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Cover Phograph: Adult Shortnose Sturgeon captured in the upper tidal Delaware River. Photograph © Harold M. Brundage III.

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Occurrence of Shortnose Sturgeon in the Tidal Schuylkill River, an Urbanized and Industrialized Tributary of the Delaware River

Harold M. Brundage III[1]

Abstract - Monitoring for acoustically-tagged sturgeon was conducted in the tidal Schuylkill River (Philadelphia, PA, USA), a highly urbanized and industrialized tributary of the Delaware River, during July 2018 through July 2019. Three adult Shortnose sturgeon were detected, initially during the summer and/or fall of 2018. The same fish were detected again in the spring and/or summer of 2019. Periods of continuous occupancy in the Schuylkill River ranged from 12–67 days and averaged 38.3 days. The Shortnose Sturgeon were absent from the Schuylkill River during the winter months but utilized known overwintering areas in the tidal Delaware River. This study suggests that a small percentage (~3% based on the proportion of acoustically-tagged Shortnose Sturgeon detected vs. at large) of adult Delaware River Shortnose Sturgeon seasonally utilize the tidal Schuylkill River, probably as a foraging area. The study also suggests that water quality in the Schuylkill River, particularly dissolved oxygen concentration, is generally suitable for adult Shortnose Sturgeon and provides further evidence that tributaries and smaller river systems may serve a more important role in the life history of Shortnose Sturgeon than previously thought.

Introduction

Acipenser brevirostrum LeSueur (Shortnose Sturgeon) is a relatively small (<1.2 m total length (TL)) sturgeon that inhabits large Atlantic coastal rivers and estuaries from the St. John River, New Brunswick, Canada, to the St. Johns River, FL, USA (Vladykov and Greeley 1963). The Shortnose Sturgeon was placed on the Endangered Species List in 1967 and is currently listed as endangered under the federal Endangered Species Act (ESA) of 1973, as amended. The International Union for the Conservation of Nature (IUCN) Red List of Threatened Species lists Shortnose Sturgeon as Vulnerable (VU) (A2ce; B1ab(iii)) (IUCN 2020).

Shortnose Sturgeon occur throughout the Delaware River estuary (Brundage and Meadows 1982). Adults are abundant in the upper tidal Delaware River from Trenton, NJ to Philadelphia, PA year-round (ERC 2006a, Hastings et al. 1987), and relatively common in the lower tidal river from approximately Chester, PA to Wilmington, DE (ERC 2006a, 2010, 2020). The Delaware River estuary supports the third largest population of Shortnose Sturgeon range wide; the Hudson River (NY) and the St. John River having larger estimated populations (Kynard et al. 2016). Environmental Research and Consulting, Inc. (ERC) (2006b) estimated the population of adult Shortnose Sturgeon in the Delaware River to be 12,047 (95% CI 10,757–13,589) using the Schnabel population estimator with mark-recapture data collected during 1999–2003. This estimate, which is the most recent available, was very similar to an earlier Schnabel estimate of the Delaware River adult Shortnose Sturgeon population of 12,796 (95% CI 10,228–16,367) based on mark-recapture data from 1981–1984 (Hastings et al. 1987). The similarity of the estimates suggests that the population of adult Shortnose Sturgeon in the Delaware River was stable during the approximately 20 year period between the estimates.

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Delaware River Shortnose Sturgeon overwinter in dense aggregations in the upper tidal river between Roebling and Bordentown, NJ, and also in the lower tidal river in the vicinity of Marcus Hook and Chester (ERC 2006a, Hastings et al. 1987). Spawning occurs primarily in the lower non-tidal Delaware River from Trenton to Lambertville, NJ from late March or early April into early May (Brundage 1986; ERC 2008, 2015, 2018). After spawning, adult Shortnose Sturgeon move back to the tidal river, where they spend the summer and fall foraging, with fish occasionally moving into Delaware Bay (O'Herron et al. 1993, ERC 2006a). Delaware River Shortnose Sturgeon generally remain in the estuary throughout their lives, although there are a few records of their occurrence in the ocean near the mouth of Delaware Bay (Brundage and Meadows 1982).

