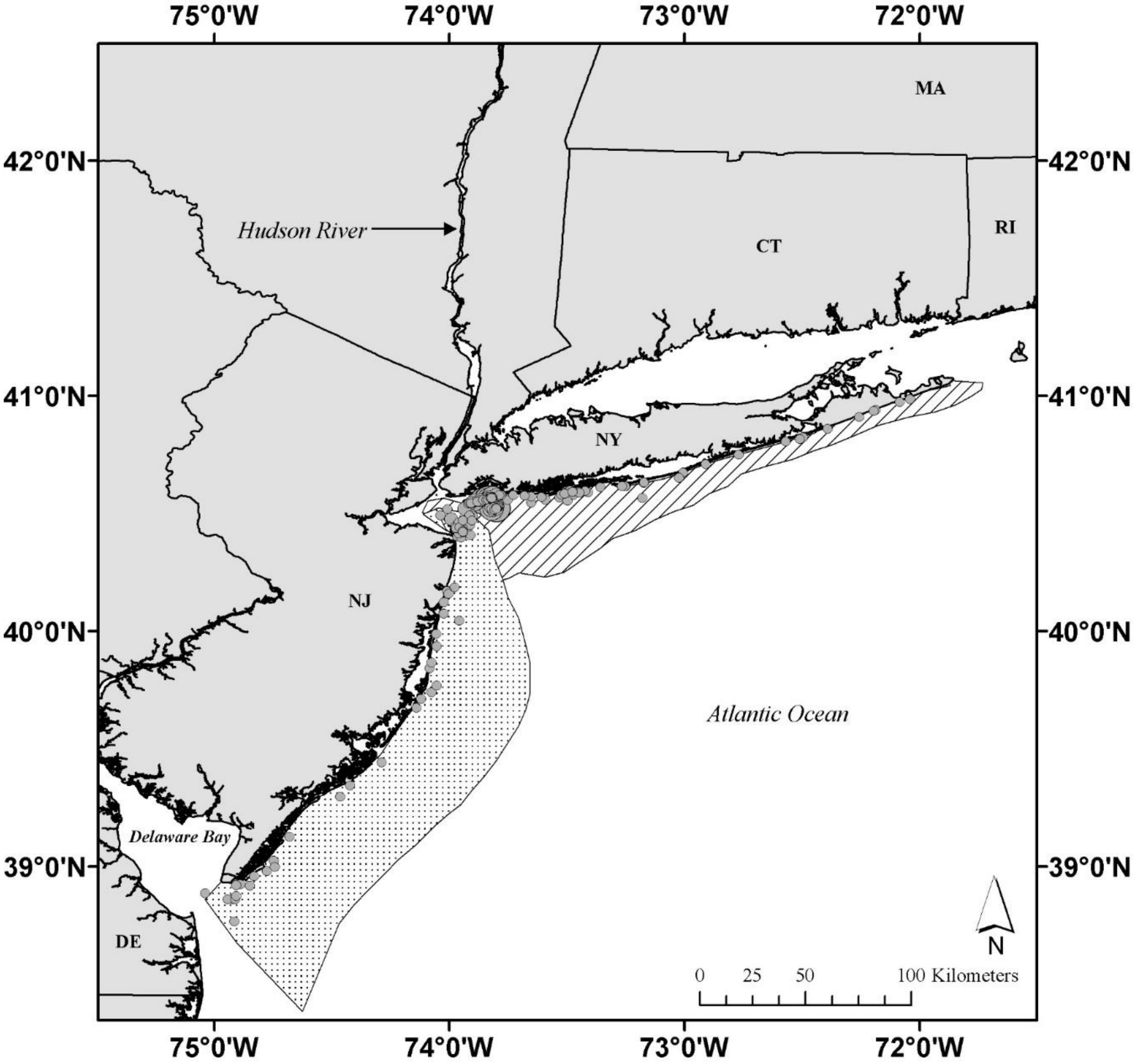


Figure 4.2. Length frequencies of Atlantic sturgeon used in age estimation from (A) Dunton (this study), (B) Thomas Kehler (2007), (C) Stevenson and Secor (1999), (D) Van Eenennam et al. (1998), (E) Johnson et al. (2005), (F) Dovel and Berggren (1983), (G) Hattela (unpublished), and (H) Fisher (unpublished).

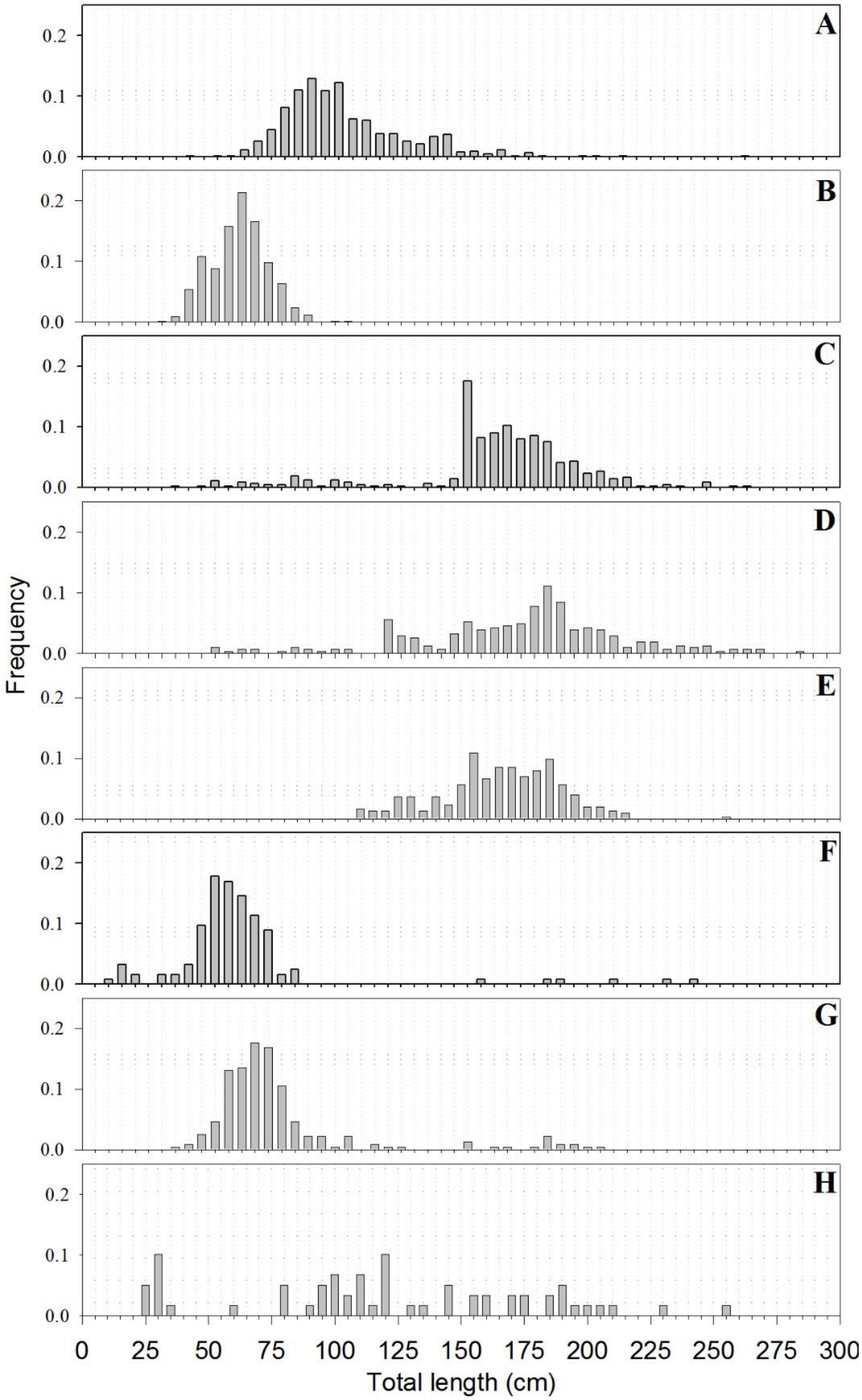


Figure 4.3. (A) Age distribution of Atlantic sturgeon (n=742) captured in NY and NJDEP trawl surveys and (B) age distribution with distinct population segments assignment using gDNA for a subset (n=203) of fish captured. Shaded box represents minimum age of maturity in the New York Bight DPS.

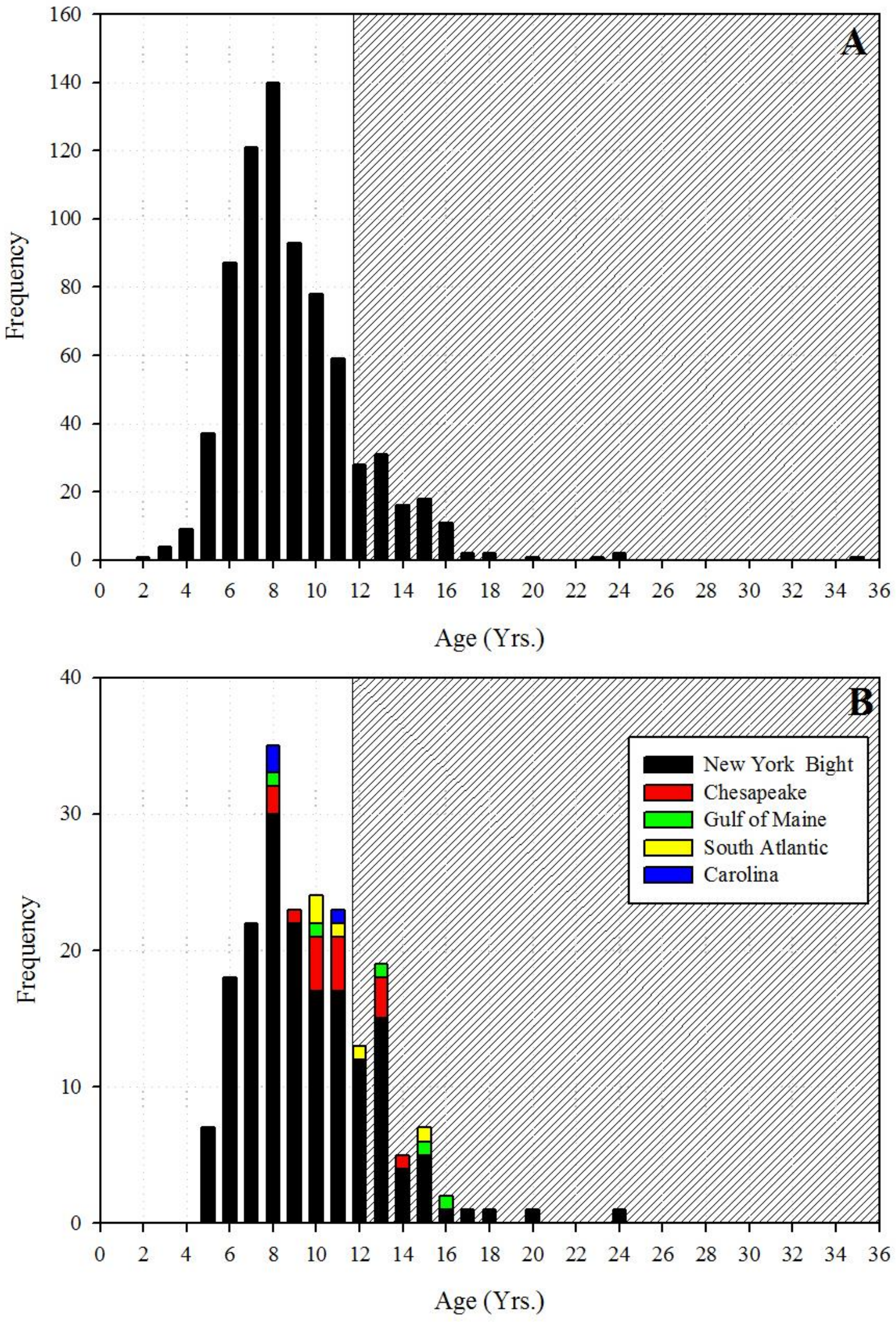


Figure 4.4. Age frequecny estimates from fin spines collected during the Stony Brook University (n=652) and New Jersey Department of Environmental Protection (n=85) bottom trawl surveys. The dashed line represnts the 1998 Atlantic States Marine Fisheries Commission fishing moratorium with fish to the the right of the line being spawned pre-moratorium and fish to the left of the line post-mortatorium. The hatched area represents the transition range of the minimum age of sexual maturity for all fish (males and females) identified in Van Eenennam et al. 1998 for the New York Bight distinct population segment.

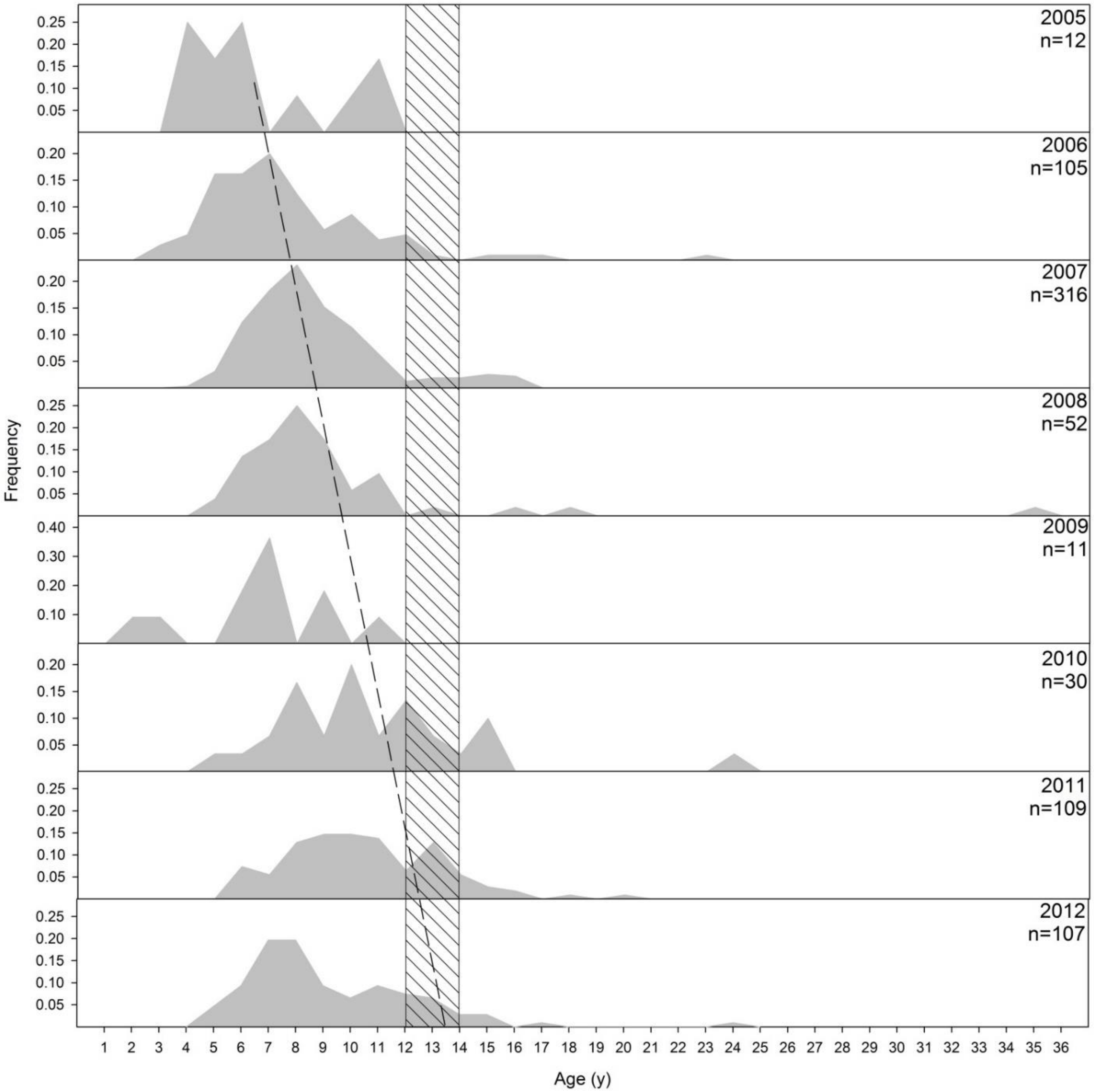


Figure 4.5. Age bias plot for a randomly selected subset (n=64) of Atlantic sturgeon captured from NY and NJDEP bottom trawls. Dotted line represents the 1:1 line between readers, CV = 3.78%. No significant differences among readers were found, indicating no systematic errors in aging (paired t-test, p = 0.469)

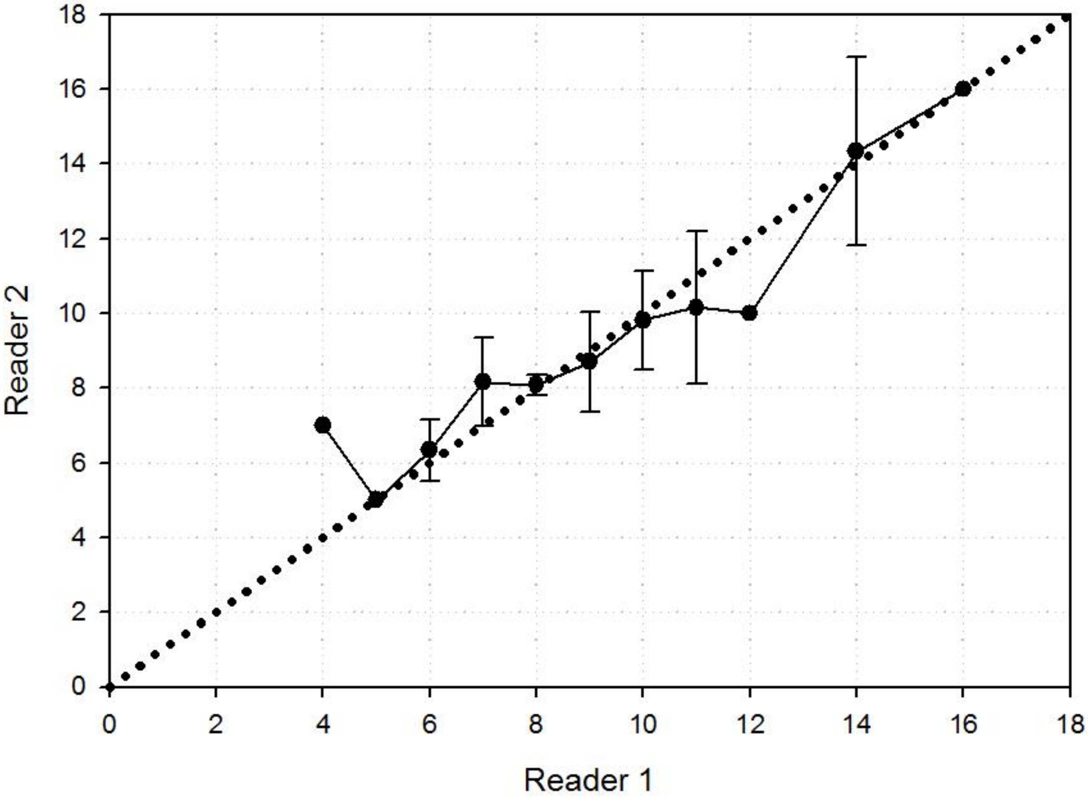


Figure 4.6. Length-at-age for all samples used to estimate the von Beralanffy growth curve (black line). Inset indicates researcher and year the samples were collected.

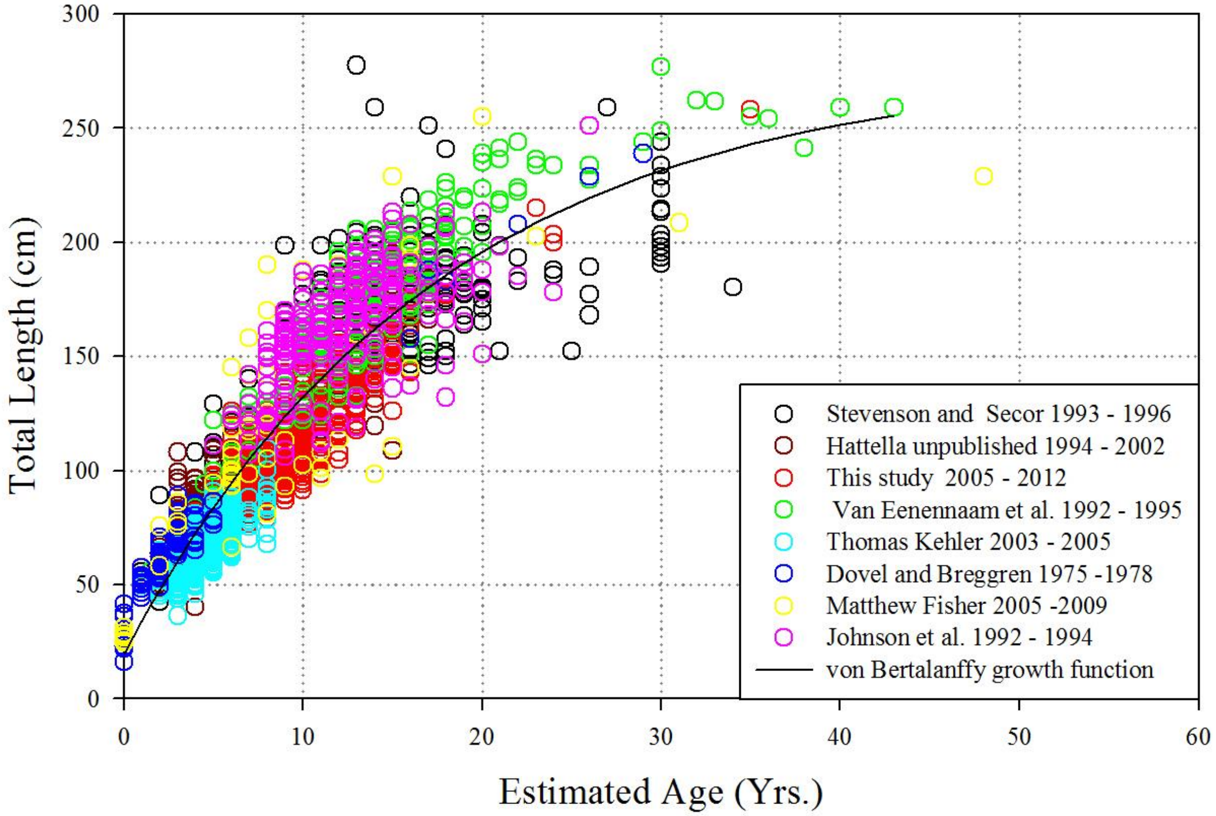


Figure 4.7. 95% confidence intervals (C.I.) on fitted (A) L_∞, (B) K and (C) t_0 from bootstrap routines on the von Bertalanffy length-at-age model. Vertical lines represent 95% C.I. for bootstrap analyses with one data source removed (indicated on x-axis). For comparison, the 95% C.I. for the entire dataset is shown as a gray, horizontal bar. Original parameter estimates are displayed as open circles.

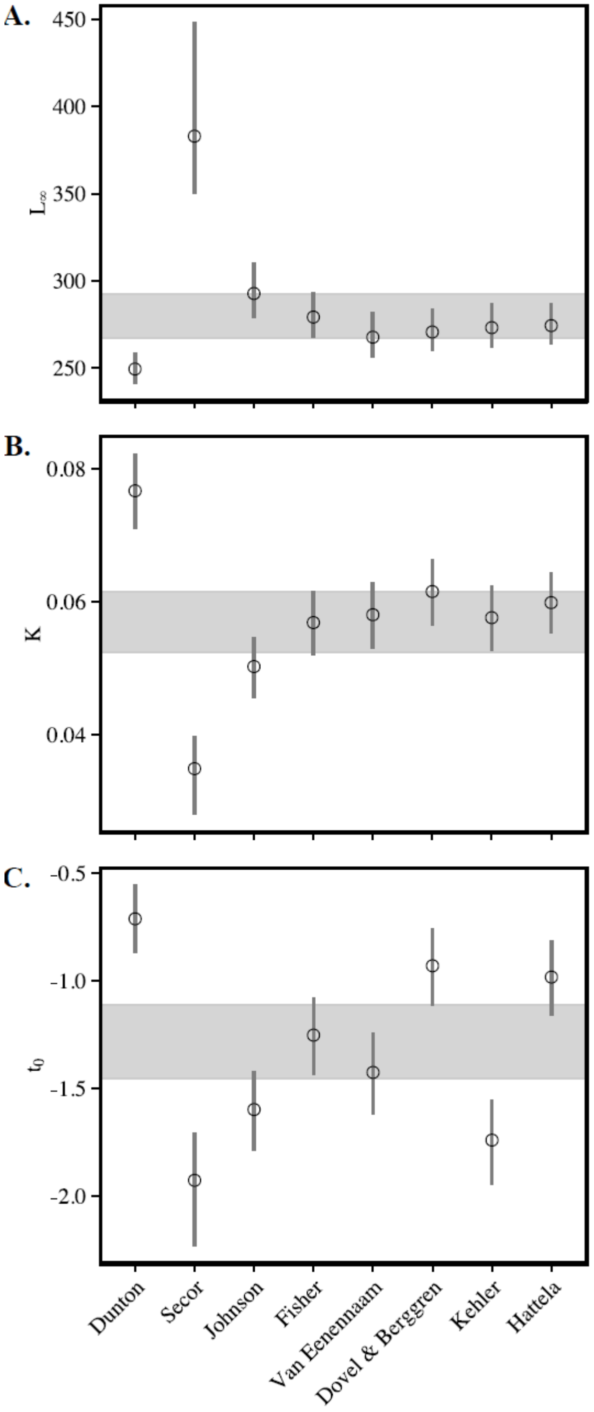
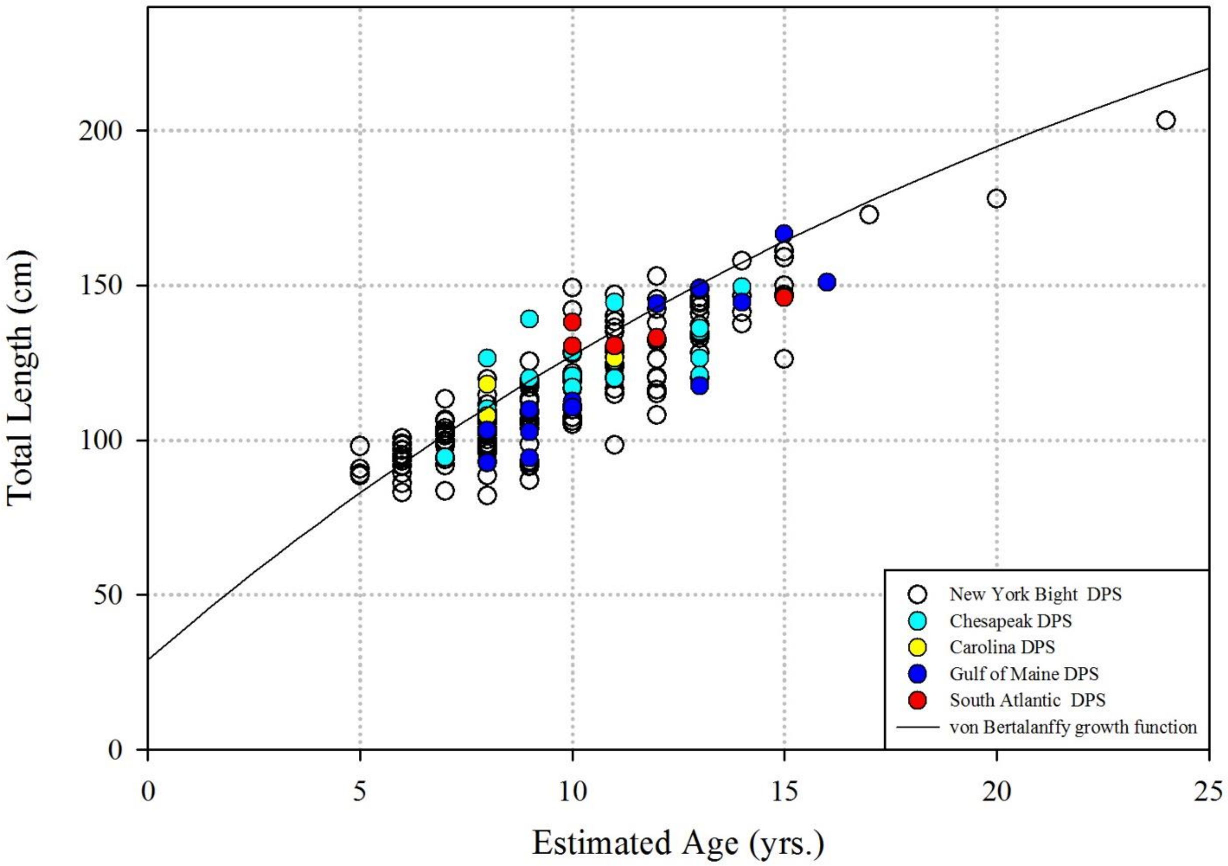


Figure 4.8. A subset (n=742) of length-at-age of Atlantic sturgeon by assigned distinct population segment (DPS) using microsatellite DNA compared with combined dataset estimated von Bertalaffy growth function.



Chapter 5

Habitat use and movement patterns of sub-adult Atlantic sturgeon, *Acipenser oxyrinchus oxyrinchus,* within the Mid-Atlantic

Abstract

Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*), a federally listed endangered species, has been shown to exhibit broad-scale movements among rivers and coastal environments periodically concentrating in aggregation areas along the Atlantic coast. Current concerns indicate that Atlantic sturgeon migrations and aggregations are leading to incidental captures in near shore coastal fisheries and may be hindering population recovery. To best manage human activities in a way that promotes recovery of the species, understanding of Atlantic sturgeon associations with ocean/estuarine habitat is required. Between, 2010-2012, a total of 429 sub-adult Atlantic sturgeon were captured and acoustically tagged in aggregation areas off Rockaway, New York. Movements of telemetered individuals were monitored by large acoustic arrays and gates located in the New York Bight and other locations maintained by cooperative partners. Atlantic sturgeon exhibited rapid seasonal migrations with strong spatial-temporal patterns in habitat use with the frequency of detections across all locations being repetitive and consistent among years. Peak abundances along the coasts of NY and NJ occurred during spring and fall months, with summer aggregations in LIS and the Hudson River, and a winter preference for the Chesapeake Bay and North Carolina. The results of this study also provided empirical evidence on the aggregatory behavior of Atlantic sturgeon migrations. Coastal estimates of residency were significantly higher for aggregations at the mouth of the Hudson River than all other locations, but overall were much shorter than hypothesized with most sturgeon residency events occurring for less than 150 minutes. Estimated coastal movement

rates were consistent with previous reported studies and ranged from 1.09 km/hr to 1.7 km/hr. The slowest rates were associated with movements between Rockaway and Jones Beach and were coupled with a higher residency period. Estimation of closure scenarios, the total number of days required to protect 50, 75, and 99% of the population, were consistent among seasons and years. The most conservative and restrictive scenarios supported substantial closure windows to protect migrating sturgeon.

