Modification of a Passive Gear to Sample Paddlefish Eggs in Sandbed Spawning Reaches of the Lower Yellowstone River

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Abstract.—A passive sampling technique was developed to collect eggs and confirm potential spawning sites for paddlefish Polyodon spathula in sandbed reaches of the lower Yellowstone River, Montana and North Dakota. In 2000, egg collectors modeled after the mats used in sturgeon research proved difficult to retrieve from the riverbed and did not collect eggs. In 2001 and 2002, tubular egg collectors designed to remain suspended off the bottom were successfully retrieved 97% of the time and collected 130 acipensiform eggs along suspected spawning sites (99% of differentiable eggs were genetically confirmed as paddlefish). In both years, eggs were typically collected in mid-June after peak periods of Yellowstone River discharge and at river temperatures of 15–22°C. During collection periods in 2001 and 2002, 20% and 45% of retrieved tubes, respectively, had at least one egg, and 84% of all eggs were found on tubes retrieved from the channel thalweg. Although eggs were spatially distributed in a clumped manner at sample sites, the mean number of eggs per tube was low (<4), suggesting either collector inefficiency, the inability to deploy collectors in close proximity to concentrations of spawning paddlefish, or the widespread distribution of spawning effort over the lower Yellowstone River.

Paddlefish Polyodon spathula occupy large river habitats within the Mississippi River system and selected Gulf slope drainages. Although found within 22 states of the central and southeastern United States, their range and abundance have diminished from historic distributions, even in areas once considered strongholds (Hoxmeier and DeVries 1996; Graham 1997). The declines have been attributed mainly to large river modifications that have not only diminished productive rearing habitats but created conditions less favorable for successful reproduction (Sparrowe 1986). Impoundments have disrupted cues used by spawning paddlefish through the alteration of spring thermal and flow regimes and have inundated and blocked access to suitable spawning habitat (Unkenholz 1986; Hesse and Mestl 1993). Because of poor natural recruitment of many stocks and the potential for spawning reaches to be further altered through ongoing large river modifications, an understanding of habitat requirements for spawning paddlefish is needed.

The general requirements for successful reproduction in the wild have been described (Jennings and Zigler 2000). Paddlefish have been found to broadcast their eggs over well-swept gravel bars coincident with periods of rising temperature and discharge during the spring (Purkett 1961; Pasch et al. 1980; Russell 1986). Gravel–rubble substrate provides suitable attachment sites for the adhesive eggs, whereas adequate current velocity prevents siltation during the incubation period (6–12 d depending on temperature; Yeager and Wallus 1982). Spawning habitat has typically been identified within tailwater reaches, where dams tend to concentrate paddlefish during the spring (Pasch et al. 1980; Wallus 1986; Lein and DeVries 1998). However, detailed studies investigating spawning habitat along unregulated rivers are few, and spawning reaches have not been delineated for most stocks (Jennings and Zigler 2000).

Sexually mature, migratory paddlefish of the Yellowstone–Sakakawea stock of eastern Montana and western North Dakota are found along the lower Yellowstone River during the spring spawning period (Robinson 1966; Rehwinkel 1978). Although larval collections have demonstrated paddlefish reproduction in the lower river reaches (Gardner 1996; Liebelt 1996), spawning sites have not yet been identified. Whether sites are confined to specific reaches or are widely scattered is not known; however, preserving existing spawning habitat requires determining the distribution of these sites along the lower Yellowstone River.

Various techniques have been used to identify paddlefish spawning habitat. Purkett (1961) first identified spawning sites along the Osage River, Missouri, as receding water levels revealed exposed eggs along gravel bars. Active methods such as plankton nets or epibenthic sleds have also been used to identify spawning events along various river systems.

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(Pasch et al. 1980; Wallus 1986; Hesse and Mestl 1993). However, these methods have been more successful in sampling larvae than eggs. In addition, the capture of larval fish may not accurately identify the location of spawning sites because of variable larval drift rates.