Juvenile Shortnose Sturgeon in the Delaware River co-occur with adults but, being sensitive to salinity (Jarvis et al. 2001), generally remain upriver of the freshwater/saltwater interface (Brundage and O'Herron 2009, O'Herron et al. 1993). Juvenile Shortnose Sturgeon appear to overwinter in a dispersed fashion rather than in the aggregations typical of adults (Brundage and O'Herron 2009).

Effects of Urbanization on Shortnose Sturgeon

Urbanization and associated industrialization have impacted Shortnose Sturgeon in a number of ways. Construction of dams has blocked upstream spawning migrations and denied Shortnose Sturgeon access to historic spawning sites in a number of rivers, including the Connecticut (CT) (Kynard 1997), Hudson (NY) (Bain 1997), and Cooper (SC) rivers (Cooke and Leach 2003), resulting in spawning and early life stage rearing in suboptimal environments (Kynard 1997, Kynard et al. 2016). The Delaware River, however, has remained undammed, so Shortnose Sturgeon have unimpeded access to spawning areas in the non-tidal river.

Deterioration of water quality associated with urbanization and industrialization, especially reduction in dissolved oxygen concentration, has had a significant impact on Shortnose Sturgeon in some rivers. Laboratory studies have shown that juvenile Shortnose Sturgeon and other sturgeons are very sensitive to hypoxia (Campbell and Goodman 2004, Secor and Gunderson 1998, Secor and Niklitschek 2001), with younger juveniles being more susceptible than older juveniles (Jenkins et al. 1993). Although laboratory studies are lacking, adult Shortnose Sturgeon are also presumed to be sensitive to low dissolved oxygen, but perhaps less so than juveniles, since resting oxygen consumption has been shown to decrease with body mass for other sturgeon species (Peake 2005).

Low dissolved oxygen concentrations caused by pulp mill effluent are thought to have made portions of the Satilla and St. Marys rivers in Georgia, and the Penobscot River in Maine unusable by Shortnose Sturgeon (Kynard et al. 2016). Low dissolved oxygen is also believed to have historically impacted Shortnose Sturgeon in the upper tidal Hudson River, and the large (400%) increase in the estimated Shortnose Sturgeon population in the Hudson between the 1970s and the late 1990s has been attributed, in part, to the return of normoxic conditions (Bain et al. 2007, Secor and Niklitschek 2001).

Low dissolved oxygen has affected the distribution and movements of Shortnose Sturgeon in the urbanized/industrialized central portion of the tidal Delaware River, both historically and more recently. Brundage and Meadows (1982), reviewing incidental capture records during 1954 through 1979, concluded that the Delaware River between Philadelphia and Wilmington would be unavailable to Shortnose Sturgeon during summer as a result of near zero dissolved oxygen concentrations. Although water quality in the Delaware River has improved significantly since the 1980s, dissolved oxygen concentrations near Philadelphia may still drop to stressful levels (~3–5 mg/l) during hot, dry summers (Moberg and DeLucia

2016). Acoustic tracking studies conducted during 2003–2004 (ERC 2006a) and 2009 (ERC 2010) indicated that adult Shortnose Sturgeon utilized the Philadelphia reach of the river as a travel corridor when moving between overwintering, spawning, and foraging areas but did not remain in that part of the river for long periods of time. Brundage and O'Herron (2009) concluded that acoustically-tagged juvenile Shortnose Sturgeon were unlikely to use the Philadelphia area in summer because of low dissolved oxygen concentrations.

Chemical contaminants released from urban areas and industrial sites may also impact Shortnose Sturgeon. Shortnose Sturgeon early life stages appear to be particularly vulnerable to contaminants, with effects ranging from sublethal deformities to mortality (Chambers et al. 2012, Kocan et al. 1996, McConnell and Chambers 2018). Shortnose Sturgeon are known to bioaccumulate various inorganic and organic chemicals, but studies linking contaminant body burdens to effects in sturgeon are lacking. ERC (2002) reported that adult Shortnose Sturgeon collected from the Delaware River had concentrations of polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), polychlorinated biphenyls (PCBs), dichlorodiphenyldichloroethylene (DDE), aluminum, cadmium, and copper in gonad and liver tissue above adverse effect concentrations reported for other fish species. PCDDs, PCDFs, PCBs, DDE, and cadmium have been identified as endocrine disrupting compounds (EDCs), and there is evidence that the adverse effects of these chemicals may be exacerbated when they occur in combination (Monosson 1997). Matsche et al. (2012) identified a relatively high incidence of intersex (11.6%), as well as altered hormone levels, in adult Shortnose Sturgeon collected in the upper tidal Delaware River, which could have been caused by exposure to EDCs, perhaps in combination with hypoxia, but cautioned that additional study would be needed to determine if reproduction was being affected.