Introduction

Acoustic telemetry, the remote monitoring of a species through transmitters and receivers, is rapidly evolving as a powerful tool in the study of marine species due to advances in technology, as well as the creation of large scale consortiums (e.g. Pacific Ocean Shelf Tracking Project, Ocean Tracking Network) and smaller cooperative networks (e.g. Atlantic Cooperative Telemetry Network, Florida Acoustic Cooperative Telemetry group) (Cooke 2008; Cooke et al. 2011; Jackson et al. 2011). These networks of individual researchers disseminating and sharing data on detected individuals have enabled researchers to cover a larger geographic range and have become important to the study of fishes that are highly migratory and transverse through multiple systems, oceans, and jurisdictional boundaries. Telemetry data has largely been used to answer traditional questions regarding habitat use, dispersal and connectivity of populations (Lindley et al. 2008; Mather et al. 2014; Kneebone 2014). Acoustic telemetry offers a major advantage over traditional methods due to its capacity to continuously monitor organisms and reduce data gaps during time periods when traditional sampling or monitoring activities cannot be conducted (Cooke 2008). Because of this capability coupled with cooperative networks, acoustic technology is becoming widely applied to species that are of special conservation concern and is used to identify critical habitats such as foraging areas, range expansions, and spawning and nursery areas (Lindley et al. 2008; Simpfendorfer et al. 2010; Kneebone et al. 2014). Conservation of marine endangered species can be complex due to low abundances and broad distributions and migrations; therefore the understanding of spatial-temporal movement and habitat use is critical in the conservation, recovery, and management of endangered species (Cooke 2008). The delineation of critical habitat towards the development of management plans, to reduce negative anthropogenic interactions and protect vital habitat to assist recovery, is a requirement under the U.S. Endangered Species Act.

Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*), an anadromous fish occurring along the east coast of North America, was federally protected in 2012 under the U.S. Endangered Species Act (77 FR 5880, 77 FR5914). Within the U.S., the National Oceanic and Atmospheric Administration (NOAA) has classified 5 distinct population segments (DPS) that warranted protection. The Gulf of Maine (GOM) DPS is listed as threatened and the New York Bight (NYB), Carolina (CAR), Chesapeake (CHES), and South Atlantic (SOA) DPS's is classified as endangered. This species was heavily overfished during the early 1900's and despite not being harvested since 1998, few signs point towards recovery. Presumably, much of the delay in population rebound stems from life history characteristics of slow growth, high longevity (>60 years), late age of maturity (10-20 years), and intermittent spawning (2-3 years) that indicate recovery should be expected to take decades.

The general life history of Atlantic sturgeon within the freshwater extent of the species habitat is well known (Smith 1985; Baine et al. 2000). Spawning occurs in natal rivers and early staged juveniles remain within these natal systems for a period of 1-6 years before entering the marine environment and migrating throughout the coastal zone, non-natal rivers and estuaries (Smith 1985; Baine et al. 2000). Habitat use in river systems has been well studied and documented. Information regarding their use and movements in the marine environment, where a majority of their life is spent, is lacking beyond evidence of broad-scale marine migrations and exchange among river systems based on tag recaptures (Dovel and Berggren 1983; Savoy and Pacileo 2003), satellite tagging (Erickson et al. 2010), commercial fisheries bycatch data (Stein et al. 2004a, 2004b) and fisheries independent data (Dunton et al. 2010). Genetic mixed stock analysis from multiple regions in the Atlantic Ocean and estuaries also supports broad-scale movements and mixing of DPS's in the marine environment (Waldman et al. 1996; Laney et. al.2007; Dunton et al. 2012).

The NYB DPS, which consists of contemporary spawning populations in the Delaware and Hudson Rivers, is currently identified as the most robust of the listed DPS units (Kahnle et al. 2007). Population genetics, using mtDNA and nDNA, have provided evidence to suggest the NYB DPS represents the dominant DPS within the Mid-Atlantic Bight (70-98% of the individuals; Waldman et al. 1996; Dunton et al. 2012), coastal North Carolina (65% of the individuals; Laney et al. 2007), and Long Island Sound (71% of the individuals; Waldman et al. 2013). Previously identified broad-scale movements of the NYB DPS have generally shown a southerly movement during the fall months and northerly movement during the spring months (Dovel and Berggren 1983; Smith 1985; Dunton et al. 2010; Erickson et al. 2011). More recently, the use of satellite tags on a small number of adult Atlantic sturgeon (n=15) have shown that fish tagged within the Hudson River spent a majority of their time in the Mid-Atlantic Bight from Cape Cod, Massachusetts, to Cape Hatteras, North Carolina, but had a range from Georgia to Nova Scotia (Erickson et al. 2011). The spatial extent, movement rate and timing that control these migrations are unknown; but our knowledge of these factors is essential to the development of conservation strategies for this critically endangered species.

Fine scale movements and marine habitat use of the NYB DPS are not well understood and little is known regarding movement rates in the mid-Atlantic or the length of residency in aggregation areas at the mouth of the Hudson River (Chapter 1; Dunton et al., 2010). This lack of knowledge is highlighted by incidental bycatch in near shore areas of the mid-Atlantic and is arguably the greatest threat to recovery of the species (Chapter 1; Collins et al. 1996; Stein et al. 2004a; ASSRT 2007). Of particular concern, is the identification and delineation of several marine aggregation areas of adults and sub-adults occurring within the MAB (Stein et al. 2004; Dunton et al. 2010; Erickson et al. 2011), where sub-adults can reach densities several orders of magnitude higher than anywhere else in the region (Chapter 1). Understanding the movement rates, timing and residency in aggregation areas along coastal habitats of the mid-Atlantic is critical for developing spatial and temporal measures to reduce the threat of marine bycatch.

Protection of essential habitat to reduce mortality of juveniles (Collins et al. 2000) is critical at this point to increase future spawning stocks and spur a recovery. Juvenile mortality is considered a primary threat in long-lived species such as sturgeon. A lack of information particularly on the sub-adult marine stage of Atlantic sturgeon has left a critical gap in our knowledge of the species. Since sub-adult Atlantic sturgeon spend a majority of their life in the marine environment, understanding movements and habitat-use in coastal waters is critical for mitigation of mortality events and eventually species recovery.

Previous research presenting analysis of survey and fisheries-dependent data have adequately described broad-scale seasonal movement and habitat use of Atlantic sturgeon; however, the surveys are individually flawed by either missing time periods of expected sturgeon migration or important depth strata (Dunton et al. 2010). The purpose of this study was to develop and utilize a large scale fixed acoustic receiver array within the NYB to continuously monitor and evaluate the fine-scale temporal-spatial movements and habitat use of sub-adult Atlantic sturgeon within marine aggregation areas within the NYB. Specifically, the objectives of this study were 1) delineate the fine-scale spatial and temporal coastal movement patterns to and from known aggregation areas, 2) estimate residency periods and movement rates at specific areas along the coast, and 3) evaluate management alternatives by estimating population proportions that can be protected under a number of spatial and temporal closure scenarios. We hypothesize that sturgeon form marine coastal aggregations during the spring and fall that make them highly susceptible to a variety of anthropogenic sources of mortality.

Methods

Ethics statement

All sampling, procedures, and handling of Atlantic sturgeon were conducted following the guidelines established within published NOAA technical documents (Kahn and Moheed 2010 “A Protocol for Use of Shortnose, Atlantic, Gulf, and Green Sturgeons; Damon-Randall et al. 2010 “Atlantic Sturgeon Research Techniques”; Moser et al. 2010 “A Protocol for the Use of Shortnose and Atlantic Sturgeon”). Procedures were conducted under University of Stony Brook IACUC #1469 (2005-2009 Dr. David Conover) and IACUC #1781 (2010-2013 Dr. Mike Frisk) and Endangered Species Permit #16422 issued to Stony Brook University (post April 2012).

Location and receiver deployment

Movements of Atlantic sturgeon were passively monitored continuously using arrays of Vemco VR2W receivers placed within the marine coastal waters of the New York Bight at 9 locations between Atlantic City (NJ) and Montauk (NY) and by seasonal deployments in the Hudson River (Figure 5.1). The coastal arrays consisted of two receiver configurations to focus on aggregations and movements. Rectangular grids (Sandy Hook and Rockaway) and detection lines (Atlantic City, Barnegat, Shark River, Jones Beach, Fire Island, Shinnecock, and Montauk) were utilized for a total of 130 individual receiver locations along the coasts of NY and NJ. First, rectangular grids of 26 receivers in Rockaway (NY) and 20 receivers at Sandy Hook (NJ) covered known aggregation areas to identify fine-scale temporal and spatial use by Atlantic sturgeon. The second array configuration consisted of a “gate” of 8 receivers extending from the shore out to depths where Atlantic sturgeon are believed to be less common (Dunton et al. 2010). Receivers deployed in the Hudson River were not deployed in gates or arrays but rather attached opportunistically to US Coastguard buoys. Weather conditions can greatly impact receiver detections and at a transmitter output power of 160 dB re 1 uPa @ 1 meter range at 69 kHz in typical ocean conditions, a receiver’s ability to detect signals range from 577 m in rough seas to 902 m in calm conditions (Table 5.1). To ensure continuous coverage within the arrays receivers were placed approximately 1 km to 1.2 km apart giving a 500-600 m minimum detection range to provide continuous coverage between at least 2 receivers at a given time.

Receivers were deployed from the R/V Seawolf anchored to a 227 kg concrete block, attached by a chain, and a rope to a surface float equipped with a 272 kg swivel breakaway whale link. VR2W receivers were equipped with batteries with an operational life of 15 months. Biofouling has been found to largely affect detection ranges of receivers (Heupel et al. 2008) therefore to help reduce negative effects caused by biofouling organisms, receivers were painted with 2 types of anti-fouling paint (West Marine Bottom Shield on the body of the receiver and INTERLUX ablative paint on the top of the receiver). Data retrieval and receiver replacement was attempted at least twice a year. SCUBA divers were used to recover and exchange receivers and maintain moorings. Once on the vessel, receivers were downloaded, maintained (cleaned, firmware and mapcode upgrades, batteries/o-rings replaced, repainted) and then redeployed.

In addition to our deployed arrays, we cooperated with other researchers within the Atlantic Cooperative Telemetry (ACT) network, which is a large scale collaborative telemetry network comprised of ~30 groups from Maine to South Carolina (Figure 5.2). The cooperative network provided a mechanism for sharing data when Atlantic sturgeon tagged in this study were detected by receivers maintained and owned by other researchers, providing access to additional systems not originally included in this study; including the Hudson River, Connecticut River, Delaware Bay, Chesapeake Bay and the Kennebec estuarine complex, among others. This greatly enhanced our ability to detect Atlantic sturgeon movements throughout the western Atlantic.

Capture methods

Atlantic sturgeon were largely captured via targeted bottom trawling aboard the R/V Seawolf during spring and fall months. Trawling primarily took place in the state and federal waters of the Atlantic Ocean within the 10-20 m depth interval off of Rockaway, New York. Trawl nets used were a three to one two-seam trawl (headrope 25 m, footrope 30.5 m) with 12 cm forward netting stretch mesh tapering down to the 8 cm rear netting. Trawl doors used were steel Thyboron Type II trawl doors (1.82 m. x 1.22 m) and weigh approximately 335 kg each. Trawling was conducted at intervals of a minimum of 5 minutes and a maximum of 20 minutes, at a speed of 3-3.5 knots during daylight hours. To reduce stress or injury from trawling, tow duration was not standard and was dependent on the total number of sturgeon within the area, with tow times continually reduced in order to decrease total handling times on Atlantic sturgeon undergoing surgical implantation of acoustic tags as per the requirements under Endangered

Species Permit #16422. To lessen benthic disturbances and recaptures of sturgeon that underwent tagging the same day, trawl nets were not towed over the same exact location more than once in a 24-hour period. Additional sturgeon were also tagged opportunistically in 2010-2011 within efforts conducted by the New York Department of Conservation's juvenile sturgeon program on the Hudson River, NY as well as the New Jersey Department of Environmental Protections finfish ocean trawl survey in the Atlantic Ocean off the coast of NJ.

Biological sampling

All captured sturgeon were immediately placed into a 757 L flowing seawater well aboard the R/V Seawolf until they were processed. Individuals captured were measured to the nearest cm (fork and total length) and weighed (kg) using a platform scale. Prior to surgical implantation of acoustic transmitters, fish were examined for general health and conventional internal and external tags (passive integrated transponder (PIT), Carlin, Dart). If no tags were detected, sturgeon were tagged with two types of tags; an external United States Fish and Wildlife Service (USFWS) dart tag and an internally implanted 134.2 kHz PIT tag. External tags, supplied by USFWS, had reporting information printed directly on the tag and were mainly used to enable fisherman and the general public to report information on encountered sturgeon, while internally implanted PIT tags are longer duration tags directed at scientific researchers with the necessary equipment able to detect tags. Post standard sampling and tagging sturgeon were placed within large live wells and extensively scanned for previously implanted acoustic tags using a Vemco VR100 omni-directional hydrophone mounted within the holding tanks. If an active acoustic tag was detected in a fish, indicating a previous surgery has occurred, the fish's tag ID was recorded and that fish was released.

DNA samples were taken to identify DPS by taking small tissue clips from the anal fin from each fish and immediately storing them in 95% ethanol until DNA extraction. DNA was isolated using up to 25 mg of tissue using DNeasy Tissue Kit (Qiagen Inc., Valencia, CA, USA) (Dunton et al. 2012; Chapter 3). Nuclear DNA was amplified and analyzed at 12 microsatellite loci at the USGS Leetown Science Center using previously described methods (King et al. 2001; Henderson-Arzapalo and King 2002). River of origin and DPS were assigned by the USGS Leetown Science Center using baseline data described by Waldman et al. (2012). Full description of methods can be found in O'leary et al. (2014).

Surgical implantation of transmitters

Only fish in optimal condition underwent surgical implantation of internal Vemco V16-6H ultrasonic transmitters (High Power output 158dB re 1uPa @1m; Length 95 mm, weight in air 34 g). Since several tagged fish may be present in aggregation areas at the same time, randomly-spaced intervals between coded tag transmissions were used to reduce the probability of repeated collisions between different tags (to detect a tag, all pulses of a pulse train must be detected, and overlap of pulse trains between different tags can result in neither tag being properly decoded). To ensure normal mobility and swimming behavior of the sturgeon receiving internal transmitters, the total weight of all transmitters and tags did not exceed 2% of the weight of the fish. Prior to implantation, all transmitters were coated using a biologically inert material (beeswax) to reduce tag rejection and expulsion. Both transmitters and surgical instruments were sterilized (soaked in alcohol or Nolvasan® solution) during surgical procedures.

Tricaine methane sulphonate (MS-222) was used to anesthetize sturgeon at concentrations up to 150 mg/L to reduce stress during surgery on captured sturgeon. Because MS-222 is acidic (resulting in a prolonged induction time), sodium bicarbonate ($NaHCO3$) was used to buffer the water. Anesthetized sturgeon were placed ventral side up in an inclined v-board that provided a reservoir of water to keep the gills submerged. Prior to the incision, the dorsal area was cleaned and swabbed with betadine solution. A small 3-4 cm lateral incision was made to the right of the ventral mid-line, starting anterior to the base of the pelvic fins. After insertion of acoustic tag, the incision was closed immediately with two to six interrupted cross stitches, using OS-4 reverse cutting (Z695) or CT taper (Z353) sutures of 3-0 polydioxane (PDS) absorbable suture material and treated with a betadine/Vaseline ointment spread over the area to deter bacterial infection. After processing, fish were allowed to recover in a 200 gallon ambient seawater flowing tank before being released near the location of capture.

Data processing and receiver evaluation

Acoustic data was processed and analyzed with a variety of software including VUE software (Vemco Inc., Halifax, NS), ESRI® ArcGIS™ v.9.2 (ESRI; Redlands, CA), and the V-track program written in R-programming language (R Core Team, 2013). Since the number of sturgeon tagged increased as the project progressed, presence/absence of sturgeon detections were reported as proportion of tagged sturgeon at liberty. Differences between the total number of sturgeon detected with increasing distance from shore as well as total number of sturgeon detected with increasing distance from the mouth of the Hudson River were compared using linear regressions.

Array detection capacity was estimated assuming multiple detection radii (r) (550, 600, 650, 700, 800, 850 m) and reported as the proportion of the transect coverage covered by the detection radius of at least one receiver (Melynchuk 2009). This method provides an index that takes into account the detection radii of receivers, spacing between adjacent receivers and shore, and proportion of receivers successfully recovered and downloaded (Appendix 7), The percent transect coverage is calculated by the following equation:

$$TC = 1 - \frac{\sum d - r}{r} \%$$

where ***d*** is the distance of the receiver line and ***r*** is the distance of successfully recovered receivers. Detection arrays with redundant receivers (multiple detection lines), arrays were collapsed into a single detection line to account for one transect since it is assumed fish swim parallel to the shore line. For the arrays with multiple lines of receivers (see Figure 5.1), detection probabilities of each line and each station were calculated to estimate the probability of each detection line and thus the detection probability of each array. This method assumes that fish pass through both detection gates and that the detection probabilities for reach receiver line are independent of one another.

Modal analysis and closure scenarios

In order to characterize aggregation periods two approaches were utilized to model the occurrence of sturgeon in aggregation areas. First, modal analysis utilizing maximum likelihood estimation assuming multinomial distributions was used to represent sturgeon occupancy in the arrays. Aggregation periods were modeled by fitting multinomial distributions and using AIC to determine the number of distributions needed to characterize aggregation periods where each distribution was represented by a mean (***x***), standard deviation (**σ**) and noise (***h***) parameters. The fitted distributions were then used to describe the estimated date of arrival sturgeon (1-10th percentiles), mean date (50th percentile) and departure date (90-100th percentile) of the array area during each seasonal aggregation period. Second, an empirical approach utilizing cumulative distribution functions (CDF), which make no distribution assumptions, was used to model occurrence in the aggregation arrays. CDF's were analyzed in similar fashion, as was done for the normal distributions. Closed area scenarios were developed by estimating number of days needed to protect sturgeon under temporal aggregation area closure scenarios. Closure scenarios determined the number of days needed protect 50%, 75%, and 99% of sturgeon occupying aggregations assuming normal distributions and CDFs.

Residency and rate of movement

Residency at each site was calculated using a minimum of two successive transmitter detections at each receiver. Duration of a residency event started with the first detection and ended with the last detection followed by a “time-out” period of 12 hours. The “time-out” period allowed the event to continue if the individual sturgeon returned to the location within the 12 hour period; otherwise, the residency event was terminated at the last known detection. Rate of movement (ROM) was calculated using a receiver-distance matrix assuming the direct distance method using the R package V-Track (Campbell et al. 2012). For this method, ROM is calculated as the linear direct distance between two relocations at different arrays divided by the total number of hours between subsequent relocations. To account for the detection range of the receiver on the influence of ROM, each receiver was given a fixed 600 m detection radius, which was subtracted from the total distance between receivers the following equation:

$$ROM = D - \frac{R \cdot 2}{t}$$

where ***D*** is the direct distance in km between two receivers, ***R*** is the detection radii in km of a given receiver and ***t*** is time in hours. Significant differences among the means for both residency duration and ROM were determined using one-way ANOVA. If significance differences were found, multiple pairwise comparisons were conducted using Tukey's honest significant differences to assess which locations were significantly different from each other.

Results

Biological data and acoustic tag implantation

A total of 429 Atlantic sturgeon were implanted with Vemco V-16H ultrasonic transmitters from 2010-2012. The individuals were captured during 199 bottoms trawls totaling 2,529 minutes of tow time (Table 5.2). Tagging effort in 2010 resulted in few captures (n=27) and additional Atlantic sturgeon were captured and tagged in coordination with the New York Department of Conservation's juvenile sturgeon program on the Hudson River, NY (n=14) and the New Jersey Department of Environmental Protections finfish ocean trawl survey (n=5). A majority of the sturgeon were tagged during 4 trips: May 2011 (n=68), October 2011 (n=60), November 2011 (n=113), and May 2012 (n=142) (Table 5.2). Most sturgeon tagged represented sub-adults with a mean fork length of 104.33 cm ± 19.71 s.d., total length 120.15 cm ± 22.63 s.d. and a weight of 11.48 kg ± 7.13 s.d. (Figure 5.3). Fish tagged from May 2010-May 2011 (n=109) fish had a variable transmission delay of 50-130 seconds with a tag life of 1952 days, while fish tagged in October 2011 – May 2012 (n=320) fish had a variable tag delay of 70/150 seconds and an estimated tag life of 2331 days. The increase in nominal delay was recommended by Vemco technical staff due to the total number of fish tagged and potential for code signal collision. The majority of tagged sturgeon were identified as belonging to the New York Bight DPS (n=309) with smaller portions originating from Chesapeake Bay (n=30), South

Atlantic (n=10), Gulf of Maine (n=6), and Carolina (n=5). Genetic DPS's could not be assigned for 69 individuals due to missing and/or contaminated samples.

Presence/absence

All coastal arrays were deployed by early January 2012 and continuously monitored. Atlantic sturgeon were detected 1,583,186 times within our coastal and Hudson River arrays. An additional 2,401,872 detections were provided by the cooperating partners in the ACT Network, with detections coming from 23 other researchers from ME to SC (Table 5.3). Estimates from the three major tagging events shows that 97-100% of all individuals were detected on an acoustic receiver within six months of release, which indicates a high survival for fish that underwent surgeries (Figure 5.4). Tag expulsion or mortality within a receiver array is differentiated from live fish by the behavior and properties of tag detections. Three tags fell into this category and were removed from analyses (Yergey et al. 2012) (Figure 5.5).

Detection of tagged fish in collaborative researchers' arrays (ACT Network) were available for Long Island Sound (n=34; Tom Savoy; Connecticut Department of Energy and Environmental Protection), Hudson River (n=314; Dewayne Fox, Delaware State University (DSU); and Amanda Higgs, New York Department of Environmental Conservation), Delaware Coast (n=160; Dewayne Fox, DSU) and Chesapeake Bay (n=97; Carter Watterson, U.S. Department of the Navy) for spatial and temporal analysis throughout the MAB (Table 5.3).

Telemetered individual Atlantic sturgeon showed strong and consistent spatial and temporal patterns at all locations among years for 2012-2013 (Figures 5.6-8; Table 5.4). The NY coast showed a higher number of detected sturgeon when compared to the NJ coast (Figure 5.8-9). May consistently included peak presence of Atlantic sturgeon across all sites and all years, except the Delaware coast in 2012, which peaked in April (Figures 5.6-8; Table 5.4). Peak sturgeon detected per day was 80 fish (27% of all fish tagged) detected by offshore receivers in the Rockaway array on March 8, 2012. NY coastal patterns showed peak presence occurring during the spring (May) and fall months (September-October-November) with low presence during the summer (July-August) and winter (January-February) months (Figure 5.6; Table 5.4). The Rockaway array had the highest total number of uniquely detected individuals for each season (n=353 in 2012, n=248 in 2013) (Figures 5.6; Figure 5.8; Figure 5.9; Table 5.4). Along the NY coast, the total number of uniquely detected sturgeon decreased west to east, with the Rockaway array having the largest amount of sturgeon detected and Montauk having the least with decreases extending into Long Island Sound (2012: $y=-1.00x + 304$, $r^2=0.87$; 2013: $y=-0.7301x + 236.86$, $r^2=0.84$) (Figure 5.9; Table 5.4). In both years sturgeon began arriving in LIS during mid-May and remained for the duration of the summer months before emigrating out of the system in November (Figure 5.8; Table 5.4).

Similar patterns were observed along the New Jersey coastal arrays with peak abundances during the spring and fall, although peaks were less defined when compared to the NY arrays, and also showed similar patterns with low abundances during the summer months (Figures 5.7-8; Table 5.4). The Sandy Hook array reported the highest detections in NJ in October 2012, accounting for 10% of all tagged fish (n=41) (Figure 5.7). During August and July of 2012 along the NJ coast no sturgeon were detected and in August of 2013 only a single Atlantic sturgeon was detected in the Sandy Hook array (Figure 5.7; Table 5.4). A large number of sturgeon (2012: n=232, 2013: n=151) begin entering the Hudson River during April with peak detections occurring during the summer months, June and July, before migrating out of the system in October (Figure 5.8; Table 5.4). Atlantic sturgeon also peaked along the Delaware coast in spring and fall (Figure 5.8) and at the mouth of the Chesapeake Bay December through

May (Figure 5.8). No distinguishable patterns in total number of unique sturgeon within the north and south arrays were observed (Figure 5.9). During 2012, there was a weak trend of increasing detection of sturgeon with distance from the Hudson River, ($y=-0.50x + 213.02$; $r^2=0.52$); while in 2013 a stronger relationship was estimated ($y= 0.13x+151.95$, $r^2=0.24$) towards Delaware Bay.

Most sites showed significant trends with decreasing sturgeon detected with increasing distance from shore; Jones Beach ($y=-12.35x + 117.59$; $r^2=0.71$), Fire Island ($y=-26.59x + 189.14$; $r^2=0.87$), Montauk ($y=-7.47x +90.55$; $r^2=0.74$), Barnegat ($y=-10.90x + 93.45$; ; $r^2=0.7403$), Shark River ($y=-7.79x + 74.179$; ; $r^2=0.7274$) and Shinnecock ($y=-12.79x + 108.06$; $r^2=0.512$). Three sites did not reveal linear trends of decreasing sturgeon increasing distance from shore, Sandy Hook ($y=-4.39x + 132.13$; $r^2=0.05$), Atlantic City ($y=-5.21x + 66.5$; $r^2=0.20$), and Rockaway ($y=6.76x + 114.41$; $r^2=0.08$) (Figure 5.10; Figure 5.11). Atlantic City detections from shore increased until a peak 4 km offshore and then decreased, which did not fit a linear model. A polynomial model was used to best describe the relationship of number of sturgeon in relation to the total distance from shore ($y=-3.80x^2 + 28.94x + 9.58$; $r^2 = 0.62$) (Figure 5.10; Figure 5.11).

Array and receiver performance

A total of 130 acoustic receivers were successfully deployed in early January 2012 throughout the MAB and Hudson River and maintained throughout the year. The Rockaway array only had receivers stretching to 3 km offshore until the array was expanded in March 2012 to 8 km offshore to replicate other arrays. Acoustic receivers were removed and replaced a minimum of twice per year to insure that array operation remained intact following damaged or missing receivers (Appendix 7). The proportion of coverage varied greatly over time among and within each array location (Figure 5.12-13). Montauk and Shark River arrays had the highest coverage throughout the sampling period with almost 100% coverage, while the Shinnecock Array continually had the lowest detection coverage recorded throughout the sampling (Figure 5.12). The Shinnecock array was particularly challenging due to high commercial fishing activities that damaged receivers and often reduced coverage to less than 50%, with its lowest coverage of 11% occurring between January-March 2013. Recovery and maintenance of receiver arrays was hampered by interactions with commercial fishing operations and extreme weather events (Hurricanes Irene and Sandy) (Figure 5.12). NY arrays, in particular, suffered major losses after Hurricane Sandy, and forced a large-scale replacement effort in March of 2013 (Figure 5.12). A total of 9 receivers were found washed-up on beaches, 4 receivers were recovered by commercial fishing operations, 2 were recovered and suffered fatal damages, 3 receivers were missing from their moorings, 1 fisherman hauled-up a receiver and was released at an unknown location, and 1 receiver was found and recovered far from its original location by a SCUBA diver. Station detection probabilities for the arrays equipped with double gates was high for Shinnecock (64-100%), Fire Island (89-100%), Barnegat (99-100%), and Atlantic City (91-100%) and were often close to 100% indicating that the double gates were sufficient in detecting migrating sturgeon. Detection probabilities of single lines of receivers ranged from 28% -100% (Table 5.5).

Modal analysis and closure scenarios

Modal analysis of NY and NJ indicated that peak presence occurred during the spring and fall months at all locations (Figure 5.6-7; Table 5.6). Deviations from a normal distribution were evident due to the sudden arrival and departure of sturgeon at sites. Three modes were found at the Sandy Hook array in 2013 (1 winter, 1 spring and 1 fall; AIC 2 modes -44808 and AIC 3 modes -44802) (Figure 5.6; Table 5.6). Modes for most sites could not be determined for fall 2013 due to the last date receivers were downloaded. Parameters generated from detections (mean, standard deviation, scaling parameter) varied among the arrays, but were consistent for each season and year at each site (Table 5.6).

In estimating the potential of bycatch mortality from seasonal fishery closures, assuming normal distributions, the total number of days were highly consistent among years along the NY coast. To protect 50%,75%, and 99% of the migrating sturgeon the total closures would have been 40, 69, and 154 days for spring 2012 and 43, 74, and 165 days for spring 2013, while fall of both years produced estimates of 36, 62, and 140 days (Figure 5.14). Although the closure periods were similar in duration, initial start dates differed among years for each seasonal closure (April-25 and October-20) and (May-21 and September-21). Closure scenarios that protect 50%, 75%, and 99% of migrating sturgeon using cumulative distribution showed similar periods of closures for all years and seasons with estimates of 42, 90, and 151 for the spring of 2012; 29, 57, 200 days for Spring of 2013; 32, 64, 141 days for the Fall of 2012, but differed in start and end dates as the percentage of the population provided protection increased (Figure 5.13; Figure 5.15). Closure scenarios were also developed individually for each NY array and fell within the NY coastal parameter estimates (Table 5.7). To make NJ coastal closure estimates for the spring and fall migrations Sandy Hook was removed from this analysis since this location had a continued presence of sturgeon. Closure estimates were also similar among years and distributions. Under the normal distribution, to protect 50%, 75%, and 99% of the migrating sturgeon, closures would have been as follows; in spring of 2012: 40, 78, and 150 days; Spring 2013: 44, 74, and 167 days; and Fall 2012 25, 42, and 95 days (Figure 5.16). Cumulative distributions produced similar results but also differed in start and end dates (Figure 5.16; Figure

5.15). Although closure estimates for fall 2013 were made using both methods, receivers at most sites were downloaded during movements of sturgeon through the area making that dataset incomplete.

Residency

Residencies varied with each site but most residency events were short in duration and lasted less than 150 min (Figures 5.17-18; Table 5.7-8). Mean residency was highest for Rockaway (739 min ± 1663 s.d.) and Sandy Hook (516 min ± 1157 s.d.) with the lowest residency occurring within the Montauk (101 min ± 1316 s.d.) and Shark River arrays (89 min ± 411 s.d.) (Table 5.8). The highest residencies reported for any fish was 16.70 and 14.75 days at the Fire Island and Rockaway arrays, respectively (Table 5.8). A one-way ANOVA detected a significant difference ($p<0.0001$; $F=122$, $DF=8$) and multiple pairwise comparisons using Tukey's honest significant difference (Tukey HSD) indicated that Rockaway and Sandy Hook had significantly higher residencies compared to other locations ($p<0.001$; Table 5.9).

