Atlantic Sturgeon Final Report
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Objective

To assess the status of the Atlantic sturgeon population in the Delaware Estuary and to use resulting data to identify population-wide and site-specific issues and develop management, restoration and habitat protection needs. Various recommendations in the Interstate Fishery Management Plan for Atlantic Sturgeon (ASMFC 1998) were addressed in this monitoring and tracking program which included: estimate juvenile abundance, conduct tagging studies, monitor and analyze movement patterns, assess present sturgeon habitat, and identify, designate, and protect critical sturgeon habitat.

Introduction

To assess the abundance of juvenile and sub-adult Atlantic sturgeon in the lower Delaware River, the Department of Natural Resources and Environmental Control, Division of Fish and Wildlife, has conducted directed gill net surveys using variable mesh gill nets. Surveys were conducted in 1991-1998, 2001, 2004, 2007, 2008 and 2009. Results of the 2009 survey indicated little change in the relative abundance of late stage juvenile Atlantic sturgeon (>600 mm TL) in the lower Delaware River with very low catch rates. However, catches of early stage juveniles (<600 mm TL) increased dramatically. Above average rainfall during the sampling period and a successful spawn as well as targeted sampling in early stage juvenile habitat with small mesh nets likely contributed to the increased early stage juvenile catch rates. This final report will address results of the 2007, 2008 and 2009 surveys that were funded by this State Wildlife Grant.

Methods

Gillnetting and tag application:

Collections were performed using sinking drift gillnets and floating drift gillnets in the sampling areas of Fort Mifflin (rkm 148), Tinicum Island (rkm 142), Marcus Hook anchorage (rkm 127), Marcus Hook bar (rkm 122), Cherry Island Flats (rkm 119), Carneys Point (rkm 114), Artificial Island (rkm 88) and Bombay Hook (rkm 63) (Figure 1). Sites were selected based on past gillnetting success, areas identified during the telemetry phase of the project, and early stage juvenile habitat in other systems (Hatin et al. 2007, McCord et al. 2007) and juvenile catches from the DFW trawl survey. Flat-bottom sites, free of snags, away from heavy ship traffic, near the freshwater-brackish water interface and out of the main channel in 3-8 meters of depth are preferred. Sinking multifilament and monofilament nets 61 to 92-meters long (51, 76, 101 and 152 mm stretch) that fished like anchored nets were used. These nets were most often tied together and set perpendicular to the tide. Floating monofilament gillnets that dragged along

the bottom as described in McCord et al. (2007) were used with limited success. The nets caught fish but often got hung on the bottom or picked up branches that weighed part of the net and ruined the drift and reduced CPUE. Soak time was from the predicted low tide until slack tide, at which point the net was retrieved. Bycatch was recorded and sturgeon were identified to species, measured, weighed, and scanned for passive integrated transponder (PIT) tags.

Tissue samples were taken from all Atlantic sturgeon, and each received tags: a T-bar tag was inserted in the dorsal sinus (if sturgeon >400 mm TL) and a PIT tag was injected at the anterior base of the dorsal fin. Atlantic sturgeon < 250 mm TL did not receive PIT tags, but if <400 mm TL they received a small PIT (8 mm). This is a requirement of our shortnose sturgeon permit (#14396) and was applied to our Atlantic sturgeon protocols. Since the conclusion of the 2009 gillnetting season the DFW has reviewed and incorporated the Atlantic Sturgeon Research Protocols (Damon-Randall et al. 2009) into field protocols. These protocols require special training to PIT tag individuals below 300 mm TL due to the mortality results of Henne et al. 2008. However, it should be noted that 11 Atlantic sturgeons between 262 and 299 mm TL were PIT tagged in the dorsal musculature and also implanted with V7 or V9 transmitters with 91% survivability. Depending on the number of sturgeon taken and size, individuals were selected for surgical implantation (Fox et al. 2000) of an ultrasonic VEMCO V7, V9 or V16 transmitter (<2% body weight). Selected fish were anesthetized using MS-222 (50-100 mg/L). During surgery, fish were placed in a cradle (commercially marketed as a muskellunge cradle) held at working height by a wooden surgery table frame. An adjustable volume hose was placed in the mouth to allow the anesthetic to pass over the gills. The incision area was cleaned, and using a sterilized scalpel, an incision just large enough for the transmitter to be inserted was made parallel and adjacent to the ventral midline. The transmitter was then implanted in the ventral peritoneal cavity and the incision closed using absorbable monofilament sutures. The incision area was covered with super glue or tissue adhesive and allowed to dry to keep the sutures in place and then a Vaseline and betadyne mixture was spread over the area to protect it. Oxytetracycline (an antibiotic) was injected (0.5ml/10 kg) in the dorsal sinus region as a prophylactic measure and the fish was released upon recovery. Sturgeon <400 mm TL were not injected due to the difficulty in working with such small injections; it was determined that the risk of overdose would have been too great.

Active Tracking:

Fish were tracked four to eight days a month from July to October from Artificial Island (rkm 88) to Commodore Barry bridge (rkm 132) in 2007 and 2008. The sampling area was divided by the Delaware Memorial Bridge (rkm 112) into upper and lowers sections due to

sampling time constraints. In 2009, fish were tracked four to eight days a month from October to December from Delaware Memorial Bridge (rkm 112) to Fort Mifflin (rkm 148). The sampling area was divided by the Marcus Hook anchorage into a lower and upper section. Intervals 400 to 1000 m apart (depending on the target's transmitter power) were scanned for sturgeon using a VEMCO© VR100 detector. When a strong signal of a targeted fish was detected, every effort was made to determine an exact location using a directional hydrophone. Global Positioning System coordinates were recorded at the point of greatest signal strength.

Passive tracking:

VEMCO© VR-2W receivers (Figure 2) were deployed to complement the existing receiver array of Delaware State University researchers and Environmental Research and Consulting, Inc (H. Brundage)(Figure 1). In 2007, 2 receivers were deployed and the DFW array contribution was augmented with additional receivers annually up to 16 in 2009. Receivers were attached to United States Coast Guard (USCG) Aid-to-Navigation (ATON) marker buoys in the Delaware River with an 8.5-m x 0.95-cm diameter stainless steel cable. Data were downloaded annually in December to determine seasonal movements within the sample area.

Results and Discussion

2007

Gillnet collections occurred on 22 days in 2007 from June 5th through Nov 1st. Collections yielded 55 sturgeon, 48 of which were Atlantic sturgeon, with a catch per unit effort (CPUE) of 1.9/net hour (6 Atlantic sturgeon not included in the CPUE due to being caught in experimental net sets) (Table 1). CPUE was low compared to a high of 32.2/net hour in 1991 (Shirey et al.1999) but consistent with recent catch rates since the 1998 survey. Water temperature increased from 23.6^{o} C in early June to a peak of 28.3^{o} C in late July and then slowly declined through the end of October (Figure 3). Atlantic sturgeon ranged in total length from 622 mm to 1181 mm and from 1.1 to 8.2 kg. The seven shortnose sturgeon ranged from 732 mm to 981 mm and from 2.1 to 5.1 kg. Thirteen Atlantic sturgeon were selected to receive ultrasonic transmitters (Table 2). Five of the 13 ultrasonic transmitters were able to sense depth.

Active tracking occurred on 16 days in 2007 and began July 10th and continued until Nov 13th. Location results are combined with 2008 in Figure 4 and discussed in the 2008 results section.

2008

Gillnet collections occurred on 18 days in 2008 from June 10th through Oct 21st. CPUE at the traditional sites was 0.8, the lowest in project history. Eighteen sturgeon, 11 of which were

Atlantic sturgeon were collected. Comparisons to the historical CPUE from the traditional sites indicate low numbers of juveniles since 1995.

Manual tracking in 2007 and 2008 indicated a concentration area at a non-traditional site in the Marcus Hook Anchorage. In an effort to increase catch rates methodology involving tracking individuals and setting nets in areas of sturgeon concentration was adopted. This approach proved highly successful and was used 8 times. These ancillary collections at Marcus Hook anchorage yielded 135 sturgeon, 134 of which were Atlantic sturgeon.

Atlantic sturgeon ranged in total length from 550 to 1716 mm and from 0.7 to 27.7 kg. The eight shortnose sturgeon ranged from 478 mm to 974 mm and from 0.4 to 7.2 kg. Twelve Atlantic sturgeon were selected to receive ultrasonic transmitters (Table 2). Ten of the 12 ultrasonic transmitters were able to sense depth.

In 2008, water temperature increased from 25.8^{o} C in mid June to a peak of 29.6^{o} C in late July and then slowly declined to 20.0^{o} C on October 16th when temperatures dropped abruptly to 12.1^{o} C by the end of October. The sharp drop in temperature caused tagged sturgeon to move to the Bay and finally into the Atlantic Ocean (Figure 5). 2008 was notably an extreme year due to high water temperatures and low amounts of rainfall causing salinity and its surrogate, conductivity, to move farther upriver than average.

Five of the 25 sturgeon implanted with transmitters in 2007 and 2008 are believed to be a mortality, shed tag or a malfunctioning tag. This has been concluded due to no detections on the receiver array (malfunctioning tag) or detections with no movement (mortality or shed). One of the detections with no movement did provide 3 months of data before it became a mortality or a shed. Two were implanted with left over 2007 tags and did not produce any data, likely due to a dead battery. Communication with VEMCO confirms this was likely the case. This experience added a transmitter test to the field protocols. This procedure intercepted one malfunctioning tag before it was implanted and was eventually replaced by the manufacturer. The extreme hot and dry conditions of the summer of 2008 likely contributed to 2 mortalities. On August 5th, water temperature was 28.2 °C and although extreme care was taken in the handling and recovery of the 5 surgery fish, 2 were mortalities based on no movement in the days after release. Even though we've had success at high water temperatures prior to this, we decided to add a no surgical procedures when water temperatures are above 27° C policy to be added to the field protocols.

2009

Gillnet collections occurred on 28 days in 2009 from June 10th through Nov 9th. Collections yielded 64 sturgeon, 55 of which were Atlantic sturgeon, with an overall catch per

unit effort (CPUE) of 1.8/net hour (Table 1). Sites at Mifflin Park, Tinicum Island, Marcus Hook anchorage, Marcus Hook bar and Cherry Island flats were selected based on their potential as early stage juvenile nursery habitat. Since traditional sites at Carney's Point and Artificial Island have not produced significant numbers of early stage juveniles during sampling efforts since 1991 they were not utilized. Due to the decrease in efficiency and utilization of new sampling sites, it is recommended to consider these factors when drawing conclusions about juvenile Atlantic sturgeon population trends from sampling CPUE. The CPUE of 1.8/net hour was low compared to a high of 32.2/net hour in 1991 (Shirey 1999) but consistent with recent catch rates since the 1998 survey. For trend analysis purposes, the juvenile population is still considered consistently low.

Atlantic sturgeon ranged in total length from 178 to 1380 mm and from 23 to 15,989 grams. The nine shortnose sturgeon ranged from 721 to 875 mm. Twenty-one Atlantic sturgeon received ultrasonic transmitters (Table 2). Twelve of the 21 ultrasonic transmitters were programmed with a 60-second delay which is an appropriate delay necessary for manual tracking. Manually tracked individuals yielded habitat information that will be used to locate nursery areas and define appropriate nursery habitat for early-stage juvenile Atlantic sturgeon (see *Active tracking* section below). Due to the limited battery life of small transmitters, the 60-second delay will only last for several months after implantation. Four transmitters will expire after the 60-second delay, however eight will switch to a 240 second delay that will provide passive array detections for approximately one year. The other nine of the 21 transmitters have a programmed delay of 240 seconds from start until to their expiration. The variation in delay programming was needed to achieve the goals of the project and to also work around the limited battery life of the small transmitters that are necessary to stay below the 2% ratio of tag weight to fish's body weight. In 2010 VEMCO® plans to release an appropriate-sized transmitter that will be high powered for manual tracking yet also have enough battery life to revert to a slower delay and provide seasonal movements. High-powered transmitters offer a tracking radius that is up to 6 times the area of a low-powered transmitter and make tracking much more efficient.

Genetic clips were collected from 34 Atlantic sturgeon young-of-the-year and genetic mitochondrial DNA haplotype (Wirgin et al. 2007) and microsatellite analysis (Tim King, USGS) was conducted on 33 of the samples at no cost or time expense to the project. Wirgin determined that there were 3 haplotypes present (Table 3). The 3 haplotypes were a subset of the 7 haplotypes that were present in adult samples from the Delaware Estuary. The A5 haplotype, a unique genetic identifier of Delaware Atlantic sturgeon population origin, was detected in 9 of 33 young-of-the-year and 8 of 29 adults (adult is defined as >1500 mm TL and all were samples

from carcasses recovered within the Delaware Estuary). Identification of the unique A5 haplotype in young-of-the-year is evidence that Delaware origin genetic stock is contributing to new year classes and that the Delaware has its own distinct population segment. Also, three haplotypes were detected in the 2009 year class which indicates that at least 3 females successfully contributed to the 2009 year class.