While Shortnose Sturgeon have been relatively well studied in the mainstem Delaware River, information on their use of tributaries is lacking. In this paper, I discuss the occurrence of Shortnose Sturgeon in the Schuylkill River, a highly urbanized and industrialized tributary of the Delaware River.

Field-Site Description

The Schuylkill River flows approximately 198 km from its headwaters in Schuylkill County, PA to its confluence with the tidal Delaware River at Philadelphia (the confluence of the Schuylkill River with the Delaware River is located at Delaware River kilometer (rkm) 148.8 based on DRBC (1969)). Tidal influence in the Schuylkill River is limited by Fairmount Dam, located 13.6 km from the confluence. The tidal Schuylkill River is fresh water year round.

The tidal segment of the Schuylkill River is located entirely within the City of Philadelphia, and adjacent land areas are heavily industrialized and densely populated. Much of the shoreline of the tidal Schuylkill River has been bulkheaded, and there is little shallow water habitat. The lower 10 km of the Schuylkill River has been dredged for navigation. The river bottom consists of course sand and gravel overlain by mud and contains a large percentage of anthracite coal from historical coal mining upriver (Ettinger 1982). Water quality in the tidal Schuylkill River has historically been degraded by sewage, industrial effluents, and urban runoff (Kaufman et al. 2011).

Methods

Capture, Handling, and Acoustic Tagging of Sturgeon

Shortnose Sturgeon and *Acipenser oxyrinchus oxyrinchus* Mitchell (Atlantic Sturgeon) were captured for acoustic tagging by bottom-set gill net (5.1–15.2 cm stretched mesh)

or semi-balloon trawls (4.9 or 16.2 m mouth widths) in the upper tidal (~ rkm 210) or lower tidal Delaware River (between approximately rkm 123–140) during November 2011 through February 2019 in studies funded by the National Marine Fisheries Service (NMFS) and the US Army Corps of Engineers (USACE).

Sturgeons were carefully removed from the nets and placed in an out-board live car or an on-board tank containing river water at ambient temperature and dissolved oxygen levels. Sturgeon were identified to species, measured for fork length (FL) and total length (TL), weighed, and tagged with a numbered T-bar tag (Floy Tag and Manufacturing, Inc., Seattle, WA), and/or a passive integrated transponder (PIT) (Biomark, Inc., Boise, ID). Selected sturgeon were internally tagged with Vemco (now Innovasea Systems, Inc., Shad Bay, Nova Scotia, Canada) 69 kHz coded acoustic transmitters (model V8, V9, V13, or V16) matched to the weight of the fish. Sturgeon for acoustic tag implantation were anesthetized using tricaine methanesulfonate (MS-222) at a dose of 50–100 mg/l and then held upside down in a cradle while the gills were perfused with aerated flowing water. The transmitter was inserted into the body through a longitudinal incision in the abdomen. The incision was closed with interrupted sutures of 3-0 polydioxanone (PDS), and treated with povidone iodine (10% solution) and petrolatum to prevent infection. Post surgery, fish were held in an aerated holding tank and released upon recovery from anesthesia. Shortnose and Atlantic sturgeons are tolerant of handling and tag implantation surgery, and, based on subsequent acoustic tag detections, it is unlikely that any mortality resulted from the procedures.

All sampling and handling of sturgeon followed established protocols (Kahn and Mohead 2010) and was performed in accordance with NMFS Permits to Take Endangered Species for Scientific Purposes Nos. 14604, 16438, or 19331 or requirements of NMFS Biological Opinions issued for the USACE Delaware River Main Channel Deepening Project.

Monitoring for Acoustically-tagged Sturgeon in the Tidal Schuylkill River

Monitoring for acoustically-tagged sturgeon in the tidal Schuylkill River was conducted during July 17, 2018 through July 17, 2019 using Vemco VR2W omnidirectional receivers deployed at two locations, 1.2 and 5.9 km upriver of the confluence with the Delaware River (Fig. 1). Based on calculated tag life, 89 Shortnose Sturgeon (6 juveniles and 83 adults) and 81 juvenile Atlantic Sturgeon were at large in the Delaware River with active acoustic tags when the Schuylkill River receivers were deployed in July 2018, and an additional 23 Shortnose Sturgeon (6 juveniles and 17 adults) and 107 juvenile Atlantic Sturgeon were tagged in January–February 2019 and, thus, available for detection during approximately the second half of the receiver deployment period.

