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Dredging Operations Technical Support Program

Assessing Impacts of Navigation Dredging on Atlantic Sturgeon (*Acipenser oxyrinchus*)

Kevin Reine, Douglas Clarke, Matt Balzaik, Sarah O'Haire, Charles Dickerson, Charles Frederickson, Greg Garman, Christian Hager, Albert Spells, and Chris Turner

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Environmental Laboratory

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Final report

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Abstract

The outcome of encounters between Atlantic sturgeon (*Acipenser oxyrinchus*) and active dredging operations in Federal navigation channels is dependent on a number of factors. Risk factors include: avoidance of or attraction to the presence of an active dredge, the proportion of time spent in bottom waters of the navigation channel along with other behavioral aspects of the target species. To assess potential entrainment by a CSD operating in the James River, Virginia, five Atlantic sturgeon (TL = 77.5-100 cm), were implanted with both active and passive transmitters, released in the immediate vicinity of the dredge, and tracked continuously for several days. During tracking the dredge intermittently pumped sediment through a pipeline to an open-water placement site. Movements were monitored using mobile vessel-based omni-directional hydrophones as well as data logging receivers placed at fixed up- and downstream locations. Data on lateral and vertical movements of individual sturgeon were examined in relation to river bathymetry, river discharge rate, dredge production rate, and vessel traffic. Continuous records of tag depths provided observations of the durations and frequencies of individual sturgeon excursions into channel basin waters. None of the tagged sturgeon showed evidence of avoidance behavior, remaining in close proximity to the dredge for as long as 21.5 hours before moving away. Likewise, no strong evidence of attraction was observed, as sturgeon moved within the channel past the operating dredge on several occasions. Movements tended to be influenced by tidal flows. Only one individual moved against the prevailing tidal flow. Three of five tagged sturgeon demonstrated similar diel movement patterns, spending approximately 95% of their time in the lower 1.5 m of the channel bottom. Two sturgeon showed a distinct pattern of moving into waters < 4 m deep at night, spending substantial time over nearby shoals.

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Preface

This study was a joint effort between the U. S. Army Engineer Research and Development Center (ERDC), HDR, Inc., Virginia Commonwealth University, the U.S. Army Engineer District: Norfolk, Bowhead Information Technology Services, James River Association, Virginia SeaGrant Program, and the U. S. Fish and Wildlife Service., under the Dredging and Operations and Environmental Research (DOER) and Dredging Operations Technical Support (DOTS) Programs.

Principal Investigator for this study was Kevin J. Reine of the Wetlands and Coastal Ecology Branch (W&CEB) of the Ecosystem Evaluation and Engineering Division, U.S. Army Engineer Research and Development Center, Environmental Laboratory. At the time of publication, Chris Noble was Acting Chief, CEERD-EE-W; Dr. Mark Farr was Chief, CEERD-EE-E; the Deputy Director of ERDC-Environmental Laboratory was Dr. Jack Davis (CEERD-EV-A), and the Director was Dr. Beth Fleming (CEERD-EV-Z).

Conduct of this study would have been impossible without the participation of multiple agencies and organizations with a common interest in protecting Atlantic sturgeon stocks in the James River and elsewhere. Numerous individuals representing the James River Atlantic Sturgeon Partnership, a cooperative assemblage of academicians, state and Federal agencies, and non-governmental organizations contributed greatly to completion of this study, and the authors wish to express their gratitude to all.

COL Jeffrey R. Eckstein was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
inches	0.0254	meters
knots	0.5144444	meters per second
miles (nautical)	1,852	meters
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
yards	0.9144	meters

Acronyms and Abbreviations

CFS	Cubic Feet per Second
Cm	Centimeters
CPUE	Catch per Unit Effort
CSD	Cutterhead Suction Dredge
ESA	Endangered Species Act
ft	Feet
Fish/yd^3	Fisher per Cubic Yard
FRGP	Fisheries Resource Grant Program
Hrs	Hours
In	Inches
yds^3	Cubic Yards
yds^3/hr	Cubic Yards per Hour
m	Meters
m^3	Cubic Meters
m^3/hr	Cubic Meters per Hour
mm	Millimeters
m/sec	Meters per Second
NMFS	National Marine Fisheries Service
RM	River Mile
SRT	Status Review Team
TL	Total Length

1 Introduction

Both capital (new work) and maintenance dredging and dredged material placement operations occur worldwide in coastal, estuarine, and inland waterways. Capital dredging includes the initial construction of Federal navigation channels or their deepening to accommodate shallow and deep-draft vessel traffic. Maintenance dredging is a reoccurring activity to maintain a minimum navigable depth requirement by removal of shoals or accumulations of sediments. The extent and frequency of maintenance dredging of Federal navigation channels varies considerably between locations or within individual reaches of the same system. During dredging, sediments are transferred either hydraulically or mechanically to upland or in-water placement sites. In general unconfined open-water placement represents the most economical and practicable placement option. For decades dredging projects have worked within environmental windows employed by state and Federal resource agencies as a precaution to avoid potential negative environmental impacts. Additional environmental windows have emerged as new regulatory actions have taken affect. The majority of Federal dredging projects are now subject to temporal restrictions, which contribute to higher dredging costs per unit volume of sediment dredged and potential restrictions to navigation and impacts to commerce during restricted periods. Attaining a balance between cost-effective dredging, maintaining safe unrestricted navigation, and adequate environmental protection has posed many challenges.

Management practices such as environmental windows are generally implemented to reduce risk to a given resource. The risks to a given resource can be difficult to quantify. The absence of definitive knowledge of categories and magnitude of impacts associated with dredging and dredged material placement operations can lead to conservative or precautionary management practices. Direct knowledge of the interactions between selected environmental resources and dredging operations allows for objective risk assessment and better informed management practices (LaSalle et al. 1991). The difficulties inherent in making informed management decisions are exacerbated when the resource of concern is given special protected status. Current costs for compliance with the Endangered Species Act (ESA) for Federal navigation projects exceed $217 million dollars annually. The NMFS issued a final determination to list the

Carolina and South Atlantic distinct population segments of Atlantic sturgeon as endangered under the Endangered Species Act (ESA) of 1973, as amended (Federal Register Vol. 77, No. 24, 6 February 2012). Listing will heightened attention and will mandate protective measures of this species. Knowledge gaps pertaining to Atlantic sturgeon identified by the Atlantic States Marine Fisheries Commission include: identifying and mapping spawning locations; identifying wintering habitat of sub-adults; habitat usage during non-spawning seasons; determining methods to quantify population abundance and habitat requirements; and potential negative impacts associated with dredging and dredged material placement operations. Detailed reviews on the status, life history, and ecology of Atlantic sturgeon can be found in Smith (1985), Smith and Clungston (1997), Waldman and Wirgin (1998), Dadswell (2006) and the Atlantic Sturgeon Status Review Team (2007). The present study was undertaken to address a knowledge gap pertaining to dredging operations as typically conducted in the Federal navigation channel in the middle portion of the James River, Virginia.

In the James River, adult Atlantic sturgeon migrate upstream to spawning habitats in spring through early summer. Juveniles may remain in fresh or brackish waters for periods of one to six years before migrating to the coast and offshore onto the continental shelf where they grow to maturity. Since juveniles are known to congregate at fresh and saltwater interfaces, these areas may serve as juvenile nursery habitat. Deep-water habitats or "sturgeon holes" are known to exist in the James River. McCord (2003) reported that Atlantic sturgeon overwintered in deep channels and holes within coastal sounds and bays. Atlantic sturgeon are known to be opportunistic benthivores, feeding primarily on mollusks, polychaete worms, amphipods, isopods, shrimps and small bottom-dwelling fishes and insect larvae (Smith 1985, Dadswell 2006). Shallow water shoals located adjacent to both sides of the Federal navigation channel, provide a well diverse benthic assemblage that provides excellent foraging habitat in the James River. The use of natural and dredged navigation channels as migratory pathways is well known. Given that Atlantic sturgeon occupy navigable waters for a significant portion of their life history, interactions between dredges and sturgeon requires further study.