King (USGS) compared the 2009 young-of-the-year and some miscellaneous adult-sized fish from the DE River with appropriate-sized fish from throughout the Atlantic sturgeon's range. Each fish was genotyped at 12 microsatellite loci developed in King's laboratory. Levels of genetic variation are relatively consistent throughout. However, no unique alleles were observed in the DE River collection while all other collections did contain some alleles only observed within that collection. Furthermore, the genetic relatedness (proportion of the shared allele distances) among the Hudson and Delaware Rivers' sturgeon are nearly completely overlapped (King, personal comm. Jan 10, 2011). This would indicate that the Delaware is not its own distinct population segment and should be included with the Hudson; the New York Bight population segment.

King suggests sex-biased dispersal as a potential explanation for the differing results with Wirgin's work. Sex-based dispersion's oversimplified definition in regards to spawning behavior is; females home and males roam. Mitochondrial haplotype analysis examines only the genetic contribution of the mother. However, until we are able to sex each fish analyzed we will not be able to determine the degree of sex-biased dispersal, if any. Another potential confounding factor is the use of adult-sized fish in King's analysis when it is unclear what portion of those adult-sized sturgeon are spawning in the Delaware River since spawning condition was not able to be evaluated.

Passive tracking-late stage juveniles

In each season (2007, 2008, and 2009) a majority of transmitter-tagged late stage juveniles exhibited a typical behavior ; immigrate into the estuary in spring, establish home range in the summer months in the river (home range for our purposes will be defined as 90% or greater receiver array detections occurring around the same 1 or 2 receivers), and emigrate from the estuary in the fall. Exceptions to that behavior type were seen in a minority of individuals that summered in the lower bay and at the mouth of the estuary and then in October when the typical behavior fish are emigrating from the estuary, these individuals made dramatic migrations upriver into the typical summering areas before exiting the estuary entirely (Figures 3, 5, and 6). Due to their size when tagged, (800-1200 mm TL) these fish are likely still immature and these spawning

run type movements are likely not resulting in a successful fall spawn. Fall spawning has not been documented in the Delaware Estuary as it has been in some southern systems (Hatin et al. 2007). However, it is interesting juvenile behavior that may explain why fall CPUE in past DFW gillnetting surveys saw a small increase in September and October (pers. com Craig Shirey). An individual that displayed both behavior types is sturgeon #12647. This fish summered at Marcus Hook Bar (rkm 123) in 2007. However, in 2008 it summered at the mouth of the bay and made a fall migration in October as far upriver as Tinicum Island (rkm 141). In 2009 it summered in the lower bay and did not make a fall migration.

Not all transmitter sturgeon returned each year to the estuary. For example, sturgeon # 12650, tagged in 2007 did not return in 2008, however, it did return in 2009. Sturgeon # 5435 was tagged in July of 2007 and exhibited the majority behavior type for the rest of the year. However, instead of returning in 2008, it passed by the mouth of the Delaware estuary and was detected heading north along the coast by DSU receivers in the spring with no other detections in 2008. In the spring of 2009, it again passed by the mouth of Delaware estuary heading north and was detected by coastal receivers. However, this time it was detected at the mouth of the Connecticut River in the Long Island Sound for several days in June (pers. com Tom Savoy CT DEP). This fish repeated the same behavior in 2010. Another sturgeon # 13996, tagged in the Delaware River in 2008, passed by the estuary heading north in spring of 2009 and 2010 and was detected on June 12th of 2010 at the mouth of the Connecticut River. Sturgeon #12649 summered in the Delaware Estuary in 2007 and 2008, however it passed by the Delaware estuary in 2009 to summer in the Hudson River (pers. com Matt Breece DSU).

The overwintering and early spring migratory behavior of the majority of transmitter-tagged late stage juvenile sturgeon is unknown. However, one sturgeon, tag #12651 was detected on the James River, VA array after leaving the Delaware array in November 2007. It spent 90 days at large in between the two systems array's and overwintered in the James from February to April in 2008 (pers. com, Chris Hager VIMS). The fish was detected as far upstream as Sturgeon Point Road above the mouth of the Chickahominy River in February and settled into a home range below the Chickahominy in March and April near the Hog Island State Waterfowl Refuge. In June of 2008 it was detected by the Delaware Estuary array and remained in the array until October 25th. The next winter it was detected by the James River array from Nov 28th to Dec 6th 2008 in the upriver location, same as the year before. It is unknown how extensive the James River array was after December 6th so total residency time is unclear. This same fish returned again in May of 2009 to summer in the Delaware Estuary. The transmitter expired in December of 2009 so detections in future winters were not expected and did not occur. Sturgeon #14002,

tagged in 2008, left the Delaware array on October 17th, 2008 and was detected 1437 times from April 3rd to April 21st 2009 in the James. The fish was detected as far upstream as Hopewell, VA and downstream in Burwell Bay. During this time it did not seem to have a home range as it made several exploratory runs up and down river in the time it was detected. Three weeks later, on May 13th, 2009 it was detected at the mouth of the Delaware Estuary and it ascended into the Delaware River where it summered until the transmitter seemingly expired a year early in August of 2009. The data suggests that this fish was exhibiting early spring exploration behavior of the James prior to its destination in the Delaware as opposed to the overwintering behavior of #12651.

The observed mixed behavior patterns of summering and wintering area selection supports what is known of the late stage juvenile Atlantic sturgeon population that it is a mixed ocean-run stock. More coastwide cooperation between primary investigators is needed to fully understand internal water and coastal movement patterns of this species. Understanding the spatial and temporal movements and behavior of juvenile sturgeon is essential in trying to manage the threats to this species within the boundaries of the distinct population segments proposed by the Endangered Species Act Listing.

Passive tracking-early stage juveniles

2009 was a successful year for young-of-the-year sturgeon and DFW gillnetting documented a successful spawn in the Delaware River. Thirty-four young-of-the-year were caught from September 9th to November 9th with a CPUE of 1.1 (1.8 CPUE in Table 1 includes all juveniles). They ranged in size from 178 to 349 mm TL. This was the first year the project has had success with young-of-the-year sturgeon. Success can be partially attributed to sampling in upriver sites in a wet year that expanded the freshwater zone and caused young-of-the-year sturgeon to push into the sampling area in a year with a successful spawn. Sampling in the past has fallen on dry or average rainfall years and more effort occurred downstream, on the edge or well downstream of young-of-the-year habitat. Gear selection (small mesh gillnets 5.1 and 7.6 cm stretch) was a contributing factor to young-of-the-year success. However, one young-of-the-year was caught in a larger mesh 12.7 cm net this year indicating the 10.2 and 15.3 cm nets used in past sampling seasons could have potentially caught young-of-the-year.

Young-of-the-year growth occurred throughout the sampling season (Figure 7) and a subset of individual (n=11) pectoral spine sections were taken from juveniles < 350 mm TL that confirmed age-0. Age and growth analysis of spines (n=48, 244 - 2550 mm TL) collected from 2006 to 2009 (Figure 8) sampling efforts and carcasses indicate multiple year classes are

represented. Spine sections were mounted on glass slides, polished down to 1 to 3 mm and aged using a dissecting scope (Rein and Beamesdorfer 1994).

Of the 34 young-of-the-year sturgeon captured in 2009, twenty received internal transmitters (VEMCO V7 and V9 @ <2% of body weight) in October and November. All were released at the Marcus Hook Anchorage (rkm 130) and passive array monitoring occurred throughout the year including the winter months. One fish (#58678) did not produce any data likely due to tag malfunction.

Individual behavior was highly variable (Figure 9) with fish dispersal from the release site occurring from several days to several months after release. Immediately after tagging three individuals dropped down river several miles but within 3 weeks reestablished themselves in the Marcus Hook Anchorage area. This drop down behavior is likely a recovery mechanism resulting from handling stress. In mid November through early March, 10 individuals migrated upstream to sites above Philadelphia (rkm 154) with 8 of those ascending to the Neshaminy State Park area (rkm 186) and 3 as far as Roebling (rkm 199). The Newbold Island and Roebling areas were identified as a juvenile Atlantic and shortnose sturgeon nursery area from July to December in 1981 through 1984 in a study by Lazzari et al. 1986. Use of this site and use of upriver habitat in general was not surprising. However, 50 km migrations into and out of this area during the harshest winter months was unexpected. Winter migration drivers were not explored and analyzed due to time constraints. However, this is a topic that could use additional analysis to understand early stage juvenile river resident movements. Individual fish that did not migrate upriver stayed within a home range of a few river kilometers of the Marcus Hook Anchorage. Detections in this area were typically not on multiple receivers in the same day suggesting that fish had established small home ranges less than 1km.

In late winter transmitters programmed with a shorter delay designed for manual tracking goals expired and by March 16th, only 10 transmitters remained active. Of the remaining 10, 6 were upstream winter migrants and all but one was detected back downstream from May to August between Philadelphia (rkm 150) and New Castle (rkm 100). The exception was # 63412 which did not provide any data after a February 9th detection at the Torresdale receiver (rkm 176). This movement back downriver suggests non-use of the upriver locations during the summer months. However, Lazzari et al. (1986) captured juveniles in July of 1981 through 1984. A hypothesis to explain this difference in behavior could be attributed to the low dissolved oxygen problems of the Delaware Estuary that lingered into the early 1980's. The low oxygen areas from Marcus Hook to Philadelphia could have deterred juveniles that migrated upstream in the winter

from migrating back down in the spring or perhaps pushed them back up after an initial migration downriver.

In September, one individual #58585 migrated upstream to the Newbold Island and Roebling area (rkm 195). Only 3 individuals persisted with active tags in September through October 10th and the 2 others remained in the Cherry Island Flats (rkm 113) and Marcus Hook Anchorage area (rkm130). This individual's behavior indicates that migration to the upper tidal areas is not limited to the winter season and that individuals will migrate between the lower (rkm 100 – 150) and upper (rkm 186-199) tidal freshwater zones in the fall and winter. This fish did not establish a home range in the upper tidal area in the fall. Within 3 weeks it was back down in the lower tidal area and was last detected at Tinicum Island (rkm 141) when the transmitter expired in October.

Young-of-the-year and age -1 Atlantic sturgeon movement and behavior is poorly understood in the Delaware River and the results of this project along with the results from late stage juvenile telemetry provide excellent information toward understanding habitat, overwintering and summering areas, and seasonal movements within the Delaware Estuary.

Active tracking – Late stage juveniles

Tracking occurred on 16 days in 2007 which began July 10th and continued until Nov 13th. The sample area was divided into 2 areas from Commodore Barry Bridge (rkm 132) to Delaware Memorial Bridge (rkm 109) and to near Liston Point (rkm 77). This area was selected based on tracking locations from a telemetry study in 1997-98 (Shirey 1999)(Figure 4). The 2007 locations are combined with 2008 (Figure 10) and discussed below. One individual fish was detected on 10 sampling days.

Tracking occurred in 2008 in the same area as 2007 on 27 days in 2008 and began January7th and continued until Oct 30th. Sixteen of the 25 sturgeon that were tagged by the project since 2007 were tracked manually. Sturgeon locations were plotted in Figure 4. The Marcus Hook Anchorage area was utilized most extensively in 2007 and 2008 (80% of manual detections were in Marcus Hook Anchorage in 2008) and also to a lesser degree areas near Oldman's Point, Carney's Point, Elsinboro Point, Artificial Island Anchorage and south of Artificial Island.

Tracking locations in 2007 and 2008 of late stage juvenile Atlantic sturgeon indicated utilization of similar home ranges between years and there are also similarities in terms of areas utilized to the 1997/98 study. However, the concentration in each area utilized shifted noticeably (Figures 4, 10, Table 4). Individuals from the 2007 and 2008 study preferred upstream sites with

the highest concentrations located in the Marcus Hook Anchorage along the eastern edge of the anchorage overlapping the Delaware and New Jersey state line. The previous highest concentration area in 1997 and 1998 was located in Marcus Hook Bar, an area 3 to 5 km downstream. The area south of Artificial Island was only used sporadically in 2007 and 2008 in contrast to the heavy use in 1997 and 1998.

Seasonal migrations of late stage juveniles are regulated by changes in temperature gradients between fresh and brackish waters (Van Den Avyle 1983). Annual changes in water quality may also shift annual habitat utilization concentrations. The USGS monitoring station at Reedy Island near Artificial Island has recorded conductivity (high correlation to salinity) and water temperature during the summering period (July through October) (Figure 11). During the peak telemetry effort months of 2007 and 2008, there was a combination of extreme high average temperatures and high conductivity (salinity) in the sample area compared to 1997 and 1998 which were above average but not extreme (Figure 11). Water quality may have contributed to the upstream habitat utilization shift. Water quality from 2009 (below average salinity and water temperature year) provides for an interesting comparison. Summering locations in 2009 shifted away from being highly concentrated in upriver sites (Table 4). There were only 4 individuals that summered in 2009 so sample size is small. However, 2 of the 4 that summered in Marcus Hook Anchorage in 2008 summered in locations downstream in 2009. This result, when combined with the low use of upriver sites in 1997 and 1998, suggests that the Marcus Hook Anchorage is a highly utilized summering area only in high salinity, high water temperature summers.

Temperatures above 27° C are considered stressful for sturgeon and in most of July and August of 2007 and 2008, the water temperature exceeded 27° C at Reedy Island Jetty (Figures 3 and 5). An outflow pipe shared by Logan Township Municipal (a water treatment plant) and Ferro Industries (produces elastomers for paint) averages approximately 2 million gallons a day output volume on the eastern side of the Marcus Hook Anchorage at approximately 35 foot depth. Water temperatures and dissolved oxygen levels coming from the pipe were slightly more favorable for sturgeon during the most extreme summer conditions. This favorable water quality, the shape of the anchorage which creates a flow refuge, and the freshwater stream inputs of Raccoon Creek and Oldman's Creek are also likely factors that contributed to the Marcus Hook Anchorage being a preferred summer location in 2007 and 2008.

