MODELING SPATIAL DISTRIBUTION AND HABITAT ASSOCIATIONS FOR JUVENILE PALLID STURGEON (*SCAPHIRHYNCHUS ALBUS*) IN THE MISSOURI RIVER

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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ABSTRACT

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Monitoring and assessment of the endangered pallid sturgeon *Scaphirhynchus albus* population is essential to the recovery of the species. Movement and distribution of pallid sturgeon is generally documented using radio telemetry methods. However, because of the time and cost involved in tracking individual fish (i.e., small sample size), it is often difficult to evaluate spatial distribution of groups of fish over long time periods (>3 years). Standardized random sampling, which relies on a variety of gear types including trammel nets, otter trawls, gillnets and setlines, has been conducted in the reach of the Missouri River downstream of Fort Randall Dam, South Dakota and Nebraska annually since 2003 to evaluate the pallid sturgeon population. This river reach is unique in that it has riverine, depositional delta, and reservoir habitats.

Although data on catch rates and capture locations of pallid sturgeon have been routinely collected since 2003 in the Fort Randall Reach of the Missouri River, there have been no attempts to use this information to evaluate spatial distribution patterns and habitat use in the riverine and depositional habitats that exist in the reach. The objectives

of this study were to: 1) quantify spatial distribution patterns of juvenile pallid sturgeon using non-telemetry methods, 2) develop a habitat assessment tool that is useful for predicting potential capture locations for juvenile pallid sturgeon, and 3) apply the model to quantify the relative distribution of potential capture locations in the Fort Randall reach, Missouri River.

Using presence/absence data, I evaluated the spatial distribution of juvenile pallid sturgeon. Spatial scan statistics were used to analyze pallid sturgeon distribution patterns based on 1) singular gear collections per season, 2) pooled gears per season 3) singular gears pooled across seasons, and 4) the overall pooled dataset. Three significant areas, characterized by 'clusters' of pallid sturgeon captures, were identified from analysis of the overall pooled dataset. These same areas were also identified using summer trammel net sampling implying that this gear/season combination could be used to reliably identify areas with a high probability of pallid sturgeon presence. This methodology could be used to effectively identify areas with a high probability of pallid sturgeon presence elsewhere in the Missouri River basin using existing data from the ongoing Pallid Sturgeon Monitoring and Assessment Program. Areas of pallid sturgeon habitat use could then be evaluated to better understand why pallid sturgeon use these habitats.

Understanding the habitat requirements of juvenile pallid sturgeon represents an important part of the monitoring and assessment program. In this study, I developed a spatially explicit habitat assessment tool that integrated information on physical habitat, aquatic invertebrate abundance, and pallid sturgeon occurrence to predict pallid sturgeon

capture. The model that I developed is the first attempt at integrating both habitat and prey parameters in predicting sturgeon capture (i.e., occurrence).

Maps for water depth, bottom water velocity, directional variation in bottom flow, percent sand substrate composition, bottom slope, and ephemeropteran and larval dipteran abundance were created for eight 3.2-km river segments using 20 m grid cell resolution. Pallid sturgeon capture and non-capture areas were then overlain onto physical habitat and prey availability maps to derive means or proportional availability for these variables. I used discriminant function analysis (DFA) to distinguish between capture (n=25) and non-capture (n=49) locations from the Missouri River downstream of Fort Randall Dam in South Dakota and Nebraska. Four variables successfully discriminated capture from non-capture locations and included: 1) water depth > 2 m, 2) percent sand substrate, 3) dipteran abundance and 4) ephemeropteran abundance. Classification functions were then used to predict pallid sturgeon occurrence in the eight 3.2-km river segments. Correct classification rates were 88% for pallid sturgeon capture areas and 100% for non-capture areas for an overall classification rate of 95%. The percentage of area in each of the eight Fort Randall reaches (n=8) that were classified as pallid sturgeon capture areas ranged from 22 to 64%; the percent area classified as potential capture locations was not significantly different between riverine and depositional habitats.

Pallid sturgeon captures often occurred within close proximity to each other in this study suggesting that the combination of physical habitat conditions (i.e., deeper water, sandy substrates) and prey availability (i.e., dipteran and ephemeropteran

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CHAPTER 1

INTRODUCTION

The pallid sturgeon, *Scaphirhynchus albus*, a riverine sturgeon species native to the Missouri River and lower Mississippi river basins (Forbes and Richardson 1905) has been listed as an endangered species since 1990 (Dryer and Sandvol 1993). The pallid sturgeon has many morphological characteristics that make it well-adapted to riverine conditions. These characteristics include a large flattened rostrum, tapered head and caudal fin, large pectoral fins, and large cartilaginous armored plates called scutes. These features allow the pallid sturgeon to maintain position in fast moving current. The absence of bony scutes on the belly is a physiological difference that separates pallid sturgeon from the closely related shovelnose sturgeon *Scaphirhynchus platorynchus* (Kallemeyn 1983). The pallid sturgeon is a benthic feeding species that thrives in fast flowing turbid water and has four sensory barbles located on the underside of the rostrum in front of a suction feeding mouth (Page and Burr 1991). Pallid sturgeon can grow up to 2 m in length, and up to 40 kg in weight (Shuman et al. 2006).