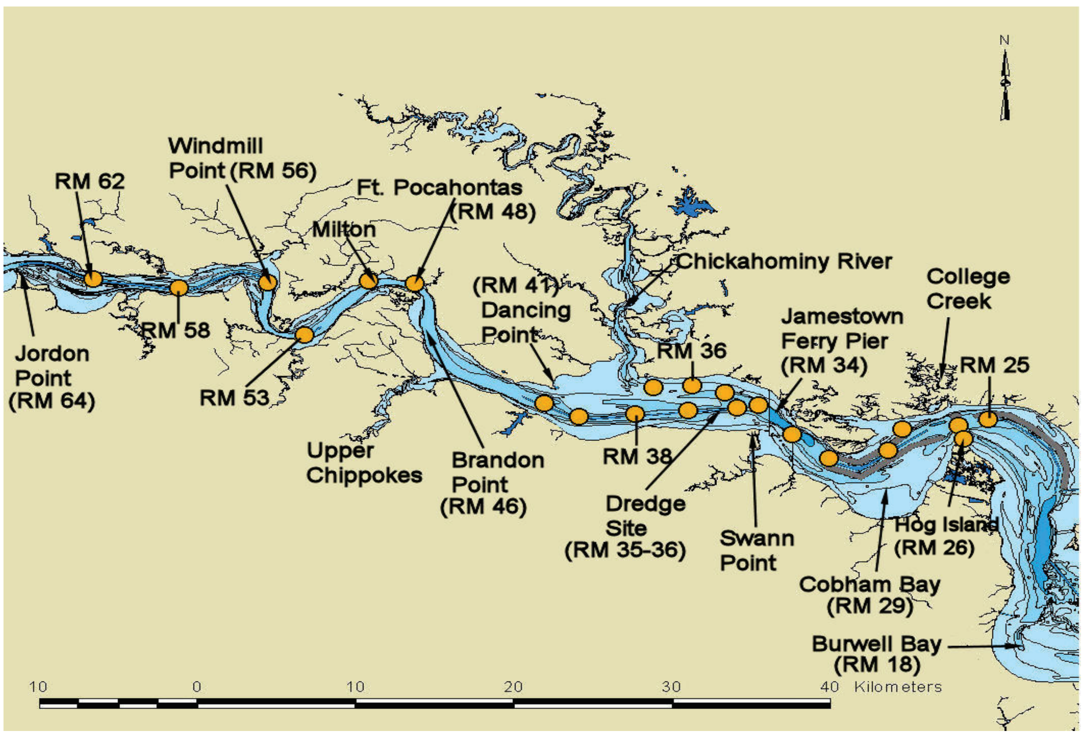
An extensive review of the scientific literature yielded few studies that examined direct or indirect impacts of dredging on Atlantic sturgeon. Hypothetical dredging impacts on sturgeon include: hydraulic and mechanical entrainment; physical disturbance of spawning behavior; destruction or modification of spawning habitat; sedimentation or turbidity related issues; disruption of pre-reproductive migratory behavior; avoidance or attraction to either the physical presence of the dredge plant or the open-water placement site; underwater noise/disturbance issues; alterations to hydrodynamic regime; and disturbance of benthic macro-invertebrates that may represent sturgeon food resources. A review of entrainment by hydraulic dredges can be found in Reine and Clarke (1998), in which the authors summarized documented entrainment rates for fishes, shellfishes and specific threatened and endangered species. To minimize potential impacts on fish species during dredging and dredged material placement, most Atlantic states impose restrictions during time periods thought to coincide with spawning or migration. In the middle reaches of the James River, dredging is restricted from 15 February to 30 June to protect anadromous fishes, although the primary focus of this restriction has been to protect American shad (*Alosa sapidissima*). The current study was conducted with the approval from the various regulatory agencies, which provided an exemption to the time-of-year (TOY) timeframe restriction normally imposed on dredging and dredged material placement activities.

2 Methods

Study Area

The study site was located near River Mile 36 of the James River, Virginia (Figure 1). This reach runs between Dancing Point (upstream) and Swann Point (downstream) and is bisected by the confluence of the Chickahominy River, as can be found on NOAA Chart 12251 at 37°13'26" N and 75°50'03" W.

Figure 1. Study Site. Filled circles indicate locations of passive telemetry receivers. Note: Not all passive receivers are depicted in the above graph. Additional receivers were deployed upstream terminating near the Port of Richmond, VA.



Dredge Plant Characteristics

The dredge *Lexington (*Figure 2*)* is owned and operated by Cottrell Contracting Corporation. The plant is typical of many used in riverine environments. The *Lexington* is a medium capacity cutterhead dredge, 200 feet (60.6 m) in length, 38 feet (11.5 m) in width with a draft of 5.2 ft (1.6 m) weighting 800 gross tons. The dredge is equipped with a 20 in (50.8 cm) pipeline and 1.4 m diameter cutterhead. In practice, the rotating cutterhead agitates the *in situ* sediments, creating a sediment/water slurry that is picked up through a suction pipe and transferred by means of a centrifugal pump to a designated placement site. The typical cutterhead swings in an arc from side to side as the dredge is stepped forward on pivoting spuds at the stern of the dredge. This process is relatively continuous, and production rates are generally high.

Figure 2. The hydraulic cutterhead dredge *Lexington* operating in the James River, Virginia.

Telemetry systems used to collect data on Atlantic sturgeon movements and occupied depths over time were obtained from Vemco, Halifax, Nova Scotia, Canada. Active tracking methodologies were used to record fine-scaled vertical and horizontal movements after sturgeon were released in close proximity to an operating dredge for evidence of attraction or avoidance responses. Data were also collected on diel movement patterns and the influence of tidal phases on movements. A Vemco VR-100 receiver was used with a combination of VH110 directional and VH165 omni-directional hydrophones to detect and record location and depth of each tagged fish from a surface support vessel. Active tracking occurred continuously from the time of sturgeon release until loss of signal for an extended period.

Records of course movements were obtained from a subset of 40 autonomous Vemco VR2W single channel receivers with Bluetooth® wireless capabilities deployed in forty stations year round, covering most of the James River and a portion of the Chickahominy River from a “gate” at Hog Island to Richmond, VA. Receivers were suspended approximately 3 m below the water surface with hydrophones oriented downward in water depths of approximately 8-11 m. The only exceptions were two VR2W deployments upriver where prevailing water depths were much shallower. Water depth for these two receivers varied from 1 m at low tide to 2 m during high water. Receivers were attached by stainless steel cables to buoys along the navigation channel or at upriver locations to day markers. Range tests revealed that transmitters could be detected consistently at distances of 750 m and as far as 1,000 m during periods of calm weather. A minimum detection range of 250 m was determined in very shallow water or during high hydrodynamic noise events associated with storms.

Two types of individually coded acoustic transmitters that operated at 69 kHz were used. The Vemco V13P-1L (36 mm x 13 mm, 6 grams in water) recorded both fish identification and depth with a pulse rate of 1 to 2 seconds and a tag life of 24 to 38 days. The V13P-1L was used for active tracking since it transmits data (depth and fish ID) on a short-duration time scale, which is typically used to determine fine-scale movement patterns. The VEMCO V16-4L (98 mm x 16 mm, 16 grams in water) is a passive coded acoustic tag that also records fish identification and depth with a signal rate of 30 to 90 seconds and a tag life of 4.5 years. The V16-4L tag is detected by the passive acoustic array and used to monitor long-range movement patterns over the course of multiple years.

Four Atlantic sturgeon (Fish #1, 2, 3, and 5) were tagged with both active and passive transmitters, and one additional Atlantic sturgeon (Fish #4) received only an active tag. All five sturgeon were released between 6 and 17 February, 2009 (Table 1). Fish ranged in length from 65.0 cm to 85.5 cm FL (TL = 77.5 to 100.0 cm). Gonad samples were not taken for histological examination to ascertain the gender of these five fish; however, none of the fish appeared to be reproductively mature at the time of capture. Given their size, it is unlikely that any of these fish had reached maturity and therefore were considered to be juveniles. Sturgeon were collected using 1,200 feet of six inch monofilament gill net through a cooperative by-catch research project with watermen funded by a Sea Grant Fisheries Resource Grant Program (FRGP). Nets were deployed in Burwell Bay, located downriver and south of Hog Island at River Mile 18. Nets were not deployed overnight to minimize injury or death to netted fish, but during early morning hours with soak times ranging from 4 to 6 hours. Fish that appeared to be in good physical condition were held in an onboard tank with river water. Selected juveniles ranging from 3 to 6 years old were surgically implanted with both passive and active transmitters whose total weight did not surpass 2% of the selected fish's body weight. Fish were measured (both total and fork length) to the nearest 1 mm and weighed to the nearest 0.5 kg. During tagging, fish were placed ventral side up and an incision approximately 4 cm long was made with a surgical scalpel along the mid-ventral line about 5 to 7 cm anterior to the insertion of the pelvic fins, and the transmitter was inserted into the abdominal cavity, as described by Fox et al. (2000). The primary incision was closed using sterile resorbitive suture material with four to five simple interrupted stitches. An iodine disinfectant was applied to the closed incision to prevent infection. Additionally, each sturgeon was tagged with a pit tag and a T-Bar tag in the pectoral fin. All tagged sturgeon were released near the dredging operation immediately after surgery and within several hours of capture.

Table 1. Fish length and tagging information.

Fish #	FL (cm)	TL (cm)	Active Tag (kHz)	Passive Tag (kHz)	Active and Passive Tracking Acoustic Detections	Date Tagged (2009)	T-Tag	Pit Tag
1	80.7	93.2	60	109	33,804	6 Feb	44847	98512112638643
2	83.0	93.0	81	178	108,345	9 Feb	44846	985121012616847
3	85.5	100.0	75	177	39,548	11 Feb	44813	470370184B
4	65.0	77.5	63	N/A	126,782	13 Feb	44819	985121011606608
5	84.5	97.3	78	173	56,703	17 Feb	44818	985121014365355

Data Analysis

Rates of movement (m/s) for individual fish were calculated from subsets of data where clear linear directional movement was evident and the tracking vessel was able to maintain a good position fix on the fish. For swimming speeds obtained from active tracking files, consecutive positions of zero gain and high signal strength were no more than 5 minutes apart. For passive data sets, swimming speeds were calculated from the time required to move between receiver locations.