Artificial substrate mats have proven to be an effective technique for determining the fine-scale location of spawning sites for various sturgeon populations (Marchant and Shutters 1996; Sulak and Clugston 1998; Fox et al. 2000; Paragamian et al. 2001; Perrin et al. 2003; Duncan et al. 2004). Similar to paddlefish eggs, the highly adhesive sturgeon eggs sink after they are broadcast by spawning adults. As a result, eggs deposited on mats positioned along the river bottom presumably have been spawned in the vicinity of the mats. Mats may be more likely to detect spawning events than active sampling methods because they can be deployed continuously for periods as long as several days. In addition, mats may be less likely to get entangled along bottom obstructions, and can be deployed in areas where high current velocities may prevent the use of other sampling techniques. Although mats have proven effective in locations where substrate is relatively stable, it was unknown if they would be effective in the lower Yellowstone River, which is characterized by unstable, shifting substrate. This study was conducted along the lower Yellowstone River during paddlefish spawning periods of 2000 through 2002 to determine whether artificial substrate collectors could be used as an effective sampling technique to collect eggs and confirm suspected spawning reaches.

Study Area

Paddlefish from the Yellowstone–Sakakawea stock rear in Lake Sakakawea, a 156,000-ha Missouri River impoundment in western North Dakota created by the closure of Garrison Dam in 1953. Adults that are reproductively ripe migrate upriver out of the reservoir during spring; many ascend into the lowermost 110 km of the Yellowstone River, a quasi-natural stretch that extends upriver from its confluence with the Missouri River (hereafter referred to as the Confluence) to the Intake Diversion Dam near Glendive, Montana (Figure 1). The 70-km reach of the river below Intake contains multiple islands and alluvial channel bars with substrate consisting primarily of cobble and gravel. Along the lowermost 40 km of the river, sand replaces gravel as the predominant substrate, although in-channel features remain common (Bramblett and White 2001). Because the Yellowstone River remains unregulated, it has retained a natural hydrograph with high levels of discharge and sediment load during the spring freshet. Average discharge has been 707 m$^3$/s and average suspended sediment has been 1,231 mg/L at river kilometer (rkm) 47 over May and June for flow years 1972–1995, the maximum daily levels attaining 2945 m$^3$/s and 26,800 mg/L, respectively (U.S. Geological Survey, Montana water resource and streamflow data homepage [http://mt.water.usgs.gov/index], 2003).

Methods

Field techniques.—Because the intent of the study was to explore the effectiveness of egg collectors, sample sites were not randomly distributed over the entire length of the lower Yellowstone River but were chosen to maximize the likelihood of collecting eggs. Based on densities of larval paddlefish collected in bottom-drifted plankton nets along the lower 30 km (Gardner 1993, 1995, 1996), potential spawning sites were identified at rkm 9.5, 13.5, 21.5, and 25.5 (Figure 1). A summary of the physical characteristics of all four sites is provided in Table 1. Although substrate consisted primarily of sand along most of the lower 30 rkm, substrate samples indicated that gravel was present at all four sites, and tactile sampling with a long-handled wooden probe indicated that cobble, boulders, or bedrock was present at the three upriver sites (Figure 1). Additionally, during an ongoing radiotelemetry study, concentrations of paddlefish had been observed in the vicinity of all four sites, which supports the potential of these sites as spawning reaches.

Egg collectors were deployed from May 25 to June 16, from May 28 to June 22, and from May 24 to June 27 in 2000, 2001, and 2002, respectively. Dates of first deployment of egg collectors were determined by using a combination of the following information: (1) time periods when paddlefish larvae were first collected during previous years; (2) the rise of water temperatures above 10°C, the lower spawning threshold reported for paddlefish (Crance 1987; Jennings and Zigler 2000); and (3) the appearance of ovulated eggs in adult paddlefish harvested from Missouri and Yellowstone Rivers. Sampling was discontinued when tagged fish from an on-going telemetry study were no longer contacted in the river (indicating descent into the reservoir and probable cessation of spawning activity) and when water temperatures exceeded 23°C, the upper thermal limit reported for spawning paddlefish (Hoxmeier and DeVries 1997).

