

Habitat use and population characteristics of potentially spawning
shovelnose sturgeon (*Scaphirhynchus platyrhynchus* (Rafinesque) 1820),
blue sucker (*Cycleptus elongatus* (Lesueur) 1817), and associated
species in the lower Wisconsin River, USA

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Brief title: Sturgeon and sucker spawning in Wisconsin River

Summary

The goal of this study was to compare the possible locations, timing, and characteristics of potentially spawning shovelnose sturgeon (*Scaphirhynchus platyrhynchus*), blue sucker (*Cycleptus elongatus*), and associated species during the spring of 2007-2015 in the 149-km-long lower Wisconsin River, Wisconsin, USA, a large, shallow, sand-dominated Mississippi River tributary. A 5-km index station of two pairs of rocky shoals surrounded by sandy areas was electrofished for shovelnose sturgeon and blue sucker in a standardized fashion a total of 40 times from late March through mid-June, the presumed spawning period. On one date in 2008 and two dates in 2012, all rocky shoals and adjacent sandy areas in the lowermost 149 km of the river were also electrofished for both species. Shovelnose sturgeon and blue sucker appeared to spawn in the limited rocky areas of the river along with at least four other species, mooneye (*Hiodon tergisus*), quillback (*Carpiodes cyprinus*), smallmouth buffalo (*Ictiobus bubalus*), and shorthead redhorse (*Moxostoma macrolepidotum*), usually at depths of 0.8-2.0 m and surface velocities of 0.4-1.0 m s⁻¹. However, apparently spawning shovelnose sturgeon were found only on mid-channel cobble and coarse gravel shoals within a single 7-km segment that included the 5-km index station, whereas apparently spawning blue suckers were encountered on these same shoals but also more widely throughout the river on eroding bluff shorelines of bedrock and boulder and on artificial boulder wing dams and shoreline rip-rap. Both species showed evidence of homing to the same mid-channel shoal complexes across years. Blue sucker tended to concentrate on the shoals earlier in the spring than shovelnose sturgeon, usually from late April through mid-May at water temperatures of 8.0-15.5°C along with quillback and shorthead redhorse. In comparison, shovelnose sturgeon usually

concentrated on the shoals from mid-May through early June at 13.5-21.8°C along with mooneye and smallmouth buffalo. Based on recaptures of tagged fish, at least some shovelnose sturgeon and blue sucker returned to the shoals at one-year intervals, although there was evidence that female blue sucker may have been more likely to return at two-year intervals. Most shovelnose sturgeon could not be reliably sexed based on external characteristics. Spawning shovelnose sturgeon ranged from 487-788 mm fork length, 500-2400 g weight, and 5-20 years of age, whereas spawning blue sucker ranged from 495-822 mm total length, 900-5100 g weight, and 5-34 years of age, although age estimates were uncertain. Females were significantly larger than males for both species although there was overlap. Growth in length was negligible for tagged and recaptured presumably spawning shovelnose sturgeon and low (3.5 mm y^{-1}) for blue sucker, suggesting that nearly all growth may have occurred prior to maturity and that fish may have matured at a wide range of sizes.

Introduction

The largest rivers of the Mississippi River Basin in the central United States have a distinctive fish fauna characterized by several species in the families Acipenseridae, Polyodontidae, Hiodontidae, Cyprinidae, and Catostomidae that are specialized for life in fast-flowing and turbid main-river channels. Many of these fishes have sharply declined over the last two centuries because of extensive human modifications of the Mississippi River and its major tributaries (Karr et al., 1985; Fremling et al., 1989). Development and implementation of strategies to restore these large-river specialist fishes have been hampered by the size, scope,

and complexity of the rivers they inhabit and the unlikelihood of reversing some of the human impacts affecting these rivers (Pracheil et al., 2013). A key information need in developing conservation and restoration strategies is an understanding of the habitat preferences, reproductive ecology, and life history requirements of these species (Abell, 2002). However, obtaining such information is challenging because of the long-distances traveled by many species to complete their life cycles (e.g. Pracheil et al., 2012) and the difficulty of sampling the large-river main-channel habitats where they are typically found (e.g. LaPointe et al., 2006).

Shovelnose sturgeon (*Scaphirhynchus platyrhynchus*; Acipenseridae) and blue sucker (*Cycleptus elongatus*; Catostomidae) are two widely co-occurring Great River specialist species. They were once abundant (e.g. Coker, 1930) but are now greatly reduced in number because of human activities (Burr and Mayden, 1999; Koch and Quist, 2010). Each species has been the focus of several recent studies on habitat, reproduction, and life history (e.g. Vokoun et al., 2003; Daugherty et al., 2008; Tripp et al., 2009; Hamel et al., 2015a), but much remains unknown. In particular, information on potential reproductive habitat and fidelity to possible spawning sites is limited because spawning areas are too deep and turbid for spawning to be observed directly in most rivers.

The Wisconsin River is a large tributary to the Mississippi River with several attributes that make it advantageous for studying the spawning of shovelnose sturgeon and blue sucker. The lowermost-reach of the Wisconsin River contains most of the large-river species found in the Mississippi River including the shovelnose sturgeon and blue sucker, which are common (Lyons, 2005a; Pracheil et al., 2013). This reach is smaller and shallower and less modified

compared to the Mississippi River (Weigel et al., 2006), and as a result, observation of potential spawning habitat and fish is easier. Possible shovelnose sturgeon and blue sucker spawning areas in the lower Wisconsin River can be delineated and defined and are relatively simple to sample.

From 2007-2015 we studied aspects of shovelnose sturgeon and blue sucker reproductive ecology in the lower Wisconsin River. The two species overlap in the presumed location and time of spawning. The goal of the study was to compare the potential reproductive ecology of the shovelnose sturgeon and blue sucker, identifying and characterizing possible spawning locations and habitat, determining the likely timing of spawning within and across years, and documenting attributes of potentially spawning fish.

Materials and Methods

Study area

The Wisconsin River is a major tributary of the Mississippi River, flowing 676 km from its source on the border of the states of Michigan and Wisconsin, USA, to its confluence with the Mississippi River in southwestern Wisconsin (Lyons, 2005a). It has a basin area of 31,800 km² and an estimated mean annual discharge of 292 m³ s⁻¹ at its mouth. The river is heavily regulated with 27 dams for power production, flood control, and recreation. The lowermost of these, the Prairie du Sac Dam, is a run-of-the-river hydroelectric facility completed in 1914 and located 149 km above the mouth. It is a complete barrier to upstream movement and defines

102 the upstream end of what is known as the Lower Wisconsin River (LWR), which extends
103 downstream to the mouth and encompasses about 8,200 ha of flowing-water habitat. Although
104 river flows and water quality in the LWR are impacted by upstream dams and agricultural runoff
105 and industrial discharges, the LWR has largely natural and intact channel, riparian, and
106 floodplain habitat, and is one of the highest quality lowland large river reaches remaining in the
107 Midwestern United States (Weigel et al., 2006). It is protected and managed by the State of
108 Wisconsin as the Lower Wisconsin State Riverway.