Comparisons were made of average fish depth during day and night periods, and during ebbing and flooding tidal stages. Daylight was defined as the period of time between official sunrise and sunset. Nighttime was defined as the time between official sunset and sunrise. Time-referenced depth data from both active and passive tracking were integrated to create a more complete composite record of fish depth over time.

3 Results

The number of acoustic detections per tagged fish varied considerably as a result of differences in patterns of individual fish movements and the duration of time spent within the reach of the river in which dredging operations were underway. Although the passive receiver array, consisting of twenty-two stations, extended from Hog Island (RM 25) to Jordan Point (RM 64), all dredging occurred near Station 4, located between River Miles 35 and 36. Therefore, fish that spent a greater part of time near or in the immediate vicinity of the dredge were the focus of dedicated active tracking efforts. As depicted in Figure 3, both Fish #1 and Fish #2 moved quickly upriver to Stations 7 through 9, located 12 to 28 miles from the dredging operation. In contrast, Fish #3 and Fish #4 (without a passive tag) spent substantial time moving back and forth between Stations 3 and 5, passing through the river segment being dredged. Fish #5 spent five days near the dredging operation before moving to upriver stations. A total of 139 hours were expended during active tracking of tagged sturgeon in the vicinity of the operating hydraulic cutterhead dredge. This effort varied from 13 hours tracking Fish # 1, which left the study area relatively quickly, to 45 hours for Fish #4.

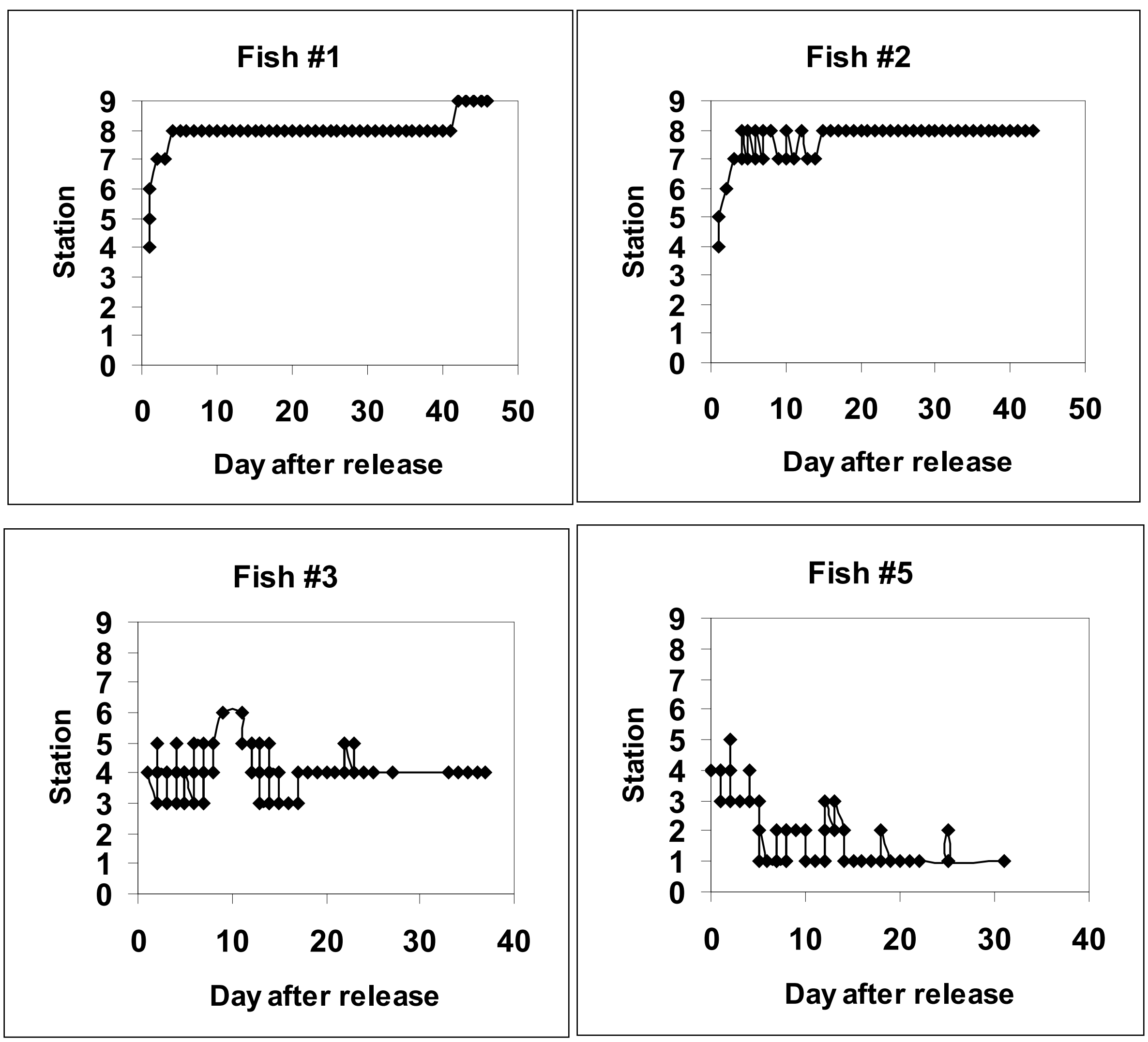
Movements during Hydraulic Dredging and Dredged Material Placement Operations

Fish #1

Tagged and released on 6 February, 30 meters upstream of the dredge's cutterhead, this sturgeon was actively tracked for 13 hours until just past midnight on 7 February. Time series depth profiles indicated occasional upward movement though the water column to just below or even breaching the surface, which occurred four times during nighttime hours. Distance from the dredging operation to the tagged fish ranged from 30 m upon release to a maximum of 150 m during the monitoring session. Fish #1 showed no evidence of avoidance behavior, either to the physical presence of the dredge as it advanced during sediment removal or in response to sounds or other potential stimuli generated by the dredge plant or tender vessels. On the following day (7 February), three hours into the flood tidal cycle, this sturgeon began moving upstream and by the end of the day had advanced upstream over 14 miles to River Mile 49, adjacent to Sturgeon

Point. Fish #1 remained at this location for 24 hours at a depth of 9 to 18 m (mean = 10 m). It then continued upstream, reaching Windmill Point (River Mile 56), a distance of 21 miles upstream beyond the initial release location, and remained there through 19 March at depths ranging from 6 to 10 m (mean = 8.2 m). At the end of the study (29 March), it was located just below Jordan Point (River Mile 64), a distance of almost 29 miles from the dredging operation. Passive receivers detected occasional movements back downstream for distances of less than one mile during ebbing tidal stages. Upstream movements generally coincide with flooding tides and usually occurred at mid-water depths.

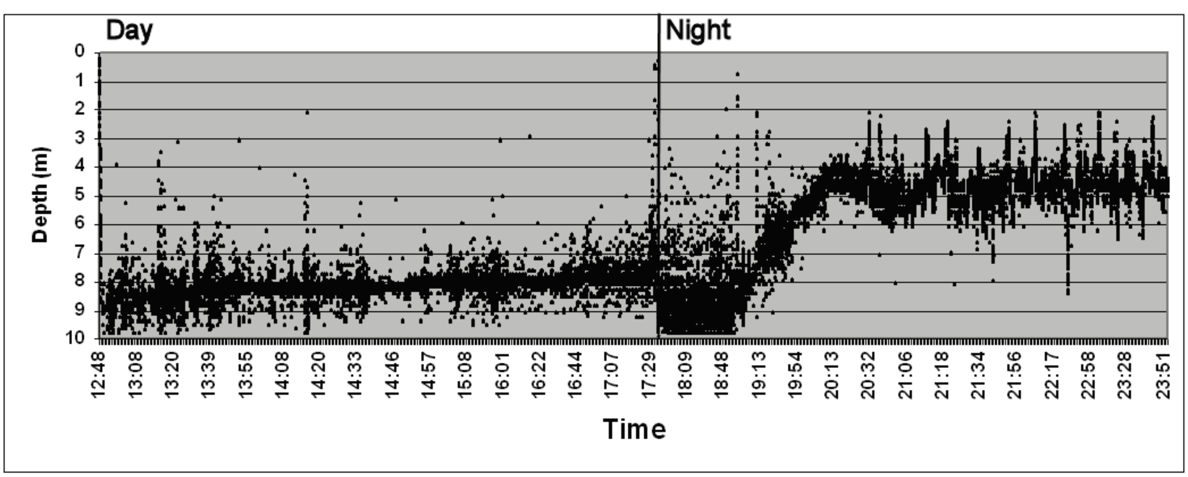
Figure 3. Sturgeon detection by location (station #) and number of days post-tagging and release by the passive acoustic array. Stations are numbered consecutively denoting increasing upstream distance in the main channel. Station 1 = Kings Mill/Hog Island; Station 2 = Cobham Bay; Station 3 = Jamestown Ferry Terminal; Station 4 = Swann Point/Dredge Site; Station 5 = Chickahominy; Station 6 = Sandy/Dancing Point; Station 7 = Milton/Ft. Pocahontas; Station 8 = Windmill Point; Station 9 = Jordon Point.