Egg collectors deployed in 2000 were mats of artificial substrate designed and used successfully by McCabe and Beckman (1990) for collecting white sturgeon Acipenser transmontanus eggs in the Columbia River. Furnace-filter material, which provided a rough surface for egg attachment, was fitted and
secured between complementary 0.60 × 0.75 m angle-iron frames. Each mat was equipped with a 4.5–5.0-kg rebar grapple anchor and a buoyed hauling line. Mats were deployed at rkm 13.5, 21.5, and 25.5 in the spring of 2000. The use of this mat design was permanently discontinued after June 16 because many of the mats were buried by sand or silt and could not be retrieved.

In 2001 and 2002, a tubular type of collector was constructed that would minimize prolonged contact with the river bottom and reduce the possibility that fine sediments would bury the collector. A single strip
of furnace filter material (0.75 m wide) was fitted and secured around an open-ended PVC cylinder 0.75 m long × 0.15 m diameter. A 4.5–5.0-kg anchor was secured to one end of the tube with a 0.20-m-long anchor line, and a buoyed hauling line was attached to the other end of the tube. The intent of this design was to suspend the collector off the riverbed while maintaining a sampling position near the bottom of the water column. To determine the effectiveness of the newly designed tubes, only rkm 13.5 was sampled in 2001 and rkm 9.5 and 13.5 in 2002.

Three to five egg collectors were deployed equidistantly as a set across the river channel. Depending on the apparent size of the potential egg deposition area, two or three sets, separated by distances of 200–300 m, were deployed within each site. Depth and channel position were recorded for each deployed collector. Every 2–5 d, collectors were retrieved and examined for presence of eggs. Acipenseriform eggs, identified by color and size, were removed and preserved in 80% ethanol. Collectors were then rinsed thoroughly before adhering onto substrate (Purkett 1961). Accordingly, egg counts were fit by the negative binomial distribution, which is described by the mean (μ) and a dispersion parameter (k) that measures degree of clumping (i.e., as k decreases, clumping increases) (Bliss and Fisher 1953; White and Bennett 1996). Conversely, eggs spawned at distant upriver sources were hypothesized to have dispersed during downriver drift and to be more randomly distributed on collectors within a site. Paddlefish eggs have been found to be swept downriver of gravel bars before adhering onto substrate (Purkett 1961). According to this hypothesis, egg counts would be better fit by the Poisson distribution, which is described by the mean parameter, λ. Because eggs were collected in sufficient numbers during only four sample periods during June 8–25 in 2002 (denoted as periods a, b, c, and d), modeling was restricted to this time period. In addition, only eggs collected along the thalweg were included in models because differences in current velocities between the thalweg and channel margins could affect egg interception and deposition rates and thus confound interpretation of results. Model construction and parameter estimation were performed using version 7 of Matlab (The MathWorks, Inc., Natick, Massachusetts).

The information-theoretic approach was used to evaluate the relative plausibility of the models derived to examine the spatial distribution of egg counts. This approach, which is well-suited for drawing inferences from observational data, quantitatively compares a set of competing models to select those that are best supported by the data (Burnham and Anderson 1998).

<table>
<thead>
<tr>
<th>Sample site</th>
<th>Rkm</th>
<th>Length (km)</th>
<th>Average width (km)</th>
<th>Range of sample depths (m)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.5</td>
<td>0.35</td>
<td>0.20</td>
<td>1.5–4.9</td>
<td>Gravel present in deep channel thalweg along the west bank</td>
</tr>
<tr>
<td>2</td>
<td>13.5</td>
<td>0.75</td>
<td>0.35</td>
<td>0.9–4.6</td>
<td>Wide midchannel thalweg; shallow gravel, rubble shoal located downriver</td>
</tr>
<tr>
<td>3</td>
<td>21.5</td>
<td>0.45</td>
<td>0.30</td>
<td>0.9–2.5</td>
<td>Shallow gravel, rubble shoal located along the north bank</td>
</tr>
<tr>
<td>4</td>
<td>25.5</td>
<td>0.65</td>
<td>0.25</td>
<td>0.9–3.8</td>
<td>Shallow gravel, rubble shoal located throughout the upriver segment</td>
</tr>
</tbody>
</table>

* Depths varied depending on river stage.

