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IS SHALLOW WATER A SUITABLE SURROGATE FOR ASSESSING EFFORTS TO ADDRESS PALLID STURGEON POPULATION DECLINES?

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ABSTRACT

It is hypothesized that slow, shallow water habitats benefit larval pallid sturgeon *Scaphirhynchus albus*; however, testing this hypothesis is difficult, given the low number of larval pallid sturgeon present in large rivers. In contrast, relatively large numbers of age-0 shovelnose sturgeon *Scaphirhynchus platorynchus* have been sampled, providing a potentially useful baseline to assess the importance of slow, shallow water to age-0 sturgeon of both species (hereafter age-0 sturgeon) in the lower Missouri River. Thus, we investigated the potential relationships between the prevalence of shallow water <1.5 m and the age-0 sturgeon catch rates at multiple scales. Age-0 sturgeon were usually sampled in water >1.5 m, and catch rates were usually highest in the upper half [i.e. river kilometre (RKM) 400 to 800] of the lower Missouri River study area, whereas the availability of water <1.5 m was usually highest in the lower half (i.e. RKM 0 to 400). Similarly, there was no relationship between age-0 sturgeon mean catch-per-unit effort and ha/km of water <1.5 m at any studied scale. Our results may suggest that shallow water, as currently defined, may not be a suitable surrogate for assessing efforts to address pallid sturgeon population declines. However, it is still unknown if lack of appropriate habitat is currently limiting pallid sturgeon. Published 2015. This article is a U.S. Government work and is in the public domain in the USA. *River Research and Applications* published by John Wiley & Sons Ltd.

KEY WORDS: shallow water; habitat restoration; pallid sturgeon; Missouri River

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INTRODUCTION

The Missouri River was greatly altered during the 20th century for the purposes of bank stabilization, flood control, commercial navigation, hydropower generation, and water supply. While these measures effectively protected and benefitted many human interests, the effects of river regulation on historic habitat were also evident as the Missouri River shifted from extensive areas of warm, shallow, and turbid habitats to extensive areas of relatively cold, deep, and clear habitat (Hesse and Sheets, 1993; U.S. Fish and Wildlife Service [USFWS], 2000; USFWS, 2003; Jacobson and Galat, 2008; National Research Council [NRC], 2011). As a result, many native species declined (Hesse *et al*., 1989; Galat *et al*., 2005; NRC, 2011), and the 1990 listing of the pallid sturgeon *Scaphirhynchus albus* as endangered (USFWS, 1990) prompted the U.S. Fish and Wildlife Service (USFWS) to issue a Biological Opinion and amendment (collectively referred to as BIOP) to the U.S. Army Corps of Engineers (USACE) (USFWS, 2000; USFWS, 2003). As part of the BIOP, a suite of management actions were proposed to avoid jeopardy to pallid sturgeon and included habitat restoration activities that would provide 5.0 to 7.6 ha/linear km (ha/km) of shallow water habitat (SWH) defined as water <1.5 m and velocities <0.61 m/s during mid-July to mid-August from Sioux City, IA, downstream to the mouth of the Missouri River near St. Louis, MO, representing approximately 20% of the estimated habitat loss.

Shallow water habitat is hypothesized to benefit young and small-bodied fishes if provided at the right time of year in synchronization with life-stage needs. For example, SWH can provide low velocity areas critical for survival and retention of larval fishes (Schiemer *et al*., 2001). It can also provide optimal thermal conditions for larval fish growth by providing areas that quickly warm relative to the main channel (Schiemer *et al*., 2003). Additionally, shallow water may provide beneficial feeding conditions by having higher retention rates of organic matter, phytoplankton, and zooplankton and increased primary and secondary productivity relative to the main channel (Knowlton and Jones, 2000; Bunn *et al*., 2003; O'Neill and Thorp, 2011). In the Missouri River, shallow water has supported high fish

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species richness, especially for age-0 fish (Pflieger and Grace, 1987; Tibbs and Galat, 1997; Berry *et al*., 2004; Sterner *et al*., 2009). Although the specific connection of shallow water to the life history of individual species undoubtedly varies, the commonalities at early life stages across species (e.g. small size, poor swimming ability, vulnerability to predators, and similar feeding requirements) has pointed to the importance of shallow water across a wide range of fishes (Welcomme, 1979; Kwak, 1988; Bovee *et al*., 1994; Scheidegger and Bain, 1995; Bowan *et al*., 1998; Gozlan *et al*., 1998; Robinson *et al*., 1998; Freeman *et al*., 2001). It is hypothesized that SWH benefits larval pallid sturgeon by slowing larval drift/increasing retention, providing nursery areas, and increasing production and/or retention of food sources in these areas of the Missouri River; however, the extent to which a lack of SWH limits the pallid sturgeon population is uncertain.

Increasing abundance of wild pallid sturgeon through increased natural recruitment is a fundamental objective of management actions directed at pallid sturgeon on the Missouri River. Although mean objectives and associated metrics (e.g. habitat acreages and depth criteria) may be important for evaluating intermediate outcomes or hypothesized linkages between management actions and pallid sturgeon, it is the response in the wild pallid sturgeon population that will determine if management efforts successfully met the needs of the species.