Manual detections from 2007 and 2008 categorized into 4 general habitat types indicate a preference for anchorage habitat (Table 5). Petite Ponar benthic grabs were taken in the area of the Marcus Hook Anchorage sturgeon concentration through the summer and into the fall of 2008

during gillnetting with no additional time expense to the project. Grabs in the sturgeon concentration area indicated the bottom was a liquid mud to fine silt composition. Grabs in the middle of the anchorage and towards the channel away from the sturgeon concentration were cobble and rock. Invertebrate (isopod and amphipod) counts in the Ponar grabs and observations of amphipods in vegetation that was caught in the sampling gear showed a linear decline throughout the summer and into the fall. Two marked sturgeon were recaptured during 2008 sampling in Marcus Hook anchorage after 16 and 30 days at large. Both fish weighed less upon recapture -340 and -227 g. No visible injuries were observed. Gillnetted sturgeon were observed to be thinner and less robust at the end of the sampling season. The stomachs of six other sturgeon that were captured in early September in the Marcus Hook Anchorage were pumped (Haley 1998) and all were empty. Based on this and the individual transmitter fish that remained in this area throughout the season, it is likely that the water quality and flow refuge preference for this area for a large percentage of the late stage juvenile population caused the forage supply in the area to run thin. An argument could be made that in extreme water quality conditions, good physical habitat trumps the need to feed. However, 2008 was an extreme year and more habitat data in future years will be needed for contrast.

Using a Schnabel estimate based on 2008 gillnetting at the Marcus Hook site, the population there was estimated to be 3,564 with a 95% CI of 990-35,640. The assumptions of this estimate are violated (no immigration or emigration) and the CI is vast because there were only 2 recaptures, so the estimate is statistically weak. However, it does suggest that the number of sturgeon in the anchorage was high.

Areas where tracking occurred (Liston to Commodore Barry Bridge) as depicted in Figures 4 and 10 should be considered high sturgeon concentration areas from July to September and they are preferred sturgeon habitat due to their ability to retain sturgeon over a period of months.

Active tracking – Early stage juveniles

Tracking in 2009 occurred weekly from Delaware Memorial Bridge to the mouth of the Schuylkill River from October 26th to December 15th. Thirteen of the 20 young-of-the-year (262-349 mm TL) were tracked manually and their locations plotted in Figure 12. During the tracking period several individuals moved up river out of tracking range. All fish were released at the Marcus Hook Anchorage from September 24th to November 9th, 2009 with the majority of fish being released on October 27th. Water quality in the sample area was between 0 and 0.5 ppt

salinity throughout the duration of the tracking period and water temperature steadily declined from 14.5 °C to 5.7 °C.

Sommerfeld and Madsen (2003) mapped the Delaware River sediment environment in the areas young-of-the-year sturgeon were tracked in 2009. They identified six types of sedimentary environments. Young-of-the-year sturgeon were tracked in 3 of the 6 types; fine-grained deposition (mud and fluid mud), mixed-grain reworking (ribbons of mixed gravel and sand transverse to flow overtop of mud), and non-deposition (cobble and bedrock). All young-of-the-year tracking locations outside of the Marcus Hook Anchorage (Cherry Island flats east, Marcus Hook bar, Tinicum Island, and Mantua Anchorage) were found over mixed-grain reworking. In the Marcus Hook Anchorage all three sediment types were present and most sturgeon selected for the fine-grained deposition or the edges of fine-grain deposition zones near mixed grain reworking. However, sturgeon locations in the northeast area of the anchorage were found over non-deposition, fine-grain deposition and mixed-grain reworking. Hard bottom types, coarse-grained bedload and coarse grained reworking (cobble and gravel) were present in the tracking area around the Chester Island area (3km upstream of Marcus Hook anchorage), however no young-of-the-year sturgeon were found in this habitat type.

Depth Summary

Fifteen late-stage juvenile sturgeon received pressure transmitters that are able to detect depth to a maximum of 68 meters (±3.4 meters). Ten of the 15 sturgeon with depth sensors that were manually tracked indicate that sturgeon depth was almost always deep (>3 meters) and near the bottom. The exception to the rule was when a sturgeon was noticeably on the move. Moving sturgeon were typically found in the channel with several exceptions at New Castle flats (rkm 110) and Cherry Island flats (rkm 117). Moving sturgeon also tended to change depth more often. Later review of the tracking logs indicated sturgeon depth typically varied by 1 to 6 meters in between detections that were 60 seconds apart on average.

Passive receiver detection depth by month of fish within the boundaries of Delaware Estuary in 2008 is summarized in Figure 13. Near shore and off shore marine detections are excluded from this figure to get a more accurate depiction of Estuary behavior. Depth is biased due to receiver location. Most receivers are located in deep water or along the federal channel (>12.4 m in depth). However, since manual tracking indicates sturgeon primarily use deep water habitat, these depths are likely an accurate representation of sturgeon depth while in the Estuary. The monthly average detection depths for April, May and June are 6.3 m, 8.4 m, and 7.8 m, respectively. July, August and September are typically when late stage juveniles settle into a

home range, move less and spend a greater amount of time at or near the bottom likely feeding and averaged 10.1 m, 10.7 m, and 10.5 m, respectively. In October they emigrate to the Atlantic Ocean and are once again on the move and the average depth of detection is shallower, 8.3 m. Utilization of variable and shallower depths at an increased rate during immigration and emigration is significant due to its correlation to an increase of occurrence of ship strikes (Brown and Murphy 2010) in the spring and to a lesser extent, the fall.

Depth is also significant to dredging activities within the Estuary so late-stage juvenile Atlantic sturgeon depth data have been summarized by river reach as defined by Army Corp of Engineers dredging project for ease of comparison. Reach AA/A extends from the upper project limit at Allegheny Avenue, Philadelphia PA to Billingsport Range, located near the Philadelphia International Airport. Late-stage juveniles were not detected in reach AA/A in 2008. Reach B extends from Tinicum Range, located opposite the airport to Cherry Island Range, located opposite of Wilmington, DE (Figure 14). Reach C extends from Deepwater Point Range, located below Wilmington, DE to New Castle Range, located at the mouth of the Chesapeake and Delaware Canal (Figure 15). Reach D extends from Reedy Island Range, located south of the Chesapeake and Delaware Canal to Liston Range, located just north of the Delaware Bay (Figure 16). Reach E covers the remaining portion of the project area from the lower portion of Liston Range in the upper portion of the Delaware Bay to naturally deep water in the lower portion of the bay (Figure 17). The Chesapeake and Delaware Canal connects the Bays and is maintained at a depth of 40 feet (Figure 18). Figures 14 through 18 should be useful information for resource managers when designing dredging windows for depth specific activities.

In 2009, young-of-the-year did not receive depth tags. However, manual tracking data locations from October to December of 2009 provided some depth data. Sturgeon were tracked in 8.5 to 15.8 m depth areas with most sturgeon being in the Marcus Hook Anchorage at 12.4 m of depth. It is not possible to tell how close to the bottom these sturgeon were without pressure transmitters but based on the directional hydrophone direction at strongest detection all were perceived to be close to the bottom.

Acknowledgements

Jared Jacobini should be acknowledged for his construction of the GIS figures. Sam Johnson, Jared Jacobini, Cathy Martin, and Lauren Johnson, were patient and efficient workers for long hours afield. Their ideas and enthusiasm were appreciated and made the field season productive and enjoyable.

TABLE 1. Annual catch rates of Atlantic sturgeon taken in the lower Delaware River from 1991 to 2009 by the Delaware Division of Fish and Wildlife.

Year	No. Taken	Days Sampled	Net Hours	N/hr
1991	565	26	17.5	32.2
1992	501	26	29.5	17.0
1993	222	24	26.2	8.0
1994	220	26	21.6	10.2
1995	111	18	21.6	5.1
1996	43	14	17.5	2.5
1997	57	17	17.2	3.2
1998	14	13	10.3	1.4
2001	27	14	15.5	1.7
2004	31	21	19.1	1.6
2007	42	22	22.6	1.9
2008	9	11	11.3	0.8

[1]In 2008, additional sites at Marcus Hook (rkm 127) and Bombay Hook (rkm 63) were utilized. Marcus Hook sampling was based on anticipated summer site fidelity from the 2007 manual tracking results. Manual tracking of individuals prior to setting the net was also used to adjust the location and orientation of the net set to provide a gear efficiency advantage.
[2]Additional sites as well as exclusive use of small mesh (5.1 and 7.6 cm stretch) were utilized to target age-0,1,2 Atlantic sturgeon
Due to changes in sampling methods and locations the 2008 and 2009 CPUE below should not be included in analysis when drawing conclusions about Delaware Estuary juvenile population trends. The 2008 CPUE above only includes sampling days in similar locations with similar methods and can be used for trend comparison purposes with CPUE from 1991 to 2007.

Year	No. Taken	Days Sampled	Net Hours	N/hr
2008[1]	134	18	21.1	6.3
2009[2]	55	28	31.5	1.8

Table 2. Selected Atlantic sturgeon that received ultrasonic transmitters from Delaware Division of Fish and Wildlife gillnetting operations on the lower Delaware River in 2007-09.

Date	Location	Transmitter ID	Type	TL (mm)	FL (mm)	Pit tag	tag life-days	expiration
6/20/2007	Artificial Is.	S256 C **224**, **12647**	V16P-6H Pinger, depth	860	743	985161008705456	890	11/27/2009
6/20/2007	Artificial Is.	S256 C **225**, **12648**	V16P-6H Pinger, depth	892	780	985161000712438	890	11/27/2009
7/3/2007	Artificial Is.	S256 C **226**, **12649**	V16P-6H Pinger, depth	1037	889	985161000849271	890	12/9/2009
7/9/2007	Artificial Is.	S256 C **227**, **12650**	V16P-6H Pinger, depth	1063	898	985161000853302	890	12/15/2009
7/18/2007	Carneys Pt	S256 C **228**, **12651**	V16P-6H Pinger, depth	1011	868	985161000711881	890	12/24/2009
7/19/2007	Carneys Pt	**5435**	V16-6H Pinger	1015	880	985161000792694	890	12/25/2009
10/17/2007	Artificial Is.	**5438**	V16-6H Pinger	1181	1011	421D587532	890	3/25/2010
10/2/2007	Carneys Pt	**5439**	V16-6H Pinger	1063	987	45494B0E69	890	3/10/2010
6/20/2007	Artificial Is.	**5440**	V16-4H Pinger	853	745	985161000849118	450	9/13/2008
7/6/2007	Artificial Is.	**5441**	V16-4H Pinger	900	770	985161000843896	450	9/28/2008
7/9/2007	Artificial Is.	**5442**	V16-4H Pinger	826	712	454B644E58	450	10/1/2008
7/9/2007	Artificial Is.	**5443**	V16-4H Pinger	953	829	985161000707872	450	10/1/2008
7/9/2007	Artificial Is.	**5444**	V16-4H Pinger	829	717	454A1F3E06	450	10/1/2008
7/21/2008	Marcus Hook	**5436**	V16-6H Pinger	1185	1002	985161000828987	890	12/28/2010
7/21/2008	Marcus Hook	**5437**	V16-6H Pinger	1204	1036	985161000707923	890	12/28/2010
7/24/2008	Cherry Island	1105-**127**, 1303-**13995**	V16P-6H Pinger, depth	1091	931	985161000797275	1630	1/9/2013
8/5/2008	Marcus Hook	1105-**128**, 1303-**13996**	V16P-6H Pinger, depth	1380	1204	985161000848554	1630	1/21/2013
10/21/2008	Bombay Hook	1105-**129**, 1303-**13997**	V16P-6H Pinger, depth	898	795	985121014347250	1630	4/8/2013
8/5/2008	Marcus Hook	1105-**130**, 1303-**13998**	V16P-6H Pinger, depth	1336	1128	985161000832724	1630	1/21/2013
8/5/2008	Marcus Hook	1105-**131**, 1303-**13999**	V16P-4H Pinger, depth	952	804	985161000850602	820	11/3/2010
8/21/2008	Marcus Hook	1105-**132**, 1303-**14000**	V16P-4H Pinger, depth	975	827	985161000714272	820	11/19/2010
8/21/2008	Marcus Hook	1105-**133**, 1303-**14001**	V16P-4H Pinger, depth	888	754	985161000844993	820	11/19/2010
6/24/2008	Carneys Point	1105-**134**, 1303-**14002**	V16P-4H Pinger, depth	1022	873	985161000707115	820	9/22/2010
6/25/2008	Carneys Point	1105-**135**, 1303-**14003**	V16P-4H Pinger, depth	972	818	985161000797756	820	9/23/2010
8/5/2008	Marcus Hook	1105-**136**, 1303-**14004**	V16P-4H Pinger, depth	985	855	985161000708194	820	11/3/2010
9/24/2009	Marcus Hook	A69-1303-**58676**	V7-4L Pinger	277	237	985121018613074	298	7/19/2010
9/25/2009	Marcus Hook	A69-1303-**58677**	V7-4L Pinger	349	296	985121014383373	298	7/20/2010
9/25/2009	Marcus Hook	A69-1303-**58678**	V7-4L Pinger	326	280	985121014383523	298	7/20/2010
11/6/2009	Marcus Hook	A69-1303-**58679**	V9-2H Pinger	310	263	985121018606380	98	2/12/2010
11/6/2009	Marcus Hook	A69-1303-**58680**	V9-2H Pinger	332	284	985121018608077	98	2/12/2010
11/9/2009	Marcus Hook	A69-1303-**58681**	V9-2H Pinger	282	264	985121018606363	98	2/15/2010
10/27/2009	Marcus Hook	A69-1303-**58682**	V9-2H Pinger	341	287	985121018609406	98	2/2/2010
8/11/2009	Marcus Hook	A69-1303-**58683**	V9-2H Pinger	633	554	985121014350536	348	7/25/2010
10/27/2009	Marcus Hook	A69-1303-**58684**	V9-2H Pinger	303	260	985121018615870	348	10/10/2010
10/27/2009	Marcus Hook	A69-1303-**58685**	V9-2H Pinger	316	268	985121018615914	348	10/10/2010
10/27/2009	Marcus Hook	A69-1303-**58686**	V9-2H Pinger	315	272	985121019132358	348	10/10/2010
10/26/2009	Marcus Hook	A69-1303-**63412**	V7-4L Pinger	283	246	985121019137607	298	8/20/2010
10/27/2009	Marcus Hook	A69-1303-**63413**	V7-4L Pinger	289	254	985121018612004	298	8/21/2010
10/27/2009	Marcus Hook	A69-1303-**63414**	V7-4L Pinger	281	243	985121019137590	298	8/21/2010