TABLE 1.—Summary of the physical characteristics of the four river sites sampled for paddlefish eggs along the lower Yellowstone River during 2000–2002.
Because it was assumed that intensity of spawning activity may vary over time and between sites, the candidate set included models with spatial parameters (m and k, or λ) unique to each site and sample period, in addition to reduced models with parameters held constant across sites, sample periods, or both. Akaike’s information criterion, corrected for small sample bias (AIC_c), was used to rank and select the models that accounted for the most variation in the data with the fewest parameters (Burnham and Anderson 1998). The model with the smallest AIC_c value was considered best at approximating the data; models with AIC_c values not more than 4 units greater than the AIC_c of the best model (i.e., ΔAIC_c ≤ 4) were also considered to receive support as best models, whereas models with ΔAIC_c values greater than 10 provided strong evidence against their consideration as best (Burnham and Anderson 1998). Uncertainty in the best model is incorporated into parameter estimates by calculating a weighted average across selected models (Burnham and Anderson 1998); however, model averaging was not used to derive estimates of spatial parameters in this analysis because the intent of the study was descriptive rather than predictive.

Results

During the study period, 326 collectors were deployed for a total of 1,179 collector days (Table 2). Less effort was expended in 2000 than in 2001 and 2002 because of the foreshortened sample period and number of mats lost. During 2000, 56 of the 71 (79%) mats were recovered during initial retrieval attempts. Three mats were later recovered after elapsed periods of 29–37 d. Mats were most likely temporarily buried by sand because they were difficult to dislodge from the riverbed. Conversely, 97% of tubes were retrieved successfully during both 2001 (88 of 91) and 2002 (159 of 164; Table 2). Although tubes typically were retrieved from the location where they had been deployed, debris accumulated along hauling lines during periods of rising discharge and tubes were occasionally recovered downriver from point of deployment. As a result, tubes were temporarily removed from the river for a period of 2 d in 2001 (June 17–18) and 5 d in 2002 (June 3–7) because of large amounts of debris transported downriver at these times.

We collected 130 acipenseriform eggs over the study period (Table 2). In 2001 and 2002, 17 and 105 eggs, respectively, were collected on tubes, whereas no eggs were found on mats at any sample site during 2000. However, eight eggs were collected on a mat deployed in 2000 at rkm 13.5 in 2002. Eighty-nine of 90 differentiable eggs (99%) were genetically confirmed as paddlefish eggs; 1 egg was determined to be either shovelnose sturgeon or pallid sturgeon. Eggs were typically collected after the first week in June and were found on 20% and 45% of tubes retrieved during these peak collection periods in 2001 and 2002, respectively (Figure 2). In 2001, egg CPUE peaked during sample period June 19–22 (0.21 eggs-cylinder^{-1} d^{-1}) after discharge had peaked on June 17 (680 m^3/s). In 2002, egg CPUE peaked during sample period June 13–17 at both rkm 9.5 (0.46 eggs-cylinder^{-1} d^{-1}) and rkm 13.5 (0.65 eggs-cylinder^{-1} d^{-1}) after discharge had peaked on June 6 (1206 m^3/s). Average daily river temperature ranged between 15°C and 22°C during periods in which eggs were collected in both years.

The eggs collected at both sites were most often found in low numbers and on tubes retrieved from the channel thalweg (Figure 3). In 2001, seven of the nine tubes with eggs were retrieved from the mid-channel thalweg at rkm 13.5, and these seven tubes accounted for 65% of eggs collected that year. Only one or two eggs were found on all but one of the nine tubes. During June 8–25 in 2002, 17 of the 25 (68%) tubes with eggs at rkm 13.5 were retrieved from the mid-channel thalweg, and these 17 accounted for 83% of

Table 2.—Effort and catch information for collectors used to sample acipenseriform eggs at four sites on the lower Yellowstone River in 2000-2002 (see Methods for descriptions of collector types). Parenthetic values are the number of eggs genetically confirmed as paddlefish.