Movement rates

Direct movement rates, or rate of movement (ROM), were calculated between adjacent sites and ranged from a low mean of 1.1 km/hr ± 0.68 s.d. (Rockaway-Jones), to 1.7 km/hr ± 0.50 s.d. (Shark River–Barnegat) (Figure 5.19; Table 5.10; Appendix 3). Mean movement rate was 1.3 km/hr ± 0.7 s.d. with a maximum movement rate observed was 3.2 km/hr for fish moving from Fire Island to Shinnecock (Figure 5.19; Table 5.10). Significant difference among means were found (ANOVA, $p<0.0001$; $F=55.69$, $DF=6$) and multiple pairwise comparisons were analyzed using Tukey HSD (Figure 5.19; Table 5.11). Tukey HSD shows the mean ROM occurring between Rockaway and Jones Beach (1.09 km/hr± 0.6847 s.d.) was significantly slower than all sites ($p <0.005$) (Figure 5.19; Table 5.11). Fastest ROM occurring between

Shinnecock-Montauk (1.7 km/hr ± 0.6 s.d.), Shark River-Barnegat (1.7 km/hr ± 0.6 s.d.), and Sandy Hook-Shark River (1.6 km/hr ± 0.7 s.d.) did not show significant differences amongst each other (Figure 5.19; Table 5.11)

Detections outside of MAB

In addition to movements within the MAB, Atlantic sturgeon were also detected from collaborative partners within the ACT Network (Figure 5.20). Few sturgeon were detected North of Cape Cod, with n=13 fish detected within coastal Massachusetts, one fish detected within New Hampshire (Little Bay) and a total of 3 detected within Maine (Saco River, Kennebec River, and coast). A large number of fish were detected south of New Jersey decreasing further south in the number of individuals. Fish were detected in Coastal Delaware/Delaware Bay (n=160), Chesapeake Bay (n=97), Cape Hatteras - North Carolina (n=34), South Carolina (n=2), and Georgia (n=1). Fish 1141, our largest individual tagged at 200 cm, was tagged in 2010 off of Delaware Bay within a NJDEP trawl, and was never recorded within our NY or NJ coastal arrays but made regular trips from Delaware to Waccamaw River, SC from 2010-2013. This fish is of unknown genetic origin and also accounts for the single fish detected in GA. This GA detection also represents a unique incident since the detection was on Greys Reef National Marine Sanctuary. Relatively few fish were detected within specific rivers other than the Hudson, despite having a large coverage from cooperating partners in non-natal rivers systems. Connecticut River, CT (n=10; genetic origins: 8 NYB and 2 unknown), Kennebec River, ME (n=3; genetic origins: 1 fish Kennebec, 1 Hudson River, and 1 unknown), Saco River, ME (n=1; unknown origin), James River, VA (n=7; 4 James River Origin, 1 NYB, and 2 unknown) and Waccamaw River, state (n=1; unknown origin) and Santee River, state (n=1; unknown origin).

Discussion

The use of coast-wide telemetry was successful at delineating fine-scale coastal aggregations and movements of sub-adult Atlantic sturgeon in the Mid-Atlantic Bight (MAB). This study provides the most comprehensive analysis of sub-adult movement and migratory behavior of Atlantic sturgeon to date. Juvenile Atlantic sturgeon showed rapid and consistent seasonal migrations with strong spatial-temporal patterns in habitat use from Delaware Bay to the eastern tip of Long Island, New York. Peak abundances along the coasts of NY and NJ occurred during spring and fall months, with summer aggregations in LIS and the Hudson River, and overwintering in Chesapeake Bay and off the coast of North Carolina. The higher abundances, longer residencies and slower rates of movement of tagged sturgeon in the Sandy Hook and Rockaway locations suggest that the region near the entrance to the Hudson River is likely acting as a spatial bottleneck and aggregation area. Previous studies involving conventional tagging (Dovel and Berggren 1983), survey data (Dunton et al. 2010; Laney et al. 2007) and fisheries dependent data (Stein et al. 2004) have been used to describe broad-scale seasonal movements of Atlantic sturgeon. The acoustic approach utilized in the current study supported previous estimates of broad-scaled movement and revealed strong repetitive fine-scale seasonal movement and habitat use, and in some cases contrasted previous results based on traditional approaches. Further, the large number of Atlantic sturgeon tagged allowed for new insights and direct empirical evidence of aggregatory behavior and highlighted the potential for successful spatial-temporal management regimes to protect the species.

Overall detection of tagged Atlantic sturgeon by the NY-NJ coastal arrays was high and accounted for 84-94% of all tagged fish in 2012 and 2013, respectively. Although, our acoustic arrays largely captured the coastal movements of most migrating sturgeon within 9 km of the coastline, it is likely that a small proportion of sturgeon occupied depths greater than our arrays covered. The decline in sturgeon detections with depth suggests only a small fraction of the population was missed, but it is possible that some migratory movements may have been missed if individuals occupied deeper and offshore waters (Lindely et al. 2008). Acoustic coverage of all potential habitats used by Atlantic sturgeon is beyond the limits of a reasonable research budget. Our design was based on shallow migratory routes identified by independent fisheries surveys and was thought to include all hypothesized habitat within the MAB. Atlantic sturgeon occurrence had been shown to be largely confined to less than 20 m (Dunton et al. 2010), but the species has been observed at depths up to 25 m (Stein et al. 2004b) and 40 m (Erickson et al. 2011). While maximum depths occupied and monitored varied at each specific array, depending on the site, we regularly monitored a max depth of 20-30 m covering most of the available and occupied habitat. Advances in acoustic telemetry observing systems such as the integration into autonomous underwater vehicle's (Grouthes et al. 2010; Oliver et al. 2012) may be able to provide insight into deeper offshore areas where arrays are costly and difficult to maintain. Still, this study confirms the general observation that sturgeon utilize a shallow (<20 m) coastal migratory pathway (Dunton et al. 2010) and suggests it is unlikely a significant proportion of sturgeon went undetected as they migrated along the coasts of NY or NJ with 82-88% of tagged individuals detected each season.

Coastal movements

Fine-scale movements of Atlantic sturgeon in the MAB strongly support southerly migrations during fall and winter and northerly movements during the spring and summer (Dovel and Breggren 1983; Smith 1985; Erickson et al. 2011). Very few fish tagged (<3%) within the study travelled north of LIS and there was a significant decrease in the total number of sturgeon detected with increasing distance from the Hudson River along NY. No significant trends were observed with increasing distance from the Hudson River along the New Jersey coast. Twenty three percent of tagged sturgeon travelled as far south as the Chesapeake Bay and only 8% were detected south of Cape Hatteras, North Carolina. Fish tagged in this study represent a mixed stock, largely composed of NYB DPS sub-adults. Other DPS units are likely to have similar regional coastal movements with natural barriers such as Cape Hatteras and Cape Cod likely defining regions (Damon-Randall et al. 2013). Atlantic sturgeon arrived in the Chesapeake Bay and coastal North Carolina regions in November and stayed through May, supporting previously identified overwintering habitats off North Carolina for then NYB DPS (Dovel and Bergrennan 1983; Laney et al. 2007; Dunton et al. 2010). Mixed stock analysis of Atlantic sturgeon that occupy coastal waters of North Carolina indicate a much larger proportion of southern stocks, when compared to similar studies conducted in the MAB and LIS (Laney et al. 2007; Dunton et al. 2012; Waldman et al. 2013). The MAB was also described as an overwintering area (Dunton et al. 2010) and may represent overwintering habitat for northern DPS since a few sturgeon were detected as far north as the Sandy Hook array during winter.

The continuous and large-scale coverage achieved with acoustic telemetry provided data that has confirmed and in some cases contradicted previous research that relied on traditional survey and telemetry analysis with limited temporal and spatial sampling. An analysis of trawl based surveys identified the south shore of Long Island as the only location in the marine environment occupied by Atlantic sturgeon during the summer months (Dunton et al. 2010). In contrast, analysis of acoustic data showed coastal habitat use along the Long Island coast by the NYB population was low to non-existent. The contrasting findings likely results from the limited timing of survey sampling towards the end of the summer in early September after the fall migration period had begun (Chapter 1) or that individuals occupying the habitat are of other natal origin. Previous observations of the summer habitat use and aggregation areas within LIS and the Hudson River (Baine et al. 2000; Savoy and Pacileo 2003) were supported. Sub-adults have also been observed to utilize other coastal rivers during the summer months including the Hudson River from June through September and LIS through autumn (Smith 1985, Keiffer and Kynard 1993; Baine et al. 2000; Hatin et al. 2002). Although neither Long Island Sound nor the CT River supports a reproductively active population, they appear to function as summer habitat for a population of mixed genetic origin (Waldman et al 2013; Savoy and Pacileo 2003). These two summer aggregation areas represent very different physio-chemical habitats (salinity, temperature, dissolved oxygen) so it is unclear why Atlantic sturgeon prefer them, although similar multiple summer aggregations in freshwater and estuaries have also been found in the St. Lawrence (Haitin et al. 2002).

In examining the percentage of DPS's by site, the Hudson River had the highest percentage of individuals from NYB (83%), followed by individuals with unknown DPSs (13.4%) and the remaining came from other DPSs (3.6%). It appears that sub-adult Atlantic sturgeon of NYB origin are homing back to the Hudson River during the late spring into summer. Homing is a migratory adaptation where spawning adults return to natal sites (McDowall 2001), and has been confirmed for adult Atlantic sturgeon through strong genetic difference among river populations (references). While this adaptive behavior is widespread and has several benefits to adults and larvae (McDowell 2001), it is unclear why sub-adults would home back to natal rivers (McDowall). Homing ability of juvenile fish back to natal sites has not been widely shown but has been known to occur in sharks (Clermont and Gruber 2005) and sea turtles (Bowen et al. 2004). Research is needed to better understand the causes and benefits of sub-adult homing behavior and site fidelity that mimic adult migration behavior.

Large scale seasonal coastal migrations have been observed in other anadromous species of Acipenseridae, including the Green sturgeon (*Acipenser medirostris*) (Lindley et al. 2008) and White sturgeon (*Acipenser transmontanus*) (Welch et al. 2006), and is likely a critical life stage that needs protection (Cooke 2008; Jackson et al. 2011). Atlantic sturgeon, like green sturgeon, (Lindley et al. 2008) are highly migratory, coordinate their movements in time and space, and aggregate, making them susceptible to hyperstability of abundance estimates derived from targeted fisheries and the potential for high rates of bycatch if fisheries occur in migration pathways (Stein et al. 2004). This study provides the tools necessary to implement and design management plans to limit interactions with commercial fishing and develop metrics to understand migratory behaviors. The coastal telemetry approach applied to Atlantic sturgeon provides a framework that is generalizable to a variety of species that make similar seasonal coastal migrations such as bluefish (*Pomatomus saltatrix*) (Juanes et al. 1996), sand tiger sharks (*Carcharias taurus*) (Kneebone et al. 2014) and striped bass (*Morone saxatilis*) (Mather et al. 2014). Such extensive seasonal migrations demonstrate the connectivity of populations and the need for incorporating sub-adult and adult mediated movements into single species and ecosystem management (Frisk et al. 2014).

Potential influence of maturity and sex on movements

It has been hypothesized that sub-adults and adults possess similar migratory behaviors (Baine et al. 2000). Erickson et al. (2011) described the movements of a limited number of satellite tagged adult Atlantic sturgeon (n=15) from the Hudson River and showed that adults occupied similar shallow depths (<40 m) and aggregation areas described within this study, and spend a large portion of their time within the MAB. These overlapping characteristics likely indicate that the two life stages share similar preferences, habitats, and movements. Similar research on adults is needed to increase the samples size for delineating the marine and river habit usage of mature individuals.

Sex and stage of maturity can also influence sturgeon habitat use and movements (Nelson et al. 2013). Sex-specific and reproductive condition effects on river movements have been shown in mature Gulf (*Acipenser oxyrinchus desotoi*) (Parkyn et al. 2007; Fox et al. 2000) and Atlantic sturgeon (Dovel and Bergren 1983). Identification of gender is essential, providing the opportunity for studies to determine sex specific movements and habitat preference (Nelson et al. 2013). Sex differentiation in Atlantic sturgeon occurs by 4 years of age and maturation occurs between 12-14 years of age (Van Eenennam and Doroshov 1998). Our study specifically focused on immature sub-adult fish where sex determination requires invasive surgical biopsies for precise determinations of gender since gonads can be underdeveloped (Kahn and Mohead 2010). Due to the large number of fish, additional handling time, and an increase in recovery time from multiple procedures, the additional stress of sex determination could have increased mortality and impacted movement patterns post release (Benson et al. 2007). Although blood plasma and ultrasound have also been identified as feasible methods, there is uncertainty in sex determination of immature fish (Kahn and Mohead 2010). If possible, future studies should employ techniques that provide this information at the time of tagging to assist in delineating migration patterns (Nelson et al. 2013). Long-lived tag deployment would benefit from sex determination since changes in behavior and movement patterns may indicate a change in reproductive condition (Nelson et al. 2013).

Residency and rate of movement

Coastal residency, specifically within known aggregation areas, was much shorter than initially hypothesized with most residency events lasting only hours. This provides evidence that aggregations are dynamic with ongoing arrivals and departures of individuals with short residency windows. The Rockaway and Sandy Hook arrays consistently had the highest number of detected sturgeon and higher residency events compared to other locations. Lack of high residency times coupled with high movement rates indicates that the coastal areas along NY and NJ are primarily transition zones between summer and winter habitats. Difference in the timing, movements, and/or residency of different DPS's was not observed through initial analyses. While it is likely these differences do occur, the small overall percentage of non NYB DPS and high percentage of NYB DPS fish tagged made direct observations difficult to detect. This information may be further analyzed through the cooperation of other Atlantic sturgeon researches along the coast, who have tagged non NYB DPS, and were detected within our arrays.

Many factors can affect swimming speed of fish, which include biological (size, age, sex) and physical factors (current velocity, temperature, diurnal factors). Rate of movements (ROM) have been described for adult Gulf sturgeon (Parkyn et al. 2007), juvenile Atlantic sturgeon (Moser and Ross 1995), and adult Atlantic sturgeon (Hatin et al. 2002; McLean et al. 2014). Our estimates of 1.1-1.7 km/hr (means between sites) and max ROM (4.7 km/hr) are higher than those reported by Pakryn et al. (2007; 0.83 km/h), but are nearly identical to the estimates reported by Moser and Ross (1995; 1.1 km/h), McLean et al. (2014) (ROM means 1.0-2.8 km/hr) for the Minas basin, and by Hatin et al. (2002) for the Saint Lawrence estuary (1.6±1.7 km/hr with a maximum ROM between 3.2-7.2 km/hr).

Directional and non-directional movements have been described in green sturgeon (Kelly et al. 2007), Atlantic sturgeon (McLean et al. 2013), and Gulf Sturgeon (Fox et al. 2002). These movements have been suggested to represent foraging (non-directional) and movement to foraging areas (directional). McCLean et al. (2013) utilized acoustic telemetry to classify three behavioral patterns during summertime foraging aggregations; feeding, searching, and directional movements. The Rockaway region consistently had significantly higher abundances, higher residencies, and slower movements to the nearest adjacent site, indicating that this is a foraging area. Lower ROM of 1.1km/hr between Rockaway and Jones Beach is consistent with estimates of ROM for foraging animals (1.04 km/hr) (McClean et al. 2013). Evidence of the Rockaway region as a foraging area was confirmed through direct observations of non-lethal stomach sampling (n=100), which indicated that the seasonal Atlantic sturgeon aggregations correspond to periods of very high abundance of benthic invertebrates, namely unidentified gammarid amphipods and polychaetes (Dunton, Unpublished Data; Appendix 4). High prey resources freshly consumed by aggregating sturgeon, coupled with slower movement rates provide evidence of foraging in the Rockaway region. Higher ROM (mean: 1.7 ±0.6 km/hr) occurring between Shinnecock and Montauk and along the NJ coast suggest more directional movements where foraging is less likely. This is supported by McLean et al.'s (2012) estimates for foraging (1.8 km/hr) and directional movements (2.8 km/hr).

Temporal and spatial variability of acoustic detections vs. survey data

The factors that drive the migrations of Atlantic sturgeon are likely linked to seasonal cues, such as temperature (Kieffer and Kynard 1993; Stein et al. 2004a; Dunton et al. 2010). Peak abundances at all locations were repetitive and consistent in both duration and relative timing among years, but varied by as much as 40 days. This supports the hypothesis that spatial and temporal scales of current independent fisheries surveys (NEAMP, NMFS spring and fall survey, NJDEP finfish) are inadequate at detecting trends in abundance or recruitment to the marine sub-adult stage (Dunton et al. 2010). Such temporal limited surveys should be used with caution when trying to develop indexes of recruitment, recovery, or population estimates. Sweka et al. (2007) suggested the sampling of known occupied habitat that provided the highest catches in order to minimize variance in abundance estimates for population monitoring of juvenile Atlantic sturgeon. Modal analysis indicates that at most locations along the coast, 50% of the population moved through a location in less than 30 days indicating that even surveys conducted on monthly basis (e.g. SBU trawl survey) would be poor proxies of recovery. The estimation of Atlantic sturgeon recruiting to the marine migrant stage is important and if surveys were specifically designed to capture the coastal migrations, they would need to operate on a weekly basis to capture peak movements unless directed in the specific summering habitats.

Closed areas

At the core of the justification of developing of closed areas to protect Atlantic sturgeon is that the study design was sufficient to make population level recommendations. The high detection of tagged individuals (429) in both NJ (84%) and NY (94%) indicates our telemetry approach is adequate at representing population trends of habitat use of Atlantic sturgeon. Regardless of the distributional assumption used, cumulative or normal, similar results were estimated for the number of days needed to protect 50, 75, and 99% of the population. However, starting dates of closures differed between methods, as arrival of Atlantic sturgeon to the arrays did not consistently follow a normal distribution. Despite the distribution used, protection under the most conservative and restrictive scenarios indicates substantial closure windows would be required to protect sturgeon migrating through the MAB. A lower proportion of tagged Atlantic sturgeon were detected along the NJ coast compared to the NY coast. The broad shallow continental shelf along NJ provides the opportunity for sturgeon to maintain a shallow depth while occupying habitat further from shore compared to coastal Long Island, where depth contours are more compressed and deeper habitat is a shorter distance from the shore. However, results for both coastal regions support depth as an important driver of sturgeon habitat selection (Stein et al. 2004a; 2004b; Dunton et al. 2010).

Seasonal closure estimates for the NY coast, using both methods to protect 50% of the population produced closure values of 30-40 days for both the spring and fall. Increasing the protection value to 99% increases closures to 140-200 days for both the spring and fall. Estimates for the NJ coast for the same closure scenarios produced similar durations. Sandy Hook had to be removed from the closed area scenario because the persistent presence of sturgeon in the array indicates a longer closure would be required. Currently these methods represent a simplistic, but effective, approach to determine data driven conservation measures that can reduce bycatch of Atlantic sturgeon. Through the continued monitoring of coastal arrays and collection of acoustic data, these closed area estimates can be refined to better account for the annual variation of sturgeon migrations. Such closures only take into account the protection and recovery of Atlantic sturgeon. A more comprehensive plan would have to factor in a variety of other elements such as socio-economic factors (e.g. economic hardships on fisherman) as well as incorporate and analyze the impacts of a shifting fleet outside of the protected area. Protected areas do not necessarily reduce fishing effort, but rather shift effort (Browman and Stergiou 2004; Murawski et al. 2005), particularly along protected area boundaries (Murawski et al. 2005; Kellner et al. 2007). This shifting effort into deeper waters could come at the expense of other species that are also in decline, such as winter flounder (*Psedopleuronectes americanus*). While these closed scenarios are largely directed at fishing effort, they can also be used to assess and influence the activities of other human induced anthropogenic inputs, such as dredging, pile driving and underwater construction projects, and beach nourishment that may negatively affect sturgeon behavior and/or survival.

Management recommendations

NYB DPS Atlantic sturgeon face increased threats outside the Hudson River during the marine migrant stage and bycatch has been identified as a major threat to recovery (ASSRT 2007). Although considered an endangered species, Atlantic sturgeon can be found in great local abundance during seasonal aggregations. The mouths of the Chesapeake Bay, Delaware Bay, and Hudson River, along with LIS have consistently been identified as aggregation areas through conventional tagging (Dovel and Berggren 1983; Savoy and Pacileo 2003), satellite tagging (Erickson et al. 2011), fisheries-dependent surveys (Stein et al. 2004), and fisheries-independent surveys (Dunton et al. 2010; Laney et al. 2007), and now through acoustic telemetry. The NYB, in particular, is a "hotspot" of aggregation activity during Atlantic sturgeon migrations, with predictable and consistent movements to and from summer and winter aggregation areas. The results of this study have delineated the fine scale marine migrations of sub-adult Atlantic sturgeon, which have been previously unknown, and provides management agencies with necessary data to inform decisions to increase conservation efforts for this species. This applied research through acoustic telemetry can be used to increase efforts to remedy or eliminate possible threats and other human induced anthropogenic sources of perturbations (e.g. dredging, pile driving) or mortality (e.g. incidental bycatch) by the establishment of time periods that will limit harmful interactions with sturgeon. Full area closures have been recommended for aggregation areas and migration corridors (Dunton et al. 2010). The consistent and predictable patterns in peak movements, coupled with a shallow depth distribution, and repeated habitat use of the same individuals along the coasts indicates that temporary spatial and temporal closures can be implemented as a conservation measure to protect a significant portion of the population. Such temporary closures need only to reflect the narrow migration corridors and be confined to waters of 30 m or less to protect a majority of the migrating sturgeon (Dunton et al. 2010; this study). Advances in acoustic telemetry, such as the Vemco VR2C, that has the ability to provide data in real-time and can be used to allow managers to directly observe and manage fisheries remotely. Cooperation with fisherman and perhaps the development of "fleet communication" programs can also report aggregations of bycatch in real-time (Gilman et al. 2006) and allow fishermen to avoid areas of high sturgeon abundance. Fleet communication programs allow the fishing fleet to reduce bycatch and can benefit them by allowing fisheries to operate longer by not reaching bycatch limits (Gilman et al. 2006).

The premise that by-batch in the marine environment is limiting recovery of Atlantic sturgeon is supported by estimates of mortality in the marine environment during migration seasons when by-catch is likely to occur. The telemetry data analyzed in this dissertation is also being used to estimate survival by Dr. Michael Melnychuk of the University of Washington. Preliminary results of mark-recapture models indicate survival during periods of marine coastal migrations in the spring and summer are lower at 81% compared to winter and fall survival estimates of 99%. Annual survival is estimated at 88% for all seasons combined (95% CI 85-91). These survival estimates are likely an improvement over catch curve analysis, which suggested that survival is 68% (0.026 SE) (Appendix 8).

This study further supports the use and infrastructure required for large scale array deployment and maintenance and cooperative networks, particularly for rare and endangered species. The costs and effort to maintain large acoustic arrays is high and needs to be well supported (Cooke 2008). Vital habitats such as Long Island Sound and the Hudson River would not have been identified without collaborative partners. Although best efforts were conducted to maintain temporal and spatial coverage at all locations throughout the year, natural disasters as well as interactions with commercial and recreational vessels were problematic. It is recommended that redundancy be incorporated into essential gates, or modifications such as trawl-proof structures, to ensure that coverage is continuous and detection data is not biased due to missing receivers.

Table 5.1. Output of detection range estimates for a VemcoVR2W 69kHz detecting a V16-6H transmitters with a power level of 158 dB re 1uPa@ 1 meter correlated with wind speed estimated by Vemco (www. http://vemco.com/)

Windspeed (Knots)	**Detection range (meters)**
0 – 2	846
3 – 6	827
11 – 16	686
28 – 34	525

Table 5.2. Sampling dates, effort, total number of sturgeon captured and sturgeon acoustically implanted with transmitters with Stony Brook University sampling efforts within the Atlantic Ocean and non-Stony Brook sampling including New Jersey Department of Environmental Protection (NJDEP) finfish survey in the Atlantic Ocean and the New York Department of Environmental Conservation (NYDEC) juvenile sturgeon survey within the Hudson River.

Stony Brook Cruise ID	**Date Range of sampling trip**	**Total number of trawls**	**Total time trawling (min)**	**Number of Atlantic sturgeon captured**	**Number of Atlantic sturgeon implanted with acoustic tags**
2010-001	5/18/2010 - 5/19/2010	27	491	13	12
2010-002	6/14/2010 - 6/15/2010	22	296	12	12
2010-003	11/2/2010 - 11/4/2010	33	366	0	0
2010-004	12/2/2010 - 12/3/2010	20	263	0	0
2011-001	5/24/2011 - 5/25/2011	14	151	85	68
2011-002	10/12/2011 - 10/13/2011	20	277	3	3
2011-003	10/31/2011 - 10/31/2011	10	103	62	60
2011-004	11/8/2011 - 11/10/2011	27	287	126	113
2012-003	5/2/2012 - 5/4/2012	26	295	161	142
2012-004	5/9/2012 - 5/11/2012	24	205	35	0
2012-005	10/23/2012 - 10/24/2012	14	135	0	0
2013-001	5/6/2013 - 5/9/2013	49	448	43	0
2013-002	10/8/2013 - 10/8/2013	11	95	41	0

Additional effort in non-Stony Brook University activities

NJDEP	10/23/2010 - 10/25/2010	----	----	3	3
NYDEC	4/13/2011 - 4/27/2011	----	----	----	14
NJDEP	10/24/2011 - 10/25/2011	----	----	2	2

Table 5.3. Summarized total number of Atlantic sturgeon detections provided by the ACT Network by individual and agency who provided the data

Researcher	Affiliation	Total # of detected Atlantic sturgeon	Total # of detections
Keith Dunton	Stony Brook University	423	1,587,180
Dewayne Fox	Delaware State University	376	1,488,128
Tom Savoy	Connecticut Department of Energy and Environmental Protection	78	573,699
Amanda Higgs	NYDEC	212	103,147
Matt Fisher	Delaware Division of Fish and Wildlife	17	86,776
Hal Brundage	ERC	19	34,064
Jarrett Gibbons	South Carolina Department of Natural Resources	1	29,051
Dave Secor	University of Maryland	57	29,021
Bruce Martin	Jasco Applied Sciences	123	27,211
Carter Watterson	U.S. Department of the Navy	82	16,153
Matt Balazick	Virginia Commonwealth University	6	3,700
Heather Corbett	New Jersey Division of Fish and Wildlife	70	2,908
Gail Wippelhauser	Maine Department of Marine Resources	2	2,236
James Sulikowski	University of New England	1	1,292
Roger Rulifson	East Carolina University	34	545
Bill Hoffman	Massachusetts Division of Marine Fisheries	9	477
Bill Post	South Carolina Department of Natural Resources	1	175
Jonathan Colby	Verdant Power	4	95
Micah Kieffer	United States Geological Survey	1	61
Jeff Kneebone	University of Massachusetts	2	25
Noelle Hawthorne	Savannah State University	1	17
Chris Chisholm	Massachusetts Division of Marine Fisheries	1	6
Graham Goulette	National Oceanic and Atmospheric Administration	1	4
James Hawkes	National Oceanic and Atmospheric Administration	1	4

Table 5.4. Total number of Atlantic sturgeon detected at each array by month. Black boxes indicate no data available

	Rockaway		**Jones**		**Fire Island**		**Shinnecock**		**Montauk**		**LIS**		**Hudson**		**Sandy Hook**		**Barnegat**		**Shark River**		**Atlantic City**		**Delaware**	
Month	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**
Jan	9	11	4	3	4	0	1	2	0	1	■	■	■	5	8	7	4	1	3	3	0	2	3	6
Feb	8	14	4	5	3	1	2	1	0	1	■	■	■	5	7	10	4	5	2	5	4	1	3	6
Mar	101	23	19	3	15	6	3	0	0	0	■	■	■	6	22	13	14	15	10	9	9	8	11	14
Apr	105	28	43	19	31	7	11	1	7	1	1		43	24	17	11	20	12	20	9	28	11	63	24
May	258	163	157	123	137	128	99	104	68	51	29	14	206	125	62	56	59	86	47	62	72	112	59	161
Jun	39	69	62	85	80	94	64	79	30	15	36	28	232	149	11	33	10	62	10	53	6	63	9	46
Jul	3	26	6	22	5	23	4	33	0	0	23	21	213	151	0	13	0	12	0	11	0	3	6	11
Aug	2	3	6	1	4	1	8	2	2	0	25	13	192	127	0	1	0	0	0	0	0	0	10	9
Sep	41	50	47	29	65	27	55	6	0	3	25	21	218	112	25	10	0	3	1	5	0	2	11	17
Oct	177	19	105	11	54	11	11	12	9	8	20	25	88	44	164	■	60	■	53	■	30	16	25	22
Nov	106	■	24	■	19	■	13	4	29	■	13	15	■	■	44	■	29	■	18	■	4	■	14	10
Dec	35	■	8	■	9	■	8	■	10	■	■	■	■	■	16	■	9	■	12	■	4	■	5	■

Table 5.5. Detection probabilities for arrays with double gates from 2012 -2013. Line 1 is receivers stretching from 1 -5 km offshore and line 2 is the detection line that stretches from 1-8 km offshore.

Detection array	Detection line	Range	Mean	St. Dev.
Barnegat	Line 1	0.85 - 0.93	0.93	0.05
	Line 2	0.98 - 1.0	1.00	0.01
	Station	0.99 - 1.0	1.00	0.00
Atlantic City	Line 1	0.38 - 0.96	0.71	0.21
	Line 2	0.68 - 1	0.92	0.12
	Station	0.91 - 1	0.98	0.03
Fire Island	Line 1	0.28 - 0.96	0.78	0.28
	Line 2	0.45 - 1	0.85	0.23
	Station	0.89 - 1	0.98	0.04
Shinnecock	Line 1	0.5 - 0.97	0.72	0.19
	Line 2	0.29 - 0.93	0.68	0.29
	Station	0.64 - 1	0.90	0.14

Table 5.6. Mean, standard deviation, noise parameters, and maximum likelihood for fitted multinomial distributions by site and year.