Results

Three adult Shortnose Sturgeon (tag codes 16490, 20767, and 55377), but no juvenile Shortnose Sturgeon or juvenile Atlantic Sturgeon, were detected by the Schuylkill River receivers (Table 1). The Shortnose Sturgeon occurred during two periods, initially in the summer and/or fall of 2018 and again in the spring and/or summer of 2019 (Fig. 2). Collectively, the Shortnose Sturgeon were present in the Schuylkill River during mid-April through mid-November but were absent during the winter months. The Shortnose Sturgeon moved back and forth between receivers and were sometimes detected by both receivers on the same day. Periods of continuous occupancy in the Schuylkill River ranged from 12–67 days (Table 1) and averaged 38.3 days. The mean lengths and weight of the Shortnose Sturgeon detected in the Schuylkill River (865 mm TL, 766 mm

FL, and 4.36 kg) (Table 1) were considerably greater than the mean lengths and weight of acoustically-tagged adults at large in the Delaware River (781 mm TL, 675 mm FL, and 2.93 kg).

The three Shortnose Sturgeon were detected at receivers throughout the tidal Delaware River during the periods they were not in the Schuylkill River. Shortnose Sturgeon tag code 16490 overwintered in the lower tidal Delaware River between Wilmington (rkm 112) and Marcus Hook (rkm 129), and tag codes 20767 and 55377 overwintered in the upper tidal Delaware River between Roebling (rkm 199) and Bordentown (rkm 207). Tag code 55377

Figure 1. Locations of acoustic receivers on the tidal Schuylkill River, City of Philadlephia, PA.

Table 1. Detections of acoustically-tagged Shortnose Sturgeon in the tidal Schuylkill River during July 17, 2018 through July 17, 2019.

		Measurements at Tagging					
Acoustic Tag Code	Date Tagged	Total Length (mm)	Fork Length (mm)	Weight (kg)	Periods of Detection	No. Days Detected	No. Detections
16490	11/16/16	928	812	4.62	9/30-10/26/18	14	283
					5/3-6/14/19	36	1556
					Total	50	1839
20767	12/27/15	863	777	5.04	7/23-11/10/18	60	2780
					4/12-7/17/19	41	5802
					Total	101	8582
55377	11/15/11	803	708	3.42	7/20-28/18	12	61
					4/30-7/17/19	67	668
	Mean	865	766	4.36	Total	79	729

was detected on the spawning grounds in the non-tidal Delaware River near Yardley, PA (rkm 221) during March 26–April 26, 2019, just before it moved back to the Schuylkill River, swimming over 73 km in five days.

Discussion

There is only one previously published record of a sturgeon in the Schuylkill River. This record, which appeared in the Philadelphia Inquirer (Bauers 2014), was of an adult Shortnose Sturgeon caught by a fisherman near the base of Fairmount Dam in summer 2014. Results of the present study suggest that a small percentage (~3% based on the proportion of acoustically-tagged Shortnose Sturgeon detected vs. at large) of adult Delaware River Shortnose Sturgeon may seasonally utilize the Schuylkill River. The return of the same three fish detected in summer/fall 2018 to the Schuylkill River in spring/summer 2019 suggests a regularity to their occurrence, at least for those individuals. The results of this study, combined with the incidental capture at Fairmount Dam, suggest that the entire tidal Schuylkill River may be utilized by Shortnose Sturgeon.