<table>
<thead>
<tr>
<th>Year</th>
<th>Collector type</th>
<th>Site (rmk)</th>
<th>Number of collectors deployed</th>
<th>Number of collectors retrieved</th>
<th>Sampling effort (collector days)</th>
<th>Number of eggs</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>Mat</td>
<td>13.5</td>
<td>35</td>
<td>31^a</td>
<td>185^b</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>21.5</td>
<td>13</td>
<td>10</td>
<td>26</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25.5</td>
<td>23</td>
<td>18</td>
<td>42</td>
<td>0</td>
</tr>
<tr>
<td>2001</td>
<td>Tube</td>
<td>13.5</td>
<td>91</td>
<td>88</td>
<td>338</td>
<td>17 (14)</td>
</tr>
<tr>
<td>2002</td>
<td>Tube</td>
<td>9.5</td>
<td>50</td>
<td>48</td>
<td>176</td>
<td>34 (19)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13.5</td>
<td>114</td>
<td>111</td>
<td>412</td>
<td>79 (56)^c</td>
</tr>
</tbody>
</table>

^a Three collectors were retrieved in midsummer after initial attempts failed.
^b Includes 103 d from the three collectors retrieved in midsummer.
^c Eight eggs were found on a recovered mat deployed in 2000.
collected eggs at that site. At rkm 9.5, 9 of the 11 (82%) tubes with eggs were retrieved along the thalweg near the west bank and accounted for 94% of eggs collected at that site. Estimates of mean egg counts over collection periods in 2002 were low, ranging between 0.42 and 3.55 eggs/collector for distribution models that received support in model selection (Table 3). Fewer than four eggs were found on 27 of the 36 (75%) tubes that had collected eggs at both sites in 2002 (Figure 3).

A clumped distribution of eggs was suggested by the finding of nine or more eggs on several tubes in combination with a lack of eggs on many tubes during collection periods in 2002 (Figure 3). Accordingly, the three models that received support as “best” in model selection were fit by a negative binomial distribution (Table 3). Conversely, large ΔAICc values calculated for Poisson models provided strong evidence against a random distribution of eggs. In addition, though selected models did not support a difference in mean

FIGURE 2.—Catch per unit effort (CPUE) of acipenseriform eggs at rkm 9.5 and 13.5 in relation to Yellowstone River discharge and temperature during the spring of 2001 and 2002. The number of symbols along each horizontal CPUE bar indicates the duration of the sample period in days.
**FIGURE 3.**—Distribution of acipenseriform eggs found on tubes retrieved from within (black bars) and outside of (gray bars) the channel thalweg at rkm 9.5 and 13.5 in the lower Yellowstone River during June 8–25, 2002.

**TABLE 3.**—Comparison of negative binomial and Poisson models describing the spatial distribution of acipenseriform eggs found on collectors retrieved along the thalweg at rkm 9.5 (site 1) and 13.5 (site 2) in the lower Yellowstone River from June 8 to 25, 2002. Subscripts in means ($m$ or $\lambda$) and dispersion parameters ($k$) refer to sites (1 and 2) and time periods (a–d); a period indicates a common estimated parameter across sites or time periods. The column headed $\Delta$AIC$_c$ indicates the difference between the model’s AIC$_c$ and the best model’s AIC$_c$ (model 1; AIC$_c$ 178.4). The set of models receiving support as best approximating the egg count data included those where $\Delta$AIC$_c$ was $\leq 4$.