Biological Opinion prescriptions and subsequent implementation efforts have primarily focussed on habitat acreage targets rather than a specific pallid sturgeon response, such as increased recruitment or population growth (Doyle *et al*., 2011; NRC, 2011). Verifying and further describing cause and effect relationships between habitat and fish are essential in the use of habitat metrics as a surrogate for pallid sturgeon response and in the effective use of adaptive management as a means to refine management actions.

The primary hypothesis linking SWH restoration to population growth is founded on the assumption that poor larval survival because of reduced nursery habitat (USFWS, 2003) is currently limiting the pallid sturgeon population. Therefore, information on larval survival rates and effects of habitat on survival are critical in better understanding the relationship between SWH and pallid sturgeon. Because little recruitment of pallid sturgeon to age 1 in the lower Missouri River has occurred (Steffensen *et al*., 2014) and only two age-0 individuals have been genetically-confirmed as pallid sturgeon to date (Edward Heist, Personal communication, Southern Illinois University) despite intensive sampling efforts initiated in 2006 (Oldenburg *et al*., 2010), evaluating habitat use and quantifying these relationships are difficult. Utilizing catch data from the closely related shovelnose sturgeon *Scaphirhynchus platorynchus* and pallid sturgeon if they are found (collectively referred to as age-0 sturgeon hereafter), however, may provide insight into the benefits of habitat restoration focussed on providing nursery habitat for age-0 sturgeon. As such, the first objective of our study was to utilize existing age-0 sturgeon catch data from a long-term monitoring programme [the Missouri River Recovery Program Pallid Sturgeon Population Assessment Program (PSPAP)] to evaluate the depths and velocities at age-0 sturgeon capture and non-capture sites (i.e. a local scale) to help characterize habitat use. The second objective of our study was a broad-scale (e.g. river bend scale) assessment of relationships between ha/km of water <1.5 m and catches of age-0 sturgeon to determine if age-0 sturgeon catch increases with increasing availability of water <1.5 m. Broad-scale relationships between catch data and the velocity metric of water less than 0.61 m/s were not assessed because of the fluctuating nature of velocities over various discharges and the lack of velocity data during a similar discharge over the large spatial scale of this study. Ultimately, this information will help determine if the depth metric of water <1.5 m is a suitable surrogate for sturgeon population response.

METHODS

Age-0 sturgeon collection

We utilized age-0 sturgeon data from 2003 to 2013 collected as part of the PSPAP, which is the primary fish monitoring element for the BIOP (Welker and Drobish, 2012). This dataset provides a long-term assessment of fish metrics (e.g. population trends, size structure, survival, movement, and distribution of pallid sturgeon and other target fishes) over a large spatial extent by utilizing a variety of sampling gears. For our analyses, we utilized data collected from four Missouri River segments (Figure 1) from river kilometre (RKM) 0 to 805, which coincided with the bathymetry dataset discussed in the succeeding texts. The PSPAP uses a three-tiered hierarchical habitat classification system (macrohabitat, mesohabitat, and microhabitat) that allows for both general and specific categorization for sampling to serve the needs for biological and physical data collection efforts. Each year, a minimum of 25% of all bends within each segment (Figure 1) were randomly selected to be sampled each year. Each mesohabitat within the macrohabitat was sampled using randomly selected subsamples. Data utilized from the PSPAP were limited to age-0 sturgeon collected during April through October utilizing the POT02 push trawl and OT16 benthic otter trawl. The POT02, a 4-mm mesh push trawl (2.4 m wide with 0.76×0.38-m otter doors) was used to sample depths up to 2 m. The OT16, a 6.3-mm mesh (cod end) trawl (4.8 m wide with 0.76×0.38-m otter doors) was used to sample depths over 2 m. Catches for all benthic trawls were standardized according to Ridenour *et al*. (2011) and are

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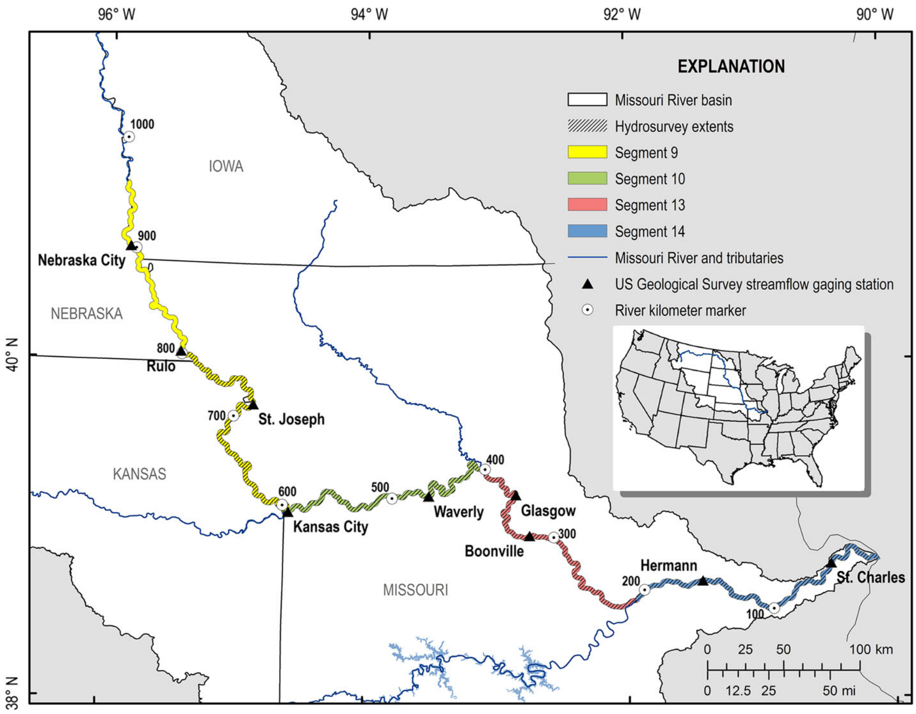