Fish #2

Fish #2 was tagged on 9 February and released 60 m directly in front of the dredge. It remained at this location for 6.5 hours during daylight and early evening hours. Depth series profiles indicated that Fish #2 spent the majority of time near the channel bottom (8 m) during the ebb portion of the tidal cycle, with only occasional and brief upward movements to mid-water depths (3-4 m), and only a single surface breach (Figure 4). At 1900 hours, an outbound deep-draft vessel passed the location of the dredge very near or directly over the tagged sturgeon's location. Within two minutes of the ship's passage, Fish #2 moved upward in the water column to the surface, and then returned to the channel bottom. Approximately 10 minutes later, this upward and downward movement was repeated. This activity coincided with low tide. Fish #2 came to mid-water depth (4.5 m) and proceeded upstream at the start of the nighttime flooding tidal cycle. This sturgeon moved past the dredge on the opposite side of the navigation channel to a position located on the northern shoal near the Chickahominy River, 1-mile upstream from the dredge. Active tracking resumed at 0730 hrs on 10 February 2009. During the interim period, passive receivers detected upstream movement against the ebbing current, and by early morning (0545 hrs) Fish #2 had reach River Mile 41, between Dancing and Sandy Points, nearly 6 miles upstream from the dredging operation. Over the next two tidal phases both upriver (1-mile) and downriver (2-miles) movements occurred at a consistent depth of approximately 5 m. This sturgeon remained within the navigation channel until moving onto the adjacent shoals at Dancing Point (River Mile 41), returning to the northern shoal at a location very near the site it occupied the previous day. It was

Figure 4. Time series profile of depth on 9 February 2009 for Fish #2. Note: Time is U.S. Eastern Standard Time. Mean low water = 1916 hrs.



detected at depths of 2 to 3 m in an area where water depths ranged from 3.5 to 4.8 meters. Active tracking concluded on 11 February near the Upper Chippokes (River Mile 44), nearly 8 miles upstream from the dredging operation. Although time series profiles of depth during active monitoring sessions indicated that the sturgeon maintained a fairly consistent depth (mean = 5.8 m), brief periods were spent at the surface as well as near the channel bottom. During the monitoring period, no evidence was seen of this fish moving toward or through the authorized (i.e., permitted) open-water placement area.

For the duration of the study, passive receivers monitored this fish for movement back downriver towards the dredging and dredged material placement site. During the period of 13-17 February, passive receivers detected Fish #2 within a 6-mile portion of the river extending from Fort Pocahontas (River Mile 48) to a receiver moored 3-miles downriver of Windmill Point, at distances of 12 to 18 miles upriver from the dredging operation. Within this segment up- and downriver movements were coincident with river flow. Depth sensors indicated that this sturgeon almost exclusively used the upper water column (range = 0 to 6 m) during this time period. From 18 to 26 February, Fish #2 was found primarily between Milton (River Mile 50) and a receiver moored 3 miles further upriver; although, now occupying the lower half of the water column (range 6 to 12 m). From 26 February through 22 March, substantially fewer signals were detected and logged by passive receivers for this fish. Logged signals did however intermittently identify this sturgeon in the same general area (River Miles 50 to 53). No detections were logged during four segments of time, the longest occurring from 13 to 21 March.

Fish #3

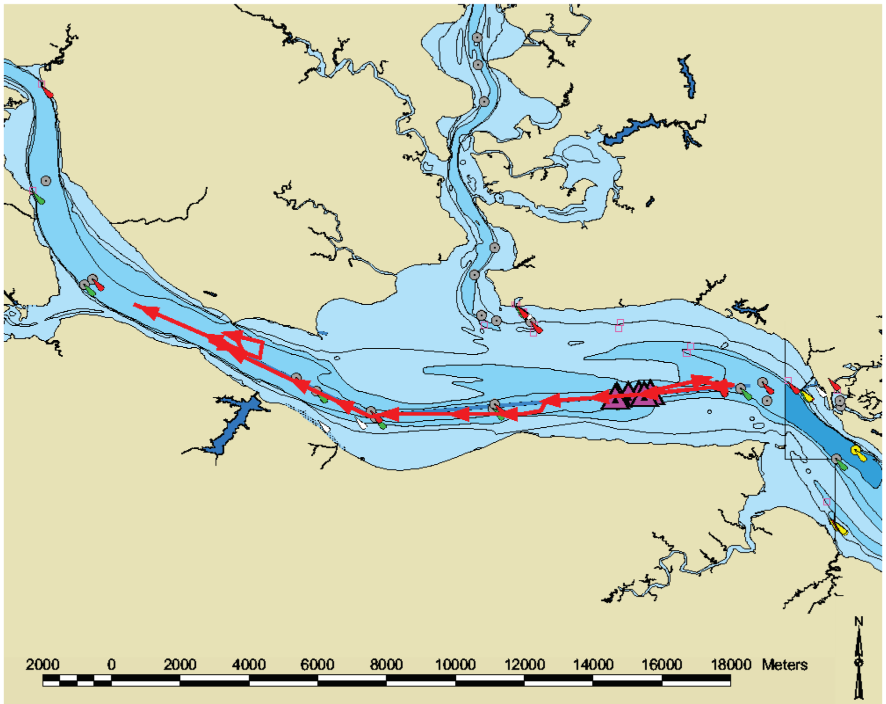
Fish #3 was tagged on 11 February and released 100 m astern of the dredge to assess if sounds generated by material moving through the pipeline and produced by the dredge tenders working in this area would have any observable effect on behavior. During 17 hours of continuous active monitoring, this fish remained essentially stationary at its release location (River Mile 36) on or near the channel bottom. Due to inclement weather on 12 February, tracking was limited to passive receivers only. The following morning (12 February, 0700 hrs), passive receivers detected this sturgeon moving within the Federal navigation channel in a downriver direction during the latter half of the ebbing tidal phase for a total distance of about two miles. It remained down-river throughout the flooding tidal phase and into the first part of the following ebb phase at depths ranging from 6 to 8.5 m, until moving once again an additional mile downriver to a location near the Jamestown Ferry Pier. It remained at this location until midnight (2400 hrs, 12 February) at a depth between 5.5 and 6 m before moving approximately 5 miles back upriver. Upriver movement coincided with the flooding tide and occurred in the Federal navigation channel until Fish #3 was within 2,700 m of the dredge *Lexington*. It then exited the channel onto the northern shoal. Time series profiles of depth indicated that the fish was near the river bottom in 4-m of water. This sturgeon then moved in the general direction of the dredge, reentering the navigation channel just downriver from the dredge plant and moved past the dredge to a distance of 1.5 miles. During the following ebbing tidal phase (13 February), it moved back to the point where it had exited the channel, about 2,750 m downriver from the dredge where it was reacquired by the active tracking crew during the early morning hours (0800 hrs) just outside of the channel. It was tracked downriver at a depth of 5.9 m (range = 4 to 9 m) with the ebbing current, three miles from the dredge. The sturgeon reached the monitoring station located at the Scotland Ferry Pier by slack tide, approximately at the same location it occupied 12 hours previously. Within 15 minutes, it began moving back upstream, repeating the pattern of the previous day. By mid-day, it was again located over the northern shoal at depths between 2 and 3 m, just north of the dredging operation.

This sturgeon exhibited a repetitive movement pattern in which it completed several complete down- and up-river and in and out of channel movements over several days and tidal cycles, perhaps indicative of a consistent forging pattern. From 14 to 18 February this pattern was repeated. On 19 February, Fish #3 arrived back over the northern shoal near the mouth of the Chickahominy River by midnight and remained there for nearly 24 hours. There was change in movement pattern on 20 February when Fish #3 moved off the northern shoal with the flooding tide and progressed four miles upriver from the dredge. Because it was not detected at the Fort Pocahontas monitoring station, the sturgeon likely went no further than Brandon Point at River Mile 46. The area between Fort Pocahontas and Dancing Point had no passive receivers. The sturgeon remained at this location through 21 February. From 22 to 28 February, Fish #3 returned to its repetitive down- and up-river movement pattern, swimming between the northern shoal near the Chickahominy River downriver to the Scotland Ferry Pier at River Mile 33. On 1 March, Fish #3 returned to the northern shoal and remained there until the end of the study. As revealed by detections at three passive receivers over the flats, this sturgeon occupied a 2-mile reach and continued a circular movement pattern, but at considerably smaller spatial scale. Given its up- and downstream movement pattern, there was no evidence of impediment to fish movement by the dredging operation.