<table>
<thead>
<tr>
<th>Model</th>
<th>$\Delta$AIC$_c$</th>
<th>Parameters</th>
<th>Parameter estimates for best models</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.00</td>
<td>$m_{a_1}, \ldots, m_{a_d}, k$</td>
<td>2.08, 3.55, 1.75, 0.42, 0.92</td>
</tr>
<tr>
<td>2</td>
<td>1.90</td>
<td>$m_{a_1}, \ldots, m_{a_d}, k_1, k_2$</td>
<td>2.22, 3.37, 1.71, 0.44, 1.58, 0.74</td>
</tr>
<tr>
<td>3</td>
<td>3.67</td>
<td>$m, k$</td>
<td>1.92, 0.61</td>
</tr>
<tr>
<td>4</td>
<td>4.53</td>
<td>$m, k_1, k_2$</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5.93</td>
<td>$m_1, m_2, k$</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>6.89</td>
<td>$m_1, m_2, k_1, k_2$</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>9.34</td>
<td>$m_{1_a}, \ldots, m_{1_d}, m_{2_a}, \ldots, m_{2_d}, k$</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>11.64</td>
<td>$m_{1_a}, \ldots, m_{1_d}, m_{2_a}, \ldots, m_{2_d}, k_1, k_2$</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>35.20</td>
<td>$\lambda_{a_1}, \ldots, \lambda_{a_d}$</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>41.11</td>
<td>$\lambda_{1_a}, \ldots, \lambda_{1_d}, \lambda_{2_a}, \ldots, \lambda_{2_d}$</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>61.59</td>
<td>$\lambda_1, \lambda_2$</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>63.67</td>
<td>$\lambda_1, \lambda_2$</td>
<td></td>
</tr>
</tbody>
</table>
egg counts between sites, the second best model indicated a higher degree of clumping at rkm 13.5 \((k = 0.74)\) than at rkm 9.5 \((k = 1.58)\).

Discussion

The tubular collectors deployed during 2001 and 2002 along the lower Yellowstone River proved to be a viable passive technique for collecting paddlefish eggs in spawning reaches characterized by predominantly sandy substrate. Tubes were successfully retrieved over 95% of the time, whereas the mats often became buried and were difficult to dislodge from the riverbed. Paragamian et al. (2001), in their efforts to document white sturgeon spawning events in the Kootenai River, Idaho, also found that egg mats became buried by shifting sand during high-flow events. Although mats that are temporarily buried may later be recovered, the sample design and interpretation of results are compromised. Tubes collected eggs during both years of deployment, whereas eggs were not found on retrieved mats in 2000. However, the effectiveness of the two types of collectors could not be directly compared because they were not deployed in concert. The discontinuation of sampling by mid-June of 2000 may have prevented the collection of eggs by mats in that year. Nonetheless, the sampling efficiency of mats that become covered by shifting sands decreases, whereas tubes suspended off the bottom retain an exposed surface area for egg attachment.

The collection and genetic confirmation of eggs at rkm 9.5 and 13.5 support the existence of spawning and egg deposition habitat for paddlefish within this stretch of the lower Yellowstone River. These results are consistent with previous larval collections, as paddlefish have been regularly collected along the lower 30 rkm with high densities found around rkm 13.5 (Gardner 1993, 1995, 1996). On the other hand, our positive results might be attributed only to interception of drifting eggs and not to egg deposition, as suggested by the high percentage of eggs collected along the thalweg. However, the finding of eight eggs on a retrieved egg mat, which presumably lay flush with the riverbed, supports the supposition of egg deposition at rkm 13.5. Additionally, the presence of cobble and bedrock at this site would provide suitable attachment sites for adhesion of eggs. The role of other physical characteristics at rkm 13.5, such as eddy currents that might facilitate egg deposition and adhesion, needs further investigation (Sulak and Clugston 1998; Perrin et al. 2003).

The clumped distribution of eggs collected at both sites also provides evidence that paddlefish spawned in the vicinity of deployed tubes. It is difficult to determine whether there were different groups of spawning adults upriver of both sites, or if any eggs collected at rkm 9.5 were the result of residual drift from rkm 13.5. Although a less clumped distribution at rkm 9.5 may indicate residual drift, model selection yielded ambiguous evidence for a detectable difference in dispersion parameters between sites. In addition, site-specific clumping patterns could be due to differences in near-bed current velocities or in the proximity of collectors to spawners between sites.