Figure 1. Map of the lower Missouri River from segments 9 to 14 This figure is available in colour online at wileyonlinelibrary.com/journal/rra

reported as fish per 100 m^2. Ridenour *et al.* (2011) assumed that trawl type had little effect on their study of age-0 sturgeon habitat use in the lower Missouri River; therefore, the same was done for this study. Water depth was recorded to the nearest 0.1 m at the beginning, middle, and end of each trawl sample. Water velocity was measured near the bottom with a Marsh-McBirney flowmeter at the middle of 25% of the trawl samples not containing a pallid sturgeon, whereas velocity was recorded for each trawl sample containing pallid sturgeon.

Quantification of water <1.5 m

Bathymetry surveys were collected using boat-mounted, single-beam echo sounders utilizing Hypack™ software (version 13.0) and differential global positioning system instrumentation to provide sub-metre or better positional accuracy of depth soundings. The surveys were conducted from June through September, 2013 from RKM 0 to 805. Depth data were collected along pre-defined transect lines spaced approximately 75 m perpendicular to flow along the main channel. Conversion of sounding depths to elevation was accomplished by measuring the relative difference in elevation between the water surface and previously established benchmarks located every 3–6 km along the river. Digital elevation maps (DEMs) of echo-sounder data were developed utilizing ArcGIS (version 10.1, Environmental Systems Research Institute, Inc., Redlands, California). Maps were generated with approximately 15-m grid cells and projected to universal time meridian zone 15′N with the North American Vertical Datum of 1988 datum. Grid cells of 15 m were chosen based on methodology described in Hengl (2006) and an optimal balance between resolution and processing time.

Habitat metrics in the BIOP define shallow water as <1.5 m and velocity <0.61 m/s from mid-July to mid-August so it was necessary to compute depths from the survey data with respect to the water surface elevation during this same time period. For a comparable reference, the flow during this time period has been simplified to median August flow or the 50% August flow exceedance probability. A median August flow water surface profile was developed from the latest steady-state flow model of the Missouri River and major tributaries developed by the Kansas City District, USACE, using the Hydrological Engineering Center’s River Analysis System (HEC-RAS, version 5.0 beta). The model, which runs from Nebraska City, Nebraska, to Saint Louis, Missouri, utilizes cross sections spaced approximately 0.8 km based on bathymetric surveys completed by USACE in 2009 and is calibrated to Missouri River mainstem US Geological Survey stream gauge stations and the water surfaces measured between the gauges during a water surface profile survey conducted by USACE in 2009. The median August flow was calculated and input into the HEC-RAS model using post-dam regulation flow data (1967–2013) from the Missouri River mainstem stream gauge stations. Major tributary inflows were also included in the model.

RAS Mapper, an interface accessed through HEC-RAS, was used to drape the median August water surface profile over the DEM derived from the 2013 bathymetric data to develop a depth map from RKM 805 to 0. Aquatic area that meets the criteria of <1.5 m was then extracted and analysed at varying spatial scales. Because of the inability of hydrographic survey vessels to obtain a complete cross section in many locations because of shallow depths or revetments preventing boats from reaching the edge of water during a survey, it was determined that approximately 8% of the estimated wetted surface area during median august flow was not surveyed. For this study, it was assumed that half of this area would be less than 1.5 m and therefore reported as water <1.5 m for analysis purposes.

Data analysis

For local-scale analyses, box plots of depth and velocity were constructed, and a Mann–Whitney rank sum test was used to test for differences between sturgeon and non-sturgeon sites for each of these habitat parameters. For this analysis, we removed the depths and velocities at non-sturgeon sites that were outside the range of those observed at sturgeon sites to ensure that this comparison was valid. Additionally, depth and velocity box plots were also constructed for each age-0 sturgeon 10-mm length category, and potential differences among length categories were assessed with a standard analysis of variance (ANOVA) (and Tukey's pairwise test if necessary) if normality and equal variance assumptions were met; if these assumptions were not met, a Kruskal–Wallis non-paramtric ANOVA (and Dunn's multiple comparison procedure if necessary) was used. Mean depth was used for these analyses because three depths were recorded during each trawl run.