Unique life history characteristics of pallid sturgeon make them vulnerable to changes in habitat that have contributed to population decline. Age at sexual maturity for pallid sturgeon is delayed compared to many other fish species. Males reach sexual maturity at 7 to 9 years of age and females reach maturity at 15 to 20 years of age (Keenlyne and Jenkins 1993). This late age to maturity creates the need for long term survival of individuals so that reproduction can occur to maintain population sustainability (Dryer and Sanvol 1993).

Natural habitat requirements that promote reproduction, growth and survival of pallid sturgeon are generally unknown because of human alterations to the Missouri River. The completion of six impoundments on the mainstem Missouri River in the 1950's (Nelson 1968; Hesse 1989) resulted in the alteration of the natural flow regime for the river. In addition to these impoundments, extensive channelization of the lower Missouri River has resulted in degradation of riverine habitats. Changes in flow regime and water temperatures are believed to have contributed to the decline of pallid sturgeon populations causing a lack of natural reproduction (Kallemeyn 1983).

The wild pallid sturgeon population in the Missouri River is composed of large, relatively old fish, implying that natural reproduction is not occurring. This has resulted in listing the species on the endangered species list and implementation of a recovery plan (Dryer and Sandvol 1993). Short-term recovery efforts are focused on stocking hatchery reared juvenile pallid sturgeon; habitat rehabilitation including creation of sand bar and shallow water habitats and restoration of natural flow regimes are being evaluated as long-term recovery plans (Quist et al. 2004). The recovery plan has designated four reaches of the Missouri River for recovery based on the status of pallid sturgeon in these reaches and the availability of existing habitat (Dryer and Sandvol 1993). These areas have been designated as Recovery Priority Management Areas (RPMAs) and are managed based on the unique physical habitat characteristics of the river reach, and composition of the remnant population of pallid sturgeon.

The Fort Randall reach (RPMA 3), the study area for this project, is unique because it can be divided into riverine (~55 km), depositional (~24 km) and reservoir

(~24 km) habitats. The reach is an impounded portion of the Missouri River that begins upstream at the tailrace of the Fort Randall Dam, near Pickstown, South Dakota and extends to Gavins Point Dam, near Yankton, South Dakota (Figure 1-1). The depositional area of the reach is characterized by a large delta complex which is being formed by large sedimentary inputs from the main tributary, the Niobrara River. Water discharge in the Fort Randall reach is regulated by the United States Army Corps of Engineers (USACE) for hydropower and flood control purposes. Water levels fluctuate as much as 1 m daily with peak discharge in the afternoon when electric power demand is highest (Klumb 2007). The highest seasonal discharge rates occur during the summer months and generally peak in early August (Figure 1-2). Water temperatures tend to be warmer at sites downstream of Fort Randall Dam tailrace, with maximum temperatures around 26°C in late August (Figure 1-3).

The Fort Randall reach has been chosen as one of four recovery areas in the Missouri River in which to stock hatchery-propagated pallid sturgeon because it has riverine habitat, and the population could be used as a source of broodstock for other recovery areas in the future (Jordan 2006). The first stocking of juvenile pallid sturgeon into the Fort Randall reach occurred in 2000 when 416 age-3 and 98 age-2 hatchery-reared juvenile pallid sturgeon were stocked near Verdel, Nebraska. The next stocking event occurred in 2002 and comprised 561 age-1 and 182 age-3 pallid sturgeon. From 2003 through 2006, a total of 2,808 age-1 fish have been stocked into Fort Randall reach. From 2000 to 2006, 4,242 (mean stock weight = 115 g) juvenile pallid sturgeon have been stocked into Fort Randall reach (Shuman et al. 2007).