109 The LWR is a sand-bed river, and coarse rocky substrates (> 16 mm maximum
110 dimension; see Simonson et al., 1994 for habitat definitions) are uncommon in the channel and
111 on the banks (Lyons, 2005a). Over 95% of the surface area of the bottom and banks is sand or a
112 mix of sand and fine gravel (< 16 mm maximum dimension). The LWR is relatively wide and
113 shallow for its flow with widths of 400-700 m and typical thalweg depths of 0.5-2.5 m during
114 normal spring flows. Boat navigation in many areas is impeded by shallow depths. The
115 dominance of sand substrate makes for shifting and unstable bottom contours and flow
116 patterns, and the channel is characterized by numerous sand bars and low islands. The sandy
117 wooded banks of the LWR are easily eroded, and where the main current flows along the bank
118 fallen trees are common, providing excellent fish habitat.

119 Coarse rocky substrate, although uncommon, is an important potential spawning
120 habitat for many fish species in the LWR, including possibly shovelnose sturgeon and blue
121 sucker (Becker, 1983). Fish surveys have been carried out over the entire length of the LWR
122 since the mid 1980's (Lyons 2005a), and from these surveys all substantial patches of coarse

rocky substrate have been identified. In the spring and summer of 2008 and again in 2012 the precise location, type, extent, substrate composition, depth, and surface velocity of all coarse rocky habitat patches in the LWR that were 1 ha or larger in area were measured or visually estimated using procedures outlined in Simonson et al. (1994) and Wang et al. (1996).

Fish Collection

Fish sampling took place during the presumed spring spawning period of shovelnose sturgeon and blue sucker from 2007-2015. Sampling prior to 2007 had detected large concentrations of possibly spawning shovelnose sturgeon and blue sucker on two pairs of rocky shoals between river kilometer (RK – distance from mouth) 139.7 and 144.7. This 5-km stretch, most of which was sandy, was established as an index station that was completely surveyed during every sampling event for both species, except for 2007 when only shovelnose sturgeon were targeted. For data recording purposes, including the location of fish tagging and recapture, the index station was further divided into two substations, upstream (RK 142.9-144.7) and downstream (RK 139.7-141.1), each corresponding to two pairs of adjacent shoals surrounded and separated by sandy areas. On 14-15 May 2008, 18-26 April 2012, and 3-10 May 2012 all other rocky habitat patches in the LWR equal to or greater than 1 ha and their surrounding sandy areas were also surveyed for spawning fish.

The number of fish sampling events each year at the index station varied from one (2014, 2015) to 10 (2012), with a grand total of 40 over the course of the study. Sampling was conducted when shovelnose sturgeon or blue sucker were likely to be captured while possibly

144 spawning based on the day of the year, river flows, and air and water temperatures. On each
145 sampling date water temperature was measured at approximately 10 a.m. and flow was
146 determined from the U.S. Geological Survey gage at Muscoda at RK 72. Surveys were carried
147 out no more than once per week to limit disturbance of potentially spawning fish. In most years
148 the sequence of sampling events did not completely encompass the entire potential spring
149 spawning season for both species, missing the earliest or latest spawning dates for at least one
150 of the species because of unavailability of staff for sampling. However, in 2012 surveys were
151 conducted from late March through mid-June and covered the entire potential spawning period
152 for both species.

153 Fish were collected using a standard Wisconsin Department of Natural Resources boat-
154 mounted pulsed DC electroshocker with two netters. The shocker had two fiberglass booms
155 extending from the bow that comprised the anode, each with a 0.9-m diameter aluminum ring
156 with ten 15-mm diameter aluminum droppers that contacted the water, and the 1.8 X 5.5 m
157 aluminum hull of the boat served as the cathode. Power was derived from a 6500 W generator
158 that produced electricity with a pulse rate of 60 Hz, a 25% duty cycle, and peaks of 15-20 A and
159 450-600 V in the water. Shocking occurred in a downstream direction at a speed of
160 approximately 0.5 m s^{-1} . At this rate, the index station took nearly 3 h of shocking to complete.

161 Attempts were made to capture all shovelnose sturgeon and blue sucker observed
162 during sampling, although many were missed. Captured fish were measured for fork length (FL;
163 shovelnose sturgeon) or total length (TL; blue sucker) to the nearest mm and weighed to the
164 nearest 50 g. When possible, sex was determined from external characteristics including nuptial

165 tubercles for blue sucker (many more and better developed for breeding males, gradually
166 fading in number and development after spawning; Moss et al., 1983) and relative shape of the
167 abdomen and expression of gametes for both species. From 2010 to 2015, the reproductive
168 status of fish was also coded, when apparent, as not yet spawned ("green"; abdomen distended
169 but no eggs or sperm expressed when gently squeezed), actively spawning ("ripe"; eggs or
170 sperm readily expressed), or completed spawning ("spent"; abdomen shrunken or flaccid and
171 no eggs or sperm expressed). During most sampling events the sex and reproductive status of
172 blue sucker could be readily ascertained, but the sex and status of shovelnose sturgeon could
173 be determined unequivocally for only a few individuals each year. Moreover, the reproductive
174 status criteria are based on relatively imprecise and sometimes misleading characteristics, so
175 this categorization must be interpreted with caution. From 2007 through 2013 fish were tagged
176 with a 134.5-Hz full-duplex Passive Integrated Transponder (PIT) tag in the dorsal surface just
177 behind the head. Fish were checked for PIT tags in all sampling years. No attempt was made to
178 estimate or adjust for tag retention over time, which has been reported to range from 73-92%
179 in shovelnose sturgeon (Hamel et al., 2012), so all recapture rates represent minimum
180 estimates. In 2007 and 2009-2013, pectoral fin rays were removed from a subsample of fish (up
181 to 5 per each 25 mm length class) for aging. Fin rays were cleaned, embedded in epoxy, finely
182 sectioned perpendicular to the long axis of the ray using an electronic low-speed circular
183 diamond-blade saw, mounted on a glass slide, and examined under a microscope for annuli.
184 Three of the authors (DW, JH, PK) independently examined the sections for each fish and
185 determined age. If age estimates for a fish differed among the three, they then examined the

sections together and, if possible, determined a consensus age. Fish for which a consensus age could not be determined were excluded from analyses.