The overall low number of eggs collected per tube at both sites, however, suggests a low collector efficiency (i.e., collecting a small percentage of available eggs). Although published accounts of passive egg collection techniques for paddlefish are scarce, collector efficiency comparisons may be drawn with regard to similar studies in which sturgeon spawning sites had been identified. Sulak and Clugston (1998) found groups of up to 63 gulf sturgeon \(A. \text{oxyrinchus desotoi}\) eggs on individual samplers deployed along the Suwanee River in Florida. McCabe and Beckman (1990) recorded counts of 423 white sturgeon eggs on individual mats set below Bonneville Dam on the Columbia River. During lake sturgeon egg sampling efforts on the Wolf River, Kempeinger (1988) calculated seasonal means of 1035–8805 on 1-m\(^2\) trays set along spawning areas. In contrast to these studies, Perrin et al. (2003) collected only 77 white sturgeon eggs on 221 deployed mats along the unregulated Fraser River and posited that this was the result of the widespread distribution of both spawners and spawning habitat. Similarly, only 42 gulf sturgeon eggs were collected at widely distributed sites along the Choctawhatchee River system, where previous knowledge of specific sturgeon spawning areas was unavailable (Fox et al. 2000). In general, egg collection efficiency increased when fish were either highly concentrated (e.g., below dams) or efforts were focused along spawning areas previously identified through telemetry, visual observation, or other sampling techniques.

The low number of paddlefish eggs collected in our study may be due to a lack of information concerning specific paddlefish spawning sites as well as the widespread distribution of spawners. The low sampling effort relative to the size of potential spawning areas probably contributed to our inability to deploy collectors in close proximity to concentrations of spawning paddlefish. Telemetry data have also indicated that fish are not concentrated within a few reaches during the spawning season and that upriver movements do not cease at specific sites but are extensive and bi-directional throughout the spawning migration (Firehammer 2004). Such a broad distribution of spawning effort would not be an unexpected
tactic in a spatially unpredictable reproductive environment such as the lower Yellowstone River (den Boer 1968). On the other hand, low egg counts may be representative of typical egg densities along Yellowstone River deposition sites. Because where in the water column paddlefish spawn is not known, eggs released in the upper portion of the water column may be dispersed by current before their adherence onto substrate (Purkett 1961).

The collection of eggs after peak periods of Yellowstone River flow in June of 2001 and 2002 implies an influential relationship between high levels of spring discharge and spawning activity consistent with that reported previously in this system (Gardner 1996; Liebelt 1996) and in other paddlefish rivers (Purkett 1961; Wallus 1986; Lein and DeVries 1998). Though eggs were collected at higher rates in the higher flow year of 2002, insufficient sampling effort precluded further conclusions regarding the effect of the fresher's profile on spawning cues. In addition, the near absence of eggs on collectors after lesser freshets in late May of both years suggests that, though discharge may be the triggering stimulus, photoperiod and temperature as factors regulating gamete maturation are also important preparatory cues in controlling the timing of spawning (Russell 1986; Wallus 1986; Pasch et al. 1980). The long, cold winters in northern latitudes may explain the detection of spawning along the Yellowstone River at dates later than those reported for paddlefish along more southerly river systems (Pasch et al. 1980; Wallus 1986; Hoxmeier and DeVries 1997; Lein and DeVries 1998).

The objective of this study was to develop an egg collection technique that would confirm paddlefish spawning sites in sandbed river reaches. Despite low collection rates, we believe the tubes proved effective in sampling eggs and suggest that more intensive sampling than was applied in this study would achieve a better spatial resolution of spawning activity within suspected reaches. In addition, our results indicate that predominant substrate type is an important factor to consider when choosing an appropriate passive gear for sampling eggs. Although tubes were effective at sand-dominated sites sampled in this study, mats may work equally well or better in reaches further upriver along the Yellowstone River, where gravel and cobble predominate. Using collector types that are suitable for riverbed conditions will increase sampling success and aid in identifying the spatial distribution of spawning sites for paddlefish.

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References


Hesse, L. W., and G. E. Mestl. 1993. The status of Nebraska fishes in the Missouri River, 1. Paddlefish (Polyodonti-


Liebelt, J. E. 1996. Lower Missouri River and Yellowstone River pallid sturgeon study. Montana Fish, Wildlife, and Parks, Western Area Power Administration grant agreement BAO-709, Helena.