Site	Year	Season	Mean	Variance	Noise	ML
Rockaway	2012	Spring	104.0447	8.0826	25.6730	53.1951
		Fall	302.7772	2.2278	23.8795	
	2013	Spring	134.0548	2.3594	44.9525	14.4916
		Fall	267.4751	0.3626	6.3285	
Jones Beach	2012	Spring	130.7957	1.6486	29.0703	14.3293
		Fall	288.6970	1.0585	19.2814	
	2013	Spring	144.2588	1.4012	24.7514	7.6292
		Fall	265.9028	0.1796	6.2784	
Fire Island	2012	Spring	135.9368	1.4323	30.9337	10.9174
		Fall	284.2953	0.6013	23.2134	
	2013	Spring	146.0901	1.1700	20.8264	6.0315
		Fall	265.0587	0.1189	8.4358	
Shinnecock	2012	Spring	142.6608	0.7294	26.0990	6.5715
		Fall	264.7918	0.4945	27.6795	
	2013	Spring	159.6631	0.9957	25.6452	5.2015
		Fall	284.4406	0.0698	18.2809	
Montauk	2012	Spring	142.1694	0.3577	16.4552	2.3652
		Fall	319.0677	0.1318	20.1657	
	2013	Spring	141.8515	0.2214	19.2963	1.1955
		Fall	281.4627	0.0303	20.1719	
Sand Hook	2012	Spring	53.4535	0.9476	36.6558	6.2481
		Fall 1	153.9782	0.2704	25.9759	
		Fall 2	263.9376	0.0373	2.8386	
	2013	Spring	159.6631	0.9957	25.6452	5.2015
		Fall	284.4406	0.0698	18.2809	
Shark River	2012	Spring	112.6059	0.3305	33.8197	3.2087
		Fall	309.5253	0.2623	22.0366	
	2013	Spring	148.2425	0.3944	45.3422	2.0615
		Fall	305.9887	0.0000	27.9259	
Barnegat	2012	Spring	111.1745	0.3616	37.4627	3.7278
		Fall	302.7353	0.3451	15.1348	
	2013	Spring	141.7381	0.5503	38.3646	2.7874
		Fall	301.5965	0.0000	14.8839	
Atlantic City	2012	Spring	122.5161	0.4713	27.1763	2.9477
		Fall	307.1125	0.1049	17.5985	
	2013	Spring	143.9810	0.6132	25.0793	3.2198
		Fall	281.7736	0.0513	10.4959	

Table 5.7. Close area estimates for all array locations assuming normal distribution.

Site	Year	Season	% Protection	Mean date	Start date	End date	Total # of days
Montauk	2012	Spring	50%	May-22	May-11	Jun-02	22
		Spring	75%	May-22	May-03	Jun-10	38
		Spring	99%	May-22	Apr-09	Jul-03	85
		Fall	50%	Nov-15	Nov-01	Nov-28	27
		Fall	75%	Nov-15	Oct-22	Dec-08	46
		Fall	99%	Nov-15	Sep-23	Dec-31	106
	2013	Spring	50%	May-21	May-08	Jun-03	26
		Spring	75%	May-21	Apr-29	Jun-13	44
		Spring	99%	May-21	Apr-02	Jul-10	99
		Fall	50%	Oct-08	Sep-24	Oct-22	27
		Fall	75%	Oct-08	Sep-15	Oct-31	46
		Fall	99%	Oct-08	Aug-17	Nov-29	104
Shinnecock	2012	Spring	50%	May-23	May-05	Jun-09	36
		Spring	75%	May-23	Apr-22	Jun-22	61
		Spring	99%	May-23	Mar-15	Jul-30	136
		Fall 1	50%	Sep-09	Sep-05	Sep-12	7
		Fall 1	75%	Sep-09	Sep-03	Sep-15	12
		Fall 1	99%	Sep-09	Aug-27	Sep-22	26
		Fall 2	50%	Nov-09	Oct-27	Nov-22	26
		Fall 2	75%	Nov-09	Oct-18	Dec-01	44
		Fall 2	99%	Nov-09	Aug-27	Dec-31	148
	2013	Spring	50%	Jun-08	May-22	Jun-25	35
		Spring	75%	Jun-08	May-10	Jul-08	59
		Spring	99%	Jun-08	Apr-03	Aug-13	132
		Fall	50%	Oct-11	Sep-29	Oct-23	25
		Fall	75%	Oct-11	Sep-20	Nov-01	42
		Fall	99%	Oct-11	Aug-25	Nov-27	94
Fire	2012	Spring	50%	May-15	Apr-25	Jun-05	42
		Spring	75%	May-15	Apr-10	Jun-20	71
		Spring	99%	May-15	Feb-25	Aug-03	159
		Fall	50%	Oct-11	Sep-25	Oct-26	31
		Fall	75%	Oct-11	Sep-14	Nov-06	53
		Fall	99%	Oct-11	Aug-12	Dec-10	120
	2013	Spring	50%	May-26	May-12	Jun-09	28
		Spring	75%	May-26	May-02	Jun-19	48
		Spring	99%	May-26	Apr-02	Jul-18	107
Jones	2012	Spring	50%	May-10	Apr-21	May-30	39
		Spring	75%	May-10	Apr-07	Jun-13	67
		Spring	99%	May-10	Feb-24	Jul-24	150
		Fall	50%	Oct-15	Oct-02	Oct-28	26
		Fall	75%	Oct-15	Sep-23	Nov-06	44
		Fall	99%	Oct-15	Aug-27	Dec-04	99
	2013	Spring	50%	May-24	May-07	Jun-09	33
		Spring	75%	May-24	Apr-25	Jun-21	57
		Spring	99%	May-24	Mar-21	Jul-27	128
Rockaway	2010	Spring	50%	May-29	May-20	Jun-07	18
		Spring	75%	May-29	May-14	Jun-13	30
		Spring	99%	May-29	Apr-26	Jul-02	67
		Fall	50%	Oct-05	Sep-29	Oct-11	12
		Fall	75%	Oct-05	Sep-25	Oct-16	21
		Fall	99%	Oct-05	Sep-12	Oct-28	46
Rockaway	2011	Spring	50%	May-23	May-10	Jun-05	26
		Spring	75%	May-23	Apr-30	Jun-14	44
		Spring	99%	May-23	Apr-03	Jul-11	99
		Fall	50%	Oct-31	Oct-17	Nov-14	29
		Fall	75%	Oct-31	Oct-07	Nov-24	49
		Fall	99%	Oct-31	Sep-06	Dec-25	109
Rockaway	2012	Spring	50%	Apr-14	Mar-27	May-01	35
		Spring	75%	Apr-14	Mar-15	May-13	59
		Spring	99%	Apr-14	Feb-06	Jun-19	132
		Fall	50%	Oct-29	Oct-13	Nov-14	32
		Fall	75%	Oct-29	Oct-02	Nov-26	55
		Fall	99%	Oct-29	Aug-29	Dec-30	123
Rockaway	2013	Spring	50%	May-14	Apr-13	Jun-13	61
		Spring	75%	May-14	Mar-23	Jul-04	103
		Spring	99%	May-14	Jan-18	Sep-06	232
Sandy Hook	2011	Fall	50%	Nov-06	Oct-26	Nov-18	23
		Fall	75%	Nov-06	Oct-18	Nov-26	39
		Fall	99%	Nov-06	Sep-24	Dec-20	87
	2012	Spring	50%	Apr-13	Mar-17	May-10	54
		Spring	75%	Apr-13	Feb-26	May-29	92
		Spring	99%	Apr-13	Jan-01	Jul-26	207
		Fall	50%	Oct-30	Oct-14	Nov-15	32
		Fall	75%	Oct-30	Oct-03	Nov-26	54
		Fall	99%	Oct-30	Aug-30	Dec-30	122
	2013	Spring	50%	Mar-01	Jan-14	Apr-15	90
		Spring	75%	Mar-01	Jan-01	Apr-30	120
		Spring	99%	Mar-01	Jan-01	Apr-30	120
Shark River	2013	Spring	50%	May-28	Apr-27	Jun-27	61
			75%	May-28	Apr-06	Jul-19	104
			99%	May-28	Jan-31	Sep-22	234
	2012	Spring	50%	Apr-22	Mar-30	May-15	46
			75%	Apr-22	Mar-14	May-31	78
			99%	Apr-22	Jan-25	Jul-18	174
	2012	Fall	50%	Nov-05	Oct-21	Nov-20	30
			75%	Nov-05	Oct-11	Nov-30	51
			99%	Nov-05	Sep-09	Dec-31	114
Barnegat	2012	Spring	50%	Apr-21	Mar-26	May-16	51
			75%	Apr-21	Mar-09	Jun-03	86
			99%	Apr-21	Jan-14	Jul-26	193
		Fall	50%	Oct-29	Oct-19	Nov-08	20
			75%	Oct-29	Oct-12	Nov-16	35
			99%	Oct-29	Sep-20	Dec-07	78
	2013	Spring	50%	May-21	Apr-25	Jun-16	52
			75%	May-21	Apr-07	Jul-04	88
			99%	May-21	Feb-11	Aug-28	198
Atlantic City	2012	Spring	50%	May-02	Apr-14	May-20	37
			75%	May-02	Apr-01	Jun-02	63
			99%	May-02	Feb-21	Jul-11	140
		Fall	50%	Nov-03	Oct-22	Nov-14	24
			75%	Nov-03	Oct-13	Nov-23	40
			99%	Nov-03	Sep-18	Dec-18	91
	2013	Spring	50%	May-23	May-07	Jun-09	34
			75%	May-23	Apr-25	Jun-21	58
			99%	May-23	Mar-20	Jul-27	129
		Fall	50%	Oct-08	Oct-01	Oct-15	14
			75%	Oct-08	Sep-26	Oct-20	24
			99%	Oct-08	Sep-11	Nov-04	54

Table 5.8. Descriptive statistics for residency events occurring at all locations.

	New York					**New Jersey**			
	Rockaway	*Jones*	*Fire Island*	*Shinnecock*	*Montauk*	*Sandy Hook*	*Shark River*	*Barnegat*	*Atlantic City*
Mean	739.94	235.79	269.86	193.25	101.77	516.20	89.25	151.59	109.08
Standard Error	43.38	18.58	38.58	15.12	16.51	39.43	22.10	18.68	13.02
Median	127.50	56.38	76.97	62.33	18.94	126.00	29.85	68.86	68.82
Mode	8.43	36.15	44.82	83.57	5.25	98.35	25.90	91.57	69.23
Standard Deviation	1663.10	724.49	1316.10	440.23	272.28	1157.08	411.75	404.22	279.56
Range	21250.47	12783.53	24151.47	5118.88	2608.07	13246.72	6947.33	3799.83	4187.27
Minimum	1.48	1.00	1.97	1.27	0.72	0	2.58	3.20	1.40
Maximum	21251.95	12784.53	24153.43	5120.15	2608.78	13212.35	6949.92	3803.03	4188.67
Count	1470	1520	1164	848	272	861	347	468	461
95% Confidence Level	85.09	36.45	75.69	29.67	32.50	77.40	43.47	36.72	25.59

Table 5.9. Tukey HSD multiple comparisons of means 95% family-wise confidence level residency

Sites	**Difference from mean**	**Lower**	**Upper**	**p adjusted**
Barnegat-Atlantic_City	42.5056	-174.1410	259.1521	0.9996
Fire-Atlantic_City	160.7788	-20.9053	342.4629	0.1322
Jones-Atlantic_City	126.7064	-48.8381	302.2509	0.3800
Montauk-Atlantic_City	-7.3097	-259.7358	245.1164	1.0000
Rockaway-Atlantic_City	630.8637	454.6258	807.1015	**0.0000**
Sandy-Atlantic_City	407.1238	216.5861	597.6615	**0.0000**
Shark_River-Atlantic_City	-19.8341	-254.4772	214.8089	1.0000
Shinnecock-Atlantic_City	84.1743	-106.8721	275.2206	0.9102
Fire-Barnegat	118.2732	-62.4350	298.9814	0.5217
Jones-Barnegat	84.2009	-90.3334	258.7351	0.8574
Montauk-Barnegat	-49.8153	-301.5399	201.9094	0.9995
Rockaway-Barnegat	588.3581	413.1265	763.5897	**0.0000**
Sandy-Barnegat	364.6183	175.0109	554.2257	**0.0000**
Shark_River-Barnegat	-62.3397	-296.2279	171.5485	0.9961
Shinnecock-Barnegat	41.6687	-148.4498	231.7872	0.9990
Jones-Fire	-34.0723	-162.6632	94.5186	0.9962
Montauk-Fire	-168.0885	-390.4366	54.2597	0.3149
Rockaway-Fire	470.0849	340.5490	599.6207	**0.0000**
Sandy-Fire	246.3451	97.9390	394.7511	**0.0000**
Shark_River-Fire	-180.6129	-382.5464	21.3205	0.1229
Shinnecock-Fire	-76.6045	-225.6631	72.4540	0.8082
Montauk-Jones	-134.0161	-351.3763	83.3440	0.6047
Rockaway-Jones	504.1572	383.3835	624.9309	**0.0000**
Sandy-Jones	280.4174	139.5944	421.2404	**0.0000**
Shark_River-Jones	-146.5406	-342.9683	49.8872	0.3332
Shinnecock-Jones	-42.5322	-184.0426	98.9782	0.9911
Rockaway-Montauk	638.1734	420.2528	856.0939	**0.0000**
Sandy-Montauk	414.4335	184.7943	644.0728	**0.0000**
Shark_River-Montauk	-12.5244	-279.8949	254.8460	1.0000
Shinnecock-Montauk	91.4840	-138.5775	321.5454	0.9491
Sandy-Rockaway	-223.7398	-365.4262	-82.0534	**0.0000**
Shark_River-Rockaway	-650.6978	-847.7454	-453.6501	**0.0000**
Shinnecock-Rockaway	-546.6894	-689.0590	-404.3198	**0.0000**
Shark_River-Sandy	-426.9580	-636.8927	-217.0232	**0.0000**
Shinnecock-Sandy	-322.9496	-482.6804	-163.2187	**0.0000**
Shinnecock-Shark_River	104.0084	-106.3881	314.4049	0.8397

Table 5.10. Descriptive statistics for rate of movement events for Atlantic sturgeon occurring between adjacent locations.

	NEW YORK				**NEW JERSEY**		
	West			East	North		South
	Rockaway ↔ *Jones Beach*	*Fire Island* ↔ *Jones Beach*	*Fire Island* ↔ *Shinnecock*	*Shinnecock* ↔ *Montauk*	*Sandy Hook* ↔ *Shark River*	*Shark River* ↔ *Barnegat*	*Barnegat* ↔ *Atlantic City*
Mean	1.0939	1.2452	1.2793	1.7078	1.5661	1.7369	1.4668
Standard Error	0.0269	0.0226	0.0296	0.0415	0.0453	0.0341	0.0317
Median	1.0666	1.2624	1.3258	1.7354	1.6779	1.8428	1.5644
Standard Deviation	0.6847	0.6488	0.7063	0.5775	0.6550	0.5891	0.5541
Sample Variance	0.4688	0.4209	0.4989	0.3335	0.4290	0.3470	0.3070
Range	2.9406	4.6395	4.3456	2.9096	2.8574	2.7232	2.5367
Minimum	0.0711	0.0592	0.1157	0.1330	0.0411	0.0833	0.1603
Maximum	3.0117	4.6988	4.4614	3.0426	2.8984	2.8066	2.6971
Count	647	822	568	194	209	299	305
95% Confidence Level	0.0529	0.0444	0.0582	0.0818	0.0893	0.0670	0.0624

Table 5.11. Tukey HSD multiple comparisons of means 95% family-wise confidence level for rate of movement between sites.

Sites	**Difference from mean**	**Lower**	**Upper**	**p adjusted**
FireJones-BarnAC	-0.2258	-0.3532	-0.0983	**0.0000**
FireShin-BarnAC	-0.1931	-0.3281	-0.0582	**0.0005**
RockJones-BarnAC	-0.3729	-0.5049	-0.2409	**0.0000**
SandShark-BarnAC	0.0993	-0.0713	0.2700	0.6046
SharkBarn-BarnAC	0.2702	0.1155	0.4248	**0.0000**
ShinMon-BarnAC	0.2410	0.0665	0.4155	**0.0009**
FireShin-FireJones	0.0326	-0.0711	0.1364	0.9681
RockJones-FireJones	-0.1471	-0.2470	-0.0472	**0.0003**
SandShark-FireJones	0.3251	0.1779	0.4724	**0.0000**
SharkBarn-FireJones	0.4959	0.3676	0.6243	**0.0000**
ShinMon-FireJones	0.4668	0.3150	0.6185	**0.0000**
RockJones-FireShin	-0.1798	-0.2891	-0.0704	**0.0000**
SandShark-FireShin	0.2925	0.1387	0.4463	**0.0000**
SharkBarn-FireShin	0.4633	0.3275	0.5991	**0.0000**
ShinMon-FireShin	0.4341	0.2760	0.5922	**0.0000**
SandShark-RockJones	0.4722	0.3210	0.6234	**0.0000**
SharkBarn-RockJones	0.6431	0.5102	0.7760	**0.0000**
ShinMon-RockJones	0.6139	0.4583	0.7695	**0.0000**
SharkBarn-SandShark	0.1708	-0.0005	0.3422	0.0513
ShinMon-SandShark	0.1417	-0.0478	0.3311	0.2925
ShinMon-SharkBarn	-0.0292	-0.2044	0.1461	0.9990

Figure 5.1. Regional map showing locations and numbers of deployed Vemco VR2W passive monitoring acoustic receivers maintained by Stony Brook University.

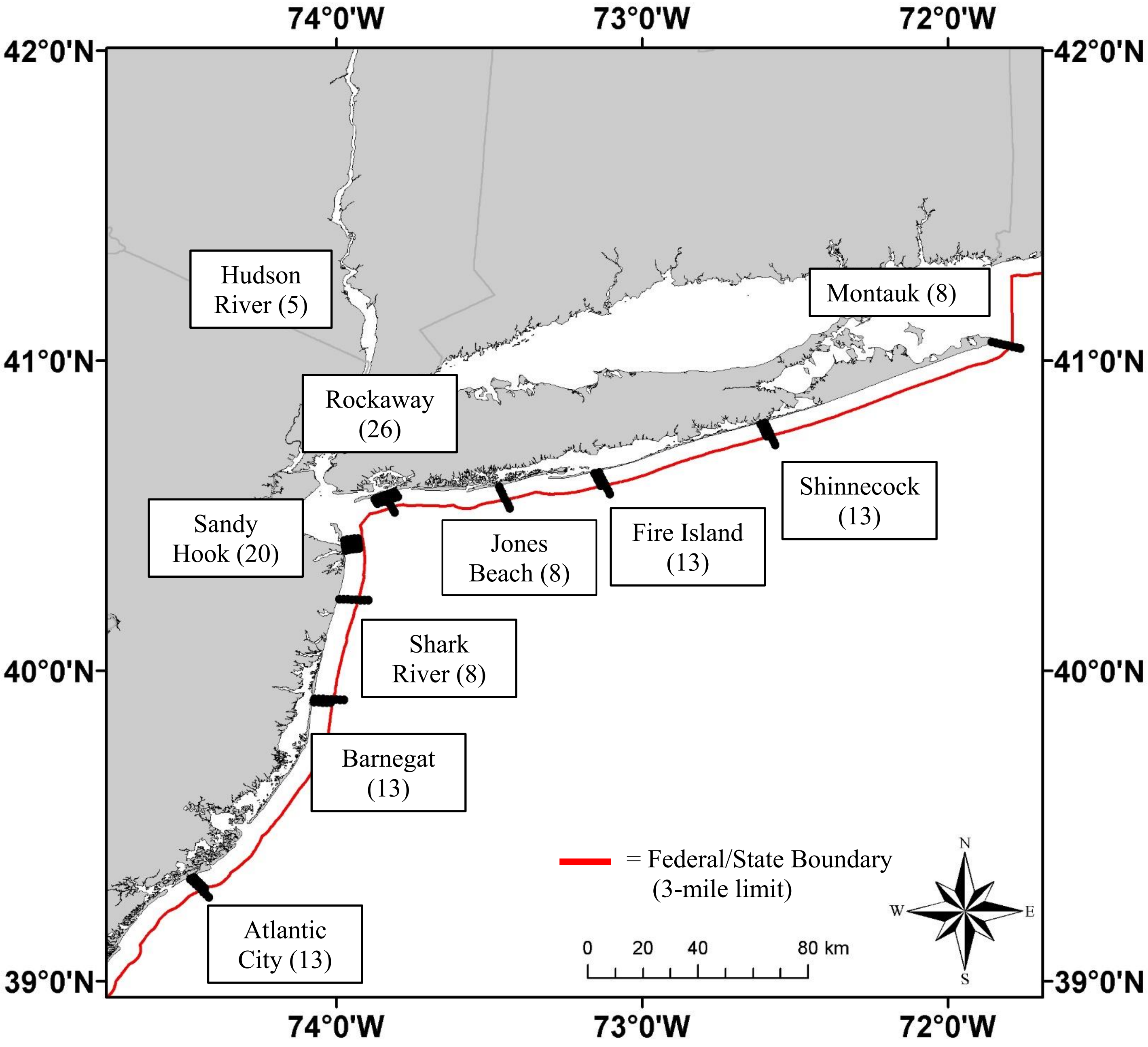


Figure 5.2. General locations of cooperating members within the Atlantic Cooperative Telemetry (ACT) network and Florida Acoustic Cooperative Telemetry (FACT) group. ACT and FACT are large scale collaborative telemetry networks comprised of ~30 groups from Maine to Florida who operate Vemco VR2W arrays and participate in data cooperative data sharing. If sturgeon tagged within this project entered these other arrays a data sharing agreement was worked out to retrieve the associated data. (Map courtesy of Lori Brown, Delaware State University).

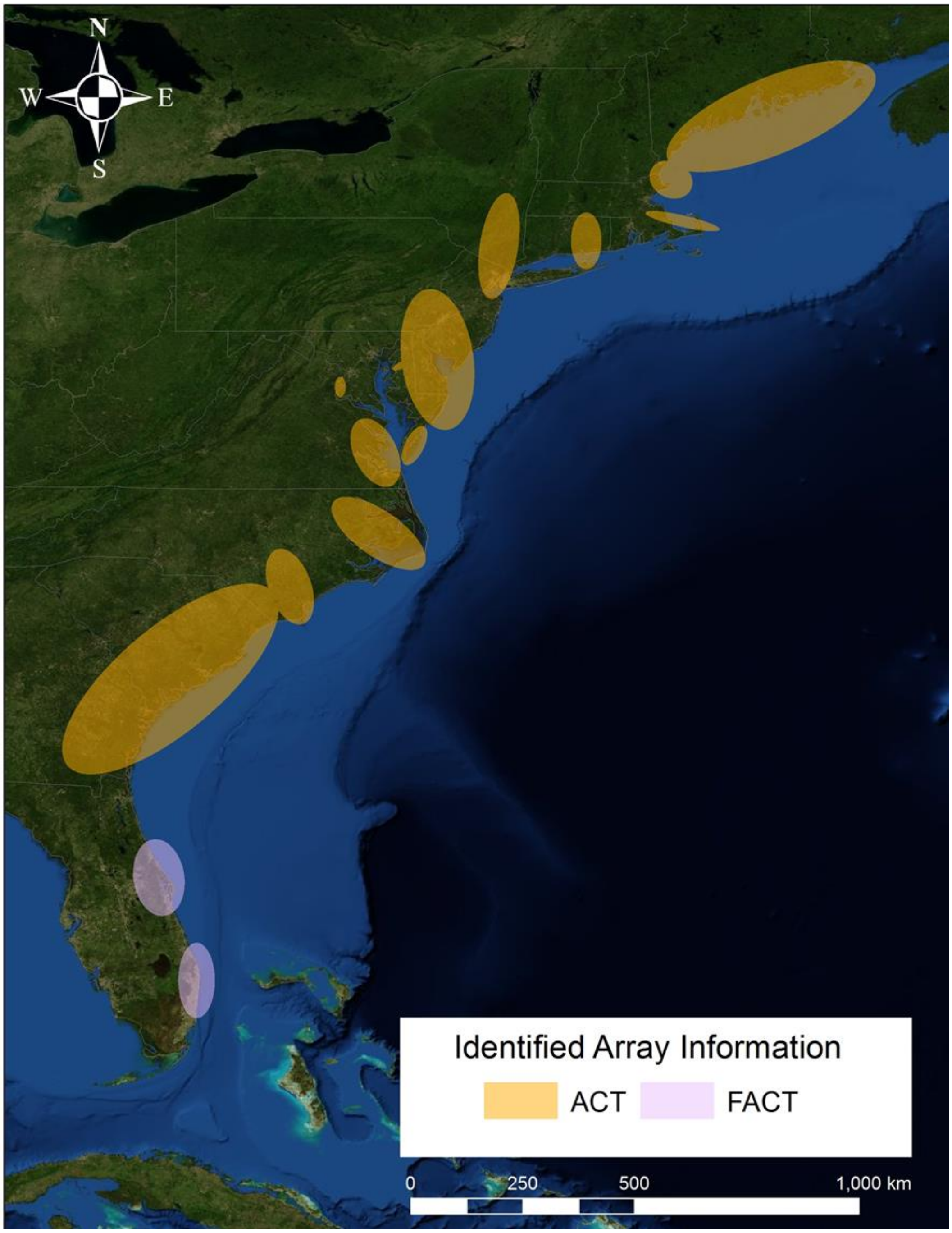


Figure 5.3. Biological characteristics of Atlantic sturgeon implanted with acoustic tags (A) Fork Length (cm) size distribution (B) weight (kg) size distribution and (C) fork length (cm) vs. weight (kg)

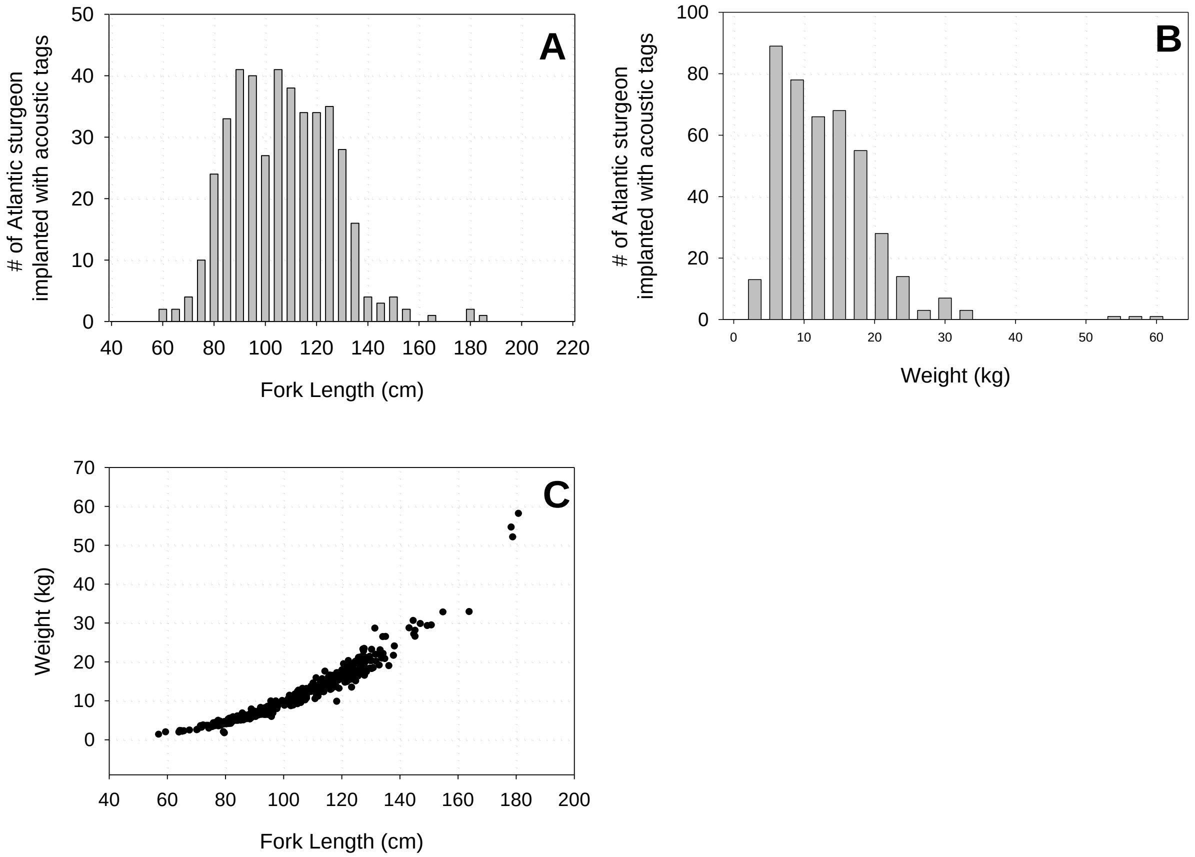


Figure 5.4. Detection probabilities of individuals over time. Rockaway and Sandy Hook Array's were operational during 2011. The coastal array was expanded to all locations in 2012.

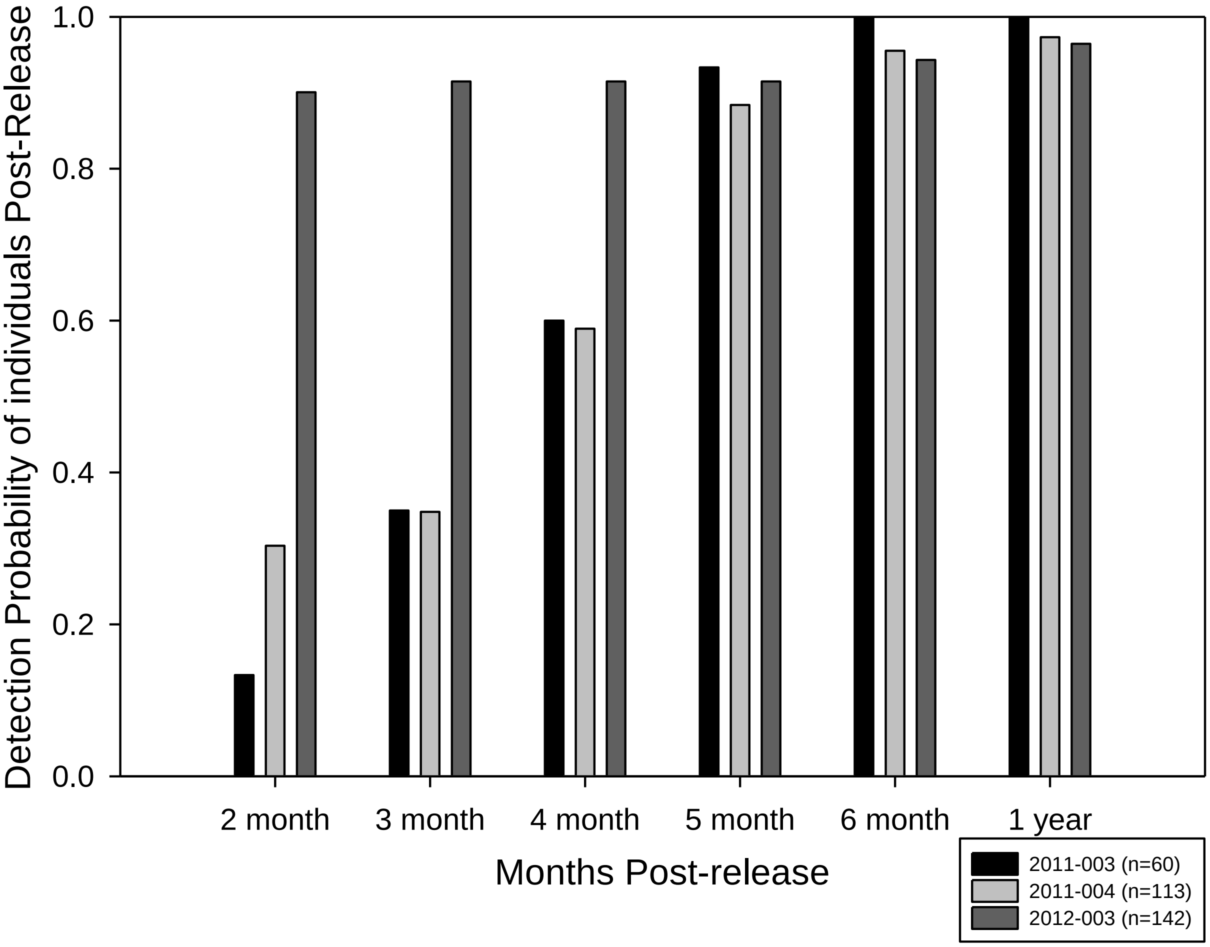


Figure 5.5. Example of the receiver detection patterns for a dead vs. living surgeon, where the fragmented line represents an active fish and the continuous line represents a "dead" fish. The temporal pattern of a living fish would result in a discontinuous series of detections.