During sampling of the index station in 2012, efforts were made to characterize the specific locations where fish were potentially spawning. A combination of strong and often turbulent currents, turbid water (Secchi depth usually < 0.8 m), and the tendency for the electroshocker to pull fish toward the anode precluded the quantitative delineation of the precise location and microhabitat that individual fish occupied, but the general location of the fish within each shoal – head (upstream portion), middle, and tail (downstream portion) – could be readily determined. As sampling conditions permitted, the depth and surface velocity ranges of these locations were estimated from the sampling boat during breaks in electrofishing. Other fishes found spawning (based on capture of ripe individuals) in the same general habitats as shovelnose sturgeon and blue sucker were also noted.

Data analyses

Catches, lengths, weights, sex, and reproductive status of potentially spawning shovelnose sturgeon and blue sucker were summarized by sampling date, year, and location. Catches were expressed as number per ha of coarse rocky substrate (Table 1) for comparisons among locations. Each sample site included substantial amounts of both rocky and sandy substrate, and while captures were not separated between the two substrate types, field observations indicated that more than 95% of captures came from the rocky areas, so it was most appropriate to make catch comparisons among sites based on the relative amount of rocky

substrate. Minimum, maximum, and mean fish lengths were calculated, and counts of males and females and green, ripe, and spent individuals were determined. Delineation of possible spawning periods was based on the dates when ripe or apparently recently spent individuals were present. Lengths and weights of males and females were compared across dates and year using t-tests and analysis of variance (ANOVA) in SAS (SAS 2015; http://www.sas.com/en_us/software/analytics/stat.html, most recently accessed 6 May 2016) and differences were considered significant if $P < 0.05$. Simple linear regression was employed to correlate estimated age and years-at-large after tagging with length metrics. Recaptures of PIT-tagged individuals were used to characterize growth, homing to the upstream and downstream substations within the index station, and potential spawning periodicity. Contingency tables of locations of captures and recaptures were analyzed with Fisher's Exact Test. We attempted to use the recapture data to estimate population sizes of spawning fish using Cormack-Jolly-Seber models in program Rcapture (R version 3.2.4; <https://www.r-project.org/>; most recently accessed 6 June 2014). However, because of no or relatively few recaptures on some dates, most population estimates were highly imprecise, with excessively wide 95% confidence intervals (e.g., population estimate for spawning male blue sucker in 2010: 1139 fish; 95% confidence interval 103 to 4891 fish), and we chose not to report them here.

Results

Possible spawning locations and habitats

228 Shovelnose sturgeon in the LWR may have spawned at fewer locations and habitats than blue
229 sucker. Presumed spawning shovelnose sturgeon were essentially limited to only one 7-km
230 segment of the LWR, from RK 137.7-144.7, which included the index station, at only one coarse
231 rocky habitat type, mid-channel shoal. The only exception was a single shovelnose sturgeon of
232 unknown reproductive status collected from an eroding bluff shoreline habitat between RK
233 74.4-76.3 on 14 May 2008. In contrast, presumed spawning blue sucker were observed at 10 of
234 the 11 coarse rocky habitat patches in the LWR and at all three habitat types, eroding bluff
235 shoreline, mid-channel shoal, and wing-dam and rip-rap shorelines (Table 1). Spatial extent,
236 depth, and velocity ranges were similar for the three habitat types, but the mid-channel shoals
237 were unique in having rocky substrate in the middle of the river channel, as opposed to just
238 along the shoreline. Also, unlike the bluff shorelines and wing-dam and rip-rap shorelines, the
239 mid-channel shoals lacked boulders and bedrock.

240 At the index station, shovelnose sturgeon and blue sucker were commonly captured
241 together, although the species differed significantly in the location within each mid-channel
242 shoal where they were most likely to be encountered (Fisher's Exact Test: $P < 0.0001$). At typical
243 spring flows the head of the shoals had moderate surface velocities ($0.4\text{--}1.0\text{ m s}^{-1}$), moderate
244 depths ($0.8\text{--}1.4\text{ m}$), and relatively smooth flows; the middle was riffle-like with high surface
245 velocities ($1.0\text{--}1.6\text{ m s}^{-1}$), shallow depths ($0.5\text{--}0.8\text{ m}$), and turbulent flows; and the tails had
246 moderate surface velocities, moderate to deep depths ($0.8\text{--}2.0\text{ m}$), and relatively smooth flows.
247 In 2012, shovelnose sturgeon ($N=213$) were most frequently observed near the river bottom in
248 the tails of the shoal (76.1%), less frequently in the head (21.6%), and infrequently in the
249 middle (2.4%). Conversely, blue sucker ($N=261$) were most frequently found near the river

bottom in the heads of the shoals (67.8%), less frequently in the tails (27.6%), and least frequently in the middle (4.6%). Thus, both species were most commonly encountered at similar velocities ($0.4\text{--}1.0\text{ m s}^{-1}$) and depths (0.8–2.0 m) and generally were infrequently observed at the shallowest, fastest, and most turbulent areas of the shoal, but the species were partially segregated spatially, with blue sucker mainly towards the upstream end of the shoal and shovelnose sturgeon towards the downstream end.

Tagging and recapture data from the two substations within the index station indicated that both species tended to home to the same location in multiple years (Table 2). Fish tagged during presumed spawning and then recaptured at least one year later during presumed spawning were significantly more likely to be recaptured in the same substation where they had been tagged than in the other substation (Fisher's Exact Test: $P < 0.0001$ for each species separately).

Possible timing of spawning

Although shovelnose sturgeon and blue sucker were captured together from the index station on all sampling dates, potential spawning, based on the presence of ripe or apparently recently spent fish, overlapped only slightly between the two species, with blue sucker presumably spawning earlier in the spring at cooler water temperatures and generally higher flows. In 2012, water temperatures warmed unusually early in the spring in late March during a period of lower-than-normal flows but then plateaued for over a month before rising along with flows in early May. The first ripe male blue sucker was collected on 28 March 2012 at a water

271 temperature of 12.0°C and a flow at the Muscoda gage of 276.1 m³ s⁻¹ and the first ripe female
272 on 5 April at 11.5°C and 239.8 m³ s⁻¹ (Figure 1). The last ripe female was sampled on 10 May at
273 15.3°C and 597.5 m³ s⁻¹ and the last ripe male on 24 May at 20.3°C and 182.4 m³ s⁻¹, for a total
274 possible spawning period of over four weeks when both ripe males and females were present.
275 The first of the few ripe shovelnose sturgeon observed (all males) occurred on 24 May, but
276 what may have been a recently spent female was observed on 17 May at 18.0°C and 288.8 m³ s⁻¹,
277 indicating a possible earlier start of spawning than the presence of ripe males would suggest.
278 The last ripe male was encountered on 31 May at 20.5°C and 227.1 m³ s⁻¹, but a possible
279 recently spent female was collected on 14 June at 21.8°C and 117.2 m³ s⁻¹, documenting that
280 possible spawning may have continued into June and suggesting a potential total spawning
281 period of three to four weeks.