Several studies of radio-tagged juvenile and adult pallid sturgeon have been used to evaluate movement rates, behavior, and habitat use in the Missouri River. Jordan et al. (2006) found that movement rates of juvenile pallid sturgeon were small in the first year after stocking compared to the second year, and were associated with mostly main channel habitat. Intensive tracking from the Fort Randall reach indicated that juvenile pallid sturgeon had an average movement rate of 1.6 km/day (Jordan et al 2006). Results from extensive tracking studies showed that juvenile pallid sturgeon were not uniformly distributed in the river reach, implying that they preferred some areas over others (Jordan et al. 2006). Elliott et al. (2004) assessed the habitat selection of the same fish in the Jordan et al. (2006) study and found juvenile pallid sturgeon used water depths > 1 m, bottom water velocities up to 1.0 m/s, and sandy substrates. Another tracking study of pallid sturgeon in the Missouri and Yellowstone rivers also found that adult pallid sturgeon used primarily main channel habitat (Bramblett and White 2001). Currently, pallid sturgeon distributions have only been evaluated using radio telemetry studies (Jordan et al. 2006; Snook et al. 2002; Hurley et al. 2006; Gerrity 2006) and there has been a lack of research examining the feasibility of using other methods such as multiple years of capture data to study pallid sturgeon distribution patterns in the Missouri River.

Success of the stocking program has been assessed by a coordinated standardized sampling effort in the Missouri River since 2003 by the Pallid Sturgeon Monitoring and Assessment Program (Drobish 2006). Specifically, in the Fort Randall reach of the Missouri River monitoring and assessing the recovery effort began in the fall of 2003 (Shuman et al. 2005). Sampling gears used as part of the assessment program for pallid

sturgeon included gillnets in fall and winter, otter trawls and drifting trammel nets year round, and setlines as deemed necessary. From 2003-2005 the monitoring and assessment program has successfully captured 172 pallid sturgeon in Fort Randall each (Shuman et al. 2007). Physical habitat data (i.e., water depths, water velocities and substrates) have been collected at locations where pallid sturgeon were captured in an effort to obtain habitat use data. These findings show that pallid sturgeon generally occurred at water depths of 0.7 to 10.1 m with bottom water velocities of 0 to 1.1 m/s; and were associated with sandy substrates (Shuman et al. 2007). As of yet, there has been very little examination of broader scale habitat characteristics related to pallid sturgeon occurrence.

Diet data for juvenile pallid sturgeon in the Fort Randall reach shows that aquatic invertebrates, especially Ephemeroptera and Chironomidae (Diptera), comprised an important component of the diet (Wanner et al. 2007; Berg 2008; Figure 1-4). This trend was particularly apparent for small fish (≤ 330 g). Consumption of fish prey by large juvenile pallid sturgeon (720 mm fork length [FL]) was more prevalent although aquatic invertebrates remained a substantial part of the diet. These diet studies have yielded valuable information regarding prey use, but as of yet there is limited knowledge of the linkage between pallid sturgeon occurrence (i.e., habitat selection) and the distribution of available aquatic macroinvertebrates in the Missouri River.

A tool that measures available suitable juvenile pallid sturgeon habitat in river segments would be valuable because it would enable managers to focus habitat restoration efforts on river segments that lack important habitat and prey availability.

This tool could also focus stocking efforts into areas where pallid sturgeon survival would be highest. This habitat assessment tool could also be used to target areas where pallid sturgeon are likely to occur for more efficient sampling to evaluate growth and condition of pallid sturgeon. As of yet no such tool exists. The objectives of this study were to 1) identify spatial patterns of pallid sturgeon occurrence using the long term catch data in the Fort Randall Reach of the Missouri River (Chapter 2), 2) develop a habitat assessment tool for juvenile pallid sturgeon that combines physical habitat and prey availability data, and 3) use this model to map potential pallid sturgeon capture areas in the Fort Randall reach (Chapter 3).

References

Berg, K. L. 2008. Relative prey use by juvenile pallid sturgeon, and longitudinal distribution of macroinvertebrates in the Missouri River below Fort Randall and Gavins Point Dams, South Dakota and Nebraska, Masters Thesis, South Dakota State University.

Bramblett, R. G. and R. G. White. 2001. Habitat use and movements of pallid and shovelnose sturgeon in the Yellowstone and Missouri Rivers in Montana and North Dakota. Transactions of the American Fisheries Society 130:1006-1025.

Drobish, M. R. (Ed.), 2006: Missouri River standard operating procedures for sampling and data collection, Volume 1.1. U. S.Army Corps of Engineers, Omaha District, Yankton, SD.

Dryer, M. P., and A. J. Sandvol. 1993. Pallid sturgeon, *Scaphirhynchus albus*, recovery plan. Department of the Interior. U.S. Fish and Wildlife Service. Washington, D.C.