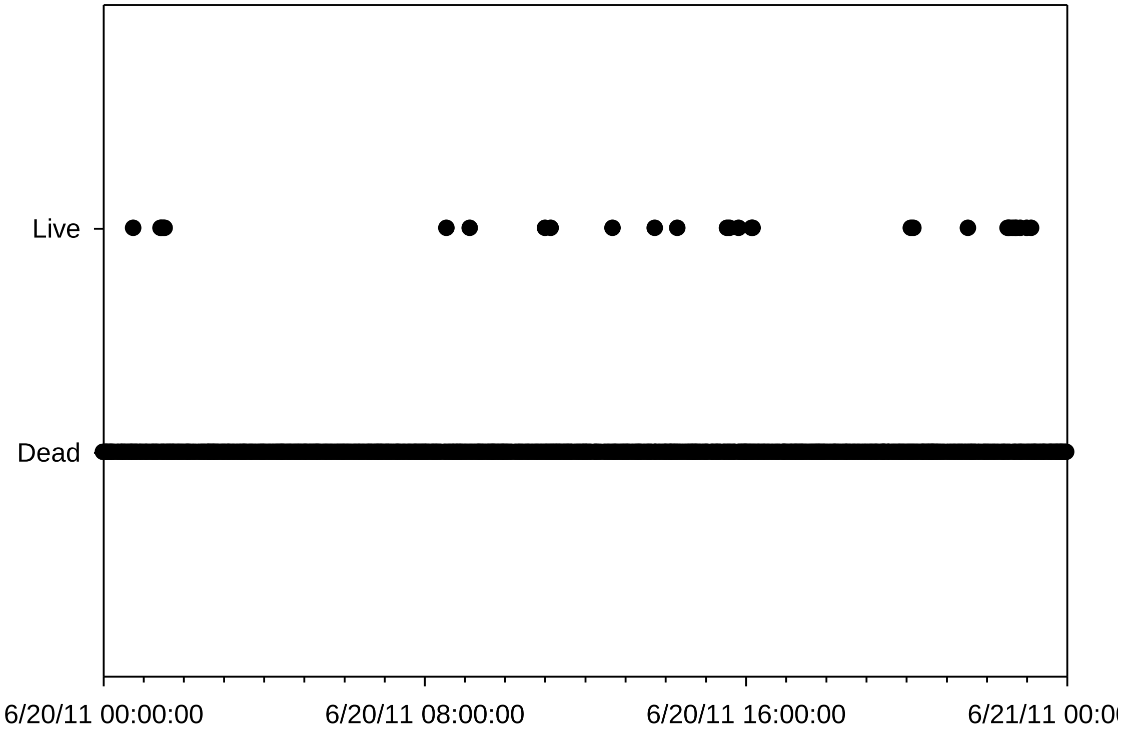


Figure 5.6. Proportion of acoustically tagged Atlantic sturgeon detected within coastal arrays along the NY Coast. Red line indicates outcome of modal analysis expected frequencies assuming a normal distribution.

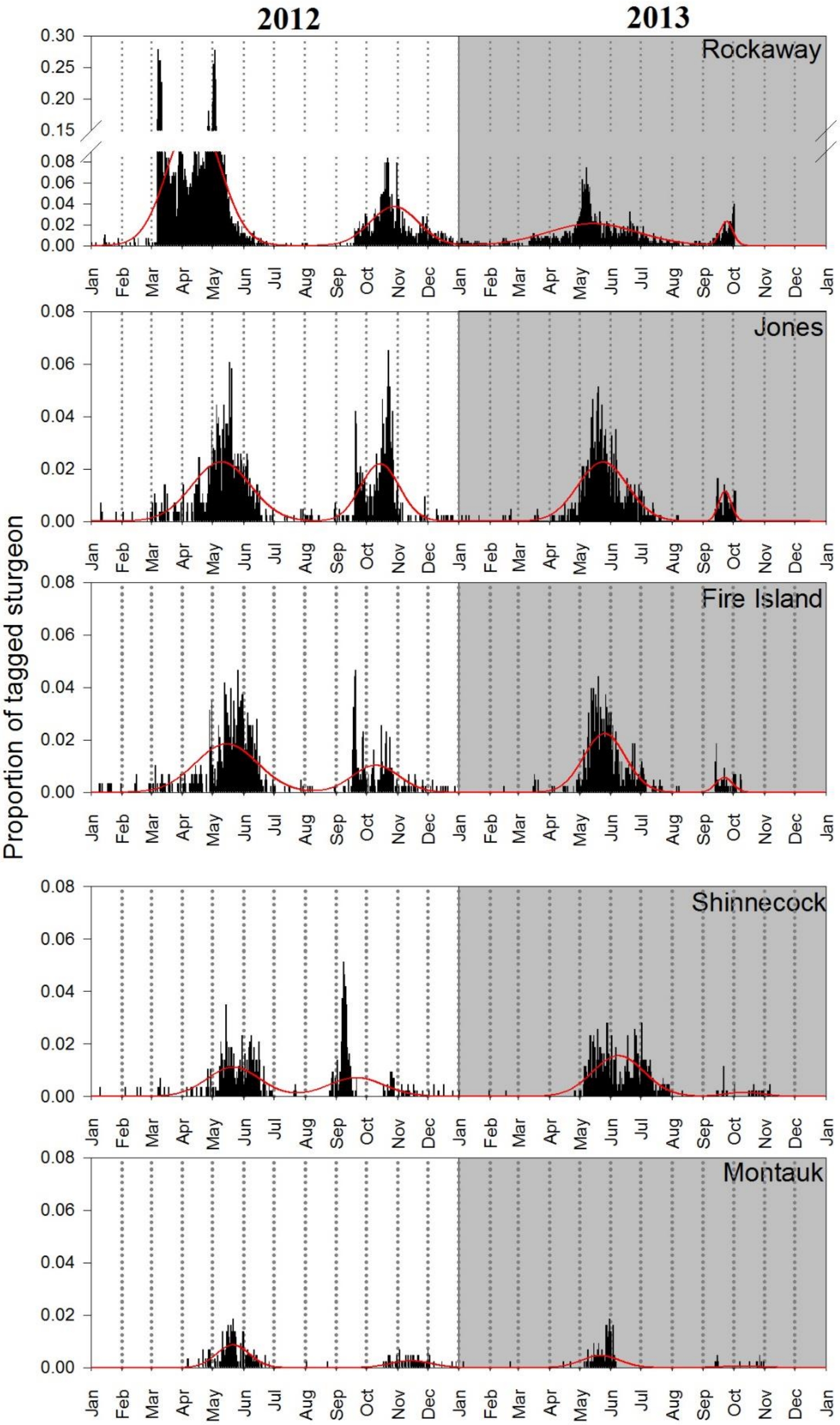

2012
2013
Rockaway
Jones
Fire Island
Shinnecock
Montauk
Proportion of tagged sturgeon
0.30
0.25
0.20
0.15
0.08
0.06
0.04
0.02
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan

Figure 5.7. Proportion of acoustically tagged Atlantic sturgeon detected within coastal arrays along the NJ Coast. Red line indicates outcome of modal analysis expected frequencies assuming a normal distribution.

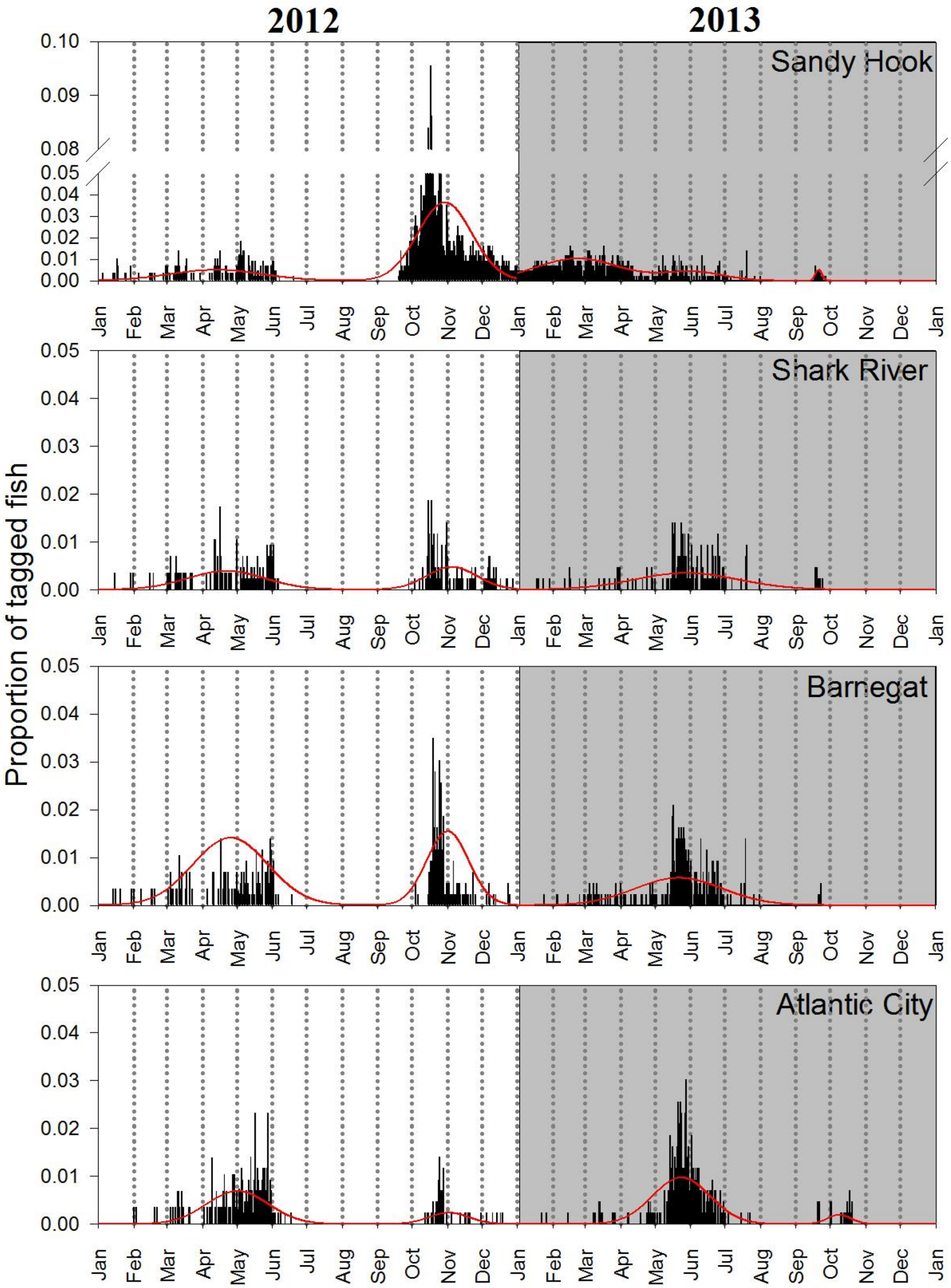


Figure 5.8. Regional habitat use of sub-adult Atlantic sturgeon. Greyed areas indicate time periods when there was no receivers monitoring.

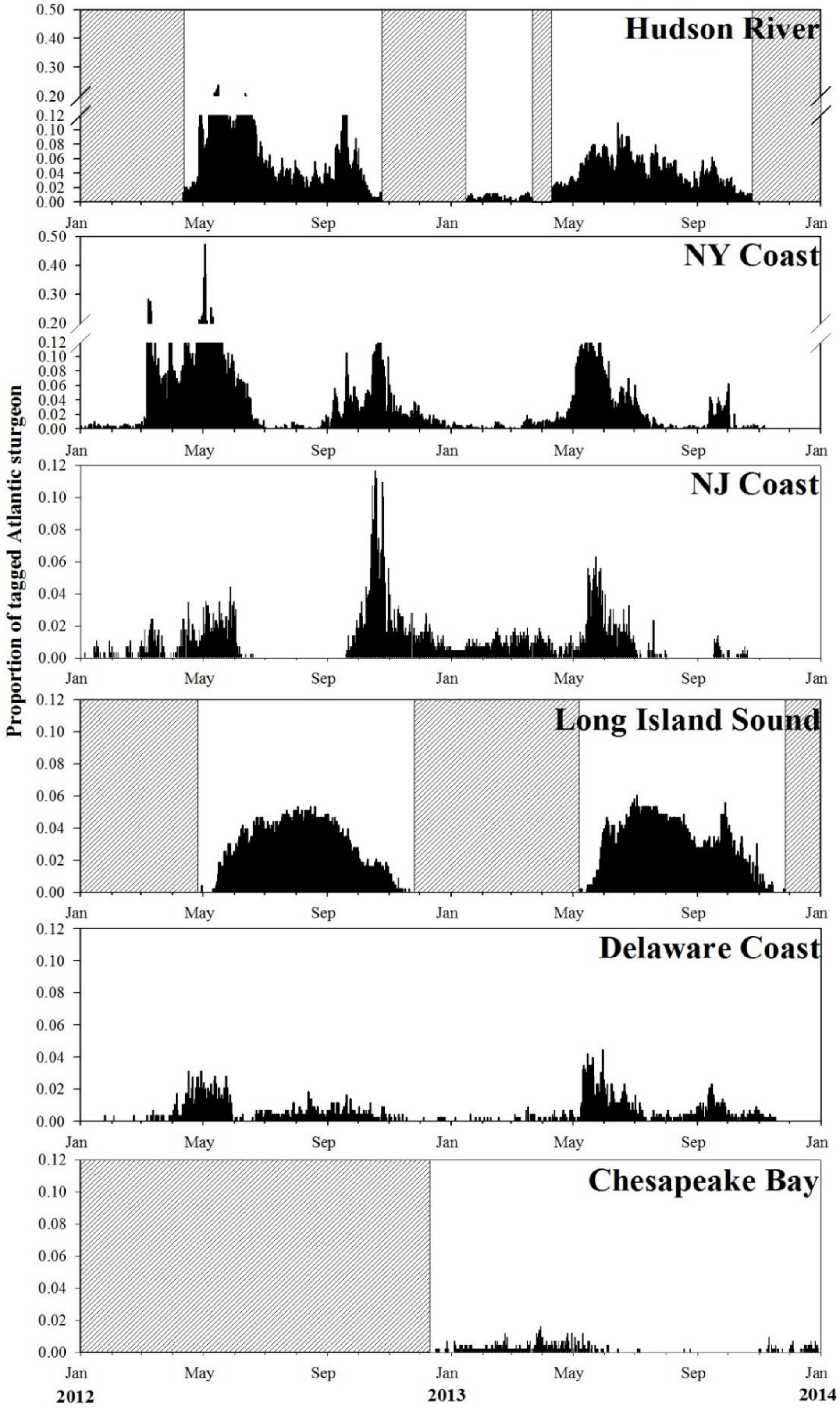


Figure 5.9. (A) Total number of uniquely tagged Atlantic sturgeon (n=429) detected at each site by year (B) Linear regressions for the NY Coast and NJ Coast for 2012 and 2013

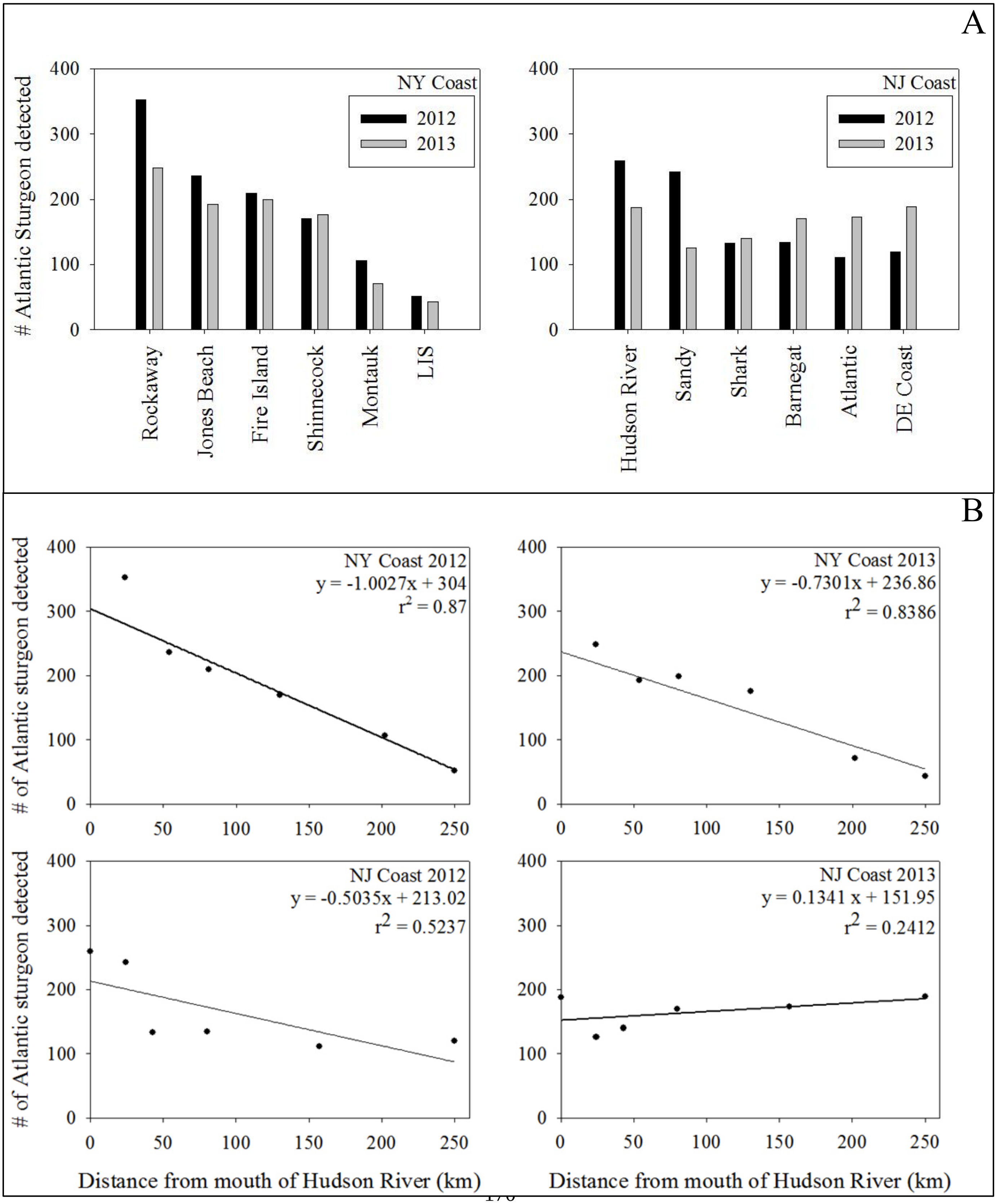


Figure 5.10. Detections of Atlantic sturgeon relative to receiver position from shore (1 being closest to shore and 8 being furthest) for time periods when all 8 receivers were operational at each site (please note that time periods vary site to site). For Montauk (grey = 1/10/2012 - 6/6/2013), Shinnecock (black = 1/9/2012 – 6/27/2012; grey = 3/11/2013 – 5/29/2013), Fire Island (grey = 3/12/2013 – 10/1/2013), Jones Beach (black = 1/7/12-6/6/12; grey = 5/22/13-9/20/13), Rockaway (black = 3/1/2012 – 6/11/2012; grey = 3/12/2013 -10/2/2013), Sandy Hook (black = 10/11/2011 – 7/12/2012; grey = 7/19/2012 – 5/13/2013), Shark River (black = 1/7/2012 – 12/13/2012; grey = 12/13/2012 – 9/26/2013), Barnegat (black = 1/8/2012 – 12/12/2012; grey = 12/13/2012 – 6/20/2013), Atlantic City (black = 1/8/2012 -6/22/2012; grey = 12/13/2012 – 6/25/2013)

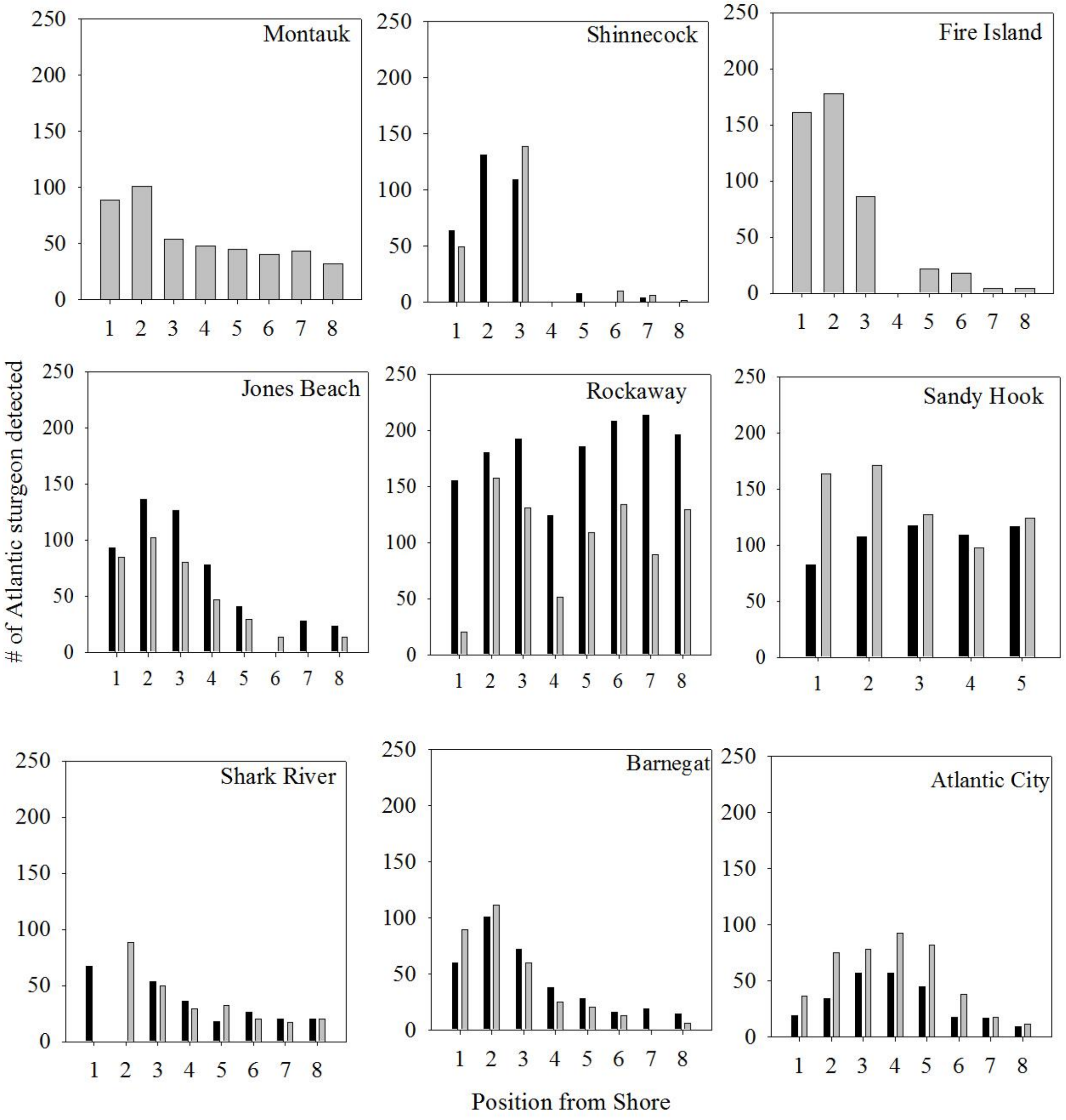


Figure 5.11. Linear regression results for total number of sturgeon detected vs. distance from shore for all coastal arrays during time periods when all receivers were present and monitoring. For Shinnecock it represents the time periods when most receivers are recovered.

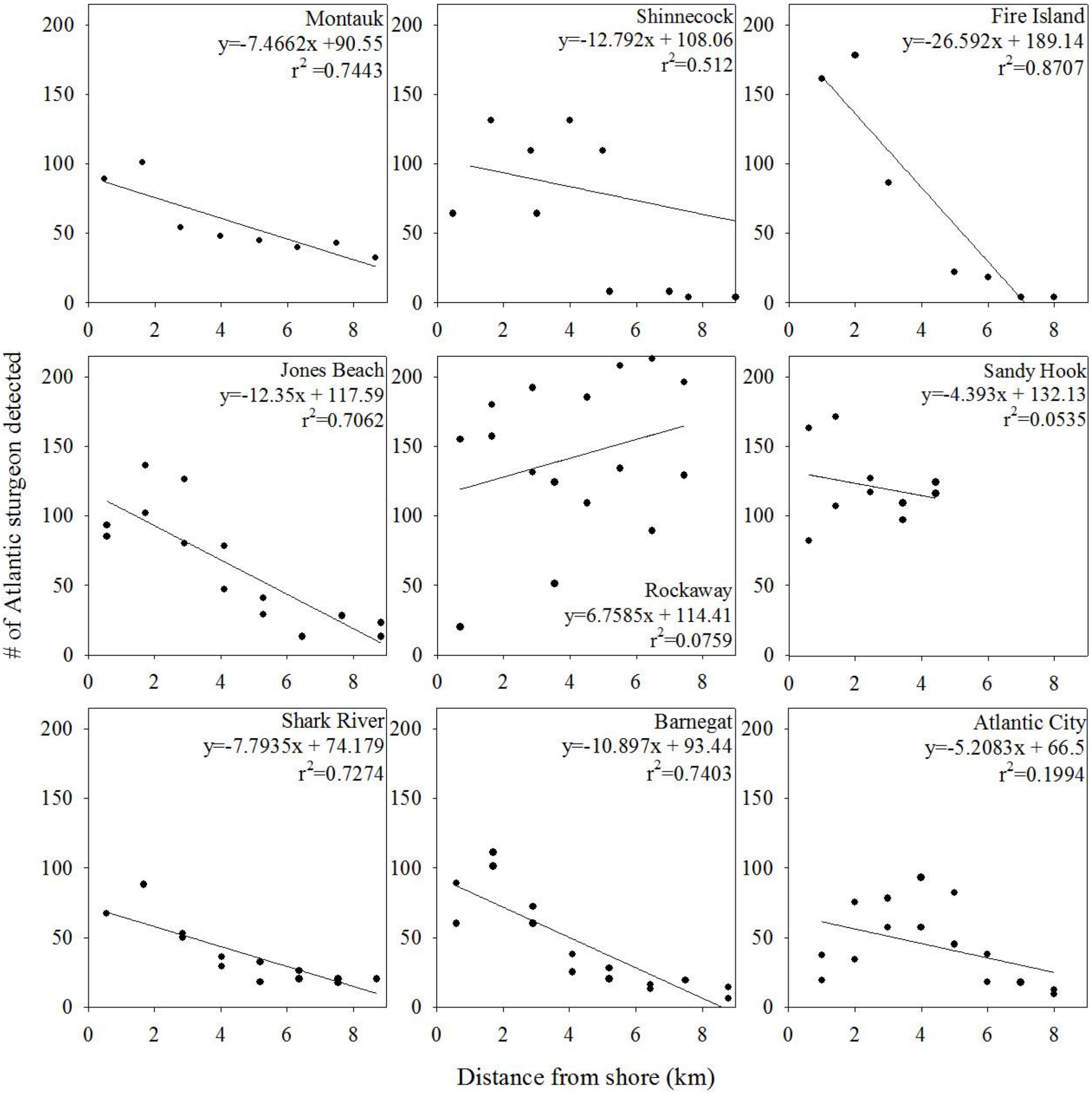


Figure 5.12. Proportion of NY Coastal array detection coverage as a gate from shore – 8km, assuming an 800m detection radii. Grey area represents modal analysis for 50% of population as reference of array coverage during peak sturgeon migrations.