282 Data from years with more typical spring warming and a variety of flow patterns,
283 although not always completely covering the entire potential spawning period, suggest that
284 blue sucker spawning may have started later and lasted for a shorter period than it did in 2012.
285 In the three other years with both multiple samples and data on reproductive status, the first
286 day of the year in which a ripe or presumably recently spent female blue sucker was collected
287 was 15 April 2010 at 13.0°C and 196.0 m³ s⁻¹, 5 May 2011 at 8.0°C and 790.0 m³ s⁻¹, and 2 May
288 2013 at 9.5°C and 716.4 m³ s⁻¹. The last day that a ripe female was encountered was 6 May
289 2010 at 15.5°C and 143.0 m³ s⁻¹, 12 May 2011 at 14.0°C and 354.0 m³ s⁻¹, and 9 May 2013 at
290 14.0°C and 540.9 m³ s⁻¹. Thus, in years with more standard warming patterns, blue sucker may
291 have had a spawning period of one to three weeks from late April through early to mid-May.
292 Considering all four years (2010-2013) together, blue sucker females may have spawned at

293 temperatures from 8.0-15.5°C and most observations of ripe fish were from 11.5-14.0°C. Flows
294 did not seem to be closely related to possible spawning since ripe females were observed in
295 April at flows of $< 200 \text{ m}^3 \text{ s}^{-1}$, well below the long-term (1913-2014) mean April flow of 470.1 m^3
296 s^{-1} , and in May at flows $> 500 \text{ m}^3 \text{ s}^{-1}$, well above the long-term mean May flow of $339.8 \text{ m}^3 \text{ s}^{-1}$.

297 Insufficient data were available to characterize the possible start, finish, or duration of
298 presumed shovelnose sturgeon spawning in years other than 2012, but limited observations of
299 ripe fish indicated dates, spawning temperatures, and flows when spawning may have taken
300 place. Ripe females were collected on 20 May 2010 at 16°C and $226.5 \text{ m}^3 \text{ s}^{-1}$ and 19 May 2011
301 at 13.5°C and $329.9 \text{ m}^3 \text{ s}^{-1}$, and ripe males were collected on 19 May 2011 and on 15 May 2014
302 at 13.8°C and $651.3 \text{ m}^3 \text{ s}^{-1}$. Combining these data with those from 2012, it appears that
303 presumed shovelnose sturgeon spawning may have occurred from mid-May through early June
304 for two weeks or more at temperatures of 13.5-21.8°C. The relation of flows to spawning was
305 unclear; ripe or possibly newly spent fish were observed at flows below, near, and well above
306 the long-term mean May flow of $338.9 \text{ m}^3 \text{ s}^{-1}$ and below the long-term mean June flow of 305.8
307 $\text{m}^3 \text{ s}^{-1}$.

308 Data from fish tagged and subsequently recaptured at least one year later at the index
309 station during the presumed spawning period provided some information on the possible
310 periodicity of reproduction. Thirty-six shovelnose sturgeon were recaptured once (3.2% of 1113
311 different fish sampled) and two were recaptured twice (0.2%) for 40 total recaptures, whereas
312 48 blue sucker were recaptured once (5.0% of 968 different fish sampled), seven twice (0.7%),
313 and two on three occasions (0.2%) for 68 total recaptures. Recapture intervals ranged from one

to five years with a mode of one year (45% of total recaptures) for shovelnose sturgeon and one to six years with a mode of one year (32%) for blue sucker (Figure 2). Only blue sucker had enough fish of known sex to compare males and females. Females had recaptures intervals of one to five years with a mode of two years (36% of female recaptures) followed by one year (30%), and males had intervals of one to six years with a mode of one year (33% of male recaptures) followed by two years and three years (each at 24%).

Shovelnose sturgeon and blue sucker potential spawning on the shoals of the index station overlapped with several other species. Over the period of 2007-2015, thousands of ripe quillback (*Carpionodes cyprinus*) and shorthead redhorse (*Moxostoma macrolepidotum*) were observed at approximately the same time as blue sucker from mid-April through early May. Although all three species were often seen together, quillback and shorthead redhorse were predominantly observed near the river bottom in shallower water (<0.8 m) than blue sucker, quillback mainly near shore in the head and tail of the shoals and shorthead redhorse across the channel in the middle of the shoal. Hundreds of ripe mooneye (*Hiodon tergisus*) and thousands of smallmouth buffalo (*Ictiobus bubalus*) were found within approximately the same time period as shovelnose sturgeon, mid to late May, with mooneye mainly in relatively deep water in the tail of the shoals but in the upper part of the water column rather than near the river bottom, and smallmouth buffalo in shallower water near shore in the head and across the channel in the middle of the shoals. A total of 46 lake sturgeon (*Acipenser fulvescens*) and 60 paddlefish (*Polyodon spathula*) were collected or observed at the head and tail of the shoals. Lake sturgeon were seen primarily during late April and early May and paddlefish mainly from late April through late May, but their reproductive status could not be determined.

336

337 **Attributes of potentially spawning fish**

338 Many sizes and ages of shovelnose sturgeon were collected at the index station during the
339 potential spawning period. Over the entire study, shovelnose sturgeon (N=1151; includes
340 recaptures) had a mean FL of 647 mm and a range of 487-788 mm with 95% of fish from 570-
341 700 mm. Mean weight was 1150 g and ranged from 500-2400 g. Female shovelnose sturgeon
342 (N=49) had a mean FL of 681 mm (range 602-782 mm) and weight of 1400 g (range 900-2150 g),
343 both of which were significantly greater ($t=5.30$ and 19.94 ; $P < 0.001$) than the male (N=39)
344 mean FL of 629 mm (range 510-733 mm) and weight of 1050 g (range 750-1500 g). Mean FL of
345 both female and male shovelnose sturgeon did not vary among years from 2008-2015, and
346 during 2012, mean FL of male and female shovelnose sturgeon did not show any significant
347 increasing or decreasing trends over the spring spawning period. Shovelnose sturgeon ages
348 (N=168) ranged from 5-20 years old with a median of 11 and 95% of aged fish from 6-16. Not
349 enough of the aged shovelnose sturgeon could be sexed to allow for age comparisons between
350 males and females. There was a significant trend for older shovelnose sturgeon to be longer
351 ($F=51.01$; $P<0.0001$; $r^2 = 0.23$), but for any particular length there was a wide variety of possible
352 ages, and for any particular age there was a wide variety of possible lengths (Figure 3). For
353 example, a 647 mm FL shovelnose sturgeon could range in age from 8-20, and an 11-year-old
354 shovelnose sturgeon could range in length from 520-720 mm FL.