10/27/2009	Marcus Hook	A69-1303-**63415**	V7-4L Pinger	286	242	985121018608178	298	8/21/2010
10/27/2009	Marcus Hook	A69-1303-**63416**	V7-4L Pinger	295	252	985121018611137	298	8/21/2010
10/27/2009	Marcus Hook	A69-1303-**63417**	V7-1L Pinger	262	227	985121018612733	127	3/3/2010
10/27/2009	Marcus Hook	A69-1303-**63418**	V7-1L Pinger	274	238	985121018611505	127	3/3/2010
10/27/2009	Marcus hook	A69-1303-**63419**	V7-1L Pinger	299	262	985121018613614	127	3/3/2010
11/6/2009	Marcus Hook	A69-1303-**63420**	V7-1L Pinger	308	264	985121018607421	127	3/13/2010
11/9/2009	Marcus Hook	A69-1303-**63421**	V7-1L Pinger	292	253	985121018605595	127	3/16/2010

Table 3. Genetic haplotype analysis (Wirgin et al. 2007) of Delaware Estuary adults and 2009 young-of-the-year. Row highlighted in yellow is a haplotype unique to the Delaware system based on analysis of most east coast Atlantic sturgeon populations.

haplotype	adult	YOY	**All**
A	7		7
A1			
A3			
A5	8	9	17
B	8	21	29
B1			
B2			
C	1		1
C1			
C2			
C3			
C4			
C5			
C6			
D	3		3
D2			
E			
E3			
N	1		1
N1	1	3	4
N2			
N3			
O			
P			
P1			
P5			
P7			
P8			
P9			
P10			
P12			
R			
S1			
total	29	33	62

Table 4. Number of late stage juvenile Atlantic sturgeon (800-1200 mm TL) utilizing summering areas based on 1997, 1998, 2007, 2008, and 2009 telemetry.

	South Artificial Island	Artificial Island Anchorage	Elsinboro Point	Carney's Point	Oldman's Point	Marcus Hook Anchorage
1997	1	2	0	1	2	0
1998	2	1	0	0	3	0
2007	0	0	2	2	1	5
2008	0	0	2	1	1	7
2009	0	1	1	0	1	1

Table 5. Number of manual tracking locations of late stage juvenile Atlantic sturgeon categorized by type. Tracking occurred 2 to 4 times a month from July to December of 2007 and April to December of 2008.

	2007	2008	Combined years - % of total
Main channel	9	16	17%
Anchorage	19	71	61%
Alternate channel	3	4	5%
Uncategorized	18	7	17%

Figure 1. Sampling sites (denoted by yellow boxes) of the early juvenile Atlantic sturgeon telemetry study on the Delaware River conducted by DE DFW personnel. Telemetry array coverage of DE DFW, Environmental Research Consultants Inc, and Delaware State University VEMCO VR-2 receivers (denoted by red dots) (map courtesy of Jared Jacobini, DE DFW).

Figure 2. VEMCO VR-2W Acoustic Monitoring Receiver.

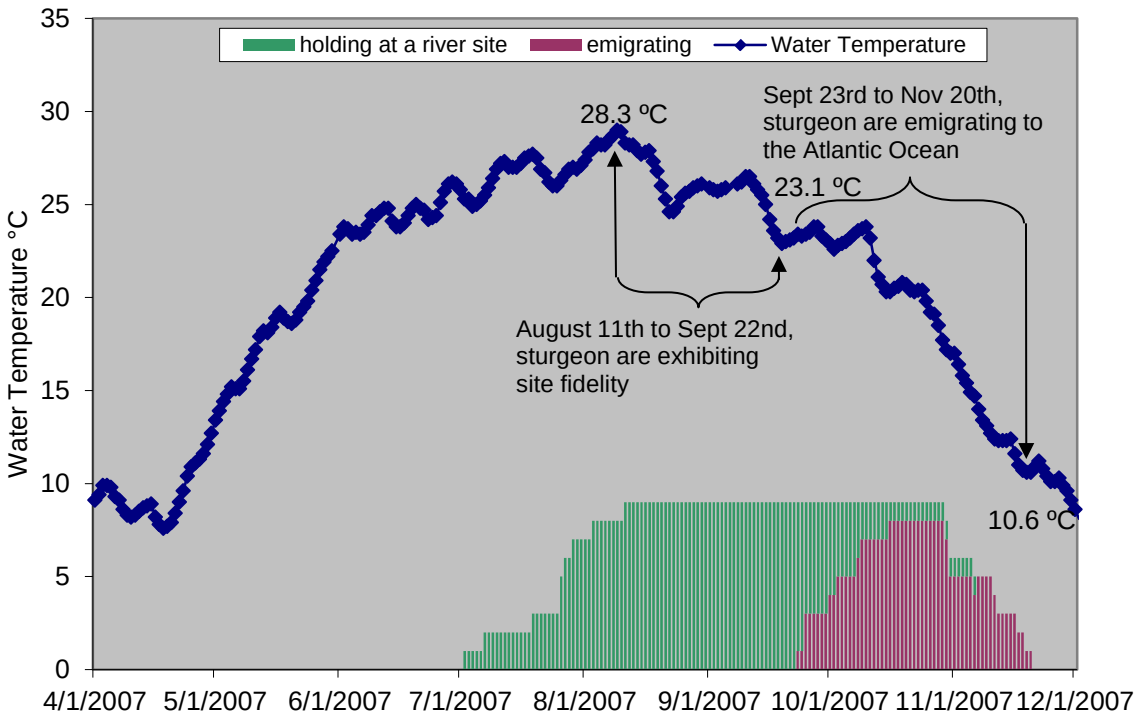


Figure 3. Late stage juvenile Atlantic sturgeon (>600 mm TL) tagged in July and August of 2007 exhibited site fidelity when water temperatures were high (green bars) and emigrated to the Atlantic Ocean when water temperatures decreased in the fall (red bars). Note there are no immigrating individuals in 2007 because tagging began in 2007. Bar height represents number of sturgeon displaying the indicated behavior type. Y-axis also represents ºC average daily water temperature in the Delaware River at Reedy Island Jetty, DE (USGS #01482800).

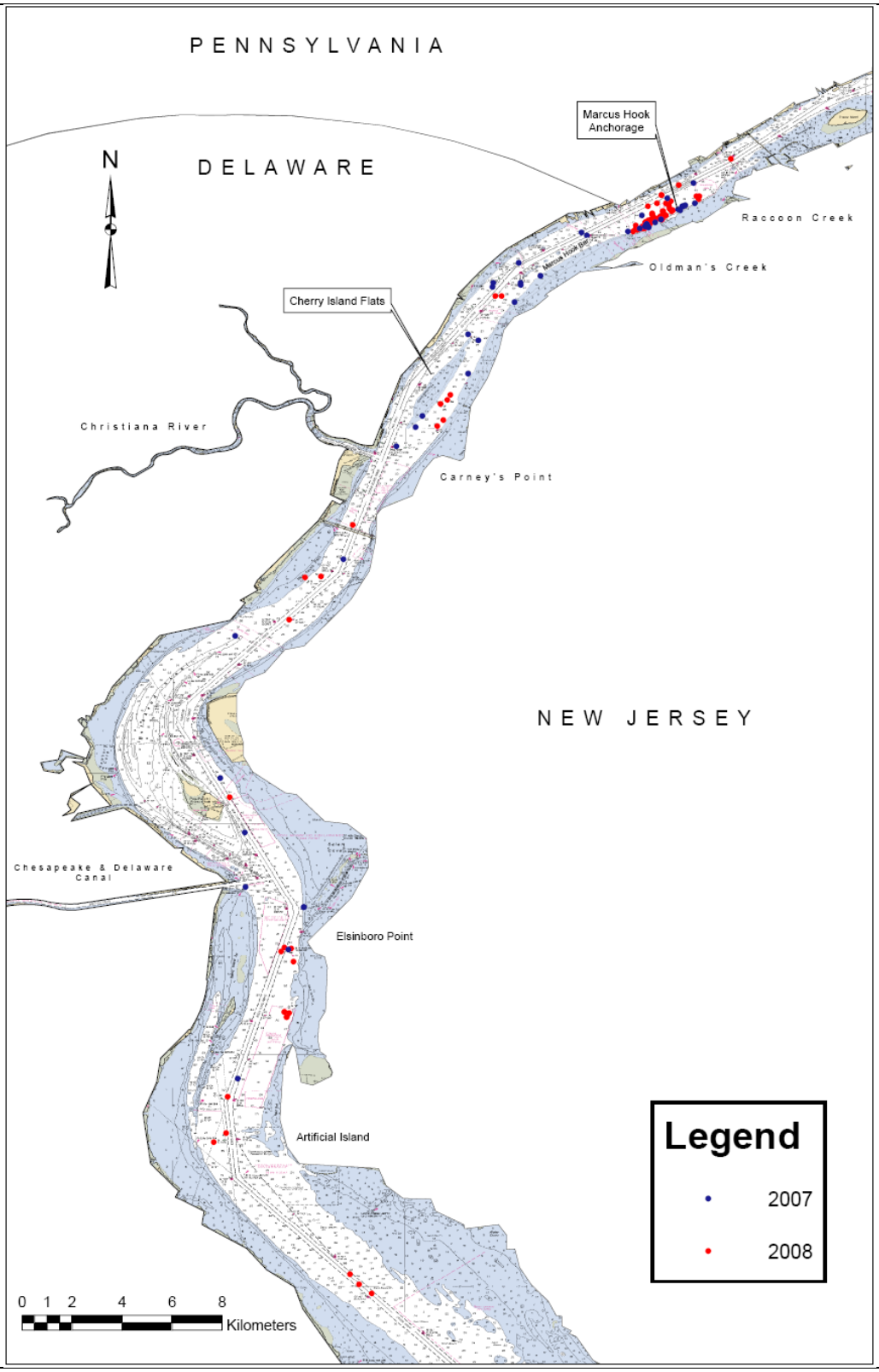


Figure 4. Manual tracking in 2007 and 2008 yielded high numbers of DFW tagged late stage juvenile Atlantic sturgeon in Marcus Hook anchorage and less frequent numbers throughout the survey area.