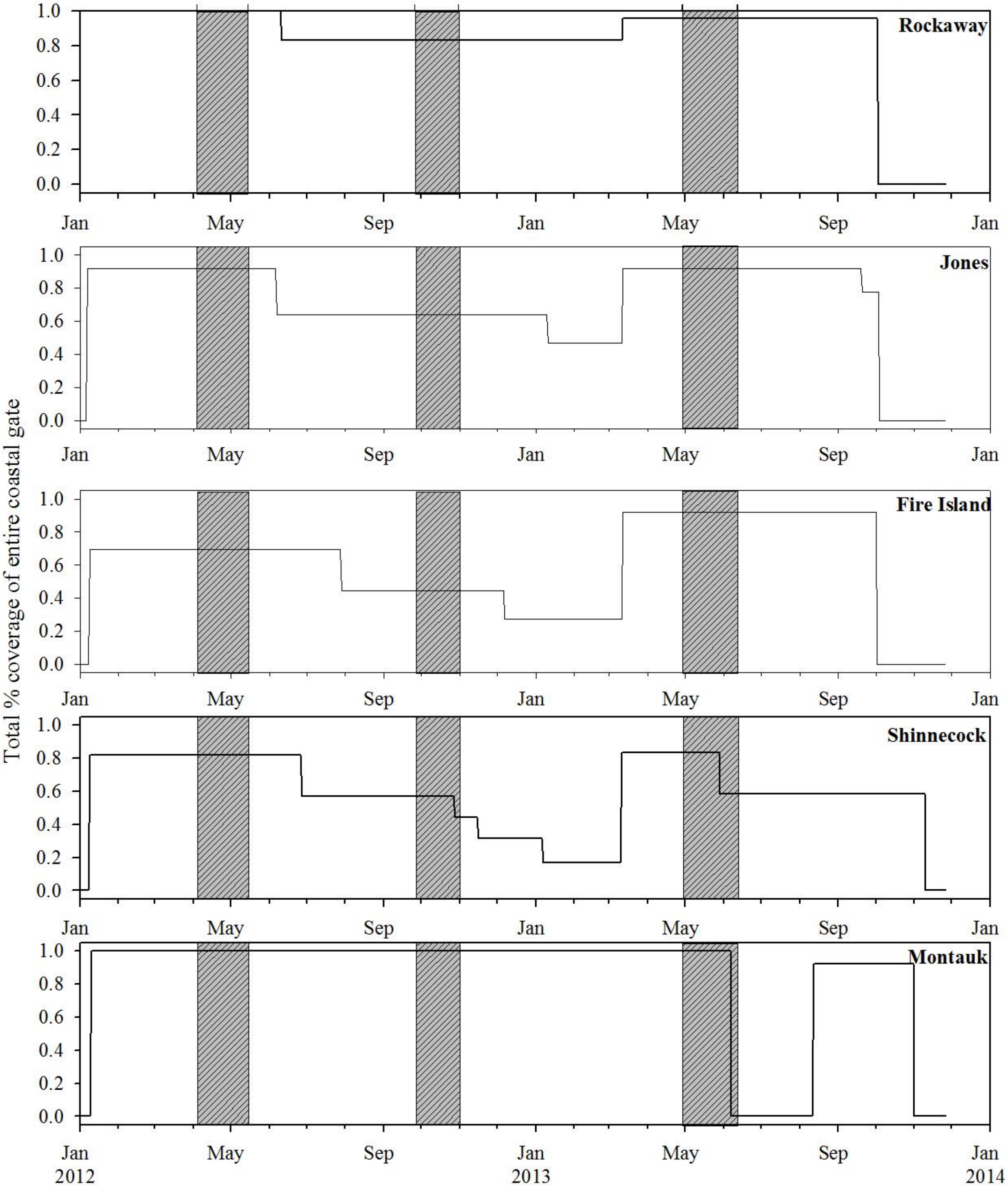


Figure 5.13. Proportion of NJ Coastal array detection coverage as a gate from shore – 8km, assuming an 800m detection radii. Grey area represents modal analysis for 50% of population as reference of array coverage during peak sturgeon migrations.

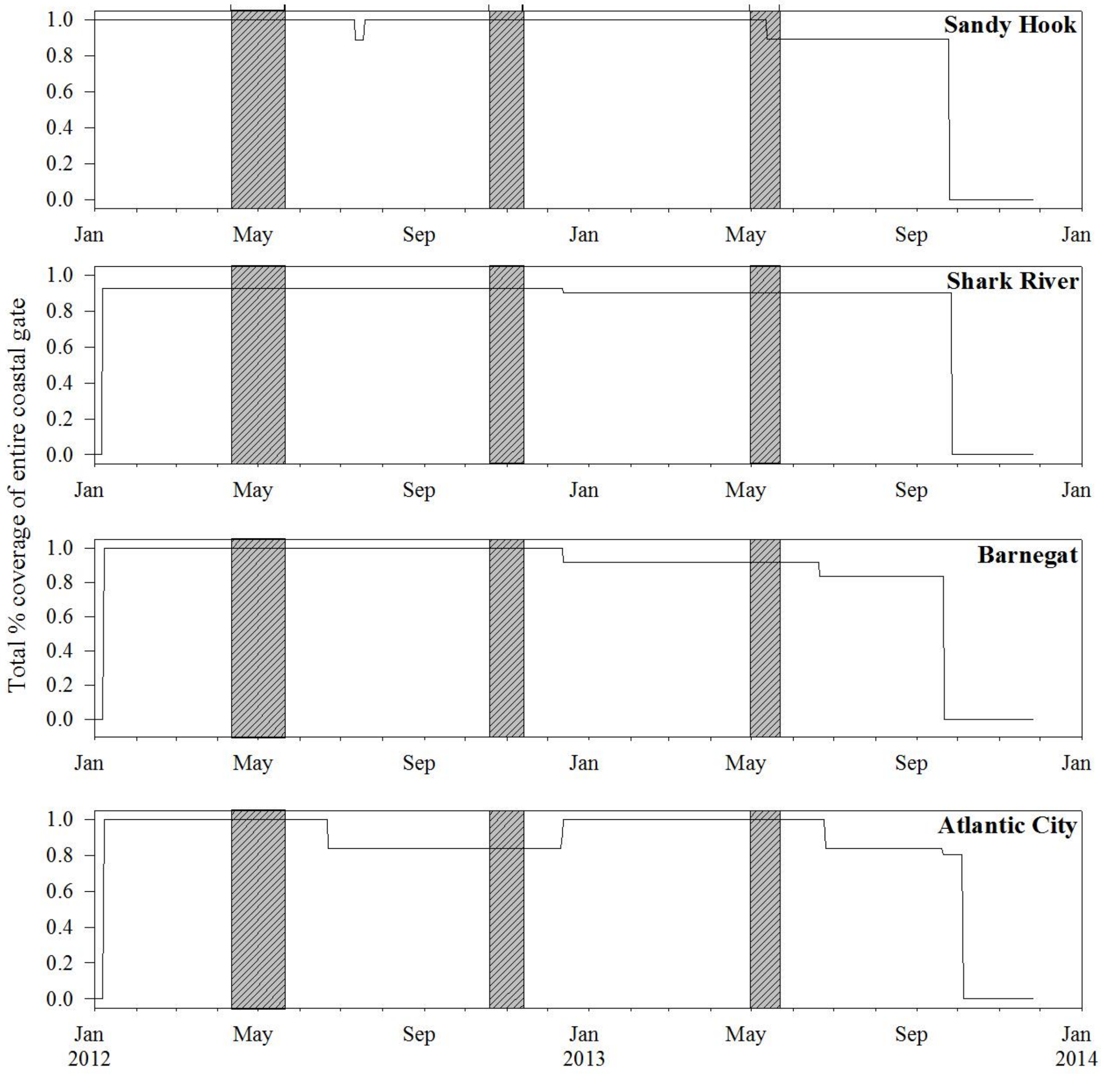
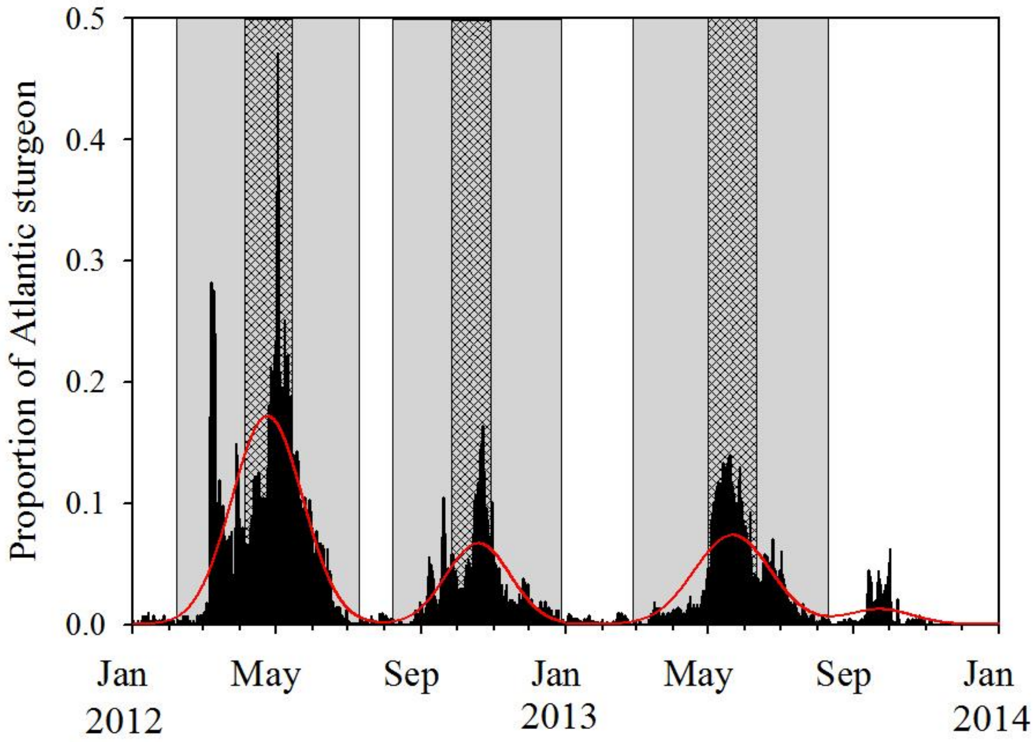


Figure 5.14 (A) Observed (black bars; left axis) and expected normal frequency distribution (red lines; right axis for the Long Island Coast. 99% closure (gray boxes) and 50% (hatched area) closure scenarios estimated using the normal distribution scenario. (B) table of closed area scenarios for 50%, 75%, and 99% closure scenarios estimated using the CDF and normal distributions.



Distribution	Year	Season	Level of protection	Peak	Start	End	Period
Normal	2012	Spring	50%	4/25/2012	4/4/2012	5/15/2012	40
Normal	2012	Spring	75%	4/25/2012	3/21/2012	5/29/2012	69
Normal	2012	Spring	99%	4/25/2012	2/7/2012	7/11/2012	154
CDF	2012	Spring	50%	04/30/2012	04/01/2012	05/13/2012	42
CDF	2012	Spring	75%	04/30/2012	02/26/2012	05/26/2012	90
CDF	2012	Spring	99%	04/30/2012	01/19/2012	06/18/2012	151
Normal	2012	Fall	50%	10/19/2012	9/30/2012	11/6/2012	37
Normal	2012	Fall	75%	10/19/2012	9/17/2012	11/19/2012	63
Normal	2012	Fall	99%	10/19/2012	8/9/2012	12/28/2012	141
CDF	2012	Fall	50%	10/20/2012	09/29/2012	10/31/2012	32
CDF	2012	Fall	75%	10/20/2012	09/19/2012	11/22/2012	64
CDF	2012	Fall	99%	10/20/2012	08/07/2012	12/26/2012	141
Normal	2013	Spring	50%	5/21/2013	4/29/2013	6/12/2013	43
Normal	2013	Spring	75%	5/21/2013	4/14/2013	6/27/2013	74
Normal	2013	Spring	99%	5/21/2013	2/27/2013	8/12/2013	166
CDF	2013	Spring	50%	05/22/2013	05/09/2013	06/07/2013	29
CDF	2013	Spring	75%	05/22/2013	04/29/2013	06/25/2013	57
CDF	2013	Spring	99%	05/22/2013	01/06/2013	07/25/2013	200
Normal	2013	Fall	50%	9/22/2013	9/4/2013	10/11/2013	37
Normal	2013	Fall	75%	9/22/2013	8/22/2013	10/24/2013	63
Normal	2013	Fall	99%	9/22/2013	7/14/2013	12/1/2013	140
CDF	2013	Fall	50%	9/23/2013	9/15/2013	10/1/2013	16
CDF	2013	Fall	75%	9/23/2013	9/13/2013	10/2/2013	19
CDF	2013	Fall	99%	9/23/2013	8/4/2013	11/5/2013	93

Figure 5.15. The distribution of occupancy dates in 2012 (black lines) and 2013 (dotted lines) are shown by cumulative distribution functions for the (A) NY Coast spring and (B) NY Coast autumn and (C) NJ Coast Spring and (D) NJ Coast Fall

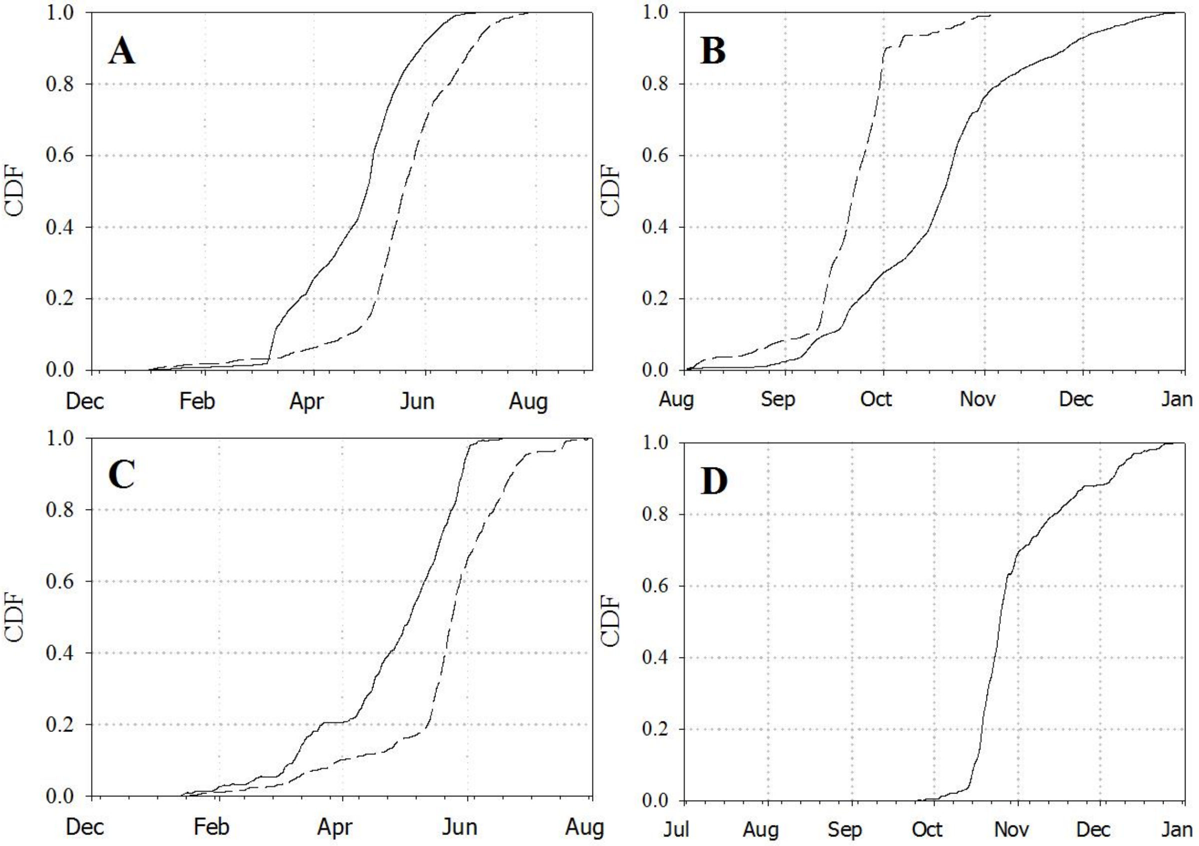
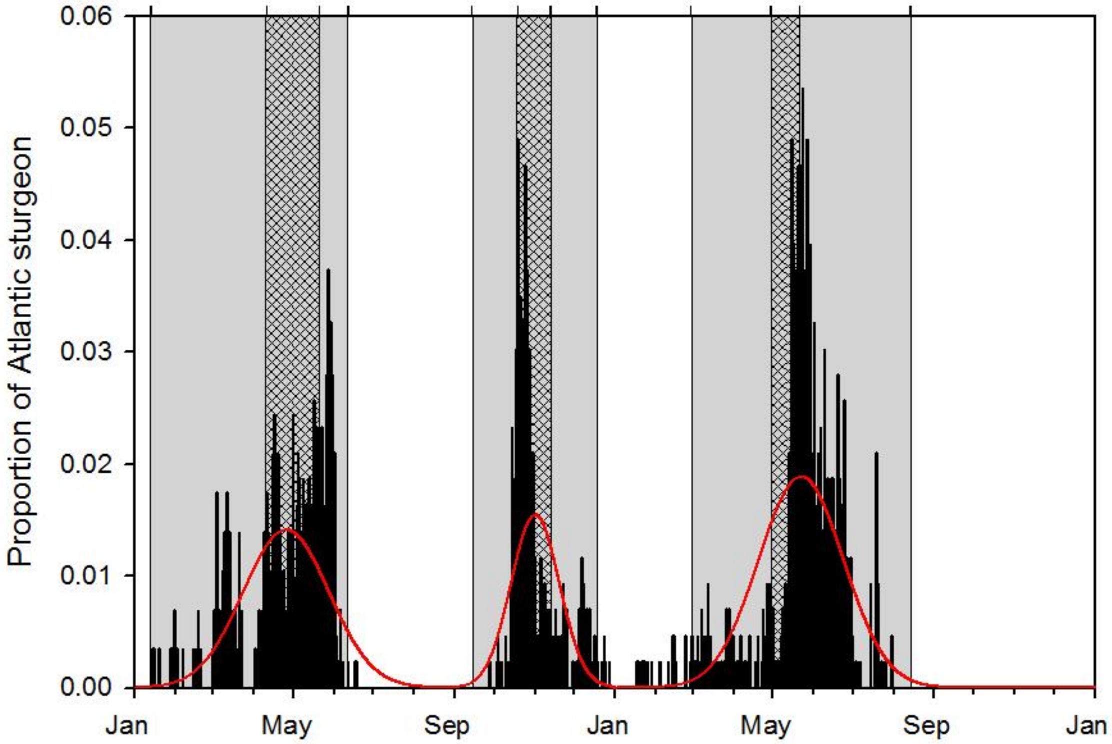


Figure 5.16 (A) Observed (black bars; left axis) and expected normal frequency distribution (red lines; right axis for the New Jersey Coast (without Sandy Hook). 99% closure (gray boxes) and 50% (hatched area) closure scenarios estimated using the normal distribution scenario. (B) table of closed area scenarios for 50%, 75%, and 99% closure scenarios estimated using the CDF and normal distributions.



Distribution	Year	Season	Level of protection	Peak	Start	End	Period
Normal	2012	Spring	50%	05/04/2012	04/11/2012	05/21/2012	40
Normal	2012	Spring	75%	05/04/2012	03/11/2012	05/28/2012	78
Normal	2012	Spring	99%	05/04/2012	01/14/2012	06/12/2012	150
CDF	2012	Spring	50%	4/25/2012	4/3/2012	5/17/2012	44
CDF	2012	Spring	75%	4/25/2012	3/18/2012	6/2/2012	75
CDF	2012	Spring	99%	4/25/2012	2/1/2012	7/18/2012	169
Normal	2012	Fall	50%	11/1/2012	10/19/2012	11/13/2012	25
Normal	2012	Fall	75%	11/1/2012	10/11/2012	11/22/2012	42
Normal	2012	Fall	99%	11/1/2012	9/14/2012	12/18/2012	95
CDF	2012	Fall	50%	10/26/2012	10/20/2012	11/09/2012	20
CDF	2012	Fall	75%	10/26/2012	10/18/2012	11/25/2012	38
CDF	2012	Fall	99%	10/26/2012	10/03/2012	12/25/2012	83
Normal	2013	Spring	50%	5/22/2013	4/30/2013	6/13/2013	44
Normal	2013	Spring	75%	5/22/2013	4/15/2013	6/28/2013	74
Normal	2013	Spring	99%	5/22/2013	2/28/2013	8/14/2013	167
CDF	2013	Spring	50%	5/26/2013	5/16/2013	6/9/2013	24
CDF	2013	Spring	75%	5/26/2013	4/23/2013	6/20/2013	58
CDF	2013	Spring	99%	5/26/2013	1/23/2013	7/22/2013	180

Figure 5.17. Total number and duration of residency events (minimum of 2 detections per site) at each array along the NY coast. For the Rockaway away only 11 receivers were used to be consistent and comparable to the other locations.

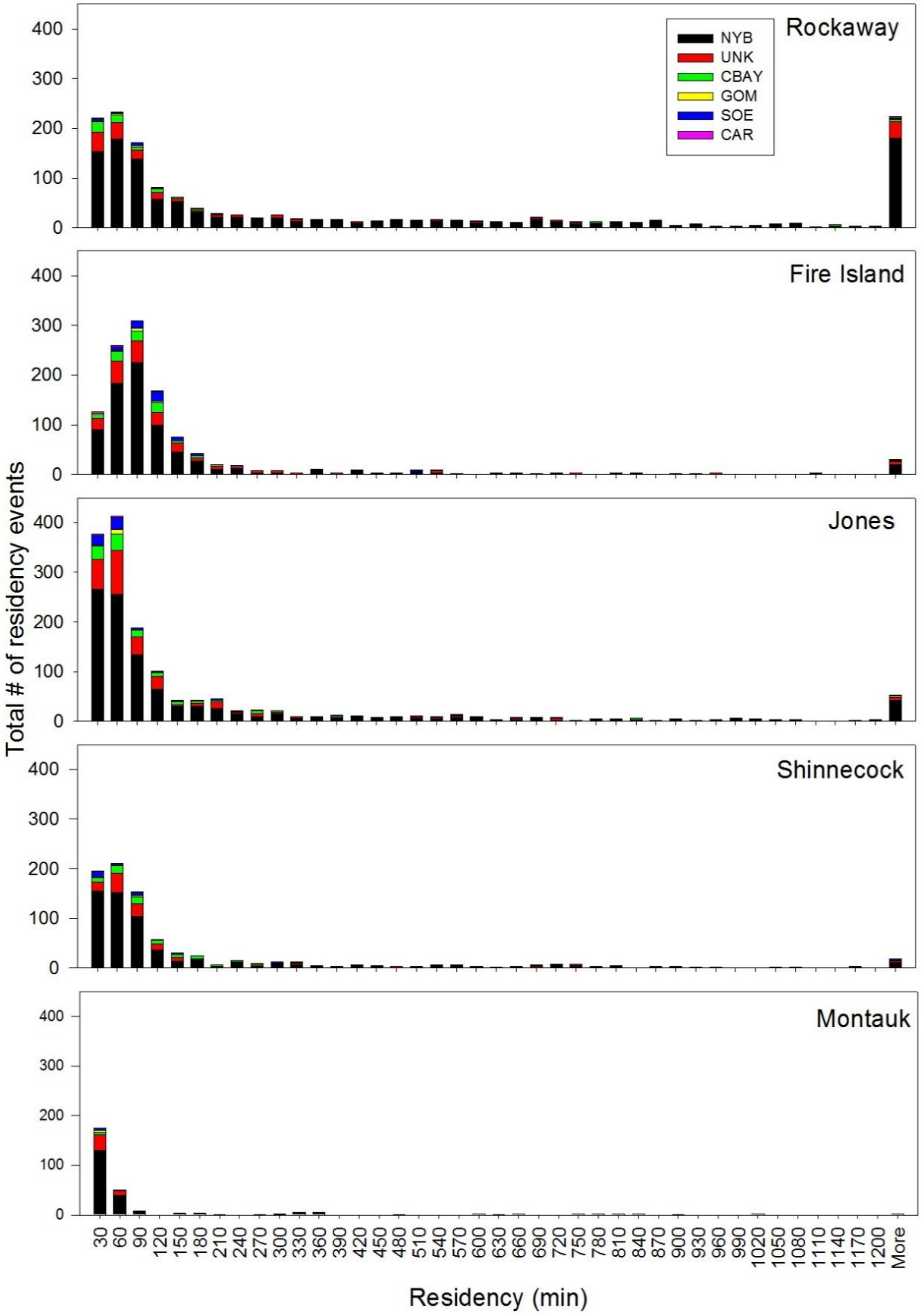


Figure 5.18. Total number and duration of residency events (minimum of 2 detections per site) at each NJ array. For the Sandy Hook array only 10 receivers were used to be consitenct and comparable to the other locations.

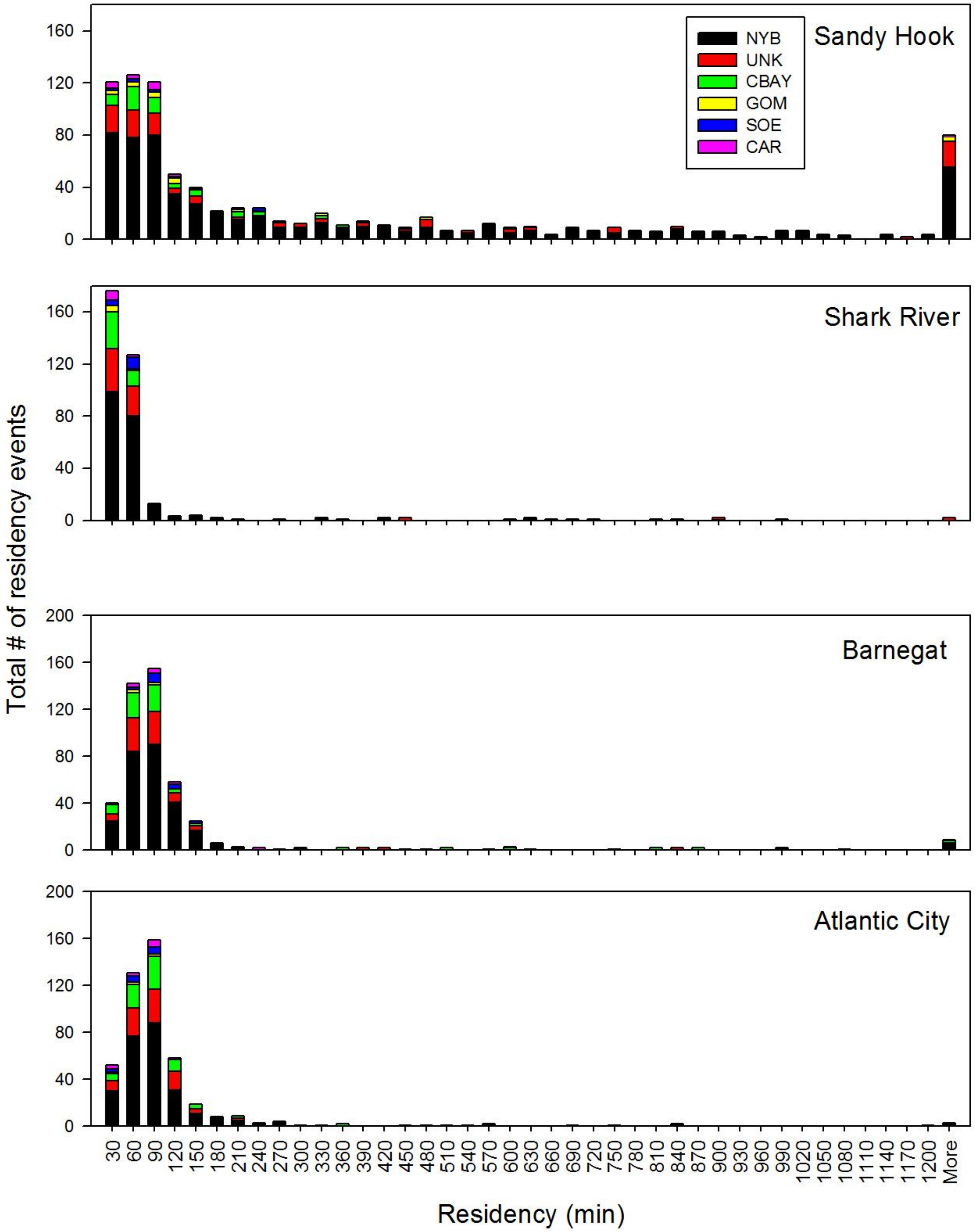


Figure 5.19. Notched box-plot of rate of movement (km/hr.) between adjacent arrays along the NY Coast. Black lines represent means, notches are 95% confidence intervals, and boxes are 25 – 75th percentile.