355 A wide variety of sizes and ages of spawning blue sucker was also observed. Blue sucker
356 (N=1025; includes recaptures) had a mean TL of 641 mm and a range of 495-822 mm with 95%

of fish from 570-730 mm. Mean weight was 2250 g and ranged from 900-5100 g. Female blue sucker (N=422) had a mean TL of 671 mm (range 564-822 mm) and weight of 2700 g (range 1,500-5,100 g), both of which were significantly greater ($t=6.15$ and 17.16 ; $P<0.001$) than the male (N=472) mean TL of 617 mm (range 511-730 mm) and weight of 1,900 g (range 900-2,900 g). From 2008-2010 to 2012-2015 mean TL of both female ($F=4.63$; $P=0.004$) and male ($F=4.42$; $P=0.006$) blue sucker increased significantly, females from 660 mm to 681 mm and males from 609 mm to 626 mm. During 2012, mean lengths of male and female blue sucker did not show any significant trends over the spring spawning period. Blue sucker ages (N=173) ranged from 5-34 with a median of 14 and 95% of fish from 8-23. Males (N=81) were observed from age 5-25 with a median of 13 and 95% of aged fish from 5-22, and females (N=83) from 7-34 with a median of 16 and 95% from 8-22. For both males ($F = 80.79$; $P < 0.0001$; $r^2 = 0.50$) and females ($F = 18.24$; $P < 0.0001$; $r^2 = 0.17$), older fish tended to be longer (Figure 3). Males were usually shorter than females at any given age, although this difference decreased with fish age, from about 50 mm at age 10 to about 30 mm at age 20.

Overall, based on tagged and recaptured fish from the index stations during presumed spawning, growth in length of mature fish was very slow for both species (Figure 4). For shovelnose sturgeon, there was no correlation between the number of years between tagging and first recapture and the change in fork length, suggesting that mature fish were not growing. Indeed, two of three individuals recaptured five years after tagging had shorter lengths at recapture, although this could have been the result of measurement error (Phelps et al., 2013). For blue sucker, there was a positive relation between the number of years between tagging and first recapture and the change in total length ($F = 18.37$; $P < 0.0001$; $r^2 = 0.28$), indicating

positive growth, but based on the slope of the relationship, the rate of growth was slow, 3.5 mm y⁻¹. This rate represented a gain of less than 1% in total length each year. There was no difference in growth rate between male and female blue suckers.

Discussion

A key assumption in our study was that the collection of apparently mature and reproductively ready individuals indicated an area where and a time when these fish were actually spawning. The locations where we captured fish were too deep and turbid to observe spawning directly, and we lacked the resources to sample for eggs or newly hatched larvae to document that spawning had occurred. For blue sucker, the assumption of actual spawning was likely valid because nearly all fish collected were mature and in reproductive condition based on tuberculation patterns and abdominal appearance, fish were concentrated at unusually high densities in particular habitats and under environmental conditions that appeared suitable for spawning based on previous studies (e.g. Moss et al., 1983; Vokoun et al., 2006; Daugherty et al., 2008), and on some dates most individuals were ripe and readily expressed gametes. For shovelnose sturgeon, the certainty of spawning was lower because overall fewer than 10% of captured individuals could be definitively sexed and designated as ready to spawn. The sex and reproductive status of shovelnose sturgeon is difficult to determine based on external characteristics (Kennedy et al., 2006), and we lacked the resources to use accurate non-lethal internal techniques such as endoscopy (Wildhaber et al., 2007; Bryan et al., 2007), so the proportion of fish captured that truly was reproductively ready was unknown. Evidence for actual spawning by shovelnose sturgeon at a particular time and place was indirect and

401 included dense concentrations of fish in habitats and under environmental conditions that
402 appeared conducive to spawning based on previous studies (e.g. Hurley and Nickum, 1984;
403 Goodman et al., 2013; Hamel et al., 2015a) and the collection of a few ripe fish that readily
404 expressed gametes. However, there was much greater uncertainty about the reproductive
405 status of shovelnose sturgeon compared to blue sucker, meaning that we have higher
406 confidence in the reliability of our findings about the potential spawning of blue sucker.

407 With this caveat in mind, based on our review of the literature (summarized in
408 Keenlyne, 1997; Burr and Mayden, 1999; Harris et al., 2014, Kuhajda, 2014), our study appears
409 to be one of only a few to describe specific attributes of the potential spawning habitat for
410 shovelnose sturgeon and blue sucker. We found that both species possibly spawned on coarse
411 rocky substrate at depths of 0.8-2.0 m and surface velocities of $0.4\text{--}1.0\text{ m s}^{-1}$. Although several
412 previous studies have inferred that shovelnose sturgeon spawn on coarse rocky substrate, we
413 could find only one literature citation of a confirmed spawning habitat for shovelnose sturgeon,
414 a natural mid-channel rocky riffle of unspecified substrate composition, depth, and current
415 velocity in the lower Marias River system, a Missouri River tributary in Montana (Goodman et
416 al., 2013). More literature is available for blue sucker. In the Wabash River Indiana, spawning
417 blue sucker were captured over substrates of sand, gravel, and cobble at depths of 0.3-3.0 m
418 (Daugherty et al., 2008). In the Neosho River, Kansas, blue sucker spawned in cobble-bedrock
419 riffles of 1-2 m depth, and spawning adults were captured in water 1.4 m deep at a velocity of
420 1.8 m s^{-1} (Moss et al., 1983). Finally, in the Grand River, Missouri, blue sucker spawning took
421 place in a cobble-boulder riffle complex with fish most concentrated in areas 0.5-1.0 m deep
422 with velocities greater than 1.0 m s^{-1} (Vokoun et al., 2003).

From our results, it appeared that shovelnose sturgeon may have used a narrower range of possible spawning locations and habitats than blue sucker in the LWR. Whereas shovelnose sturgeon were found possibly spawning essentially only within a 7-km reach on natural mid-channel shoals, possibly spawning blue sucker occurred over much of the length of the LWR and were found on both natural and artificial rocky substrate. However, based on other studies there is some indication that possible shovelnose sturgeon use of mid-channel shoals in the LWR may represent a spawning habitat preference rather than a habitat requirement. Radio telemetry and netting of ripe shovelnose sturgeon in areas of the Mississippi and Missouri rivers where mid-channel shoals are absent suggest that shovelnose sturgeon may spawn in areas of artificial boulder and cobble substrate, including wing dams, rip-rapped banks, and dam tailwaters, and even directly on sand, although direct confirmation of spawning is lacking (Hurley and Nickum, 1984; DeLonay et al., 2009; Bonnott et al., 2011; Hamel et al., 2015a).