Fish #4

Similar to Fish #3, Fish #4 was tagged on 13 February and released (1030 hrs) 100 m directly astern of the dredge, which was removing material in the upstream direction. At the end of active tracking on the first day the sturgeon was positioned 70 m astern of the dredge. By the following morning the distance between dredge and fish had increased to 300 m, which appeared to be due entirely to advancement by the dredge rather than swimming movements. Through several tidal cycles during 21.5 hours of monitoring, discernable fish movements were few. This sturgeon remained in the navigation channel at an average depth of 8.5 m. During the daytime ebbing tidal phase on 14 February, the fish moved away from the dredge with the outgoing tide to a point 2,100 m downstream near River Mile 34. Time series profiles of depth indicated that the sturgeon used a mid-water depth (4m) during movement, while GPS mapping of active tracking data indicated usage of the navigation channel as the movement corridor (Figure 5). At the start of the flooding tide, Fish #4 briefly surfaced before moving back upstream. During the late phase of the flooding tide it moved within the navigation channel parallel to the dredge to position 2,500 m upstream from the dredging and dredged material placement operation. Then it retreated 2,000 m back downstream on the ebbing tide. Fish depth during these movements ranged from 5 to 6 m, but occasionally became as shallow as 3 m. By the end of the tracking day (2400 hrs), the fish was located 500 m upstream from the dredge near the channel bottom (8 m) with no clear directional movement. It was reacquired the following morning 4-miles upstream from the dredging operation. Between 15 and 19 February, it occupied a 1-mile reach from River Mile 40 to 41, located between Sandy and Dancing Points, at an average depth of 9 m. This fish was not tagged with a passive transmitter; therefore no additional location data are available beyond this date.

Figure 5. Active tracking results from 13 to 19 February 2009 for Fish #3. Dredge location for the monitoring period indicated by triangles.



Fish #5

Fish #5 was tagged on 17 February and released (1530 hrs) during a flooding tide at River Mile 36.5 at a point directly astride the middle of the dredge. This sturgeon remained at its release location near the bottom (8 m) for 3.5 hours, the shortest duration of remaining stationary following release for tagged fish in this study. The dredge was inactive at the time of fish release, but resumed removing sediment by 1600 hrs. Within twenty minutes, Fish #5 had surfaced and then immediately descended back to channel depth. By 1700 hrs, the dredge had advanced past the release location. The fish breached the surface for a second time ten minutes later, but again returned to channel depth, where it remained for the duration of the flooding tidal cycle. Shortly after the start of the ebbing tide, this sturgeon made several up and down excursions through the water column to mid- and upper water depths, breaching the surface once again. This activity occurred at the point of release, which by now was 45 m astern of the advancing dredge. At 2130 hrs, Fish #5 was now located 90 m astern of the dredge and began moving downriver with the ebbing currents. It passed the dredge at a distance of less than 50 m within the Federal navigation channel in the upper water column at depth averaging 3.1 m. Once beyond the dredge plant, the sturgeon crossed in front of the dredge and moved out of the Federal navigation channel and onto the southern shoal, traveling a distance of 4,700 m before reentering the channel near the Jamestown Island Ferry Terminal (River Mile 34). By midnight, when active tracking ended, the sturgeon had become stationary at slack tide, nearly 3 miles from the dredging operation near bottom in 12 m of water. Until active tracking resumed Fish #5 was monitored by passive receivers, which recorded its upstream movement with the flood currents to a distance of 1 mile, occupying an area over the northern shoal just east of the dredging operation. The fish was reacquired the following day (1330 hrs) in the navigation channel, 1,500 m downriver from the dredging operation between River Miles 35 and 36. No clear directional movement occurred over the next five hours as the fish remained within a 600 m wide area. Four hours past low tide, the fish began moving upstream with the flooding currents. It moved past the dredging operation, just outside of the navigation channel proper, but in the deeper water of the natural channel thalweg. After passing the dredge, it moved back into the navigation channel to a point 1,000 m (near River Mile 37) on the upstream side of the dredging operation at a depth of 7 m.

Passive monitoring over the four day period from 19 to 22 February indicated a tidally-driven movement pattern; that is, the sturgeon oriented and moved in the direction of current flow. This repetitive pattern occurred between River Mile 34, near the Jamestown Ferry Terminal, to a point 9 miles downriver in the vicinity of Hog Island. This pattern was repeated on a much smaller scale over the five day period from 23 to 28 February. During this time up- and downriver movements were confined to within approximately one mile of the monitoring station at Hog Island (River Mile 26). Fish depth ranged from 1 to 6 m. During the first two days of March, Fish #5 moved back upriver as far as the monitoring station located at the Scotland Ferry Terminal. From 3 March to the end of the study, passive monitors detected this sturgeon back downriver in the vicinity of Hog Island, generally at depths of less than 6 m. There were several days (5, 12, and 15 March) when no detections were recorded, indicating the fish had moved further downstream towards Burwell Bay and out of the lower detection range of the Hog Island array gate.

Temporal Patterns of Occupation of Navigation Channel and Shoal Habitats

Patterns of time spent by individual sturgeon in the comparatively deeper water (> 6 m) of the navigation channel and natural river basin versus in the shallower adjacent shoals (< 5.5 m) is one factor that can be used to assess the relative risk of entrainment by hydraulic cutterhead dredging operations. Because active pumping is generally restricted while the cutterhead is in contact with the substrate or just above the substrate (such as when the pipeline is being flushed), the risk of entrainment is essentially zero when the sturgeon is above the deeper strata. Therefore a conservative "zone of potential entrainment" in the James River Federal navigation channel might be defined as that volume of the water column below 6 m. Time budgets were developed for each tagged sturgeon to determine the proportion of time spent within selected strata in the water column. Sturgeon whose depths exceeded 6 m, or 1.5 m off the navigation channel (maintained at 7.6 m) bottom were considered to be in the "potential entrainment zone" where an encounter with the cutterhead would be possible. During daytime hours, three (Fish #1, #4, and #5) of the five tagged sturgeon were found at water depths > 6 m approximately 95% of the total time monitored. Approximately 5% of the time was spent in mid-water strata (4 to 5 m) during episodes of active swimming. The remaining two tagged sturgeon (Fish #2 and #3) spent one-third to one-half of their time budget at depths less than 6 m. Position mapping indicated that these two sturgeon spent considerable durations of time in shoal habitat outside of the channel.

Two sturgeon tended to occupy the upper portion of the water column during nighttime hours. Tracking of Fish #2 revealed that this sturgeon spent 34 percent of the time in water 2-4 m deep and 46.7%of the time in water 4-6 m deep. On two consecutive days, these depths were occupied during a flooding tide during an upstream movement. Time spent at depths less than 2 m accounted for only 2.6%of the total time monitored, limited to occasional excursions near the surface or breaches of short duration. Time spent in the entrainment zone by Fish #2 equated to less than 17%of the total time. Fish #5 spent nearly half (48.7%) of its time in the upper portion of the water column. Almost all of this time spanned a downstream movement across the southern shoal. Although the remaining portion of time (51.3%) was spent within the zone of potential entrainment, this sturgeon did not venture near the dredging operation, remaining near the Jamestown Ferry Pier in 8-10 m of waters. The other three tagged sturgeon (Fish #1, #3, and #4) spent well over 90%of the time at depths greater than 6 m, the majority of which occurred within the navigation channel.

Swimming Speed

Estimates of average swimming speed (m/sec), measured as the rate of movement over ground, were calculated for five subsets of tracking data during which clearly defined directional movements were evident (Table 2). Four estimates were obtained for two sturgeon (Fishes 1 and 2) during upstream movements with the river flow, whereas one measurement was obtained for Fish #5, moving downstream with ebbing currents. Linear distances traveled ranged from 2,000 to 7,200 m, for durations ranging from one to five hours. Average swimming speeds ranged from 0.31 to 0.60 m/sec.

Table 2. Average swimming speeds and rate of movement over ground for five subsets of Atlantic sturgeon tracking data.