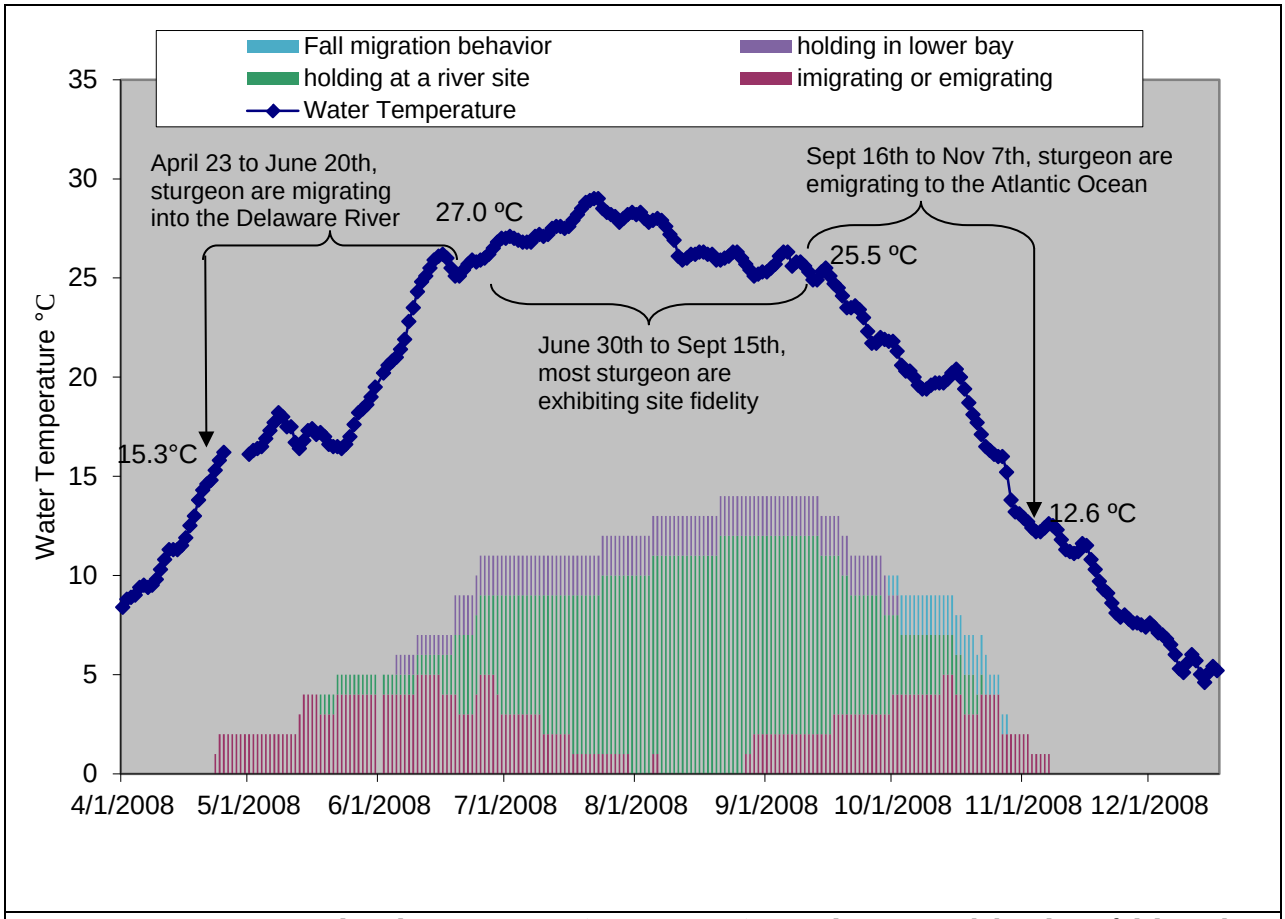


Figure 5. Late stage juvenile Atlantic sturgeon (>600 mm TL) tagged in 2008 exhibited site fidelity when water temperatures were high (green bars) and emigrated to the Atlantic Ocean when water temperatures decreased in the fall (red bars). The sturgeon tagged in 2007 that immigrated back into the estuary in 2008 are also included (red bars). Two individual behavior exceptions; holding in the lower bay or marine waters (purple bars) and fall migration (blue bars) were exhibited in 2008. Bar height represents number of sturgeon displaying the indicated behavior type. Y-axis also represents ºC average daily water temperature in the Delaware River at Reedy Island Jetty, DE (USGS #01482800).

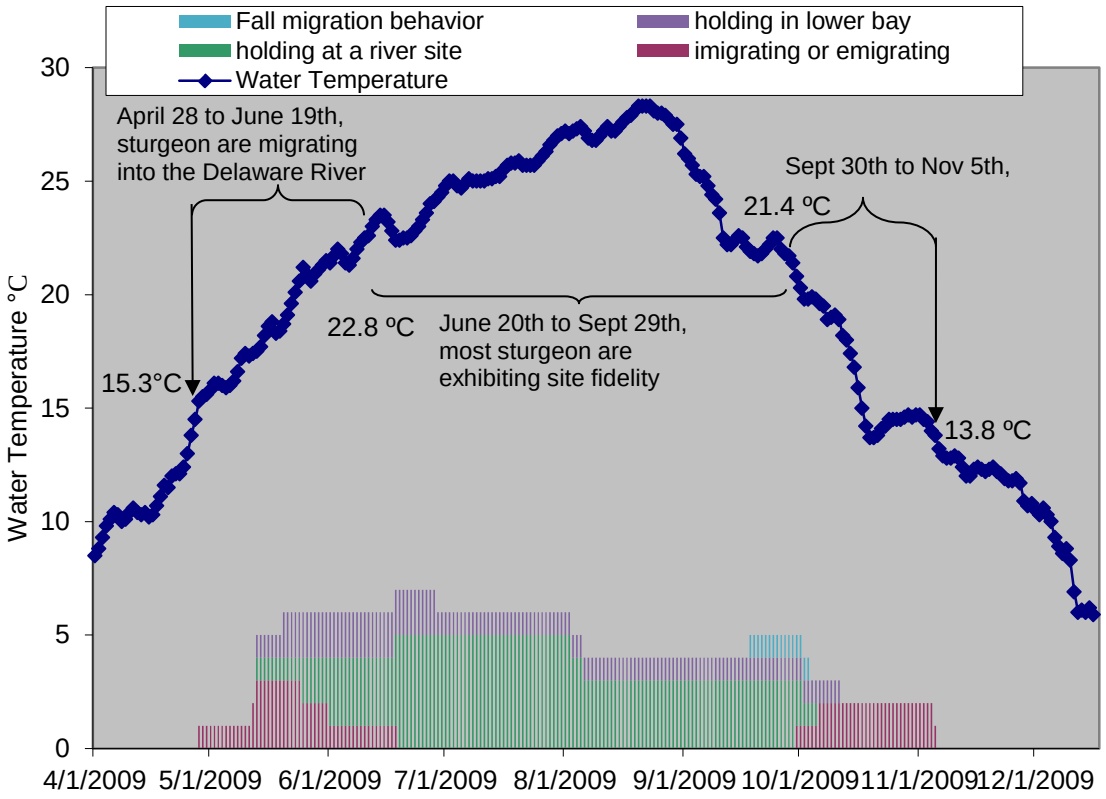


Figure 6. Late stage juvenile Atlantic sturgeon (>600 mm TL) tagged in 2007 and 2008 exhibited site fidelity when water temperatures were high (green bars) and emigrated to the Atlantic Ocean when water temperatures decreased in the fall (red bars). Two individual behavior exceptions; holding in the lower bay or marine waters (purple bars) and fall migration (blue bars) were exhibited in 2009. Bar height represents number of sturgeon displaying the indicated behavior type. Y-axis also represents ºC average daily water temperature in the Delaware River at Reedy Island Jetty, DE (USGS #01482800).

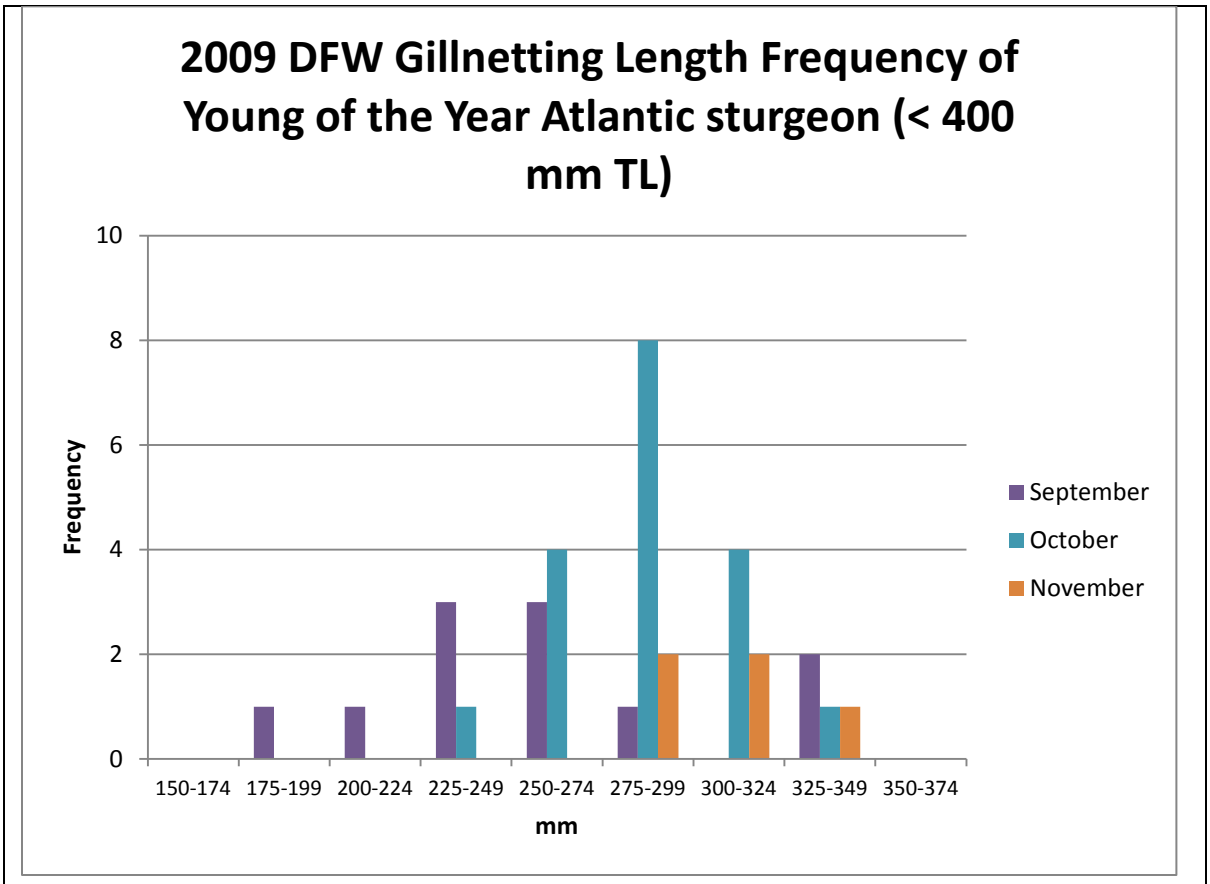


Figure 7. Length frequency plot of monthly young-of-the-year Atlantic sturgeon catches in 2009. Growth increased throughout the sampling period from September 9th to November 9th.

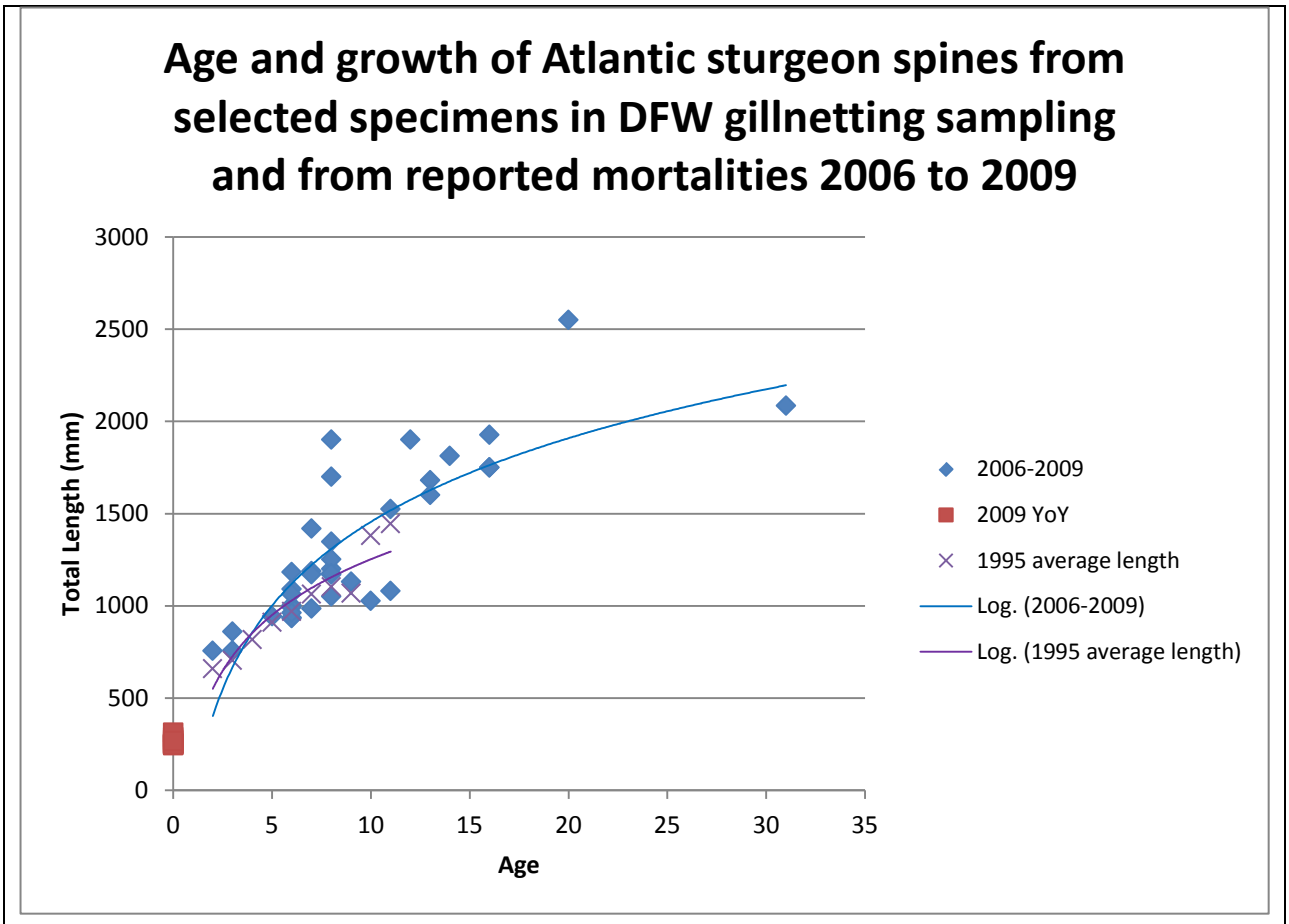


Figure 8. Age and growth curve of Delaware Estuary Atlantic sturgeon collected from 2006-2009. Age and growth of 1995 late stage juvenile samples are included for reference.