The use of artificial rocky substrates by presumably spawning blue sucker in the LWR and possibly by shovelnose sturgeon in the Mississippi and Missouri rivers suggests that additions of cobble and boulder might increase available blue sucker and shovelnose sturgeon spawning habitat in predominantly fine-substrate channels where suitable coarse rocky substrate was absent or limiting. Shoreline rip-rap additions have been used to increase spawning habitat for lake sturgeon in the lower Wolf River, Wisconsin, and the St. Lawrence River, New York (Folz and Meyers, 1985; Bruch and Binkowski, 2002; Johnson et al., 2006). Lake sturgeon readily spawned on recently added shoreline rip rap, and their eggs hatched and yielded viable fry. However, we have no data on relative egg survival or hatching success for blue sucker or shovelnose sturgeon in natural vs. artificial coarse rocky areas, and additional

study is needed before rock addition can be recommended as a spawning habitat enhancement technique for these two species. Moreover, even if artificial rocky substrates did prove to yield successful blue sucker or shovelnose sturgeon spawning and fry production, care would be needed in determining the placement and amount of artificial rocky substrate used in a spawning habitat enhancement initiative. Shoreline rip-rap and wing dams alter flow and erosion patterns and can reduce large woody debris recruitment from the river banks (Angradi et al., 2010), possibly leading to reduced species diversity and biotic integrity, as may have occurred in some areas of the Wolf River (Lyons, 2005b).

In the natural mid-channel shoals of the LWR, shovelnose sturgeon and blue sucker each appeared to spawn at the same time and in the same general area as several other species. However, our qualitative observations suggested that at least some habitat partitioning occurred. Blue sucker appeared to use deeper and slower areas for presumed spawning than either quillback or shorthead redhorse. Those two species used shallower and, in the case of shorthead redhorse, more turbulent, areas, consistent with published descriptions of their spawning habitat (Burr and Morris, 1977; Sule and Skelly, 1985; Parker and Franzin 1991, Catalano and Bozek, 2015). Shovelnose sturgeon also appeared to use deeper and slower areas than apparently spawning smallmouth buffalo. Previous descriptions of smallmouth buffalo spawning habitat, albeit limited in scope, have emphasized deep pools and backwaters with vegetation (Edwards and Twomey, 1982), so our observations of smallmouth buffalo spawning on main-channel shoals may represent a novel spawning habitat. Shovelnose sturgeon appeared to spawn in the same areas of the shoals as mooneye, but shovelnose sturgeon presumably deposited their eggs on the bottom whereas mooneye appeared to spawn off the

bottom in the middle to upper part of the water column (see also Wallus and Buchanan, 1989). Lake sturgeon and paddlefish used the same benthic areas of the shoals as did presumably spawning shovelnose sturgeon and blue sucker, but they were far less numerous, with never more than six individuals observed on a sampling date, and we could not confirm that they were actually spawning.

To our knowledge, homing of potentially spawning fish to specific river areas, as we observed on the mid-channel shoals in the LWR, has not been tested for or documented for other populations of shovelnose sturgeon or blue sucker. However, site-specific homing has been observed for several other sturgeon species (Kuhajda, 2014) and for the southeastern blue sucker, *C. meridionalis* (Harris et al., 2014), and thus seems likely to occur more widely in shovelnose sturgeon and blue sucker. The minimum rate of straying from previous potential spawning sites in the LWR, on the order of 14-18%, is within the 0-20% range that has been reported for most anadromous and marine fishes (Quinn, 1993; Thorrold et al., 2001). Neely et al. (2009) used telemetry of radio-tagged fish to determine that blue sucker in the Missouri River migrated upstream as much as 200 km to spawn but then after spawning quickly returned to an area within 4 km of their original tagging location, indicating a tendency to home outside of the spawning season.

Our data on the timing of and environmental conditions during presumed spawning are consistent with previous studies on shovelnose sturgeon. Across their range, shovelnose sturgeon have been reported to spawn from late April through late June at water temperatures of 12-24°C (Keenlyne, 1997; Kennedy et al., 2006; Tripp et al., 2009; Goodman et al., 2012),

which fully encompasses the presumed spawning period (mid-May-early June) and temperatures (13.5-21.8°C) inferred for shovelnose sturgeon in the LWR. In the nearby Red Cedar-Chippewa River system in west-central Wisconsin, shovelnose sturgeon spawning was reported to occur mainly in late May and early June at 14.4-21.1°C (Christenson, 1975). Shovelnose sturgeon in the Middle Mississippi River in Missouri and Illinois and in the Platte River in Nebraska have also been observed to spawn in September and October (Tripp et al., 2009; Hamel et al., 2015a), but we did not check for fall spawning in the LWR. In the LWR, timing and duration of presumed shovelnose sturgeon spawning had no obvious relation with river discharge. Conversely, in the Marias River system in Montana, a tributary of the upper Missouri River, spring spawning was associated with rising flows, and spawning did not occur in dry years without a strong spring rise in discharge (Goodman et al., 2012). However, the Marias River was much smaller, with spring low flows only about 10-25% of those in the LWR. In the upper Missouri River, which had about twice the flow of the LWR, shovelnose sturgeon spawning activities did not differ between two years with substantially different spring flows (Richards et al., 2013). Thus the potential importance of river flow to shovelnose sturgeon spawning is complex and may depend on the size of the river.

For blue sucker, the timing of and environmental conditions during presumed spawning in the LWR were only partially concordant with values from the literature. Blue sucker spawning has been reported to occur from March through June, depending on latitude and elevation, but mainly during April and May at water temperatures of 10-23°C with spawning peaks at 14-20°C (Moss et al., 1983; Burr and Mayden, 1999; Vokoun et al., 2003; Bednarski and Scarnecchia, 2006). In the LWR, spawning appeared to occur during late April and early May at water

510 temperatures of 8-15.5°C, somewhat cooler than other sites where the species has been
511 studied. For example, in the Neosho River, Kansas, spawning did not occur until water
512 temperatures reached 17-20°C (Moss et al., 1983), and in the Grand River, Missouri, spawning
513 peaked at 16.5°C, temperatures at which spawning had apparently already ended in the LWR.
514 In the mid-channel shoals of the LWR there was little relation between river flow and catches of
515 possibly spawning fish, but elsewhere, spawning was often associated with a rise in river stage
516 (Moss et al., 1983; Vokoun et al., 2003; Bednarski and Scarnecchia, 2006). Blue sucker in the
517 LWR may also have spawned at somewhat lower current velocities ($0.4\text{-}1.0\text{ m s}^{-1}$) than has been
518 reported for other populations ($>1.0\text{-}1.8\text{ m s}^{-1}$; Moss et al., 1983; Vokoun et al., 2003).