For broad-scale analyses, area graphs were constructed to visually compare distributions of age-0 sturgeon mean catch-per-unit effort (CPUE) and water <1.5 m. Furthermore, simple linear regression was used to assess potential relationships between mean CPUE and water <1.5 m (ha/km). These analyses were also conducted at additional scales (ha/km at the bend, 2-bend, and 3-bend scales) because Schapaugh *et al*. (2010) suggested that sampling at more than one spatial scale may provide important insight regarding the response of sturgeon to habitat restoration efforts. An analysis was also conducted for various smaller length categories (<20, 20–30, <30, and <40 mm) because Ridenour *et al*. (2011) suggested that smaller age-0 sturgeon (e.g. 20–30 mm) may utilize habitats differently than larger individuals in the 30–40-mm size range. All statistical analyses were performed using SigmaPlot 12 and $\alpha = 0.05$ for all tests.

RESULTS

The median depth was significantly different between sturgeon and non-sturgeon sites; however, there was a high degree of overlap between these box plots as depths at both sturgeon and non-sturgeon sites, usually exceeded 2 m (Figure 2). The mean depth (95% CI) was slightly lower at sturgeon sites [3.0 m (0.10)] than non-sturgeon sites [3.2 m (0.03)]. Similarly, the median velocity between sturgeon and non-sturgeon sites was also significantly different despite a high degree of overlap between these box plots as velocities were often >0.6 m/s at both sturgeon and non-sturgeon sites (Figure 2). The mean velocity (95% CI) was slightly higher at sturgeon sites [0.61 m/s (0.03)] than at non-sturgeon sites [0.56 m/s (0.01)]. Additionally, depth at age-0 sturgeon capture sites was not significantly different among length categories, and there was a high degree of overlap among these box plots (Figure 3). In contrast, velocity at age-0 sturgeon capture sites was significantly different among the length categories; however, pairwise differences were rare (Figure 3). The 10 and 20-mm length categories

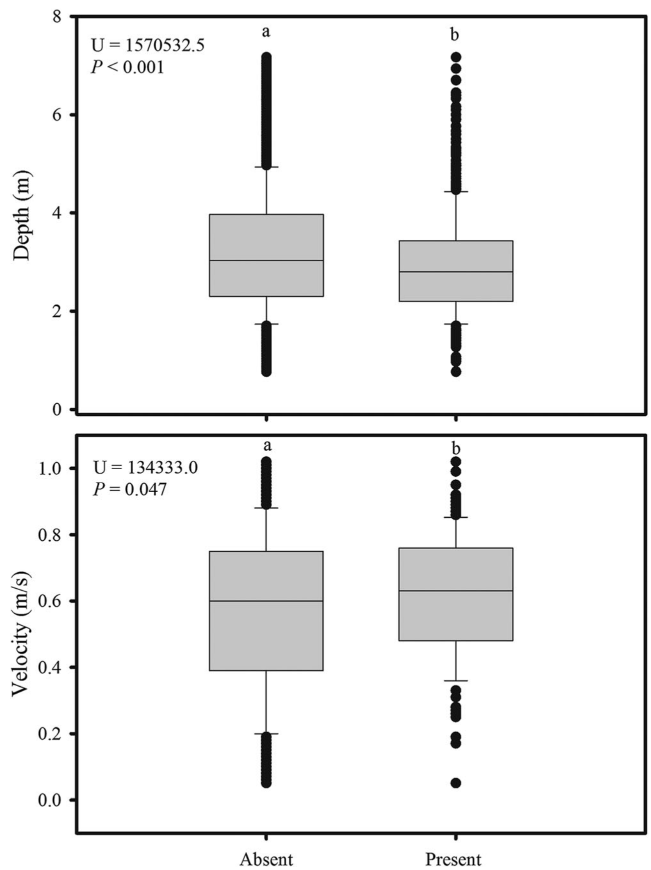

Figure 2. Box plots of depth and velocity at sturgeon (present) and non-sturgeon (absent) sites. Box plots with different letters are statistically different