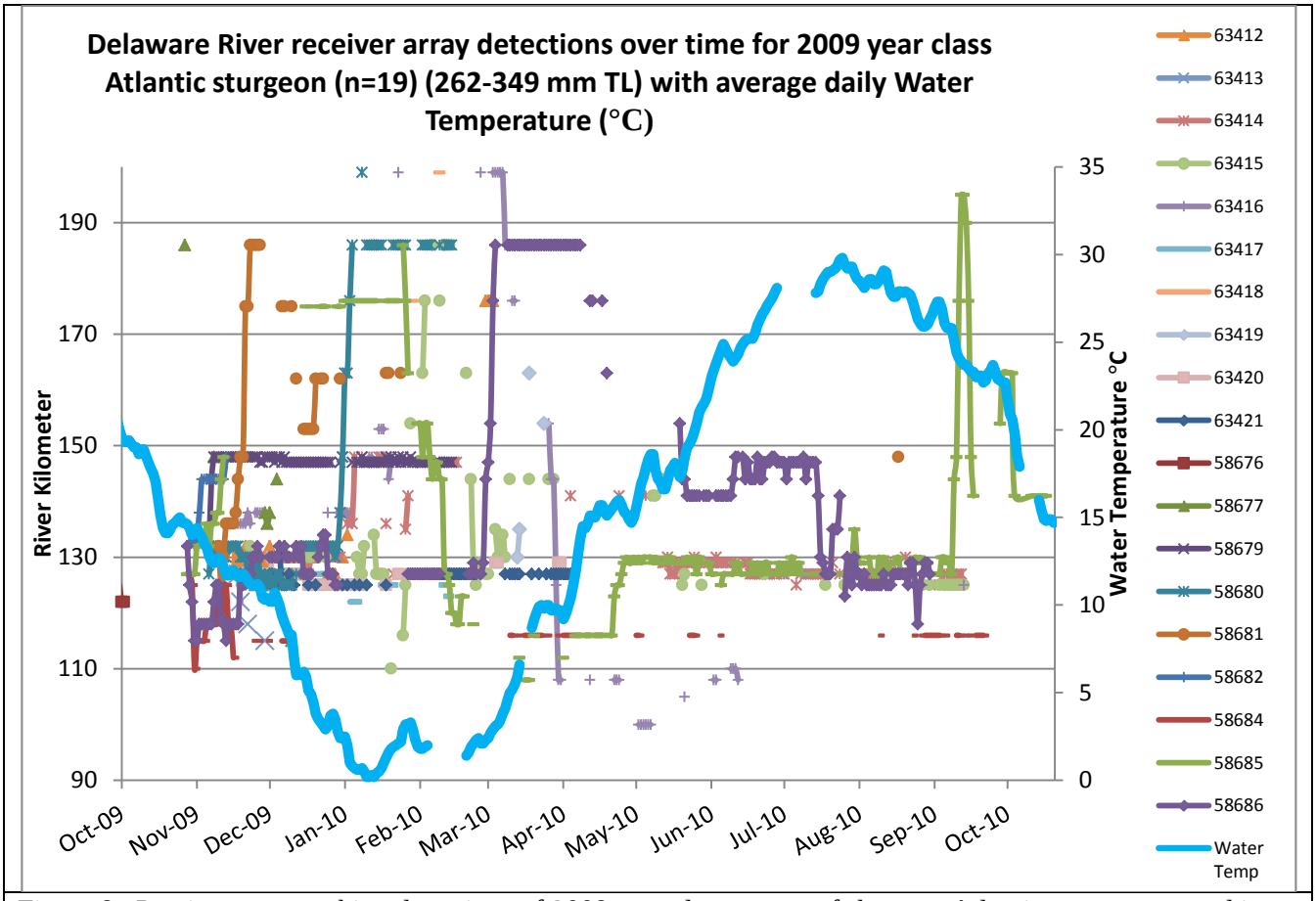


Figure 9. Passive array tracking detections of 2009 year class young-of-the-year Atlantic sturgeon tagged in late October and early November by DFW personnel. All sturgeon were internally implanted with VEMCO V7 and V9 transmitters and released at Marcus Hook Anchorage (rkm 130). Nine of the 19 transmitters expired in February and March of 2010 due to a scheduled shorter battery life. Water Temperature (°C) is from the USGS Reedy Island Gage #01482800 (some data is provisional at publication time).

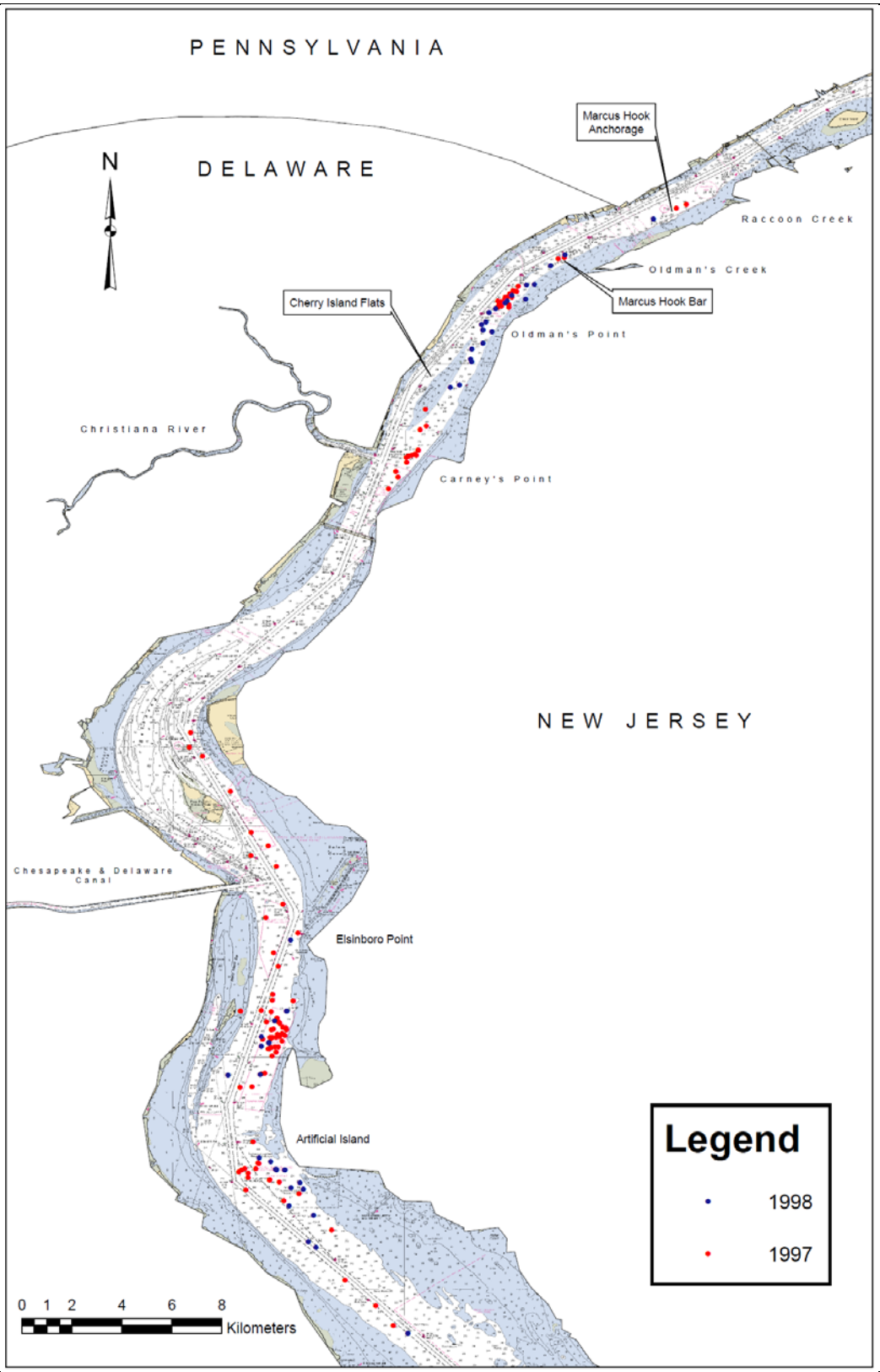
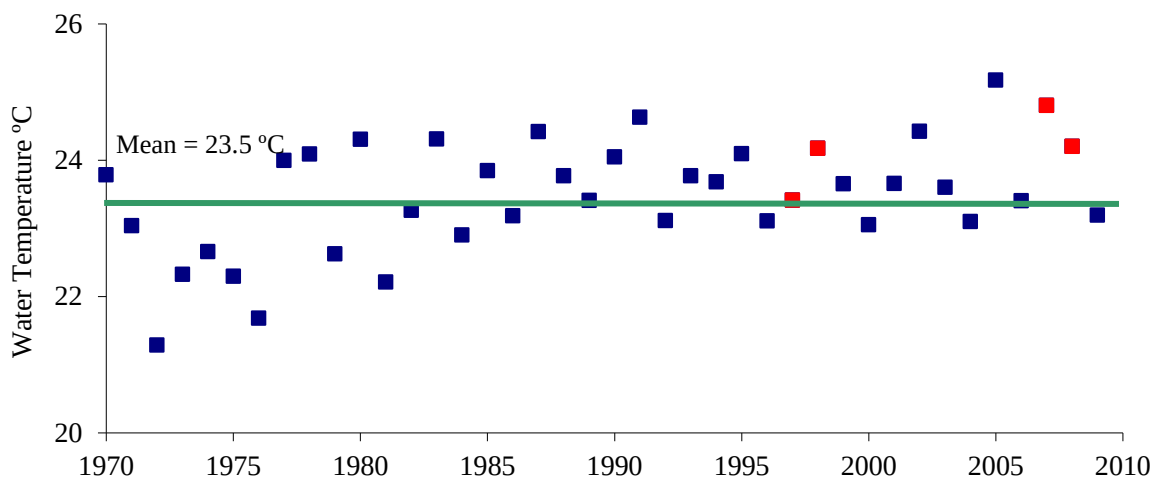


Figure 10. Manual tracking locations of late stage Atlantic sturgeon juveniles from a telemetry study in 1997 and 1998 from Shirey 1999.



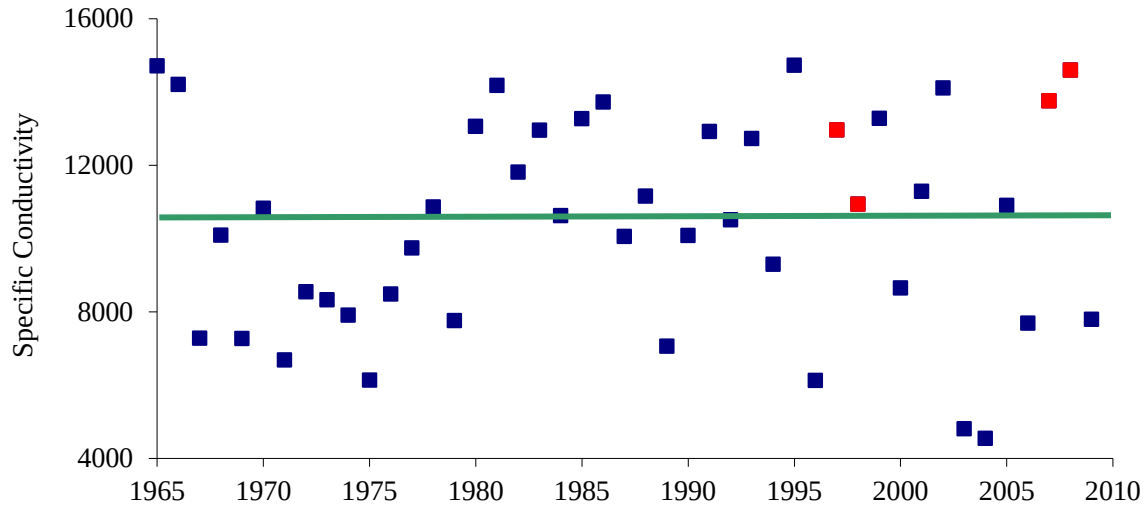


Figure 11. Specific conductivity and water temperature monthly means (July through October combined) at Reedy Island, USGS #01482800. Green line represents the long term average and red dots denote telemetry study years (1997, 1998, 2007, and 2008).