Fish #	Data	Start Time / Location	Stop Time / Location	Distance (m)	Time (sec)	Swim Speed (m/sec)	Current	Predicted Flow (m/sec)
1	Passive	05:30 R62	10:30 R66	7,200	18,000	0.40	Flood	0.8 to 0.6
2	Active	21:15 R60	23:05 R62	2,700	6,600	0.41	Flood	0.4 to 0.8
2	Active	10:45 R60	23:05 R62	2,000	3,600	0.56	Flood	0.8 to 0.9
2	Active	09:20 G67	11:45 G68	4,500	14,400	0.31	Flood	0.3 to 0.7
5	Active	21:30 R60	23:30 G55	4,400	7,200	0.60	Ebb	0.2 to 0.4

Dredge Production Rates

Based on estimates from the dredge manufacturer, the average production rates for this type and size of dredge plant is 600 to 800 yd^3 (459 to 612 m^3) of sediment per hour. The actual solids content of the slurry varies however depending on sediment properties and the manner in which the cutterhead is operated. The actual solids content typically ranges from 10 to 20 percent by volume. The dredge *Lexington* began production on 30 January 2009 and concluded dredging activities on 19 February 2009. Based upon daily dredging logs the dredge removed 166,545 yds^3 (127,332 m^3) of sediment, which were pumped to a nearby permitted open-water placement site. On average 7,930 yds^3 (6,063 m^3) (range = 1,387 to 12,672 yds^3/hour or 1,064 to 9,688 m^3/hour) of sediment were removed per day. Active pumping generally involved 20 hours of each day, with intermittent stoppages for maintenance, crew changes, dredge maneuvering, and other reasons. Actual production rates therefore ranged from 213.4 to 592.1 yds^3/hour (mean = 398.8 yds^3hr) or 162.9 to 452.6 m^3/hour (mean = 304.2 m^3/hr). Thus during the course of the project, the dredge was actively removing sediment nearly 92 percent of the total time. Based on the total cubic yards removed during the course of the dredging operation, the estimated volume of water entrained during the course of the dredging is 666,180 yd^3 (509,300 m^3). Thus the intake of water in the sediment slurry actually occurred over a span of approximately 504 hours given actual production rates of 400 yds^3 per hour, peaking at slightly less than 600 yds^3 (458.7 m^3) per hour. Assuming a constant maximum production rate, the dredge would entrain 2,446 m^3 (3,199 yds^3/hr) of water per hour, or 0.68 m^3 (0.9 yds^3/sec) per second. Under actual operating conditions, the effective production rate would be significantly lower. Based on an average production rate of 400 m^3 (523.2 yds^3/hr) the dredge would realistically entrain 1,224 m^3 (1,601 yds^3/hr) of water per hour, or 0.34 m^3 (0.44 yds^3/sec) per second.

4 Discussion

The Entrainment Issue

Entrainment of aquatic organisms can occur when flow fields created near the suction intakes of hydraulic dredges exceed the capabilities of fishes and other aquatic species to escape. Early entrainment studies involved juvenile salmon in the lower Fraser River, British Columbia, Canada, a major source of recruitment to pacific salmon populations (Braun 1974, Dutta and Sookachoff 1975, Tutty 1976). While Braun (1974) found no evidence of fish entrainment by hydraulic cutterhead pipeline dredges, Dutta and Sookachoff (1975) concluded that fry and smolts were exposed to entrainment by hydraulic dredges, especially when salmon occupied the entire water column in narrow, constricted channels. Arsenault (1981) estimated that 0.4 percent of the out-migration of salmon fry and smolts were entrained by hydraulic dredges.

Armstrong et al. (1982) reported entrainment rates for 15 species of sport and commercial fishes, ranging from 0.001 to 0.135 fish/yd^3 of dredged sediment removed during both hydraulic hopper dredging and pipeline dredging operations. Larson and Moehl (1990) studied fish entrainment during a 4-year study at the mouth of the Columbia River, Oregon. Entrainment rates of 14 species or taxonomic groups of largely demersal fishes ranged from 0.001 to 0.341 fish/yd^3 of sediment removed. However, a few pelagic species were collected, including both anchovies and herring. McGraw and Armstrong (1990) collected entrainment rate data for 28 species over a 10 year period, and reported that most species had relatively low entrainment rates (~0.001 fish/yd^3).

Buell (1992), in a study conducted on the Columbia River, Near Portland, Oregon, reported that a substantial number of juvenile sturgeon (300-500 mm TL) were entrained by a cutterhead dredge from one location known as the local “sturgeon hole”, supposedly when pumps remained on while the cutterhead was off the bottom. Veschev (1981) concluded that larval stages of sturgeon were less capable of escaping flow fields and therefore more susceptible to hydraulic entrainment. Sturgeon entrainment or “takes” from dredging activities with observer programs are summarized in the U. S. Army Corps of Engineers Sea Turtle Data Warehouse (2013). From 1995 through January 2013, a total of 42 sturgeon takes (3 Gulf sturgeon, 11 shortnose sturgeon, 34 Atlantic sturgeon) have been recorded. Of these 3 Atlantic and 2 shortnose sturgeon were released alive, the remainder were mortalities. Of the 34 observed Atlantic sturgeon mortalities, the majority were associated with hopper dredging (n=22) and mechanical clamshell dredging (n=3), operations; although takes by mechanical dredges are more appropriately classified as impingement rather than entrainment or “takes”. During this period a single Atlantic sturgeon was entrained by a hydraulic pipeline (i.e. cutterhead) dredge. Of the 11 shortnose sturgeon entrained, 5 each were taken by hopper and cutterhead dredge, while only 1 was entrained by a mechanical bucket dredge. All three Gulf sturgeon were entrained by hopper dredge. Two other takes in which the species was not reported was taken by hopper dredge. The Status Review Team (SRT) calculated a minimum take of 0.6 Atlantic sturgeon per year, based strictly on hopper dredging operations and an assumption that dredging efforts were relatively similar among years (Atlantic Sturgeon Status Review Team 2007).

USACE Districts with the most number of Atlantic sturgeon entrainment incidents were Savannah (n = 12), followed by Charleston, South Carolina., and Wilmington, North Carolina., with 5 each. Only two sturgeon have been entrained by dredging operations (York Spit Channel) conducted by the Norfolk District, Virginia to include 1 Atlantic sturgeon and 1 additional sturgeon whose species was not reported. Both sturgeon were taken by hopper dredge. To date no Atlantic sturgeon have been entrained by cutterhead pipeline dredging in the James River, Va. The New York District, New York, also reported two entrainment incidents: 1 Atlantic sturgeon and 1 whose species was not reported. All entrained shortnose sturgeon are attributed with two Corps Districts, Philadelphia, Pennsylvania (n = 6) and New England District, Massachusetts (n = 5). All three Gulf sturgeon were entrained by the USACE Mobile District, Alabama.

Hoover et al. (2011, 2005), Boysen and Hoover (2009) and Smith (2006) examined entrainment of paddlefish and juvenile lake (*Acipenser fulvescens*), pallid (*Scaphirhynchus albus*) and white (*Acipenser transmontanus)* sturgeon by dredges and developed a conceptual model for estimating risk based on swimming performance. They concluded that juvenile sturgeon were susceptible to entrainment by dredges, but risk varies among populations. The authors identified three separate and distinct swimming responses that cumulatively dictate entrainment risk at any given water velocity. They determined the degree of rheotaxis behavior (i.e., an individual fish's behavioral preference to orient with or against prevailing current flows) by species. Those incapable of orientation were called non-swimmers. Escape or burst speeds were measured, which indicated whether a fish was capable of resisting flows of a given velocity. Capabilities of individuals and species were identified by morphology, mode of locomotion, or station holding behavior. The authors observed six swimming behaviors, two of which, "skimming" and "hunkering", were frequently observed in all species of sturgeon. They defined skimming to be when a sturgeon holds station with its ventral surface on or just above the bottom, accompanied by gently undulations of its tail. Hunkering was defined as when a fish held station with its ventral surface on bottom, body straight, with no undulation of the body or tail. Paddlefish exhibited the lowest percentage of non-swimmers as well as continuous swimming behavior, imparting the lowest overall risk of entrainment of the three species studied. Lake sturgeon had a slightly higher percentage of non-swimmers compared to paddlefish, but displayed degrees of hunkering or skimming that produced an increased risk of entrainment. The authors qualified this finding by reporting that overall entrainment risk for this species was relatively low due largely to its high escape speed. Pallid sturgeon had the highest risk of entrainment, particularly those individuals less than 115 mm in length. Of the three species tested, they had the largest percentage of non-swimmers, a fairly low escape speed, and a large amount of time spent hunkering or skimming. Unpublished data from Hoover (personnel communication) produced results indicating high escape speeds (90 cm/sec) for Atlantic sturgeon (< 115 mm), reducing the risk of entrainment. Other factors such as time spent within the lower 1-m of the water column (as much as 95% of the time budget for some fish in the current study), would increase the risk of entrainment. Based on the work by Hoover et al. (2011, 2009, 2005), it appears that juvenile Atlantic sturgeon could potentially be susceptible to entrainment by dredges, but risk might vary among populations, similar to other sturgeon species. In areas that serve as juvenile nursery habitat, entrainment risk could be reduced by using smaller capacity cutterhead dredges, which would reduce the intake velocities and spatial extents of the flow fields around the cutterheads.

The present study was not designed to quantify actual entrainment rates, which can only be done by screening discharges, but to determine relative probabilities of entrainment contingent upon behaviors of free ranging individuals in relation to the presence of an active cutterhead dredge in the

James River. These factors include behavioral responses manifested as attraction to or avoidance of dredging operations. Additional factors that affect the risk of entrainment are morphology of the waterway (e.g., depth and width of the Federal navigation channel used as a corridor for fish movement) and river discharge conditions.