519 Our recapture data suggest that many shovelnose sturgeon and blue sucker may spawn
520 in consecutive years in the LWR. If we assume that occurrence on the mid-channel shoal during
521 a period when fish were reproducing meant that an individual was spawning, our recapture
522 intervals indicate that at least 45% of shovelnose sturgeon, 36% of female blue sucker, and 33%
523 of male blue sucker might spawn annually. These are minimum estimates because even though
524 a fish might be spawning every year, our sampling could have missed them in some years,
525 giving the false appearance of a multi-year return time for spawning. Our finding of large
526 proportions of shovelnose sturgeon possibly spawning annually, including at least one female,
527 is unusual; previous studies from other populations have consistently reported that most
528 shovelnose sturgeon do not spawn every year, with a spawning periodicity of 2-5 years for
529 females and 1-2 years for males (Keenlyne, 1997; Tripp et al., 2009; Hamel et al., 2015a).
530 Several of these studies have examined gonad characteristics during the spring spawning period
531 to document actual spawning by individuals. It is possible that most of the shovelnose sturgeon

that appeared to spawn in consecutive years in the LWR were males. We cannot find any previous estimates of spawning periodicity in blue sucker. Pledger et al. (2013) developed a statistical model that used recapture data to estimate the precise distribution of spawning return times within a population. We attempted to use this model, but it required more individuals with multiple recapture histories than we had, and consequently the model did not converge and we could not generate spawning interval estimates.

The sizes and ages of possibly spawning shovelnose sturgeon and blue sucker in the LWR generally agreed with results from past studies. In the LWR, mature shovelnose sturgeon ranged from 487-798 mm FL and 5-20 years in age whereas mature blue sucker ranged from 495-822 mm TL and 5-34 years in age, with females generally longer than males at any given age. Elsewhere, the smallest and youngest mature shovelnose sturgeon in a population were 449-601 mm FL and age 5-9, and the largest and oldest were 725-848 mm FL and age 16-43 (Keenlyne et al., 1999; Everett et al., 2003; Kennedy et al., 2006; Tripp et al., 2009; Hamel et al., 2015a; Nepal KC et al., 2015). The smallest and youngest mature blue sucker were 444-515 mm TL and age 3-9, and largest and oldest were 701-822 mm TL and age 16-37, with females larger than males at a given age (Rupprecht and Jahn, 1980; Moss et al., 1983; Vokoun et al., 2003; Bednarski and Scarnecchia, 2006; Daugherty et al., 2008; Bacula et al., 2009).

However, the accuracy of shovelnose sturgeon and blue sucker ages from our and other studies is uncertain. Some studies of blue sucker age relied on scales, which yielded lower ages than fin rays once age exceeded 7 years (Rupprecht and Jahn, 1980; Moss et al., 1983; Bacula et al., 2009; Labay et al., 2011). We found blue sucker fin rays difficult to age above 10 years, and

we lack confidence in the accuracy of many of our older ages. For shovelnose sturgeon, marginal increment analysis of fin rays indicated that features on the ray that were perceived as annuli did not necessarily correspond to true annual growth marks, suggesting that age estimates from fin rays may be inaccurate (Rugg et al., 2014). If that is the case, then all shovelnose sturgeons ages (and perhaps blue sucker as well) are in question.

Our mark-recapture results for shovelnose sturgeon and blue sucker from the LWR and literature values for shovelnose sturgeon indicate that growth in length was minimal for adult fish. We observed negligible growth in shovelnose sturgeon and very slow growth in blue sucker, < 1% per year. A meta-analysis of 14 shovelnose sturgeon populations (including the LWR) throughout the species range concluded that most fish had almost no growth in length after they reached maturity (Hamel et al., 2015b). In the Red Cedar-Chippewa River system, Wisconsin, recaptured shovelnose sturgeon had only grown an average of 0.75 mm per year since tagging (Christenson and Hatzenbeler, 1996), well within the range of measurement error (Phelps et al., 2013). We could not find any mark-recapture growth estimates for adult blue sucker in the literature.

Despite negligible growth for adult shovelnose sturgeon and very slow growth for adult blue sucker in the LWR, a wide range of adult sizes was present, 487-788 mm FL for shovelnose sturgeon and 495-822 mm TL for blue sucker. To account for size ranges of this magnitude, one or more of the following must have been true: 1) the largest fish were much older than our maximum estimates of 20-34 years, perhaps on the order of 50-100 years, reaching a large size despite a slow growth rate by living for many years; 2) substantial growth of mature fish

574 occurred in the past but was episodic and infrequent and did not take place during the six-year
575 period for which we had recaptures of tagged fish; or 3) individuals matured at different sizes
576 and perhaps ages such that some matured and then essentially stopped growing at relatively
577 small sizes and presumably young ages whereas others deferred maturation and continued
578 growing until they had reached a larger size and older age and then matured and ceased or
579 greatly reduced growth.

580 These three explanations are not mutually exclusive and could all be occurring in the
581 LWR, although we believe number three is most important. A von Bertalanffy analysis for LWR
582 shovelnose sturgeon estimated a maximum age of over 60, the highest of any of 14 populations
583 analyzed (Hamel et al., 2015b). However, the oldest ages ever actually reported for any
584 populations based on fin rays were 43 for shovelnose sturgeon (Everett et al., 2003) and 37 for
585 blue sucker (Bednarski and Scarnecchia, 2006). We believe that it is possible that some
586 shovelnose sturgeon and blue sucker in the LWR live well beyond age 20-34, but our estimates
587 for the largest fish we collected were only age 11-23 (Figure 3), and despite some lack of
588 confidence in these values, we are skeptical that our age estimates were off by a factor of three
589 to five. Thus we do not believe that long life alone can explain the sizes of our largest
590 individuals. Episodic and infrequent bursts of growth in response to varying environmental
591 conditions have been reported for some riverine populations of long-lived freshwater mussels
592 based on analyses of annuli spacing on their shells (Haag and Rypel, 2011), and similar growth
593 patterns seem plausible for riverine fishes. However, we did not see patterns of annuli spacing
594 on the fin rays we examined that would suggest episodic growth. Moreover, if such bursts of
595 growth were as infrequent as our mark-recapture data suggest, occurring with return intervals

596 of several years or more, a very old age would be required to achieve a large size, much greater
597 than the ages we observed.