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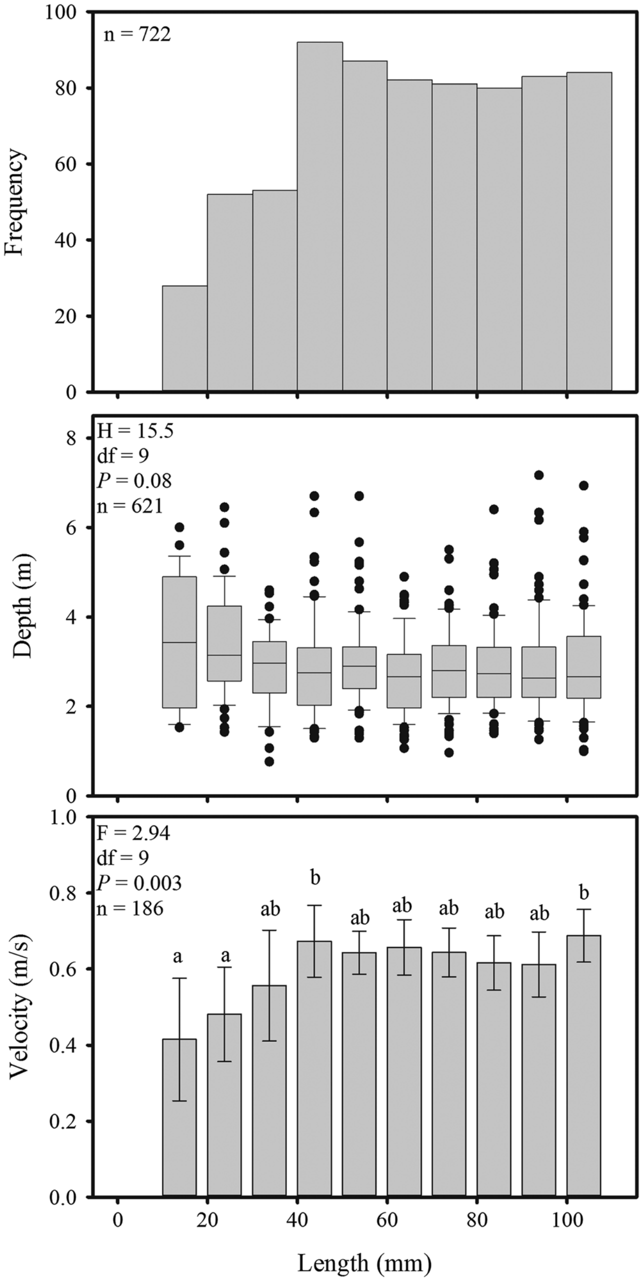

Figure 3. Length frequency distribution (upper panel), box plots of depth (middle panel), and bar chart of mean velocity ± 95% CI (lower panel) by 10-mm length category for age-0 sturgeon. The different letters indicate statistical differences between length categories

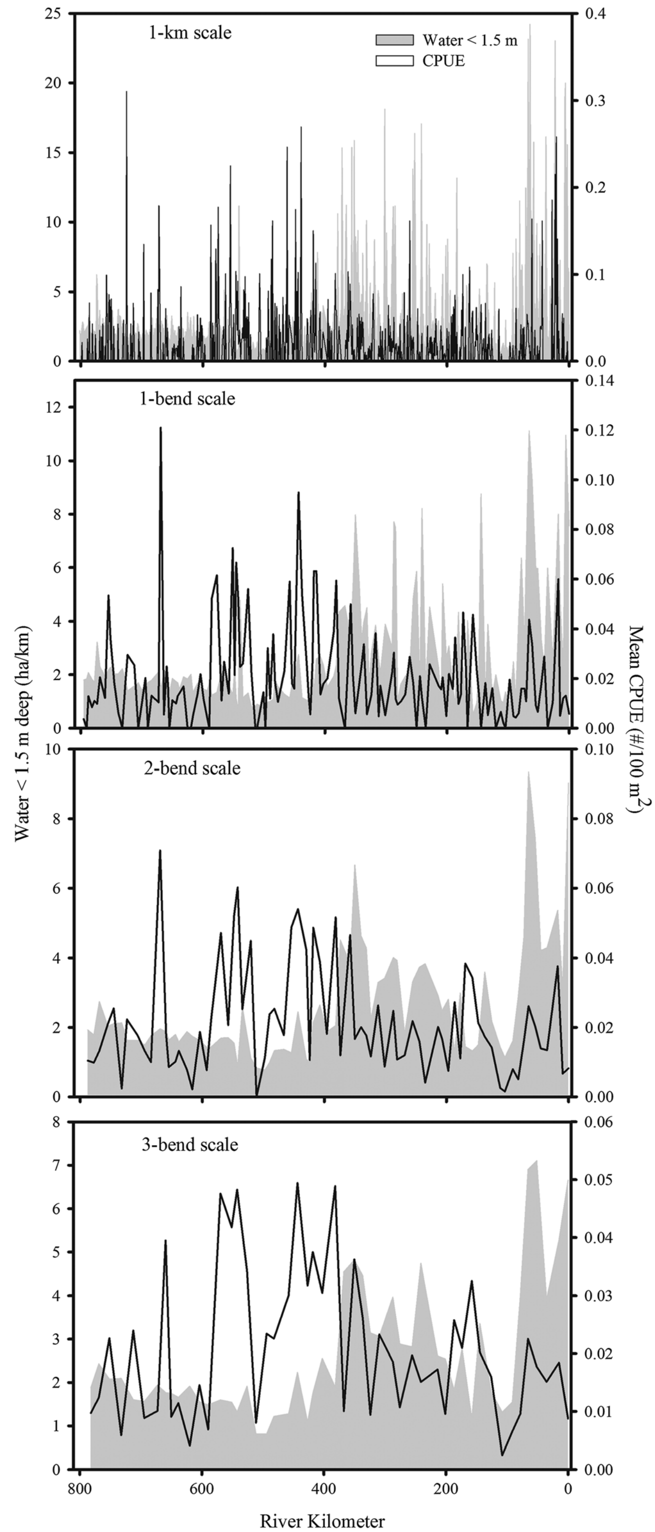

Figure 4. Availability of water <1.5 m (ha/km) overlaid with mean catch-per-unit-effort (CPUE) for age-0 sturgeon (<109 mm) at multiple scales

were sampled from significantly slower velocities than the 40 and 100-mm length categories (Figure 3).