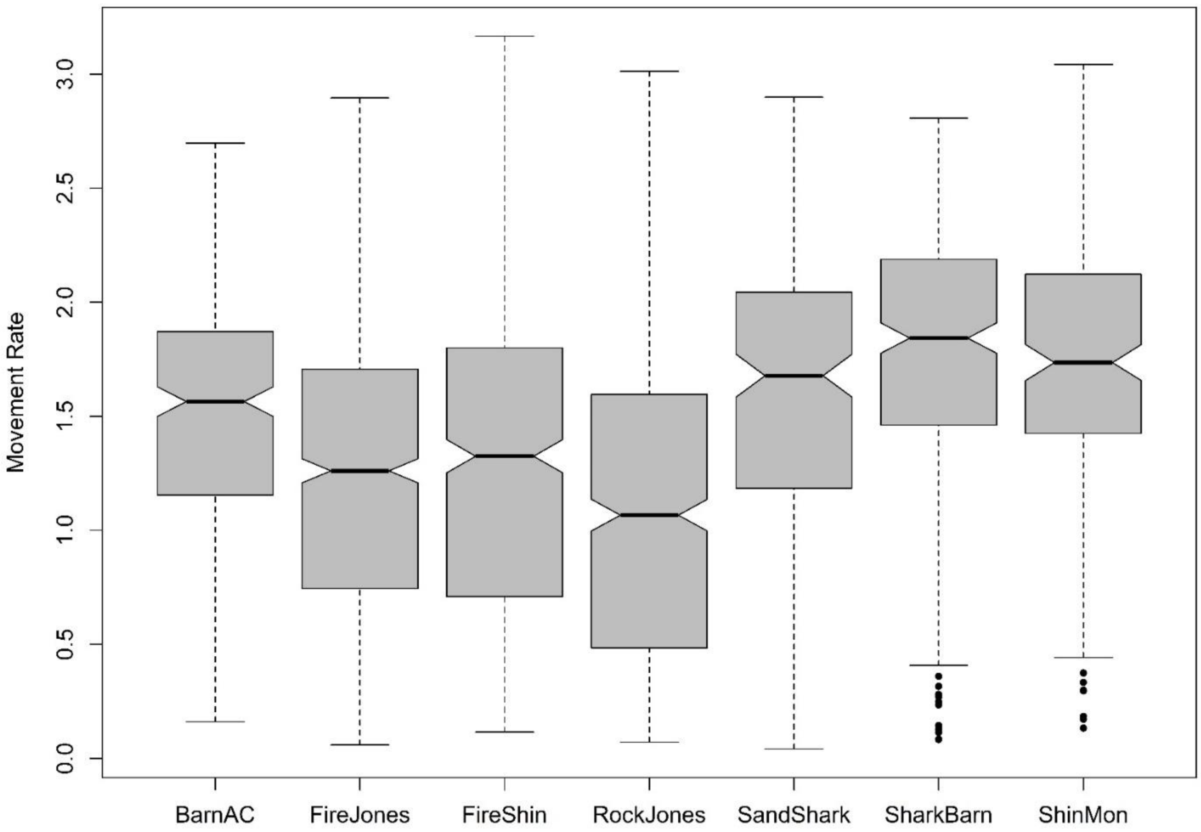
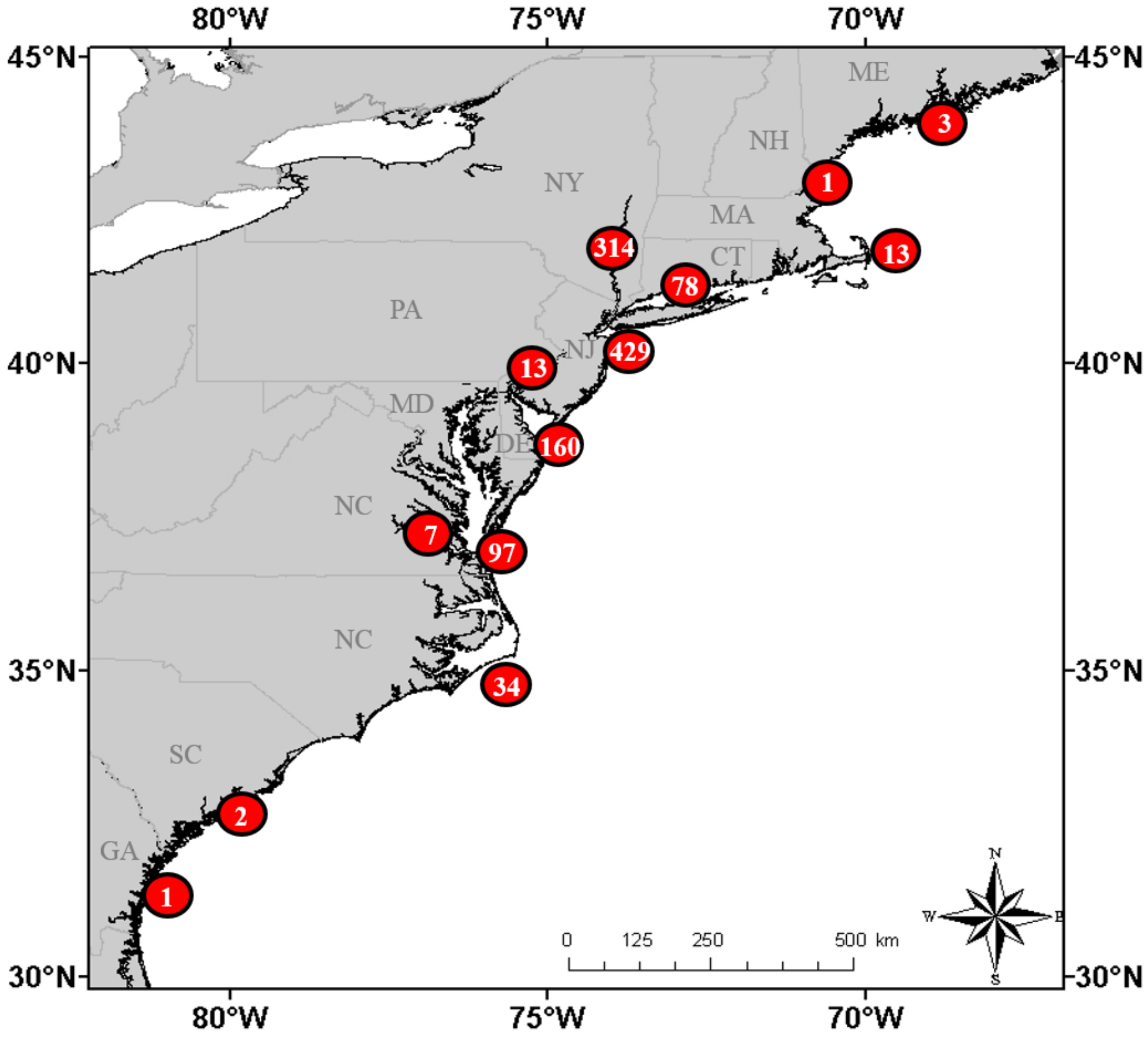


Figure 5.20. Total number of acoustically tagged sub-adult Atlantic sturgeon (n=429) tagged within the MAB and detected by researchers within the ACT network in ME (Gail Wippelhauser, Graham Goulette, James Hawkes, James Sulikowski), NH (Micah Kieffer), MA (Bill Hoffman, Greg Chisholm, Graham Goulette, Jeff Kneebone), Long Island Sound (Tom Savoy), Delaware Bay-Delaware Coast (Dewayne Fox, Heather Corbett), Delaware River (Dewayne Fox, Matt Fisher, Hal Brundage), Chesapeake Bay (Carter Watterson), James River (Matt Balazik, Anne Wright, Patrick McGrath), North Carolina (Roger Rulifson), South Carolina (Bill Post, Jarrett Gibbons), Georgia (Noelle Hawthorne).



Summary and Conclusions

One challenge of managing anadromous fish is that they face threats during both the freshwater and marine stages of their life cycle. Although river-based threats primarily affect a single spawning stock due to natal homing, localized marine threats have the potential to affect many stocks due to mixing during the oceanic phase of their life-cycle (Crozier et al., 2004). For many species, recovery and conservation efforts are often hindered by gaps in the knowledge of critical life stages occurring in both marine and freshwater habitats. While this thesis explored data gaps of a single species, the conclusions and overall results are transferable to many species such as other anadromous species. In particular, the identification of migrations and habitat use is essential for the protection and management of anadromous species.

In this dissertation I explored the largely unknown marine habitat use of sub-adult Atlantic sturgeon. Since previous Atlantic sturgeon management policies have not resulted in significant improvements to populations, it is obvious that gaps in basic life history knowledge have hindered recovery efforts. This study provides a substantial increase in our knowledge of sub-adult behaviors, and use of marine habitat, providing information necessary for the conservation and recovery of this endangered species. While the road to recovery will likely be a long process I am able to provide insight into limiting the interaction of one of the biggest and unknown threats to Atlantic sturgeon populations which is incidental bycatch. With an understanding of habitat use and the time periods of localized aggregations and movements among them, management will be better able to limit the interactions between fisheries and Atlantic sturgeon through spatial and temporal closures. Effective plans could then be developed that would minimize the extent and length of closures; hopefully, minimizing economic impacts to the fishing industry.

While NY once supported a lucrative commercial coastal fishery for Atlantic sturgeon very little was known about the marine distribution. In Chapter 1, I identified the broad temporal and seasonal habitat use occurring in coastal waters of NY. Abundance varied seasonally, with the highest catches occurring during the spring and fall, with the highest observed catches occurring in the west. Targeted trawling efforts within the west revealed a major aggregation area occurring off the coast of Rockaway NY during the spring and fall with abundances several orders of magnitude higher than anywhere along the coast. Analyzing observer data from commercial fisheries, this aggregation area was also identified as a major bycatch region during the summer flounder bottom trawl fishery. While sturgeon bycatch along the coast largely occurs in sink gillnets, observer and tagging data analyzed within this chapter indicates that trawling may represent a bigger regional threat to Atlantic sturgeon in the NYB. Bycatch of Atlantic sturgeon continues to be a chronic source of mortality (Stein et al. 2004) and with the identification of aggregation areas, and the fisheries that affect them, it is hoped that commercial fishermen and State and Federal agencies can work towards the development of management policies to reduce the impacts on migrating sturgeon.

In Chapter 2, I expanded upon identifying broad temporal and spatial patterns by examining 5 fishery independent bottom trawls occurring from ME to NC. This analysis helped identify several marine concentration areas along the coast occurring at the entrance of large bays and estuaries and revealed a potential narrow migratory pathway used for northerly movement in the spring and southerly movement in the fall. These broad N-S movement patterns have also been described through tagging studies (Dovel and Bergrennan 1983). In examining habitat preferences within the surveys, depth was found to be a significant factor in determining sturgeon habitat/distributions with sturgeon largely confined to depths of less than

20m. With the presence of Atlantic sturgeon in such narrow bands of water I suggest that seasonal or temporary closures would be successful at reducing bycatch and by focusing immediate efforts on the identified concentration areas and migratory corridors bycatch mortality can be reduced effectively through protection of habitat.

The results of chapters 3 and 4 provided insight into the population structure in the MAB. The population was found to consist of largely immature juveniles of the NYB DPS. While the NYB DPS does dominate the catch all 5 DPS's were found to occur within the NYB which supports broad-scale movements. Significant differences were found between spring and summer seasons with a higher percentage of NYB DPS occurring during the spring months. The overall relative proportion of the NYB DPS has declined from a similar study conducted prior to the 1998 moratorium (Waldman et al. 1996), which indicates the NYB populations are either declining or other DPS's are increasing. While it is likely a combination of the two, given the variation among seasons and years, regular genetic monitoring is needed to track recovery and to assess risks in the marine environment by localize threats to various spawning populations.

Age structure within the NYB indicates a bias towards juveniles with few reproductive adults captured. Although this may be a function of gear selectivity, it is likely the result of low abundance of adults which is a legacy effect of commercial fishing for large individuals. While there is minimal evidence that the number of spawning fish is increasing, the next few years will be crucial in determining whether the 1998 moratorium was effective as fish born after the closure begin to mature. I obtained a large number of datasets from previously published age and growth studies that focused on individual life stages of Atlantic sturgeon. Using the combined dataset allowed for the estimation of a single VBGF growth model. Although researcher influences on the overall L_∞ were shown, it is unclear whether these differences were related to life-stage, sex, time of collection, or researcher. This analysis of growth represents the first to include all life-stages and will aid in the development of age-based population models to inform management decisions.

In Chapter 5, I utilized a large coastal network of acoustic telemetry receivers and revealed fine scale coastal aggregations and movements of sub-adult Atlantic sturgeon in the MAB. Atlantic sturgeon showed rapid seasonal migrations with strong spatial-temporal patterns in habitat use and abundance that were consistent and repetitive on a yearly basis. This study is the first to provide new insight and direct empirical evidence on large scale aggregatory behavior and spatial-temporal marine patterns in movements and habitat use of sub-adult Atlantic sturgeon in the MAB. Estimates in movement and residency rates indicates that the marine environment is largely a transitional area. Individuals in the Rockaway area had significantly longer residencies and slower movement rates, which is indicative of a foraging area (McLean et al. 2013). Utilizing the acoustic telemetry data I was able to evaluate management alternatives by estimating population proportions that can be protected under a number of spatial and temporal closure scenarios. Protection under the most conservative and restrictive scenarios indicates substantial closure windows would be required to protect sturgeon migrating through this area.

The amount of data generated from the acoustically tagged fish and presented in this chapter was quite large. The analyses and results presented herein represent initial analysis on the movements and distributions of Atlantic sturgeon. The 429 tagged fish and arrays will continue to collect data for years to come and additional analyses will be completed. Currently, I’m collaborating with Dr. Mike Melnychuk from the University of Washington to conduct analyses to estimate and understand the variation in survival during marine and freshwater stages of juvenile Atlantic sturgeon. Preliminary model outputs, indicate annual survival is 88% (95% CI

85-91) with survival the lowest in the spring (81%) and summer (81%) and highest in the fall (99%) and winter (99%). These survival estimates are likely an improvement over catch curve analysis, which suggested that annual survival is 68% (0.026 SE) (Appendix 8). Additional work is planned to describe movement and habitat use in the Hudson River, Long Island Sound, and other systems. However, these estimates indicate mortality is above sustainable levels needed for rebuilding (0.05 Boreman (1997); 0.03 Kahnle *et al.* 2007), and seasonal patterns suggest that survival is lowest in the marine environment during coastal migrations. The temporal and spatial closures explored in Chapter 5 provide a tool to greatly reduce the risk of marine derived by-catch mortality.

Through my research, I have shown that the NYB, in particular is a “hotspot” of activity essential for sub-adult Atlantic sturgeon migrations, with predictable and consistent movements to and from summer and winter aggregation areas. Although the drivers and factors that influence the migration events are unclear, the results of this study have delineated the fine scale marine migrations of sub-adult Atlantic sturgeon, which have been previously unknown. This should provide management agencies with necessary data to inform and engage in decision-making that will support competent stewardship of Atlantic sturgeon populations. This applied research can be used to increase efforts to remedy or eliminate possible threats and other human induced anthropogenic sources of perturbations (e.g. dredging, pile driving) or mortality (e.g. incidental bycatch) by establishing temporal and spatial closures. This research has already provided immediate impacts to influence and reduce human activities. My project has provided information that has been used to help federal and state agencies determine effective windows for projects involving dredging, beach nourishment, pipeline construction, bridge construction, tidal turbines, as well as the providing valuable data to the United States Navy.

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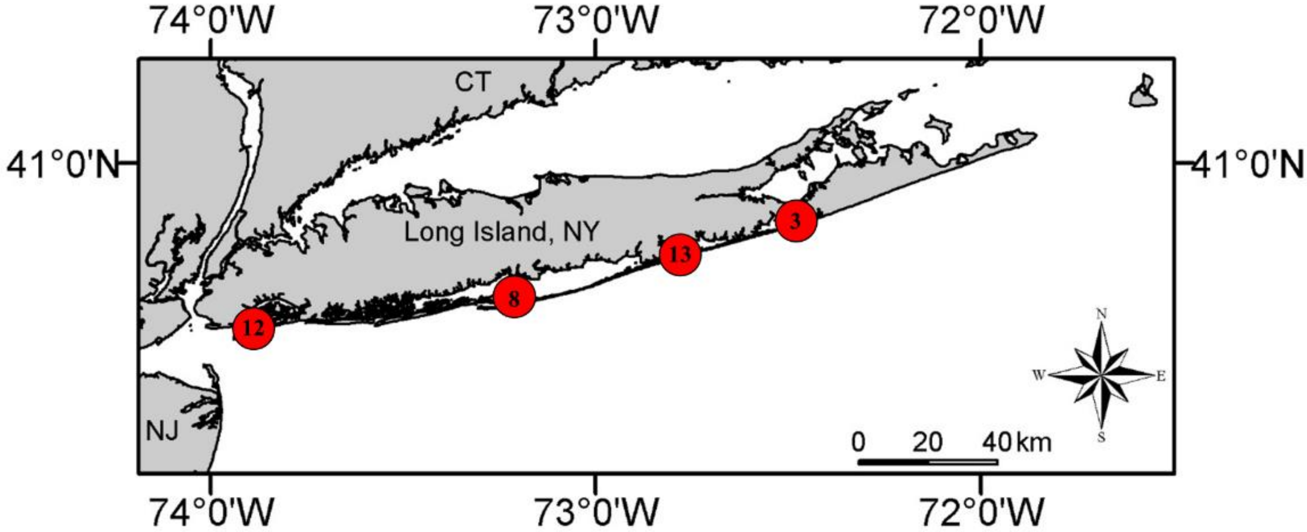
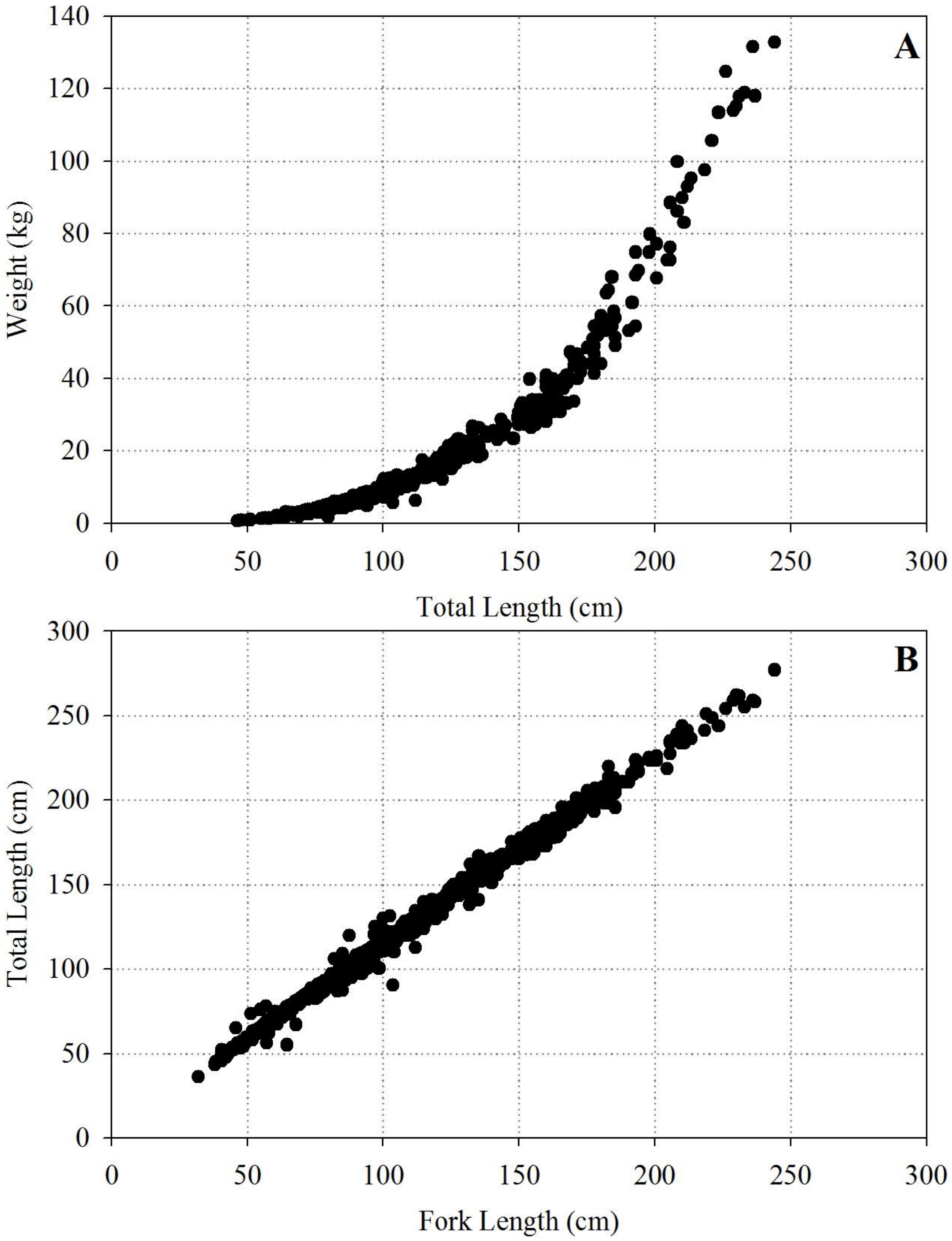
Appendix

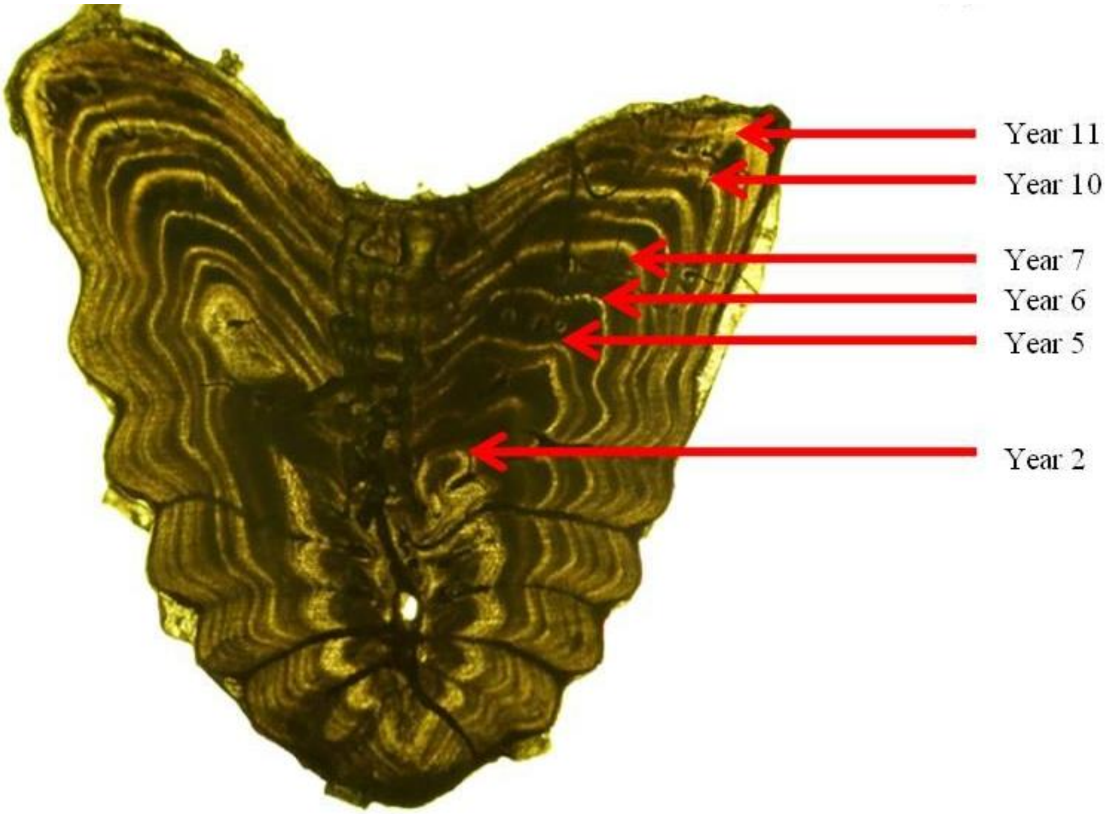
Appendix 1. General Regions of collected dead Atlantic sturgeon found on beaches off the south shore of Long Island by Stony Brook University 2007-2012.



Appendix 2. (A) Total length versus weight (n=1,364) and fork length versus total length relationships (n=1,829)for all Atlantic sturgeon that had available measurements used to estimate von Bertlanffy growth function. The linear relationship of FL to TL was found to be TL = 1.10FL+5.02 (r^2=0.993)



Appendix 3. Cross section of the primary pectoral fin spine showing alternating opaque and translucent zones which equate to one year of growth.



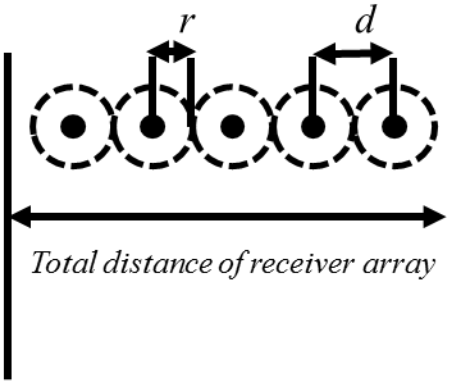
Appendix 4. Age distribution by year of Atlantic sturgeon captured in the NYB. Grey area indicates fish that are spawned pre-1998 moratorium.

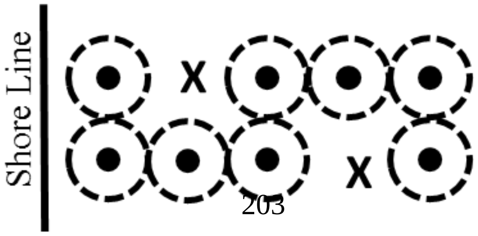
Estimated Age (Years)	2005	2006	2007	2008	2009	2010	2011	2012	Total
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	1	0	0	0	1
3	0	3	0	0	1	0	0	0	4
4	3	5	1	0	0	0	0	0	9
5	2	17	10	2	0	1	0	5	37
6	3	17	39	7	2	1	8	10	87
7	0	21	58	9	4	2	6	21	121
8	1	13	73	13	0	5	14	21	140
9	0	6	48	9	2	2	16	10	93
10	1	9	36	3	0	6	16	7	78
11	2	4	20	5	1	2	15	10	59
12	0	5	4	0	0	4	7	8	28
13	0	1	6	1	0	2	14	7	31
14	0	0	6	0	0	1	6	3	16
15	0	1	8	0	0	3	3	3	18
16	0	1	7	1	0	0	2	0	11
17	0	1	0	0	0	0	0	1	2
18	0	0	0	1	0	0	1	0	2
19	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	1	0	1
21	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0
23	0	1	0	0	0	0	0	0	1
24	0	0	0	0	0	1	0	1	2
25	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0
35	0	0	0	1	0	0	0	0	1
36	0	0	0	0	0	0	0	0	0
Total	**12**	**105**	**316**	**52**	**11**	**30**	**109**	**107**	**742**

Appendix 5. (A) Schematic in the calculation of percent transect coverage where r is the detection radii of an individual Vemco VR2W receiver and d is the distance between each receivers (B) the collapse of a double gated array to a single transect to eliminate redundancy. It is a assumed that fish swim parallel to the shoreline

A

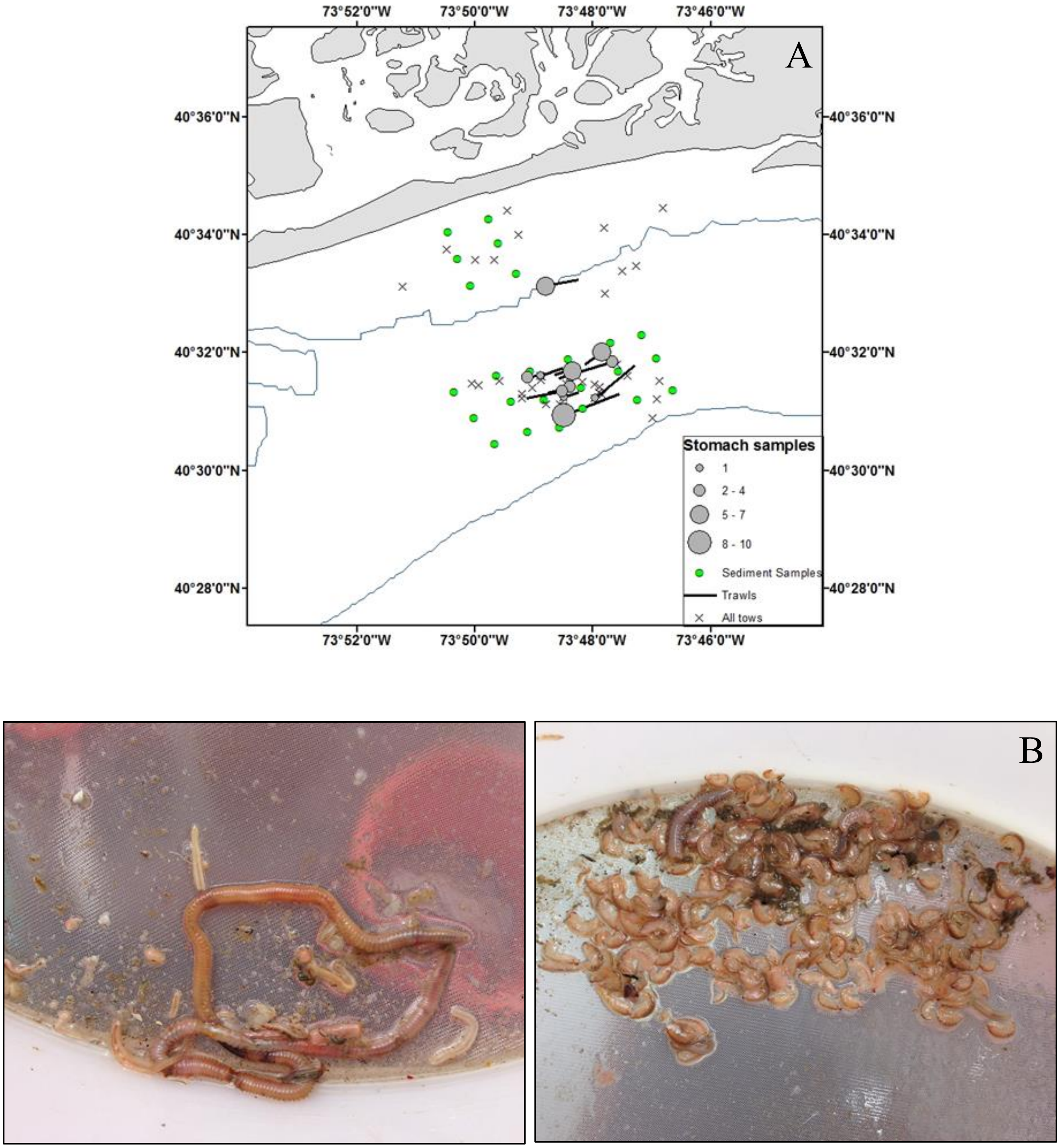
B



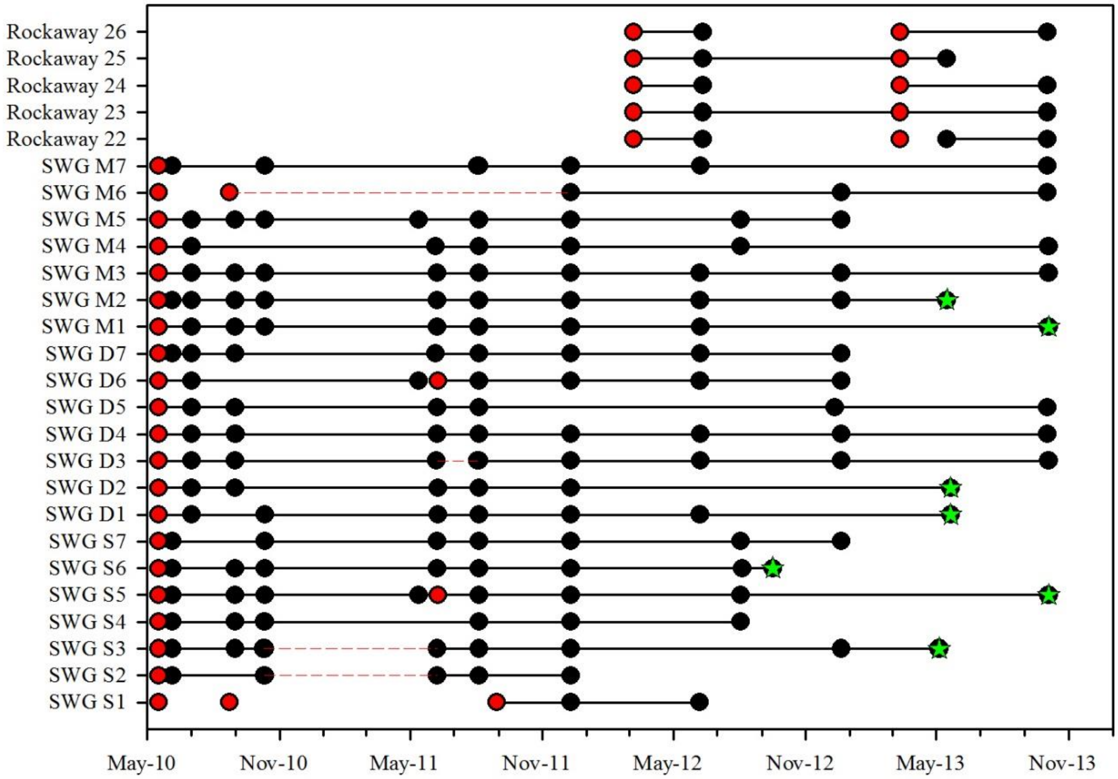


Receiver array
collapse to a

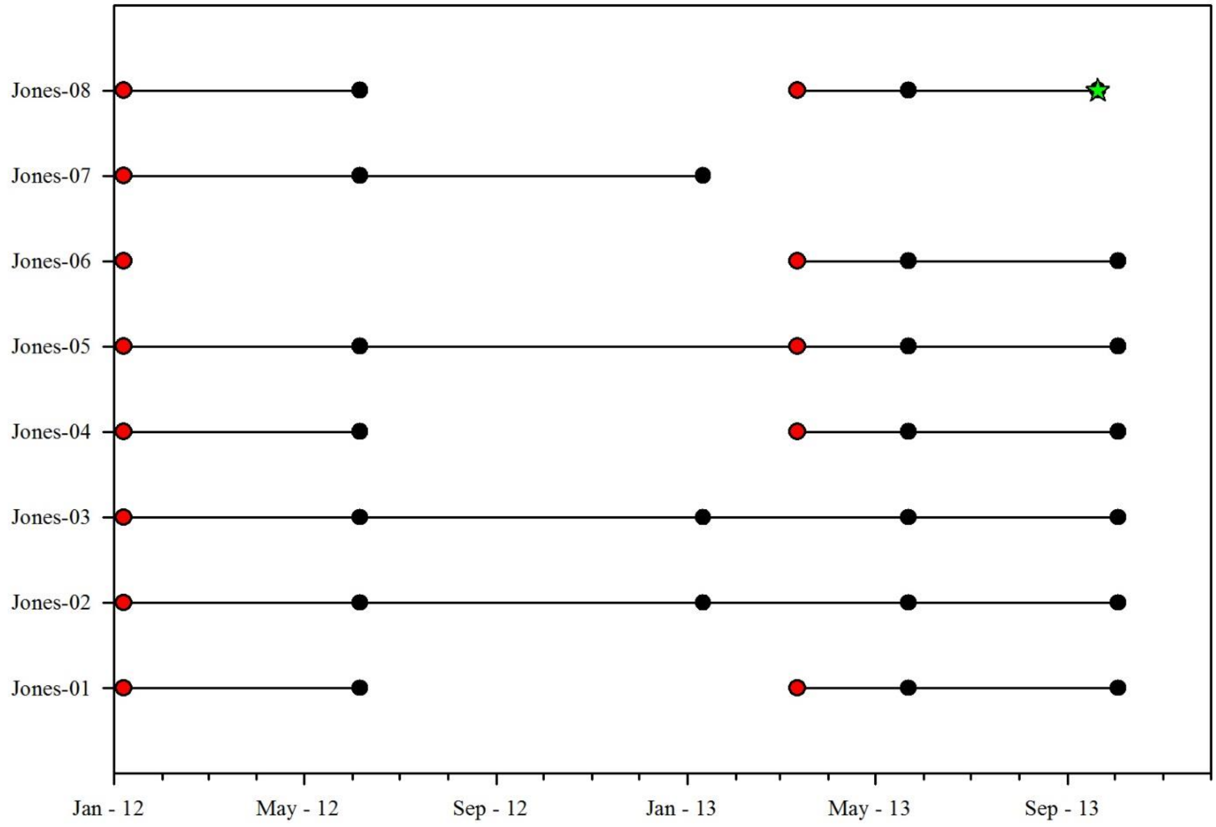
Appendix 6. Figure A. Stomach (n=49) and sediment samples (n=24) collected in sturgeon aggregation areas during May 2012 (B) Diet items post gastric lavage on Atlantic sturgeon. Left photo shows and abundance of gammarid amphipods from offshore aggregation area, while right photo if from “inshore” station.