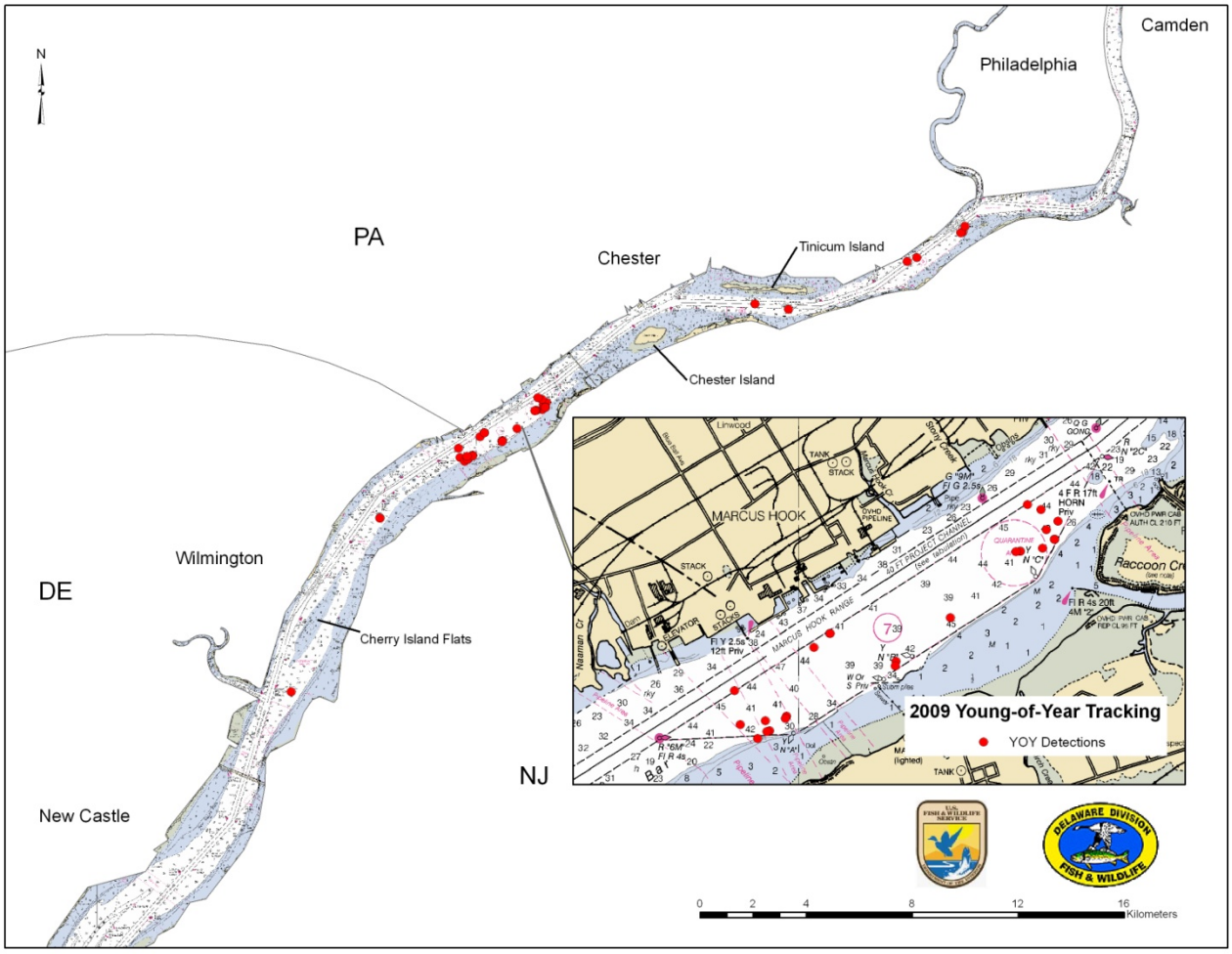


Figure 12. Manual tracking locations of transmitter (VEMCO) implanted young-of-the-year (262-349 mm TL) Atlantic sturgeon from October 26th to December 15th, 2009. Weekly tracking ranged from the Delaware Memorial Bridge to the mouth of the Schuylkill River. During the tracking period several individuals moved up river out of tracking range. All fish were released at the Marcus Hook anchorage (expanded map section) from September 24th to November 9th, 2009 with the majority of fish being released on October 27th.

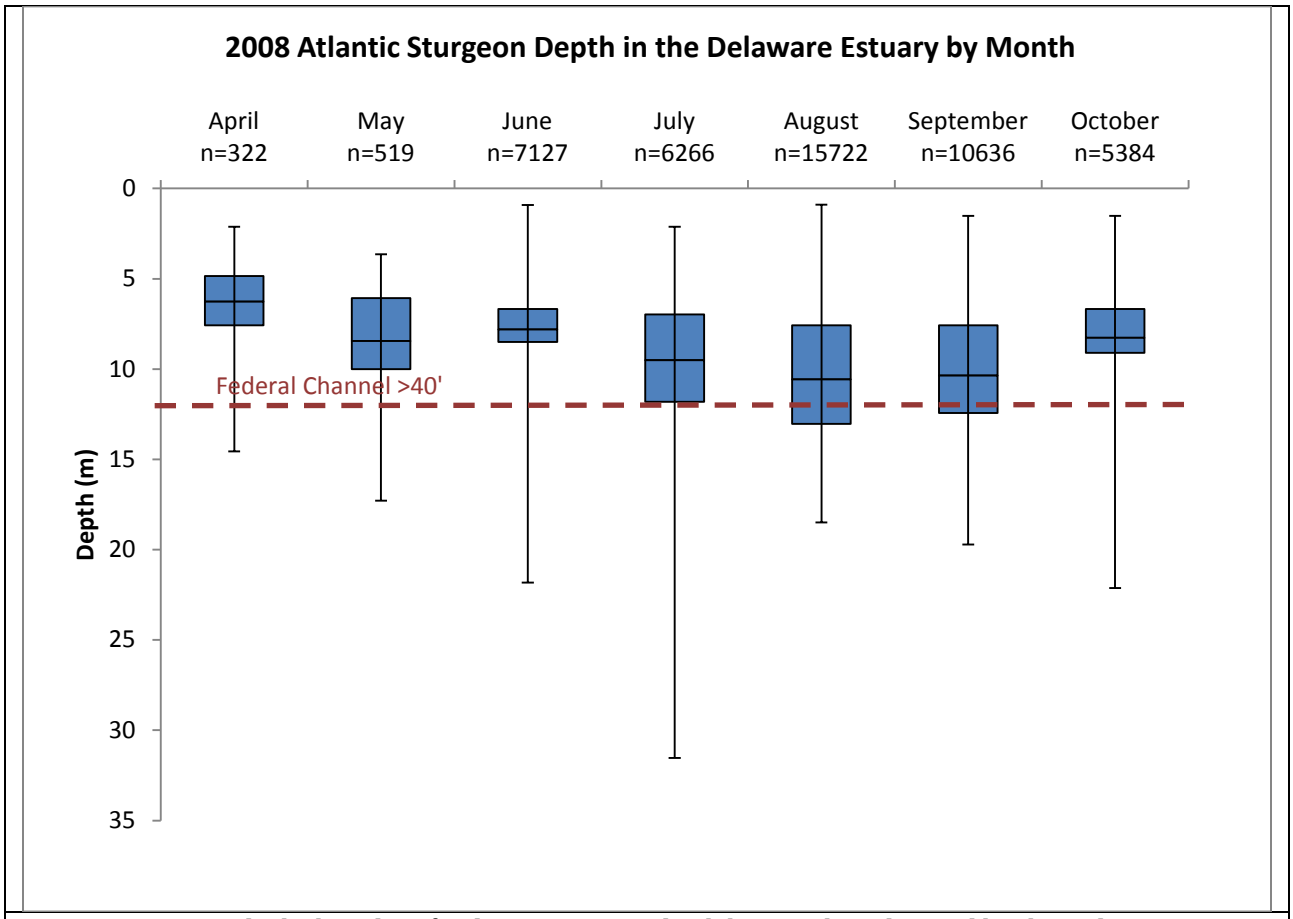


Figure 13. Box and whisker plot of Atlantic sturgeon depth by month as detected by the Delaware estuary receiver array in 2008. Box represents the depth of the 25th through 75th quartile of detections. Horizontal line within the box represents the average depth. Whiskers represent the minimum and maximum depth. Available detection depth of receiver varies by receiver location within the Estuary. Note that November detection sample size was small (n=24) and all detections were in deeper than average habitat (eg. tanker anchorage and the entrance to the Bay) as sturgeon emigrated the bay.

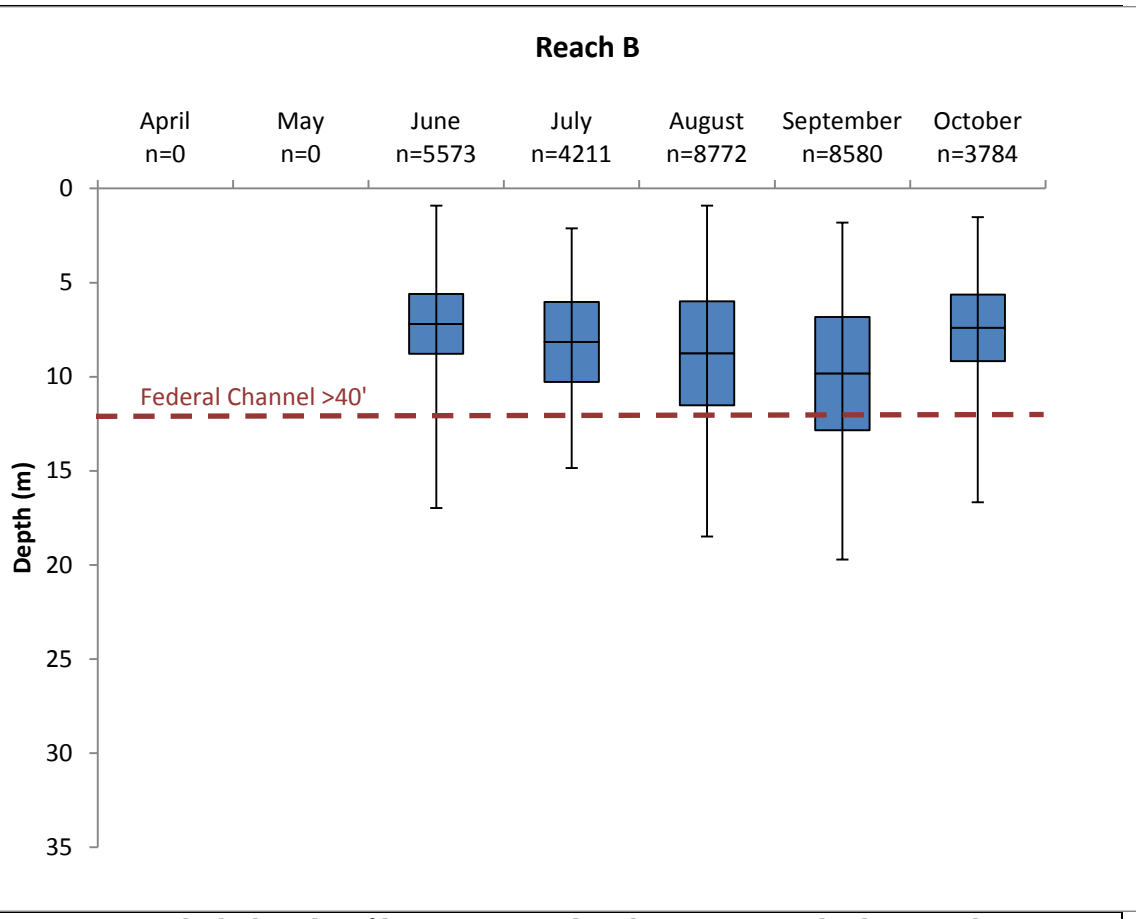


Figure 14. Box and whisker plot of late stage juvenile Atlantic sturgeon depth in Reach B 2008 by month. Reach B extends from Tinicum Range, located opposite the airport to Cherry Island Range, located opposite of Wilmington, DE. Box represents the depth of the 25th through 75th quartile of detections. Horizontal line within the box represents the average depth. Whiskers represent the minimum and maximum depth. Available detection depth of receiver varies by receiver location.