At all studied scales (1 km, bend, 2 bend, and 3 bend), age-0 sturgeon mean CPUE was usually highest in the upper half (i.e. RKM 400 to 800) of the study area, whereas the availability of water <1.5 m was usually highest in the lower half (i.e. RKM 0 to 400) (Figure 4). Similarly, there was no relationship between age-0 sturgeon mean CPUE and ha/km of water <1.5 m at any studied scale (Figure 5). Additionally, these findings were similar for the smaller age-0 sturgeon length categories that were investigated (<20, 20–30, <30, and <40 mm).

DISCUSSION

At the local scale, the median depth at age-0 sturgeon capture sites in this study was similar to the depths reported in other studies (Phelps *et al*., 2010; Ridenour *et al*., 2011; Gosch *et al*., 2015). Furthermore, the average depth at age-0 sturgeon capture sites was 3 m, while Gosch *et al*. (2015) found average depths of 2.2 and 2.3 m in mainstem and chute habitats respectively. Similarly, Ridenour *et al*. (2011) found that the mean depth in mesohabitats with the highest age-0 sturgeon catch rates ranged from approximately 1.8 to 2.5 m. Thus, these studies suggest that depth at age-0 sturgeon capture sites is fairly consistent (usually 2 to 3 m) across a wide variety of flow conditions. In addition to depth, velocities at age-0 sturgeon capture sites (usually 0.5 to 0.8 m/s) were similar to velocities reported in other Missouri River studies (Ridenour *et al*., 2011; Gosch *et al*., 2015). Interestingly, the mean velocities observed for the 10 and 20-mm size classes, although only significantly different from two of the other size classes (40 and 100 mm), were slower than every other size class. This may support the suggestion by Ridenour *et al*. (2011) that lower velocity areas may be important to these small sturgeon, albeit only for a short time after they settle from the drift, before moving to faster water. Overall, our depth and velocity results were similar to the findings of Gosch *et al*. (2015) that age-0 sturgeon were usually found in local areas that do not have depth <1.5 m and velocity <0.61 m/s. It is also important to note, however, that these local depth and velocity results should be interpreted cautiously. For example, it is possible that some of these age-0 sturgeon were entrained at the depths and velocities observed in this study because of the engineered conditions present in lower Missouri River. The relatively large variation in depths and velocities at sturgeon sites for the 10 and 20-mm size classes may be further evidence that some of these individuals were not able to select their habitats. If this is the case and entrainment results in low survival, then habitat restoration projects should focus on drift dynamics of these fish and the river characteristics necessary to place these fish into beneficial habitats. Furthermore, there is some uncertainty associated with representing an entire trawl run with a single bottom velocity reading. For example, data from laboratory studies indicated that age-0 sturgeon up to 75 mm long may have difficulty holding position in