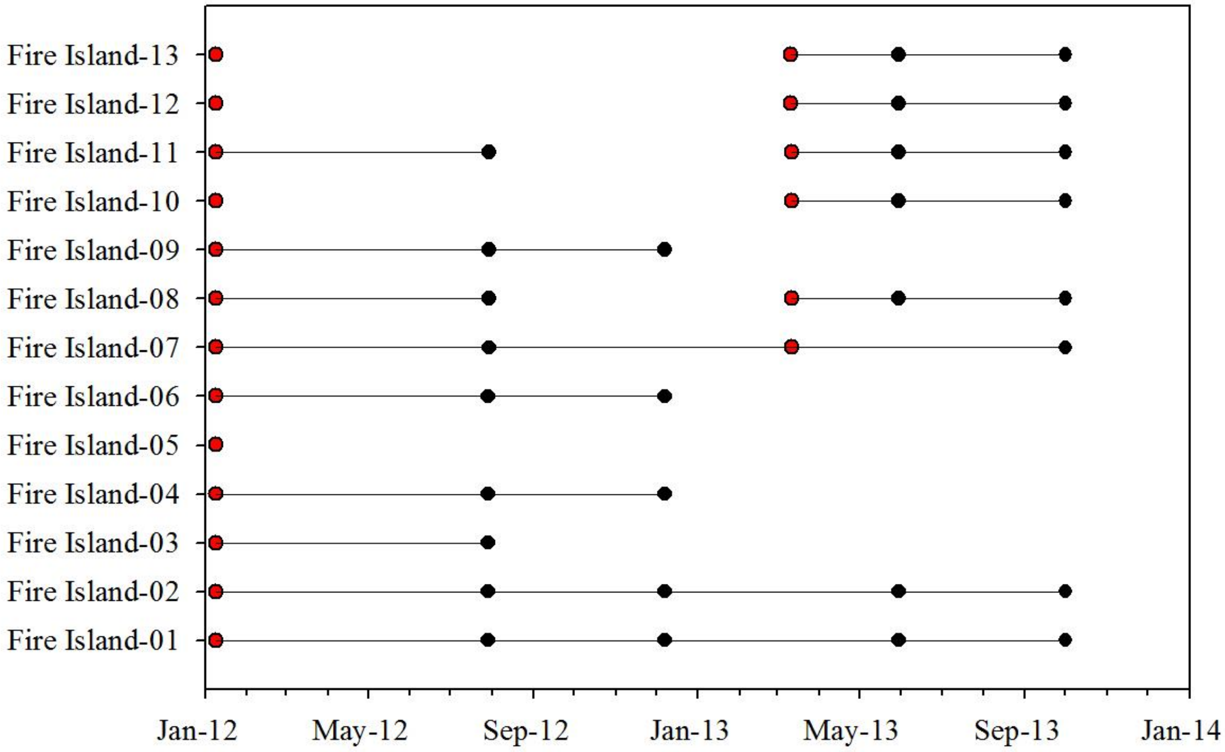
Appendix 7. Array and individual station coverage and maintenance. Red dots equals deployment/redeployment dates, black dots are maintenance/download dates, and black lines indicate receiver was operational and detection data was recovered. Red dotted lines indicates receiver was recovered but malfunctioned or was damaged and data was not recovered and stars indicate the receiver is no longer operational (either it was found on the beach or removed). For arrays with double gates, receiver coverage for a single detection line is also shown (redundancy removed).

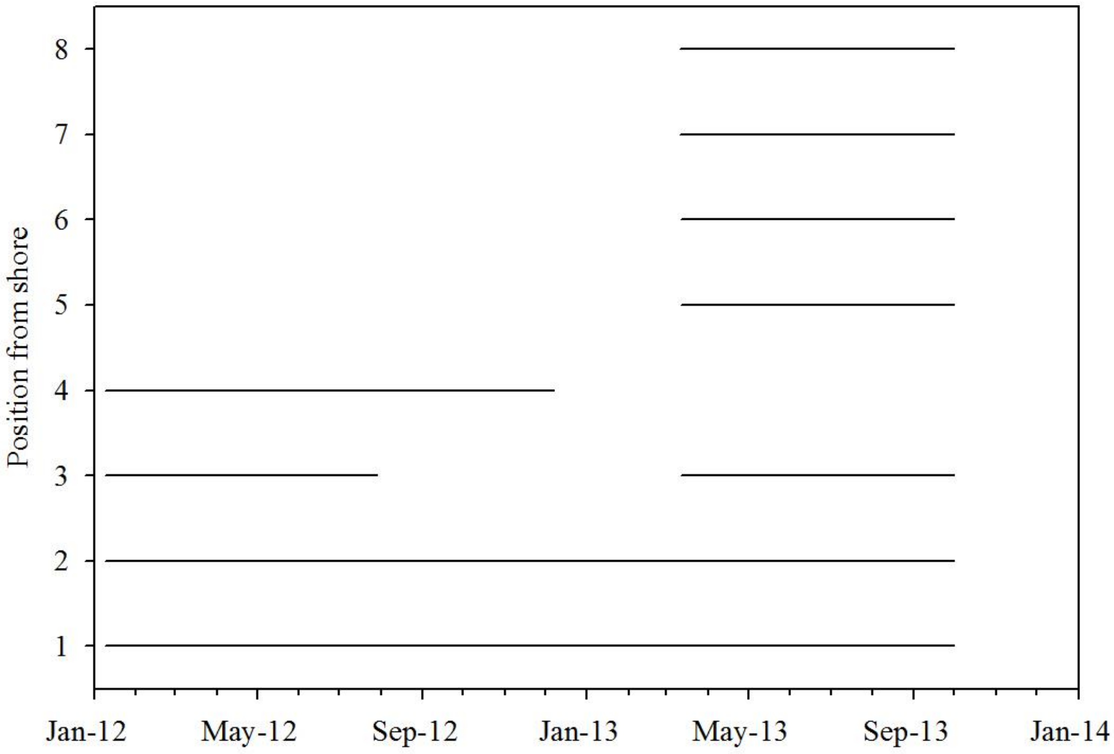


Appendix 7 cont.

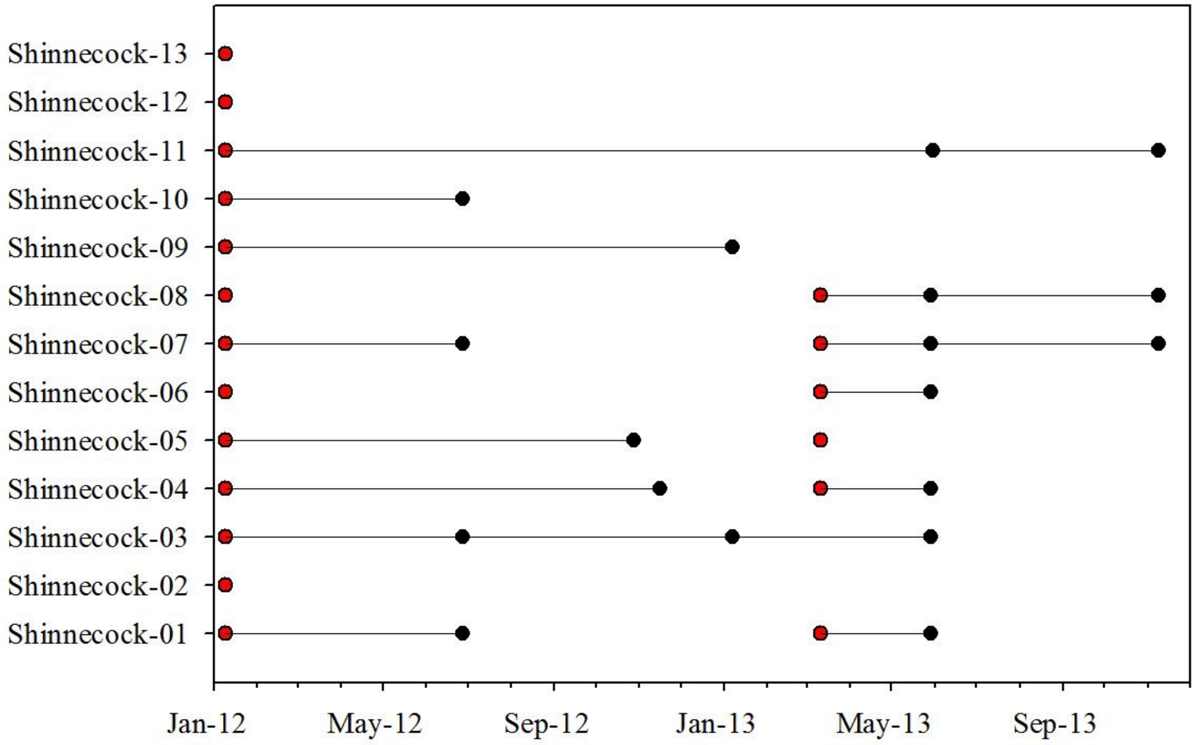


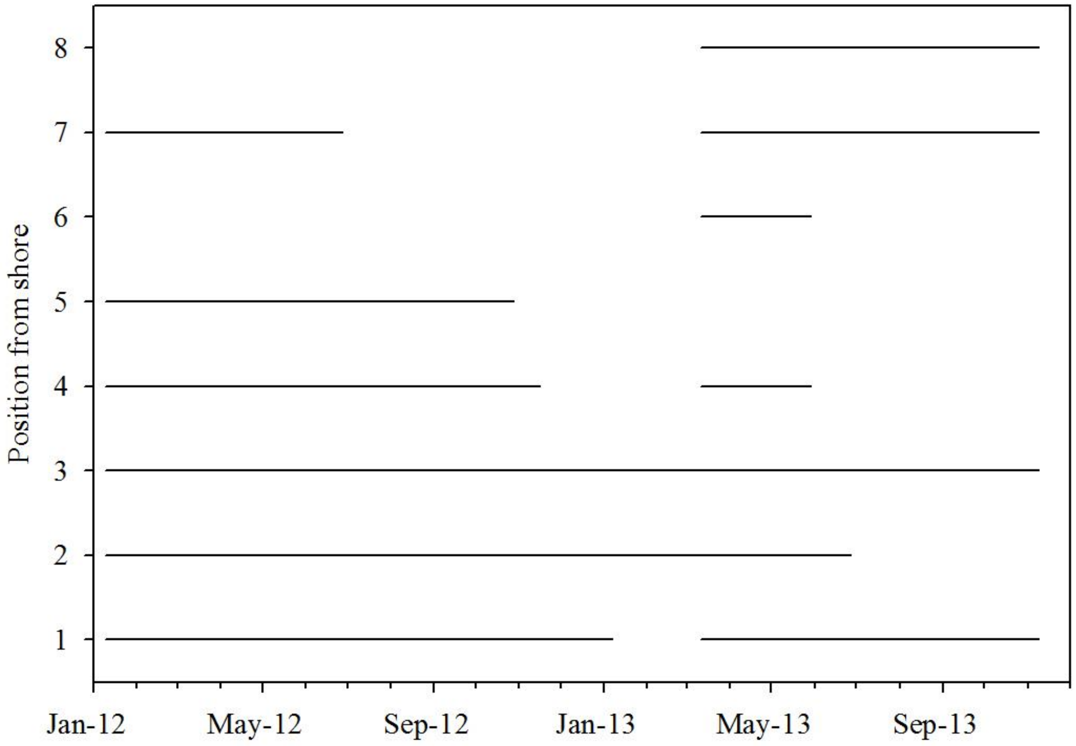
Appendix 7 cont.



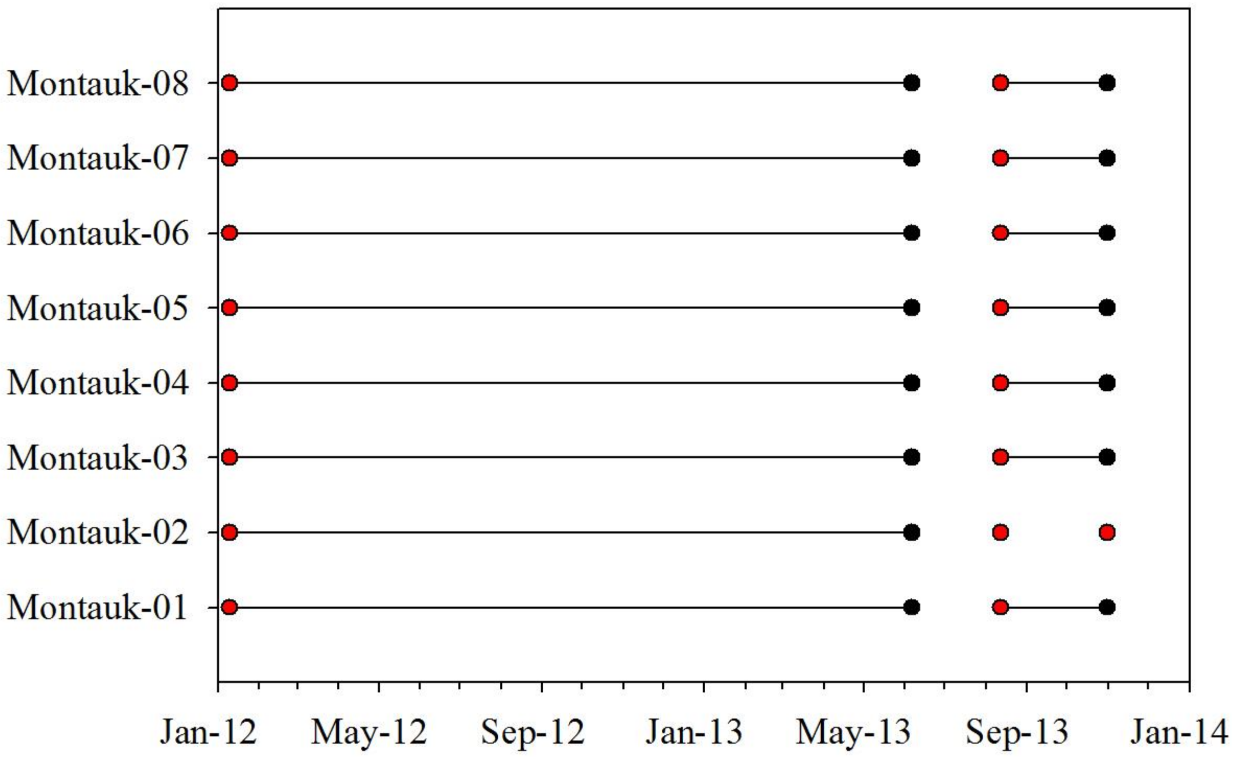


Appendix 7 cont.

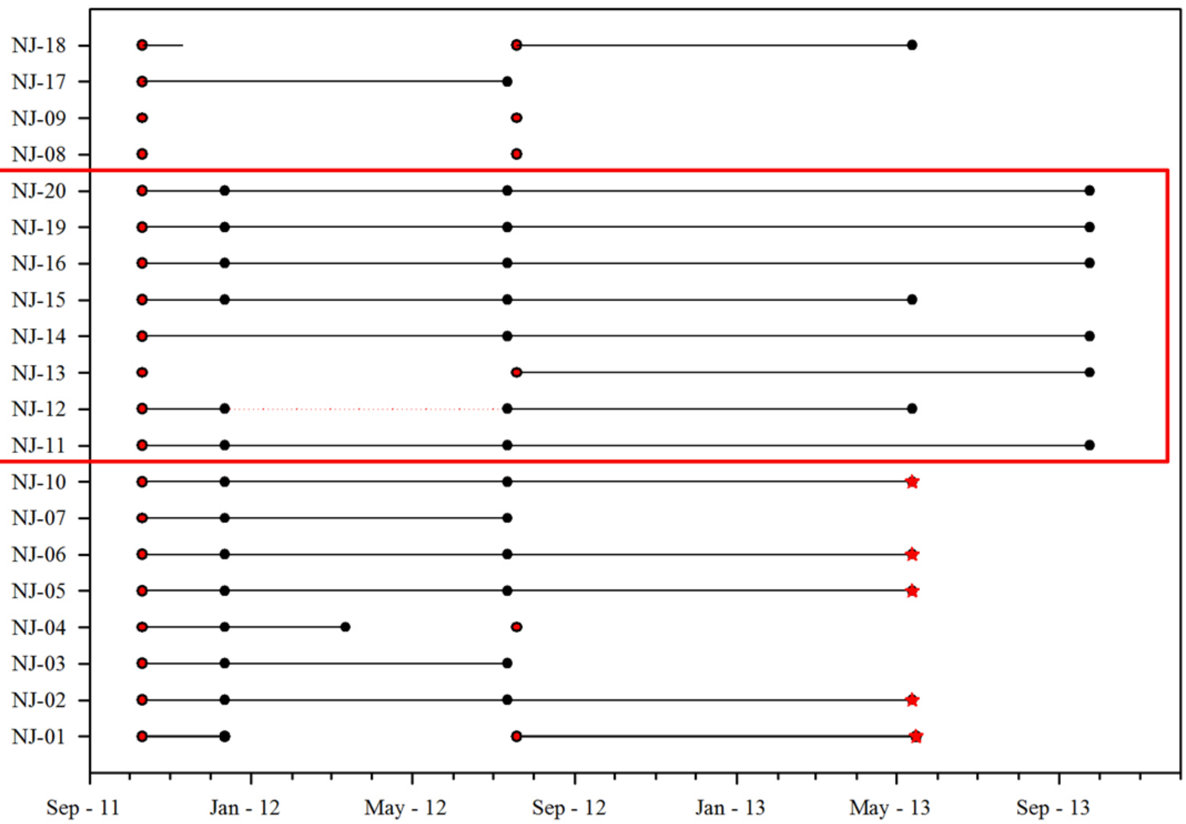




Appendix 7 cont.

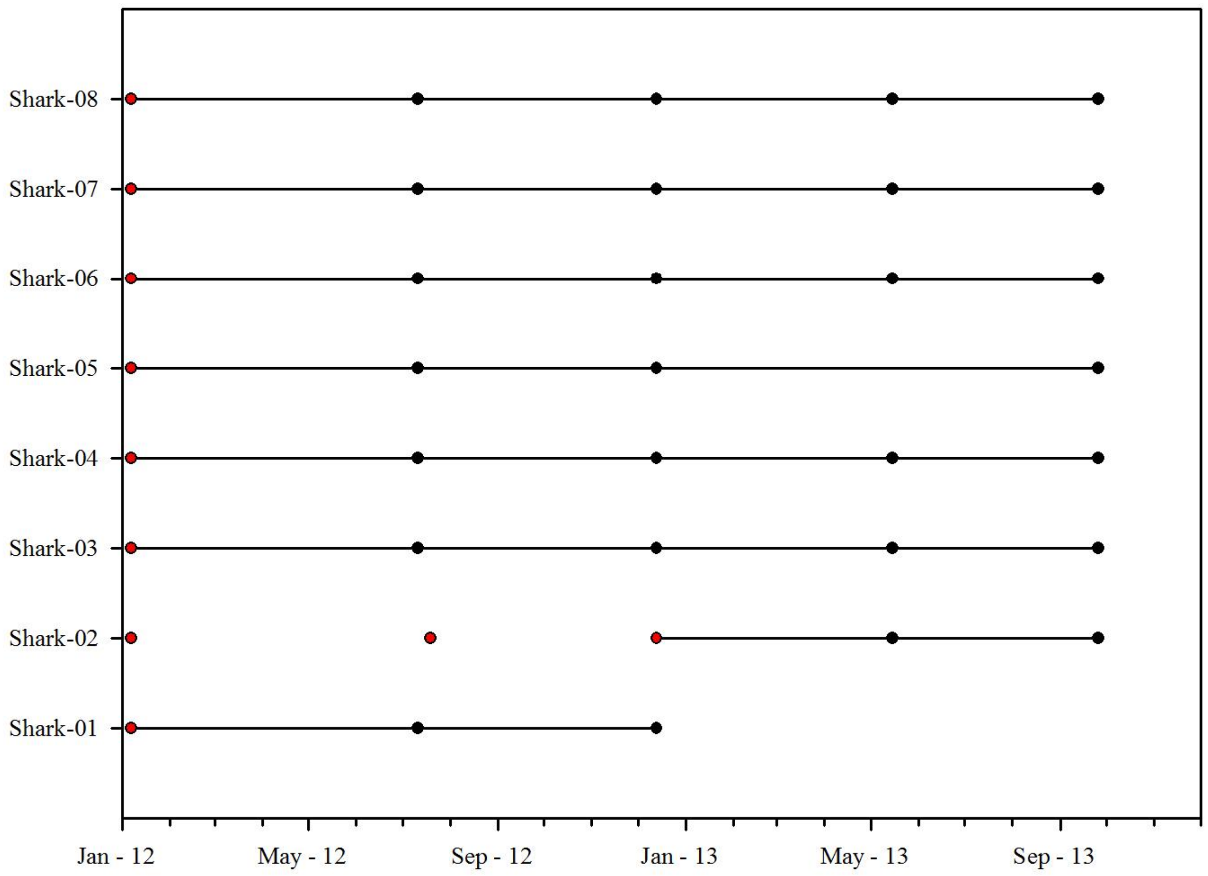


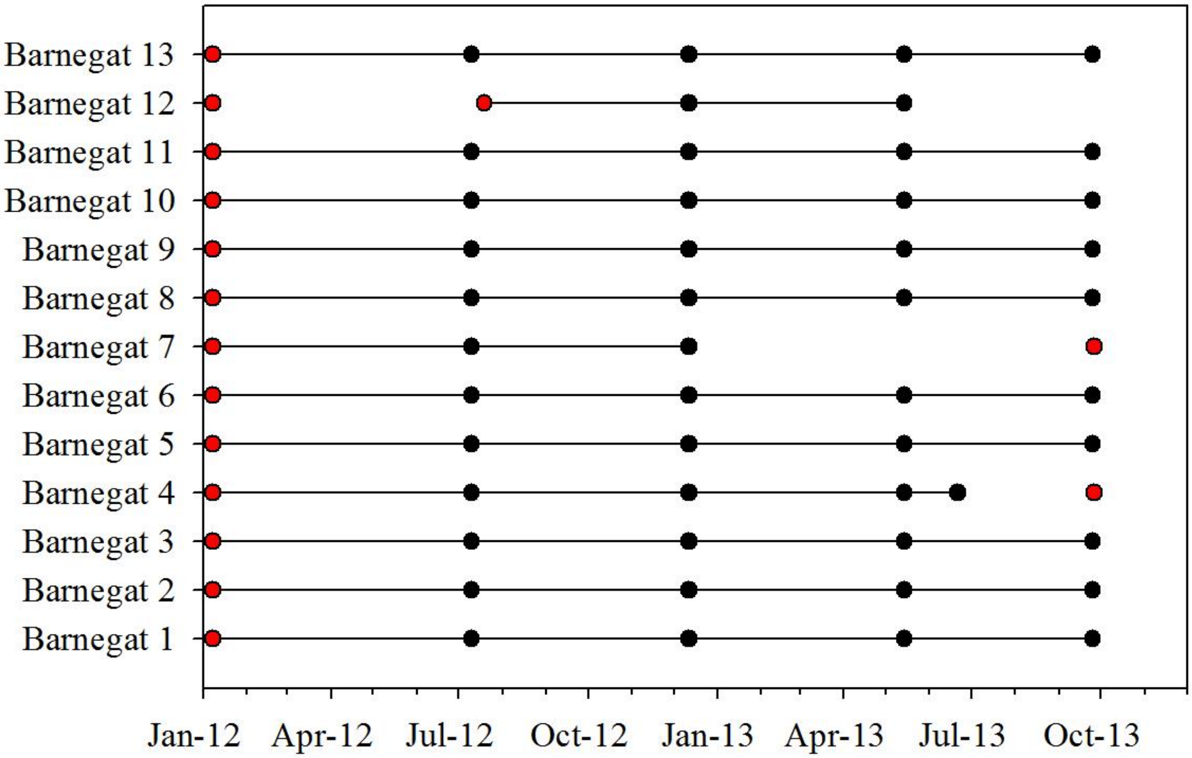
Appendix 7 cont.

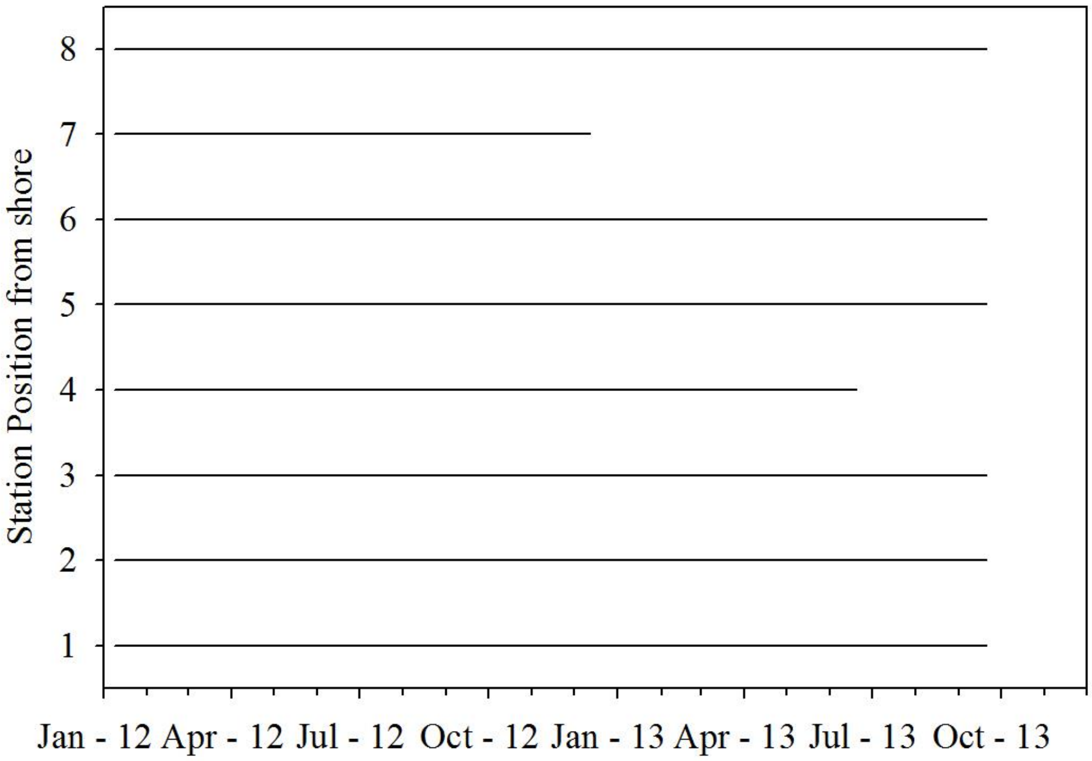


Appendix 7 cont.

Appendix 7 cont.




Barnegat 13
Barnegat 12
Barnegat 11
Barnegat 10
Barnegat 9
Barnegat 8
Barnegat 7
Barnegat 6
Barnegat 5
Barnegat 4
Barnegat 3
Barnegat 2
Barnegat 1
Jan-12
Apr-12
Jul-12
Oct-12
Jan-13
Apr-13
Jul-13
Oct-13


Station Position from shore
8
7
6
5
4
3
2
1
Jan - 12
Apr - 12
Jul - 12
Oct - 12
Jan - 13
Apr - 13
Jul - 13
Oct - 13

Appendix 8. Catch curve analysis of age data (Chapter 4) conducted in the package fishmethods in R. Ages greater than 7 years old (black circles) were included in the catch-curve to account for a full recruitment to ocean by age 7, ages greater than 20 years old were not used due to potential gear biases on large fish. Linear regression (y=0.38x+8.03 (R^2=0.9104)) shows survival to be 0.68 ± 0.026SE and mortality to be 0.38 ± 0.038SE.