598 We believe that variation in the size and age at which individuals become mature and
599 cease growth is the most parsimonious explanation for the wide size ranges of adult shovelnose
600 sturgeon and blue sucker that we observed in the LWR. Under this explanation, extremely long
601 lifetimes need not be invoked to account for large size. Data on size and age at maturation from
602 shovelnose sturgeon from the Middle Mississippi River, Missouri/Illinois, and the Platte River,
603 Nebraska, support this idea and indicate that whereas the smallest and youngest mature fish
604 were on the order of 450-500 mm FL and age 4-7 and that most fish had matured by about 600-
605 650 FL and age 10-12, some fish did not mature until 700-750 mm FL and age 13-18 (Tripp et
606 al., 2009; Hamel et al., 2015a). This variation nearly encompasses the range of size and ages we
607 found in mature shovelnose sturgeon in the LWR. No maturity schedules have been published
608 for blue sucker, but many other species also display a wide range of sizes and ages at maturity
609 within a population (e.g. Stahl and Kruse, 2008).

610 Our study has provided new insights into the potential reproductive ecology of
611 shovelnose sturgeon and blue sucker that are relevant to their conservation, particularly
612 regarding possible spawning habitat, homing to spawning sites, timing of reproduction and
613 potential environmental cues, and attributes of spawners. But it has raised many new questions
614 as well, such as if presumed shovelnose sturgeon use of mid-channel rocky shoals for spawning
615 is obligatory or facultative, whether either or both species reach much greater ages than fin-ray
616 sections indicate, and how a wide range of adult sizes can be achieved when adult growth of

617 both species appears to be minimal. Research has revealed much about the biology of
618 shovelnose sturgeon and blue sucker in recent years, but as our study illustrates, much remains
619 to be learned.

620

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777

778 Table 1. Characteristics of rocky habitat patches in the 149-km-long, 8,200 ha Lower Wisconsin River, and electrofishing catch rates
 779 (number/ha of rocky habitat) of presumably spawning shovelnose sturgeon and blue sucker during three time periods: A = 14-15 May 2008;
 780 B = 18-26 April 2012; C = 3-10 May 2012. A “—” indicates that the habitat patch was not sampled during a time period. River kilometer
 781 specifies the distance from the mouth of the river to the downstream and upstream boundaries of the habitat patch. For rocky substrate,
 782 Be = bedrock, Bo = small boulder, C = cobble, G = coarse gravel. Rocky substrates > 10% of the surface area of the patch are listed in order of
 783 prevalence.

784	River	Habitat	Surface	Substrate	Depth	Velocity	<u>S. sturgeon catch</u>			<u>Blue sucker catch</u>		
785	kilometer	type	area (ha)	types	(m)	(m s ⁻¹)	A	B	C	A	B	C
786												
787	30.0-31.1	Eroding bluff	2.2	C, Bo, G	0.5-2.0	0.5-1.2	---	0.0	0.0	---	0.0	0.5
788	59.1-60.4	Eroding bluff	3.9	Be, C, Bo, G	0.0-1.5	0.5-1.2	0.0	0.0	0.0	1.0	0.5	1.8
789	69.8-71.4	Eroding bluff	4.8	Bo, Be, C, G	0.5-1.0	0.5-1.2	0.0	---	---	2.3	---	---
790	74.4-76.3	Eroding bluff	5.7	Be, C, Bo, G	0.5-1.0	0.5-1.0	0.2	0.0	0.0	2.1	0.0	1.4
791	136.6-137.1	Eroding bluff	1.5	Be, Bo, C	0.6-0.9	0.3-0.7	---	0.0	0.0	---	0.0	0.0
792	137.7-139.0	Mid-channel shoal	2.6	C, G	0.3-1.8	0.8-1.6	---	4.6	5.4	---	0.4	1.2
793	139.7-141.1	Mid-channel shoal	3.9	C, G	0.5-1.8	0.5-1.5	12.3	2.4	0.9	2.1	0.8	1.8
794	142.9-144.7	Mid-channel shoal	5.0	C, G	0.0-2.0	0.8-1.6	1.8	2.3	3.2	2.2	1.4	2.6
795	147.0-147.4	Wing-dam, rip-rap	1.0	Bo, C	0.0-1.8	0.5-1.3	0.0	0.0	0.0	0.0	1.0	1.0
796	147.9-148.2	Wing-dam, rip-rap	1.0	Bo, C	0.0-1.5	0.8-1.5	0.0	0.0	0.0	0.0	1.0	1.0
797	148.5-149.1	Wing-dam, rip-rap	2.9	Bo, C, G	0.0-3.0	0.3-1.8	0.0	0.0	0.0	0.0	0.3	1.1
798												

799 Table 2. Number of fish tagged and then recaptured at least one year later, from 2007-2015, with percent of total recaptures in
800 parentheses, during presumed spawning at the two substations of the 5-km index sampling station between river kilometer 139.7-144.7.

801

		Recapture substation			
		(% of total recaptures)			
		Tagging	Number	-----	
		substation	tagged	Upstream	Downstream
					Total
Shovelnose Sturgeon		Upstream	382	18 (40%)	3 (7%)
		Downstream	681	3 (7%)	21 (47%)

		Total	1063	21	24
					55
Blue Sucker		Upstream	405	25 (42%)	5 (8%)
		Downstream	459	6 (10%)	23 (40%)

		Total	864	31	28
					59

817

818

819 Fig. 1. Presumed spawning status of shovelnose sturgeon (N=198) and blue sucker (n=276) sampled
820 from the 5-km index station between river kilometer 139.7 and 144.7 during spring 2012. A)
821 shovelnose sturgeon, both sexes. For this and panels B and C, solid gray indicates that sex and
822 spawning status could not be determined based on external characteristics, vertical hatching
823 indicates individuals that could be sexed but appeared not yet to have spawned ("green), black
824 indicates individuals apparently in the midst of spawning ("ripe"), and diagonal hatching indicates
825 individuals that appeared to have completed spawning ("spent"). B) blue sucker females. C) blue
826 sucker males. D) surface water temperature measured at approximately 10 a.m. during sampling.

827

828 Fig. 2. Frequency histograms (expressed as a percentage of total recaptures; shovelnose sturgeon =
829 55; blue sucker = 59) for number of years between tagging and recapture for fish tagged and
830 subsequently recaptured within the index station during presumed spawning for the years 2007-
831 2015. For each bar, solid indicates fish of unknown sex, hatched females, and diagonal males.
832 Overall, 1063 shovelnose sturgeon and 864 blue sucker were tagged at the index station.

833

834 Fig. 3. Estimated ages vs. length for mature shovelnose sturgeon (N=168) and blue sucker (N=160)
835 with regression lines. Open circles indicate unknown sex, solid circles females, and solid triangles
836 males.

837

838 Fig. 4. Change in length in mm vs. years between tagging and first recapture during presumed
839 spawning at the index station for shovelnose sturgeon (N=37) and blue sucker (N=45) for the years
840 2007-2015. There is a significant regression line only for blue sucker.