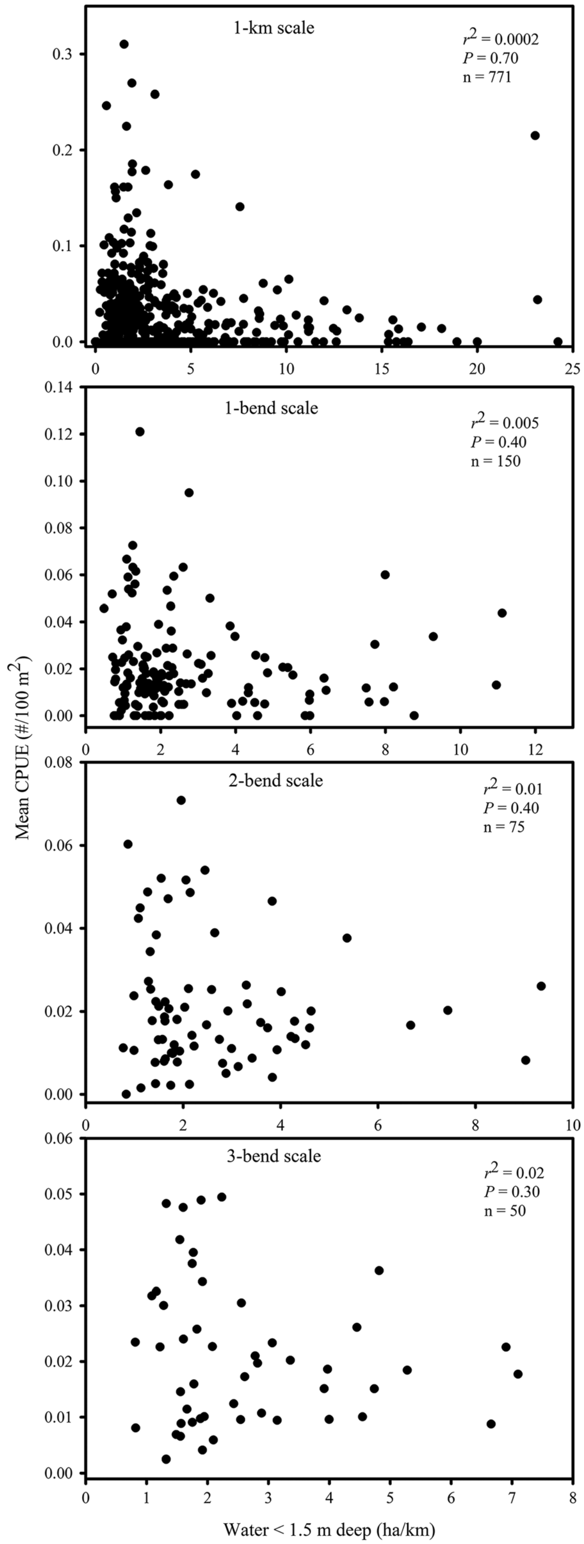

Figure 5. Scatter plots of mean catch-per-unit-effort (CPUE) and water <1.5 m for age-0 sturgeon (<109 mm) at multiple scales

velocities that exceed 0.3 m/s (Kynard *et al*., 2007; D. Deslauriers, South Dakota State University, unpublished data), suggesting that field measurements may not accurately represent the velocities actually acting upon age-0 sturgeon. It also suggests that laboratory studies designed to evaluate velocity impacts to age-0 sturgeon do not accurately account for conditions in the actual river as measured velocities often exceed laboratory thresholds; instead, microhabitat features (e.g. sand dunes and current seams) likely provide velocity refugia for age-0 sturgeon. Nonetheless, this highlights the need to better understand the microhabitats used by age-0 sturgeon, which will help guide future habitat restoration projects.

Another source of uncertainty during this study was the relatively low sample size for age-0 sturgeon <40 mm (refer to Figure 5). Gear bias may have contributed to this observation; however, it is still important to point out that these smaller fish were well represented as over 130 individuals <40 mm were captured during this study, which was almost 20% of the total age-0 sturgeon catch. It is also likely that sampling design affected the catch of age-0 sturgeon <40 mm because free embryo larvae are likely concentrated in the thalweg (Braaten *et al*., 2010), and thalweg sampling is not conducted as part of the PSPAP. Additionally, it is possible that larger (i.e. exogenously feeding) individuals in this size class might also be entrained in the thalweg in this highly engineered system, further contributing to the lower catch of fish <40 mm. An improved understanding of the size range at which age-0 sturgeon are capable of selecting habitats in the highly engineered lower Missouri River would reduce some of the uncertainty inherent in age-0 sturgeon studies within this system as would future research on the potential bias of gears used to sample age-0 sturgeon in shallow habitats (Gosch *et al*., 2015).

The broad-scale analyses focussed on evaluating the relationship between ha/km of water <1.5 m and catches of age-0 sturgeon because it is infeasible to measure velocity over large spatial scales (kilometre or multiple kilometre). We found little to no relationship between ha/km of water <1.5 m and catches of age-0 sturgeon at the 1-km and 1-bend spatial scales. Similarly, Schapaugh *et al*. (2010) reported little to no change in the fish community among bends that had been modified to obtain water <1.5 m and velocities <0.61 m/s, although the authors mentioned that insufficient time between modification and monitoring as well as a lack of analysis at broader spatial scales (e.g. larger than 1 bend) may have limited their ability to detect changes. Subsequent work by Ridenour *et al*. (2010) on the lower Missouri River compared fish composition and abundance among 'endpoint' sites (areas with existing high amounts of water <1.5 m and velocities <0.61 m/s) and 'non-endpoint' sites (areas with little to no activity to obtain water <1.5 m and velocities <0.61 m/s) and concluded that 'a positive response by fishes to SWH mitigation sites' existed; however, this conclusion was primarily drawn on the overall fish community (including only five age-0 sturgeon) but also suggested that a larger spatial scale may be appropriate for evaluating fish response to SWH restoration efforts. Therefore, we also evaluated the relationship of water <1.5 m at the 2-bend and 3-bend spatial scales. Similarly, no relationship existed between ha/km of water <1.5 m and catches of age-0 sturgeon at these larger spatial scales. This observation may be a function of reduced probability of capture in the lower reaches of the study area. Often, sampling for age-0 sturgeon in the lower Missouri River yields a high percentage of trawls with no age-0 sturgeon captured (i.e. only a small number of successful trawls occur). Given that the size and habitat complexity of the river increases from upstream to downstream, it is possible that finding those locations with age-0 sturgeon becomes more difficult as sampling moves downstream. Given that most, if not all, of the age-0 sturgeon captured during this study were shovelnose sturgeon, it is also possible that the shorter expected drift distance of this species compared with pallid sturgeon (see Braaten *et al*., 2008) may have accounted for the decrease in age-0 sturgeon catch rates in the lower portion of the study area despite a higher prevalence of water <1.5 m.