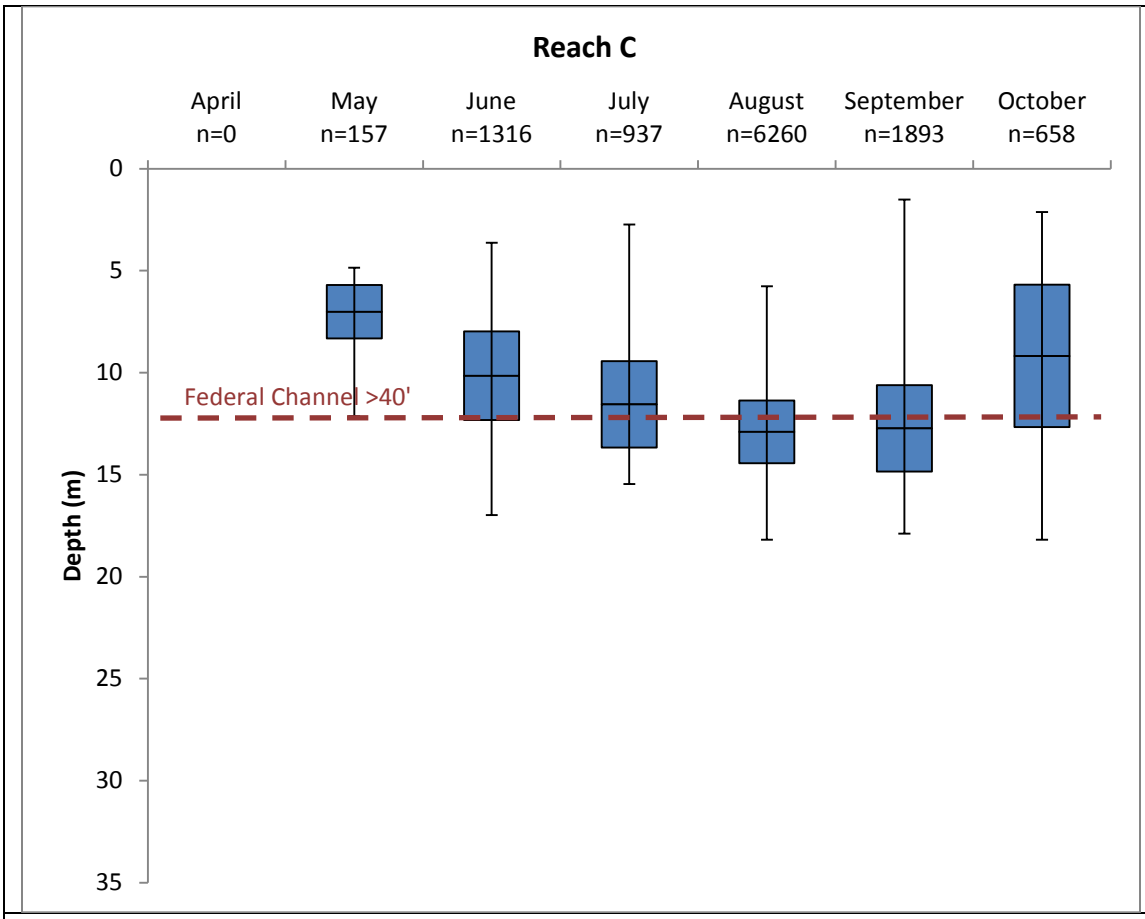


Figure 15. Box and whisker plot of late stage juvenile Atlantic sturgeon depth in Reach C, 2008 by month. Reach C extends from Deepwater Point Range, located below Wilmington, DE to New Castle Range, located at the mouth of the Chesapeake and Delaware Canal. Box represents the depth of the 25th through 75th quartile of detections. Horizontal line within the box represents the average depth. Whiskers represent the minimum and maximum depth. Available detection depth of receiver varies by receiver location.

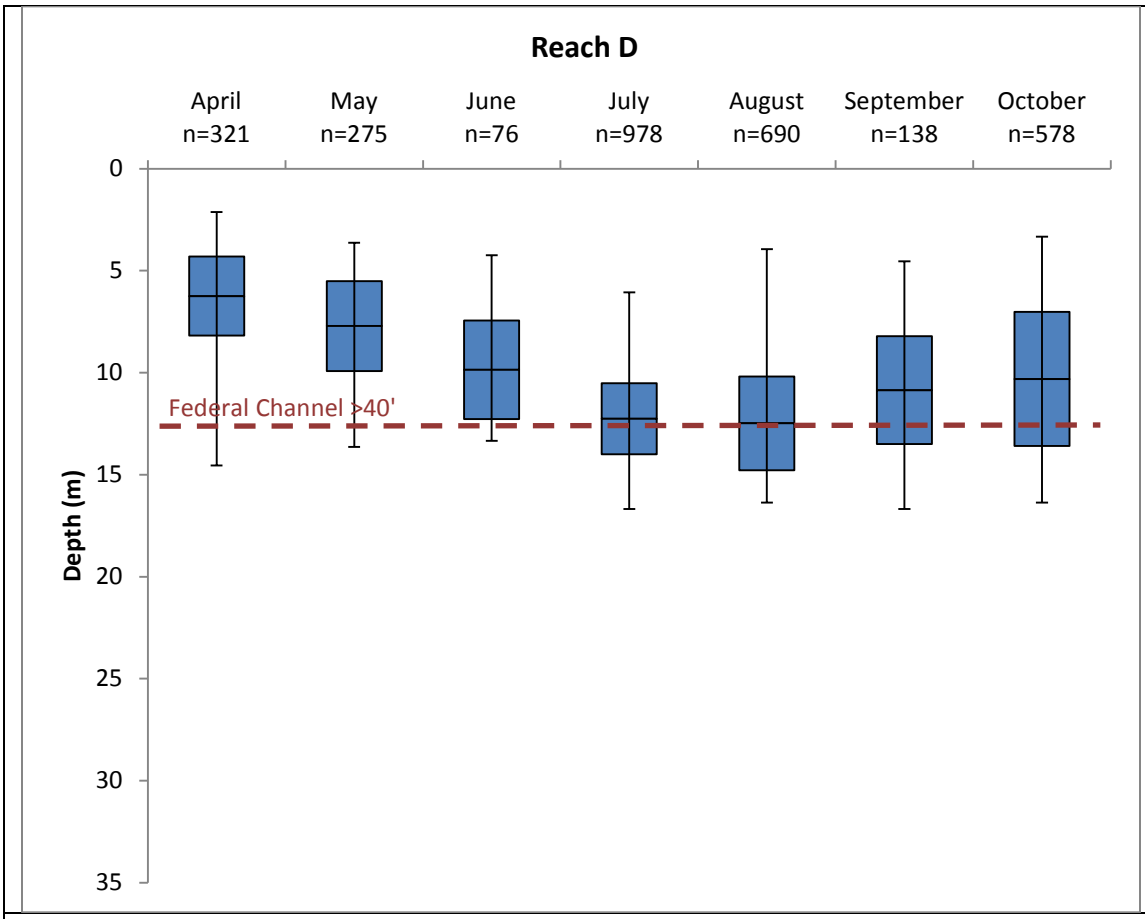


Figure 16. Box and whisker plot of late stage juvenile Atlantic sturgeon depth in Reach D, 2008 by month. Reach D extends from Reedy Island Range, located south of the Chesapeake and Delaware Canal to Liston Range, located just north of the Delaware Bay. Box represents the depth of the 25th through 75th quartile of detections. Horizontal line within the box represents the average depth. Whiskers represent the minimum and maximum depth. Available detection depth of receiver varies by receiver location.

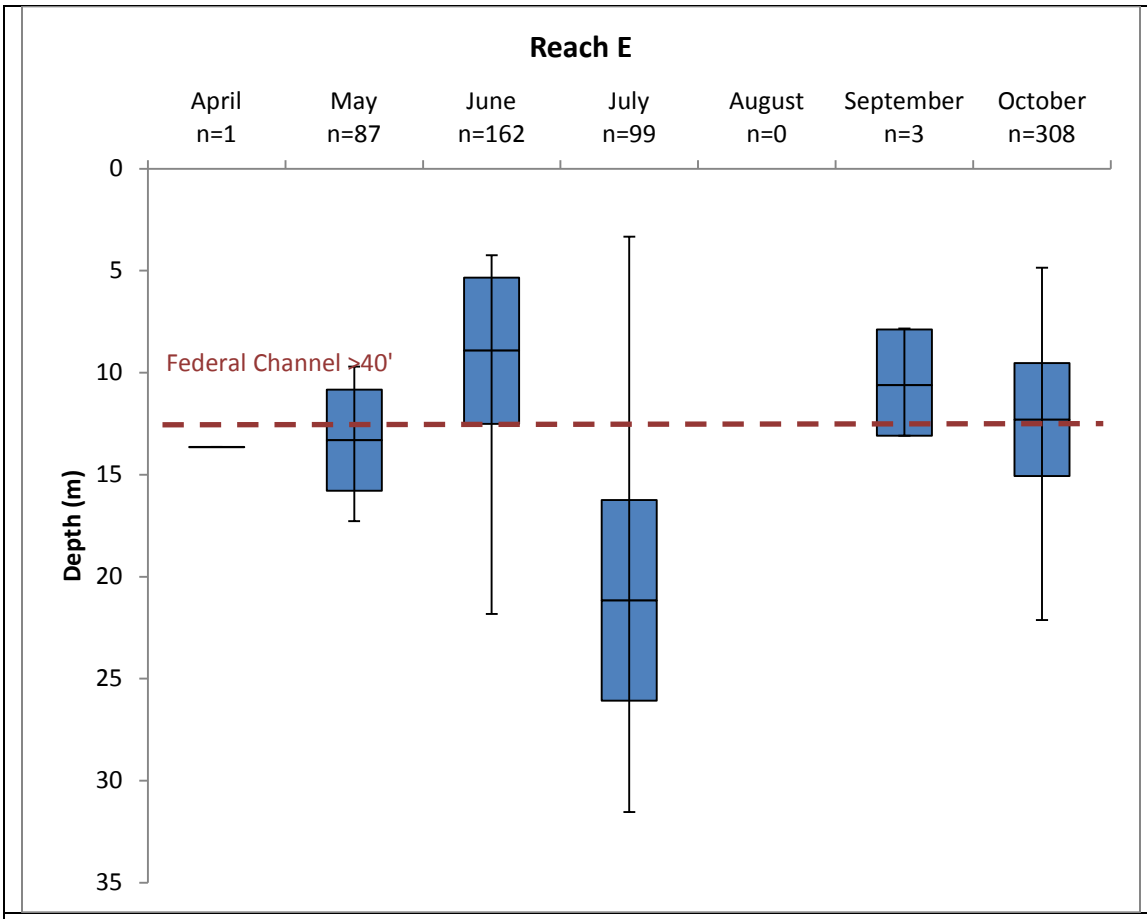


Figure 17. Box and whisker plot of late stage juvenile Atlantic sturgeon depth in Reach E, 2008 by month. Reach E covers the remaining portion of the project area from the lower portion of Liston Range in the upper portion of the Delaware Bay to naturally deep water in the lower portion of the bay. Box represents the depth of the 25th through 75th quartile of detections. Horizontal line within the box represents the average depth. Whiskers represent the minimum and maximum depth. Available detection depth of receiver varies by receiver location.

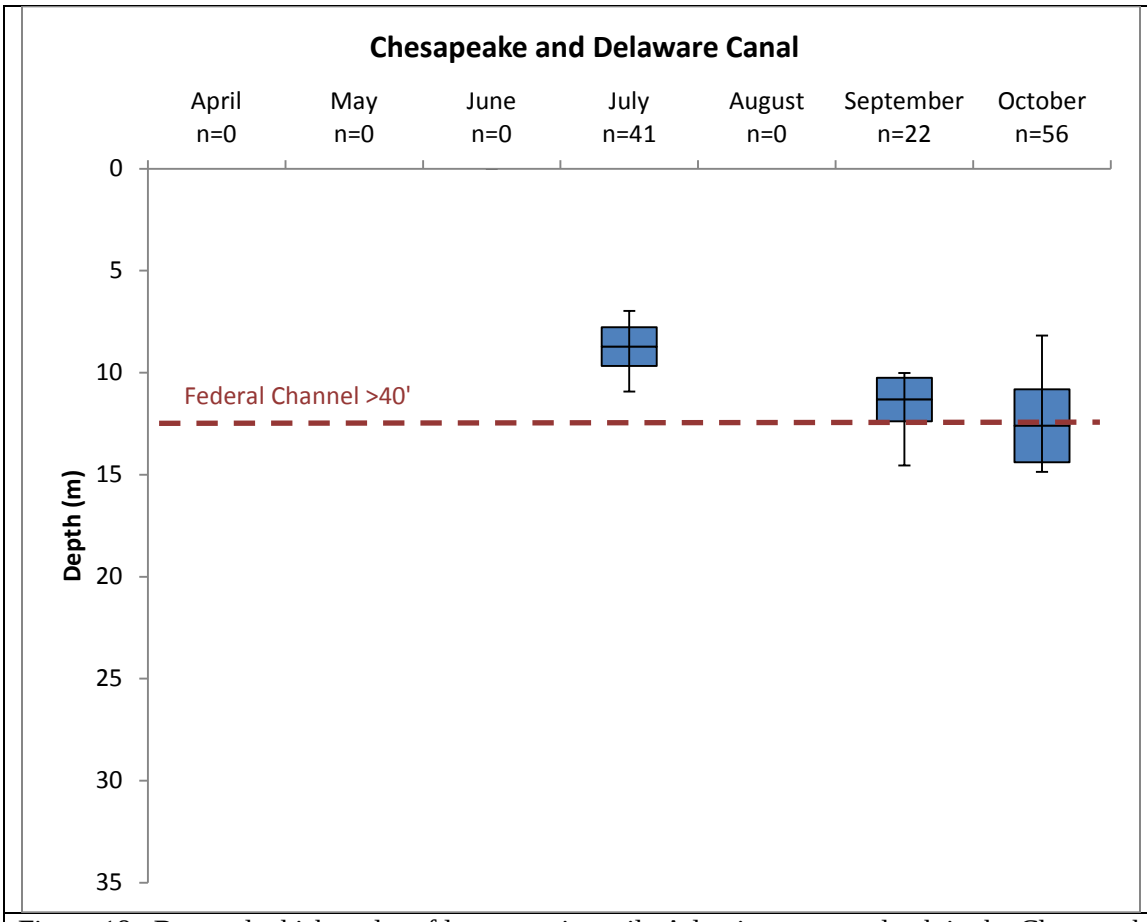


Figure 18. Box and whisker plot of late stage juvenile Atlantic sturgeon depth in the Chesapeake and Delaware Canal, 2008 by month. The Chesapeake and Delaware Canal connects the Bays and is maintained at a depth of 40 feet. Box represents the depth of the 25th through 75th quartile of detections. Horizontal line within the box represents the average depth. Whiskers represent the minimum and maximum depth. Available detection depth of receiver varies by receiver location.

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