River Flow Regime

Flow fields around the cutterhead have been studied largely from the standpoint of designing more efficient cutterheads. Intake flows have been described within an entrainment context by McNair and Banks (1986). Although a complex circulation pattern exits in the vicinity of the intake, theoretical velocity fields calculated for a 20 in (50.8 cm) dredge predicted intake velocities of 118 cm/sec and 30 cm/sec at distances of 0.5 and 1.0 m from the intake respectively (Table 3). By 1.5 m, for example the decay rate of the velocity field would produce intake velocities around only 6.55 cm/sec. Thus at any instant in time, the cutterhead would be entraining water from a 1.5 m wide and 0.375 m high parcel of bottom water if 75% of the cutterhead was embedded in channel bottom during sediment excavation. At the project site the James River Federal navigation channel is 300 ft (91.4 m) wide, so at any point in time the cutterhead would potentially influence 1.4 percent of the available channel cross-sectional width when considering intake velocities which exceed sturgeon escape speeds within 0.5 m of either side of the cutterhead apparatus. The percentage of the available cross-sectional profile of the river influenced by intake velocities increases to 2.9%, if using 1 m on each side of the cutterhead as a conservative value in determining the potential entrainment zone. Figure 6 shows the minimum, average and maximum intake velocities based on the following scenario:

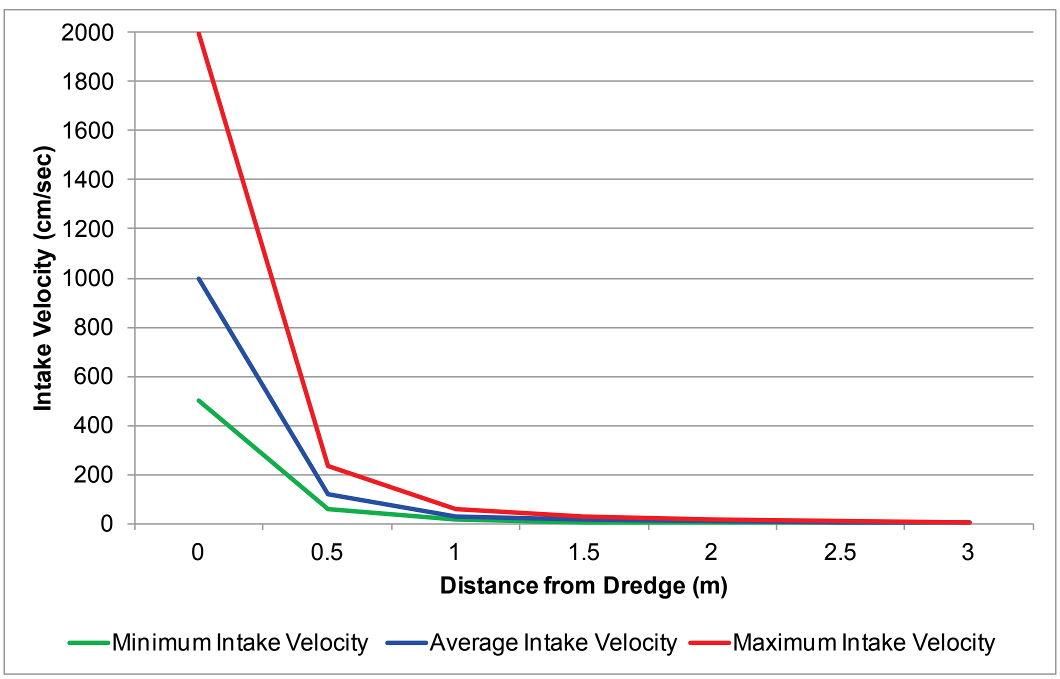
- Suction pipe diameter = 20 inches.
- Suction pipe area = 314.16 sq/in or 2.18 sq/ft.
- Minimum suction line velocity = 7.5 ft/sec (228 cm/sec) or 16.4 cubic feet/sec.
- Average suction line velocity = 15 ft/sec (457.2 cm/sec) or 32.7 cubic feet/sec.
- Maximum suction line velocity = 30 ft/sec (914.4 cm/sec.) or 65.4 cubic feet/sec.
- Percent Sphere = 15
- Escape speed of juvenile Atlantic sturgeon, based on unpublished data from Hoover et al. (personnel communication) and predicted from

other sturgeon species, measuring less than 115 mm (11.5 cm) = 90 cm/sec. Note: escape speed were determined for juvenile sturgeon tested in a swim tunnel at the Engineer Research and Development Center, Environmental Laboratory (See Hoover et al. 2011, 2009, 2205, and Boysen and Hoover 2009). Currently only very limited data exists for Atlantic sturgeon.

Table 3. Intake velocities (cm/sec) for a 20 inch hydraulic pipeline dredge to distances of 3 m from the intake source.

Distance from Dredge	Minimum Intake Velocity (cm/sec)	Average Intake Velocity (cm/sec)	Maximum Intake Velocity (cm/sec)
0	498.7	997.5	1994.9
0.5	58.99	118.0	236.0
1	14.75	29.50	58.99
1.5	6.55	13.11	26.22
2	3.69	7.37	14.75
2.5	2.36	4.72	9.44
3.0	1.64	3.28	6.55

Figure 6. Intake water velocity at increasing distances from a 20 inch hydraulic cutterhead dredge.



Parameters that are unknown or have limited data that are contributing factors in determining the likelihood of entrainment of Atlantic Sturgeon include:

- Rheotaxis: Percent of non-swimmers and swimmers. Positive rheotaxis is defined as head-first orientation into flowing water. Although the sample size in the current study was small, most sturgeon movement occurred in the direction of tidal flow. Only one test subject moved against the direction of tidal flow.
- Endurance or time to fatigue
- Station holding behavior: This behavior can be described as the percentage of time sturgeon are exhibiting benthic or pelagic behavior. Three of the five actively tracked fish in the current study considerable time at or near the channel bottom with very little overall movement. This behavior could increase their overall risk for entrainment.
- Swimming speeds: sustained, prolonged, or burst based on endurance observed or predicated for a given water velocity.

Based on intake velocity, a juvenile Atlantic sturgeon with an escape speed of 90 cm/sec would most likely be able to avoid entrainment when using the minimum intake velocity to nearly 0 meters from the cutterhead intake. Using the average intake velocity, juvenile Atlantic sturgeon would be entrained at distance to 0.5 m from the intake source. The "entrainment zone" is similar when using the maximum intake velocity. Values highlighted in red in Table 3 would entrain juvenile Atlantic sturgeon, while those given in black are below the predicted escape speed for juveniles. At distances of 1 m from the intake, maximum intake velocities are slightly less than 60 cm/sec and would reduce significantly the risk of entrainment. However some very small (< 82 mm TL) juvenile white sturgeon had escape speeds of 40 cm/sec and would be potentially susceptible to entrainment at a minimum intake velocity to 0.5 m and at a maximum intake velocity to 1 m from the cutterhead (Values highlighted in orange, Table 3). It is uncertain if very small Atlantic sturgeon would also have reduced escape speeds, but the probability is high.

The absolute volumes of water entrained by the dredge should also be placed into perspective with the total volume of water within the waterway. Because the system is dynamic rather than static, one logical approach is to compare the entrained volume with river discharge. River flow data were obtained from the U.S. Geological Survey (USGS) monitoring station on the James River near Richmond (USGS gauge 02037500 at RM 102) for the period from 30 January to 19 February 2009 (USGE 2009). The mean daily discharge rate was 3,167 cfs (89.7 m^3/sec), with a standard deviation of ± 623 cfs (17.6 m^3/sec). Discharge rates ranged from 2,380 to 4,230 cfs

(67.4 to 119.8 m^3/sec). These values were well below historical, long-term discharges recorded for 72 prior years. January and February discharge rates typically averaged 9,020 cfs (255.4 m^3/sec) and 10,600 cfs (300.2 m^3/sec), respectively. The highest recorded discharge rate during these two months occurred in February 1998 at 34,960 cfs (990 m^3/sec). Excluding this value, the highest monthly flow rate typically did not exceed 20,000 cfs (566.3 m^3/sec). Because the Richmond station is located a considerable distance from the study site, the stated discharge rates must be used with caution, although the values are likely conservative. Thus at maximum production (0.34 m^3/sec water entrainment rate), the dredge could conceivably remove 0.28 to 0.50 (mean = 0.38) percent of the net flow based on mean daily discharge (89.7 m^3/sec) during the study. If historical discharge rates are applied (255.4 to 300.2 m^3/sec) 0.12 percent of the net flow could potentially be removed by the dredge. However, assuming continuous maximum production is an unrealistic representation of the dredging process; actual water entrainment rates would be somewhat lower.