Despite these possibilities, the relatively low catch rates in areas with higher amounts of water <1.5 m may not be that surprising because of the predominance of age-0 sturgeon captures from depths >1.5 m during other studies (Phelps *et al*., 2010; Ridenour *et al*., 2011; Gosch *et al*., 2015). Regardless, it is possible that water <1.5 m may be necessary for increased survivorship of age-0 sturgeon. For example, although catch rates for age-0 sturgeon were lower in areas with a higher availability of water <1.5 m, perhaps these individuals experienced more favourable conditions (e.g. abundant food) resulting in better condition, but navigation to shallow areas was limited in some way. It is also possible that the population-level benefits may not be measurable until a threshold amount of habitat is restored as only a small fraction of the more than 40 000 ha of SWH lost as a result of river modification has been restored (USACE, 2003). Another potential scenario is that the benefits of restoring some natural form to the Missouri River may not solely be achievable through changes to channel form but also the interaction with flows (Jacobson and Galat, 2006; Doyle *et al*., 2011). Increased survivorship of age-0 pallid sturgeon may not be achieved even with habitat restoration if flows negatively affect the quantity, functionality, and timing of the restored habitats. Additional insight into these potential scenarios would be beneficial to recovery efforts on the lower Missouri River.

A primary assumption of our study was that age-0 shovelnose sturgeon were an adequate surrogate, regarding habitat use, for age-0 pallid sturgeon. Murphy *et al.* (2011) cautioned against the use of surrogates in conservation planning for rare species and suggested that surrogate species must respond in a similar fashion to the target species. Some studies suggest that shovelnose sturgeon may not be an adequate surrogate for pallid sturgeon in terms of habitat use (Bramblett and White, 2001) and diet (Gerrity *et al*., 2006; Wanner *et al*., 2007) during adult and/or juvenile stages. Additionally, Braaten *et al*. (2008) found that free embryo drift distance was different between the two species in the upper Missouri River. However, similarities between the two species also exist. For example, despite disparity in drift distance, both shovelnose and pallid sturgeon usually drifted in the lower 0.5 m of the water column (Braaten *et al*., 2008). It has also been suggested that shovelnose sturgeon can be a model for pallid sturgeon as developmental patterns between these two species are similar during early life history (Colombo *et al*., 2007). Additionally, others have shown that shovelnose sturgeon are adequate surrogates for studies regarding contaminants and contaminant uptake (Ruelle and Keenlyne, 1994; Schwarz *et al*., 2006; Buckler, 2011). Finally, other recent studies have also pooled age-0 shovelnose and pallid sturgeon data for the purposes of habitat evaluation (Phelps *et al*., 2010; Ridenour *et al*., 2011; Sechler *et al*., 2012). As such, age-0 shovelnose sturgeon may have been an appropriate surrogate given the scope of this study, potentially providing insight into the habitat use of age-0 pallid sturgeon on the lower Missouri River. However, further evaluation of the use of age-0 shovelnose sturgeon as a surrogate for habitat use by age-0 pallid sturgeon should be investigated.

Implications for adaptive management

The existing BIOP emphasizes the utilization of an adaptive management strategy to guide efforts as new information becomes available. To date, effort has focussed on creating specific amounts of habitat with both depth <1.5 m and velocity <0.61 m/s. Both the NRC (2011) and Doyle *et al.* (2011) have criticized this approach and recommended a programmatic adaptive management strategy focussed on measurable species outcomes with defined targets. Following recommendations from these two reviews, the USACE has undertaken the development of a comprehensive adaptive management strategy that will use a structured decision making approach to evaluate and implement existing and potential management actions. As part of this effort, an ‘Effects Analysis’ (described in Murphy and Weiland, 2011) is currently underway, involving teams of scientists and stakeholder interaction, which will provide a scientific foundation for the structured decision making process. One component of the ‘Effects Analysis’ is a thorough review and analysis of existing data, and as such, this study should provide an improved understanding of the relationship between habitat use and catches of age-0 sturgeon.

The primary hypothesis linking habitat restoration to pallid sturgeon population growth is founded on the assumption that poor larval survival because of reduced nursery habitat (e.g. lack of food) is currently limiting pallid sturgeon populations (USFWS, 2003). Given the uncertainties associated with habitat restoration designed to benefit age-0 sturgeon and lack of demonstrated cause-and-effect relationships, we recommend and are currently involved in focussed investigations to better understand what habitat types are beneficial to age-0 sturgeon and if habitat availability is currently a limiting factor. Because larval survival may not be low or limited by a lack of nursery habitat (e.g. completion of earlier life stage transitions are more limiting to population growth), investigations should focus on evaluating additional hypotheses regarding survivorship and population growth of pallid sturgeon. Based on the results of this and other studies, we recommend increased focus on elucidating those factors that most limit pallid sturgeon population growth.

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