Although there appears to be ample invertebrate food resources in the Delaware River (Kreeger et al. 2010), it is likely that Shortnose Sturgeon use the tidal Schuylkill River as

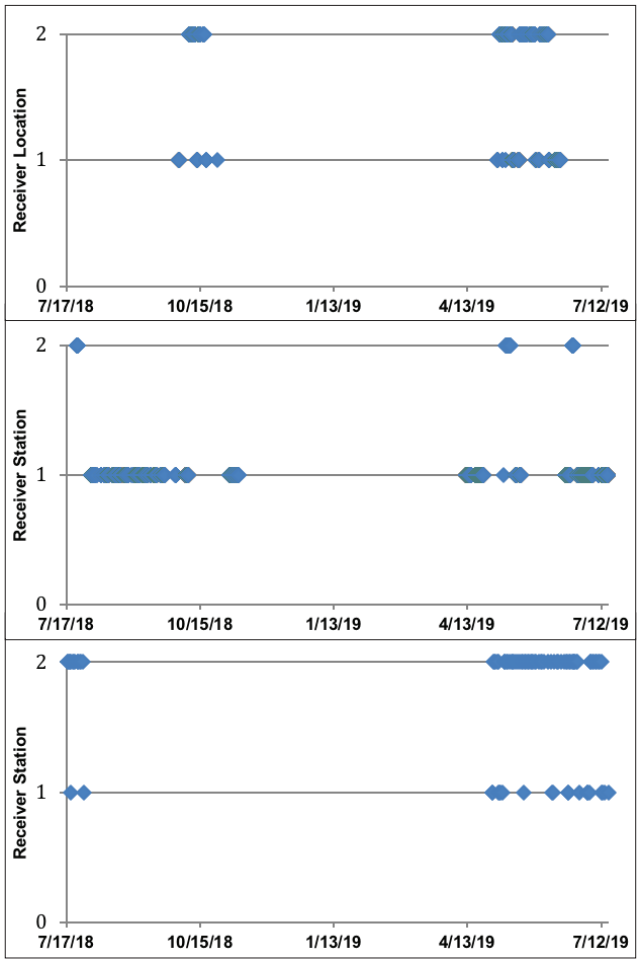

Figure 2. Occurrence of Shortnose Sturgeon tag codes 16490 (top), 20767 (middle), and 55377 (bottom) in the tidal Schuylkill River during July 17, 2018 through July 17, 2019.

foraging habitat considering the times of year and long durations they spent there. Shortnose Sturgeon are benthic feeders with a broad diet, feeding opportunistically on insect larvae, crustaceans, mollusks, and polychaetes (Dadswell et al. 1984, Kynard et al. 2016). Ettinger (1982) reported 22 genera of benthic invertebrates in the tidal Schuylkill River, many of which are known prey items of Shortnose Sturgeon.

The occurrence of the three Shortnose Sturgeon in the Schuylkill River may be related to an innate tendency of some individuals to roam. Acoustically-tagged adult Shortnose Sturgeon in the Delaware River typically evidence one of two generalized movement patterns, either making long excursions throughout the tidal river or remaining locally in the upper tidal river (ERC 2006a, 2010). Such dichotomy in movement behavior has been documented in other fish species (Secor 2015), and fish making more wide-ranging movements can be referred to as "roamers" or "explorers". Secor (2015) proffers that the tendency to roam is a personality trait that is part of an individual fish's "behavioral syndrome", and Sih and Bell (2008) suggest that this trait may be heritable. Roamers have a tendency to explore novel situations regardless of risk (Secor 2015). Exploratory behavior allows fish to discover and utilize new areas and, thereby, extend their range if environmental conditions allow. The occurrence of the three Shortnose Sturgeon in the tidal Schuylkill River over multiple seasons indicates that environmental conditions in the system were suitable for those individuals.

The Schuylkill River has a long history of pollution by municipal and industrial discharges, and urban runoff, and in the early 1900's, it was described as "grossly polluted" and "almost exhausted of dissolved oxygen" (Stevenson 1914). Water quality in the Schuylkill River has improved through implementation of pollution control programs pursuant to the 1961 Delaware River Basin Compact, the 1972 Clean Water Act and subsequent amendments, and other initiatives. Based on analysis of 1980–2005 data, Kaufman et al. (2011) reported significant improvements in dissolved oxygen, total suspended sediment (TSS), and phosphorus concentrations in the Schuylkill River, although nitrogen concentrations remained high, probably because of the ongoing input of organic matter to the river.