The capacity of a dredge plant to remove water from a finite volume could serve as a basis for assessing the probability of fish entrainment if fishes within the entrainment zone reacted passively or had no ability to resist intakes flows. However, even juvenile fishes generally have some capability to maneuver within flow vortices such as produced by rotating cutterheads. Specific behavioral responses would significantly affect the outcome of encounters with altered flow fields. Fishes that react to a sudden disturbance or increase in flow velocity by orienting into the current and initiating a burst swimming response should be able to avoid entrainment by most cutterheads. Many species of even very small fishes are capable of high swimming speeds for short distances (Weihs 1974, He and Wardle 1988, Videler and Wardle 1991) with speeds commonly exceeding 1.0 m/sec. Species more likely to be entrained are those that react to disturbance by becoming motionless or burying in the substrate. A small sturgeon hunkering or skimming over the substrate could be entrained by a simple hydraulic draghead, as could a free-swimming sturgeon moving over the open spaces of a cutterhead, but in either case the fish would need to be almost on top of the draghead, and unaffected by association disturbance (e.g., turbidity or noise) (Hoover et al. 2011). Although juvenile sturgeon in general, are highly rheotactic, they are not powerful swimmers and most notably they are prone to bottom holding behaviors. The latter two characteristics make them particularity susceptible to entrainment when in close proximity (< 1 m) to either dragheads or rotating cutterheads. This may explain the taxonomic composition of fishes entrained by hopper dredges in studies by Armstrong et al. (1982), Larson and Moehl (1990) and McGraw and Armstrong (1990). Pacific sand lance, which accounted for the large majority of fishes entrained, typically seek refuge from disturbance by diving into sediment. Diel and temporal movements of two of the five sturgeon tracked in the current study indicated movement to mid-water depths when occupying the Federal navigation channel or movement to adjacent shallow water shoals, both of which would dramatically reduce the risk of entrainment. Three of the five sturgeon tracked in the current study spent nearly 95% of the time within the lower 1.5 m of the water column, a potential entrainment risk factor.

Avoidance and Attraction Responses

Few studies published in the scientific literature directly address potential impacts of dredging and dredged material placement activities on sturgeon. A general review of impacts associated with estuarine dredge and fill activities can be found in Johnston (1981) and Wilber and Clarke (2001), which assessed the biological effects of suspended sediments associated with dredging on fish and shellfish. With specific reference to sturgeon, Smith and Clungston (1997) and Van Dolah et al. (1984) speculated that dredging and filling could impact important habitat features of Atlantic sturgeon by disturbing benthic fauna, eliminating deep holes, and depositing silt over rocky substrates used as spawning sites. The removal of hard, rocky outcropping and channel bottom has removed a significant amount of important potential spawning habitat for Atlantic sturgeon on the James River in particular.

There have been a few anecdotal observations on the attraction of fishes to dredging operations, and one study of comparative trawl catch data taken in a dredged material disposal plume versus “clear” ambient water (Maragos et al. 1977, Harper 1993) as cited in LaSalle et al. (1991). Moser and Ross (1993) tracked shortnose and Atlantic sturgeon through Wilmington Harbor on the Cape Fear River, North Carolina and found both species present in both regularly dredged and non-dredged areas. There were somewhat fewer sturgeon detected in the dredged areas, when compared to the non-dredged areas, but no obvious causes for avoidance. The authors found that both species occupied both undisturbed and regularly dredged areas during concurrent dredging operations with no negative impacts. McQuinn and

Nellis (2007) used acoustic trawl surveys to investigate the effects of dredged sediment disposal on Atlantic and lake sturgeon in Canadian waters of the Saint Lawrence Estuary. They found that Atlantic and lake sturgeon appeared to avoid areas of accumulated dredged sediments.

In Canadian waters, Hatin et al. (2007) examined potential effects of dredging operations on Atlantic sturgeon behavior by comparing trawl catch per unit effort (CPUE) before and after dredging events in 1999 and 2000. CPUE at monitoring sites in the dredged material placement area were three to seven times lower than at a nearby control site. The authors concluded that the reduced Atlantic sturgeon presence after dredging activities was evidence that sturgeon were actively avoiding these areas. They found no similar effect of dredging on lake sturgeon. With shortnose sturgeon, Hastings (1983) was unable to correlate dredging impacts with shortnose sturgeon densities in the upper tidal reach of the Delaware River.

More recently, Parsley et al. (2011) assessed the short-term response of subadult white sturgeon (*Acipenser transmontanus*) to hopper dredge disposal operations. Movement patterns and depth use of fish before, during and after a series of dredged material placement events were studied by tracking acoustically tagged sturgeon using a Vemco acoustic automated positioning system. The rates of movement, depths used, and diel movement patterns of the white sturgeon showed little changed over all monitored periods, suggesting that natural behaviors were not altered during and immediately after hopper disposal operations.

5 Conclusions

Based on results of the present study no evidence was observed that would suggest that the presence of an active dredging operation represented a physical barrier to sturgeon movement. Tagged fish were actively tracked throughout a section of the James River during the conduct of dredging, including passage both upstream and downstream movements in the vicinity of the dredge. Atlantic sturgeon behavior did not show either attraction or avoidance responses to any stimuli likely associated with the dredging operation (i.e., the physical presence of the dredge plant itself, noise generated during the dredging operation, or disturbance of sediment, either from increase turbidity or resuspending potential food resources in the water column). Tagged sturgeon were not detected within the open-water placement area, but there was no evidence of active avoidance of the pipeline discharge site.

Several Atlantic sturgeon tagged in this study were released in close proximity to an active dredge, and all spent a substantial portion of their time budgets near the channel bottom where encounters with a dredge cutterhead could possibly occur. However, none of the tagged sturgeon appeared to be at risk of entrainment at any time, and all were successfully detected by passive receivers through the end of March, well beyond the termination of dredging activities.

Based on unpublished data of laboratory investigations of Atlantic sturgeon swimming capabilities by Hoover et al. (personnel communication), it is unlikely that flow fields generated by hydraulic cutterhead dredges would pose significant risks to Atlantic sturgeon. This finding is based on measurements of relatively high burst or escape speeds (90 cm/sec), even for relatively small sturgeon (< 115 mm). Considering the relatively high escape speeds of juvenile sturgeon and estimated cutterhead intake flow field velocities, the entrainment zone or area of greatest risk would extend approximately 0.5 m from the periphery of the rotating cutterhead. Based solely on size class and escape speeds, entrainment risk, albeit low, would be greatest for Young of Year, followed by juveniles, but only in very close proximity (0.5 m) to the cutterhead. Since sub-adults and adults would have a greater swimming escape speed, the risk of entrainment would be even further reduced. Again it should be noted that swimming escape speeds are only one factor to consider and those used in this paper were predicted from limited data and from data from several different species (e.g., lake and pallid) of sturgeon obtained during swim tunnel experiments. Information on escape speeds, and other behaviors such as station holding behavior (e.g. skimming, and hunkering) and rheotaxis behavior, specific to Atlantic sturgeon would have to be confirmed in a more extensive swim tunnel study.

Active and passive tracking studies of Atlantic sturgeon are extremely challenging in terms of equipment deployment and maintenance. Commitments in terms of acquiring skills for capturing, handling, and surgically implanting tags are demanding and require collaborative team efforts. Likewise, active tracking, which is necessary to discern fine scale spatial movements, is labor intensive with continuous needs for logistical support and attention to safety, especially during nighttime hours. Consequently, one caveat to the present study that must be acknowledged is sample size. Certainly it would be beneficial to obtain data on movements of larger numbers of Atlantic sturgeon in order to discern consistent patterns. Two of five sturgeon in the present study showed indications of repeated excursions over shoals adjacent to the navigation channel, whereas three sturgeon remained within deeper portions of the river reach. Regardless, observations obtained in the present study shed light on sturgeon movements and reduce the uncertainty surrounding potential interactions between Atlantic sturgeon and active dredging operations.

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14. ABSTRACT
The outcome of encounters between Atlantic sturgeon (*Acipenser oxyrinchus*) and active dredging operations in Federal navigation channels is dependent on a number of factors. Risk factors include: avoidance of or attraction to the presence of an active dredge, the proportion of time spent in bottom waters of the navigation channel along with other behavioral aspects of the target species. To assess potential entrainment by a CSD operating in the James River, Virginia, five Atlantic sturgeon (TL = 77.5-100 cm), were implanted with both active and passive transmitters, released in the immediate vicinity of the dredge, and tracked continuously for several days. During tracking the dredge intermittently pumped sediment through a pipeline to an open-water placement site. Movements were monitored using mobile vessel-based omni-directional hydrophones as well as data logging receivers placed at fixed up- and downstream locations. Data on lateral and vertical movements of individual sturgeon were examined in relation to river bathymetry, river discharge rate, dredge production rate, and vessel traffic. Continuous records of tag depths provided observations of the durations and frequencies of individual sturgeon excursions into channel basin waters. None of the tagged sturgeon showed evidence of avoidance behavior, remaining in close proximity to the dredge for as long as 21.5 hours before moving away. Likewise, no strong evidence of attraction was observed, as sturgeon moved within the channel past the operating dredge on several occasions. Movements tended to be influenced by tidal flows. Only one individual moved against the prevailing tidal flow. Three of five tagged sturgeon demonstrated similar diel movement patterns, spending approximately 95% of their time in the lower 1.5 m of the channel bottom. Two sturgeon showed a distinct pattern of moving into waters < 4 m deep at night, spending substantial time over nearby shoals.

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