There are no dissolved oxygen data for the tidal Schuylkill River for the period of sturgeon monitoring. The most recent data was collected by the Philadelphia Water Department (PWD 2015) using continuously recording sondes located 0.8 and 7.8 km upriver of the Delaware River confluence during the summers (July–September) of 2012 and 2013. PWD's data showed that individual dissolved oxygen concentrations at the 0.8 km station (usable data were obtained only in 2013 at this station) ranged from ~3.8–9.6 mg/l (daily average ~4.9–7.9 mg/l), with most individual readings above 5 mg/l. Dissolved oxygen concentrations at the 7.8 km station ranged from ~4.0–10.0 mg/l (daily average ~4.8–8.9 mg/l), with most readings above 5.5 mg/l in 2012; and ~5.9–9.0 mg/l (daily average ~6.9–9.0 mg/l,), with most readings above 7 mg/l, in 2013 (PWD 2015).

Secor and Niklitschek (2001) concluded that young-of-year Shortnose Sturgeon will experience lost production in habitats with <60% dissolved oxygen saturation, which corresponds to 4.3–4.7 mg/l at summertime temperatures (22–27C°), and observed lethal effects at dissolved oxygen concentrations ≤ 3.3 mg/l. Assuming that the dissolved oxygen concentrations observed by PWD (2015) in 2012 and 2013 are representative of prevailing conditions, dissolved oxygen levels in the tidal Schuylkill River appear to be generally suitable for Shortnose Sturgeon, particularly adults, which likely have a greater tolerance for low dissolved oxygen conditions than juveniles, although oxygen levels may transiently drop to stressful levels during periods of high water temperature and low fresh water inflow. The three Shortnose Sturgeon detected in the Schuylkill River may have been better adapted to transient low dissolved oxygen conditions since they were large fish and, based on Peake

(2005), would have lower resting oxygen consumption rates than smaller individuals.

The absence of detection of juvenile Shortnose or Atlantic sturgeons suggests that the Schuylkill River is not currently utilized by this life stage, although juveniles of both species occur in the adjacent Delaware River, particularly during the non-summer months (Brundage and O'Herron 2009; Hale et al. 2016; H. Brundage, ERC, Lewes, DE, unpubl. data). This may be the result of the juvenile sturgeon's requirement for higher dissolved oxygen conditions.

Shortnose Sturgeon are generally thought to inhabit deep, mainstem reaches of large coastal rivers (Bain 1997, Dadswell et al. 1984, Kynard et al. 2016), although Kieffer and Kynard (2012a, b), reported that some Shortnose Sturgeon may forage in the lower reaches of large tributaries of the Connecticut River. More recently, Hodgdon et al. (2019) identified the Saco River estuary, a proportionally small river flowing into the Gulf of Maine, as a seasonal foraging area for Shortnose Sturgeon. The pattern of occurrence of Saco River Shortnose Sturgeon, where the same individuals returned to the same river reaches over multiple years, is similar to what I observed in the Schuylkill River. Together, these studies suggest that tributaries and smaller river systems may serve a more important role in the life history of Shortnose Sturgeon than previously thought.

Water quality improvement has allowed the return of a number of formerly extirpated fish species to the tidal Schuylkill River. Perillo and Butler (2009) identified 29 fish species in the tidal Schuylkill River, including the anadromous *Alosa aestivalis* Mitchill (Blueback Herring), *Alosa mediocris* Mitchill (Hickory Shad), *Alosa pseudoharengus* Wilson (Alewife), *Alosa sapidissima* Wilson (American Shad), and *Morone saxatilis* Walbaum (Striped Bass), which can now pass into the non-tidal river through a fishway constructed at Fairmount Dam. Other species that are now common in the tidal river include *Carpiodes cyprinus* LeSueur (Quillback), *Catostomus commersonii* Lacepède (White Sucker), *Cyprinus carpio* Linnaeus (Common Carp), *Dorosoma cepedianum* LeSueur (Gizzard Shad), *Ictalurus punctatus* Rafinesque (Channel Catfish), *Micropterus dolomieu* Lacepède (Smallmouth Bass), *Morone americana* Gmelin (White Perch), and the invasive *Pylodictis olivaris* Rafinesque (Flathead Catfish) (Perillo and Butler 2009).

This study provides further evidence of the unique capabilities of acoustic telemetry for studying the occurrence and movements of aquatic animals (see reviews by Cooke et al. 2004, Crossin et al. 2017, and Hussey et al. 2015) and is an example of how acoustic tagging for specific projects can be leveraged to study other areas and address other topics. Longer-term investigation of the use of the tidal Schuylkill River, as well as other tributaries and small rivers, by sturgeons, combined with the collection of relevant water quality data, is encouraged.

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