Elliott, C. E., R. B. Jacobson, and A.J. DeLonay. 2004. Aquatic habitat assessment, Fort Randall segment of the Missouri River, Nebraska and South Dakota. USGS Report prepared for the USACOE Columbia Missouri.

Forbes, S. A. and R. E. Richardson. 1905. On a new shovelnose sturgeon from the Mississippi River. Bulletin of the Illinois State Laboratory of Natural History 7:39-44.

Gerrity P. C. 2005. Habitat use diet and growth of hatchery-reared juvenile pallid sturgeon and indigenous shovelnose sturgeon in the Missouri River above Fort Peck Reservoir. Masters Thesis Montana State University.

Hesse, L.W., J. C. Schmulbach, K. D. Keenlyne, D. G. Unkenholz, J. W. Robinson, and G. E. Mestl. 1989. Missouri River fishery resources in relation to past present and future stress. Canadian Special Publication of Fisheries and Aquatic Sciences 106:352-371.

Hurley K. L., R. J. Sheehan, R. C. Heidinger, P. S. Wills, and B. Clevenstine.2004. Habitat Use by Middle Mississippi River Pallid Sturgeon. Transactions of the American Fisheries Society 133:1033–1041.

Jordan, G. R. 2006. Pallid sturgeon (*Scaphirhynchus albus*) range-wide stocking and augmentation plan. Pallid Sturgeon Recovery Team plan submitted to U.S. Fish and Wildlife Service. Billings, Montana.

Jordan, G. R., R. A. Klumb, G. A. Wanner, and W. J. Stancill.2006. Poststocking movements and habitat use of hatchery-reared juvenile pallid sturgeon in the Missouri River below Fort Randall Dam, South Dakota and Nebraska. Transactions of the American Fisheries Society. 135, 6:1499–1511

Kallemeyn, L. W. 1983. Status of the pallid sturgeon, *Scaphirhynchus albus*. Fisheries 8:3-9

Keenlyne, K. D. and L. G. Jenkins. 1993. Age at Sexual Maturity of the Pallid Sturgeon Transactions of the American Fisheries Society 122:393–396.

Keenlyne, K. D., C. J. Henry, A. Tews, and P. Clancey 1994. Morphometric comparisons

of Upper Missouri River sturgeons. Transactions of the American Fisheries Society 123:779–785.

Klumb R. A. 2007. Shallow water fish communities in the Missouri River downstream of Fort Randall and Gavins Point dams in 2003 and 2004 with emphasis on Asian carps. Prepared for the Aquatic Nuisance Species Coordinator, U.S. Fish and Wildlife Service –Region 6, 134 Union Boulevard, Lakewood, Colorado 80228. USFWS Great Plains Fish and Wildlife Management Assistance Office, Pierre, South Dakota.

Nelson, W. R. 1968. Reproduction and early life history of sauger, *Stizostedion canadense*, in Lewis and Clark Lake. Transactions of the American Fisheries Society 97:159-166.

Page, L. M. and B. M. Burr. 1991. A field guide to freshwater fishes. Houghton Mifflin Company New York.

Quist, M. C., and 12 coathors. 2004. Research and Assessment Needs for Pallid Sturgeon Recovery in the Missouri River. Final report to the U.S. Geological Survey.

Shuman, D. A., G. A.,Wanner, R. A. Klumb, and W. J. Stancill. 2007. Pallid sturgeon population assessment and associated fish community monitoring for the Missouri River: segments 5 and 6. 2006 Annual Repot prepared for the U.S. Army Corps of Engineers- Northwest Division Kansas City and Omaha Districts.

Shuman, D. A., D. W. Willis, and S. C. Krentz. 2006. Application of a length-categorization system for pallid sturgeon (*Scaphirhynchus albus*). Journal of Freshwater Ecology 21:71-76.

Shuman, D. A., R. A. Klumb, and S. T. McAlpin. 2005. Pallid Sturgeon Population Assessment and Associated Fish Community Monitoring for the Missouri River: Segments 5 and 6, 2004 Annual Repot prepared for the U.S. Army Corps of Engineers- Northwest Division Kansas City and Omaha Districts.

Snook, V. A., E. J. Peters, and L. J. Young. 2002. Movements and habitat use by hatchery-reared pallid sturgeon in the lower Platte River, Nebraska. In W. Van Winkleeditor. Biology, management, and protection of North American sturgeon. American Fisheries Society, Symposium 28:161-174.

Wanner, G. A., D. A. Shuman, and D. W. Willis. 2007. Food habits of juvenile pallid sturgeon and adult shovelnose sturgeon in the Missouri River downstream of Fort Randall Dam, South Dakota. Journal of Freshwater Ecology 22:81-92.

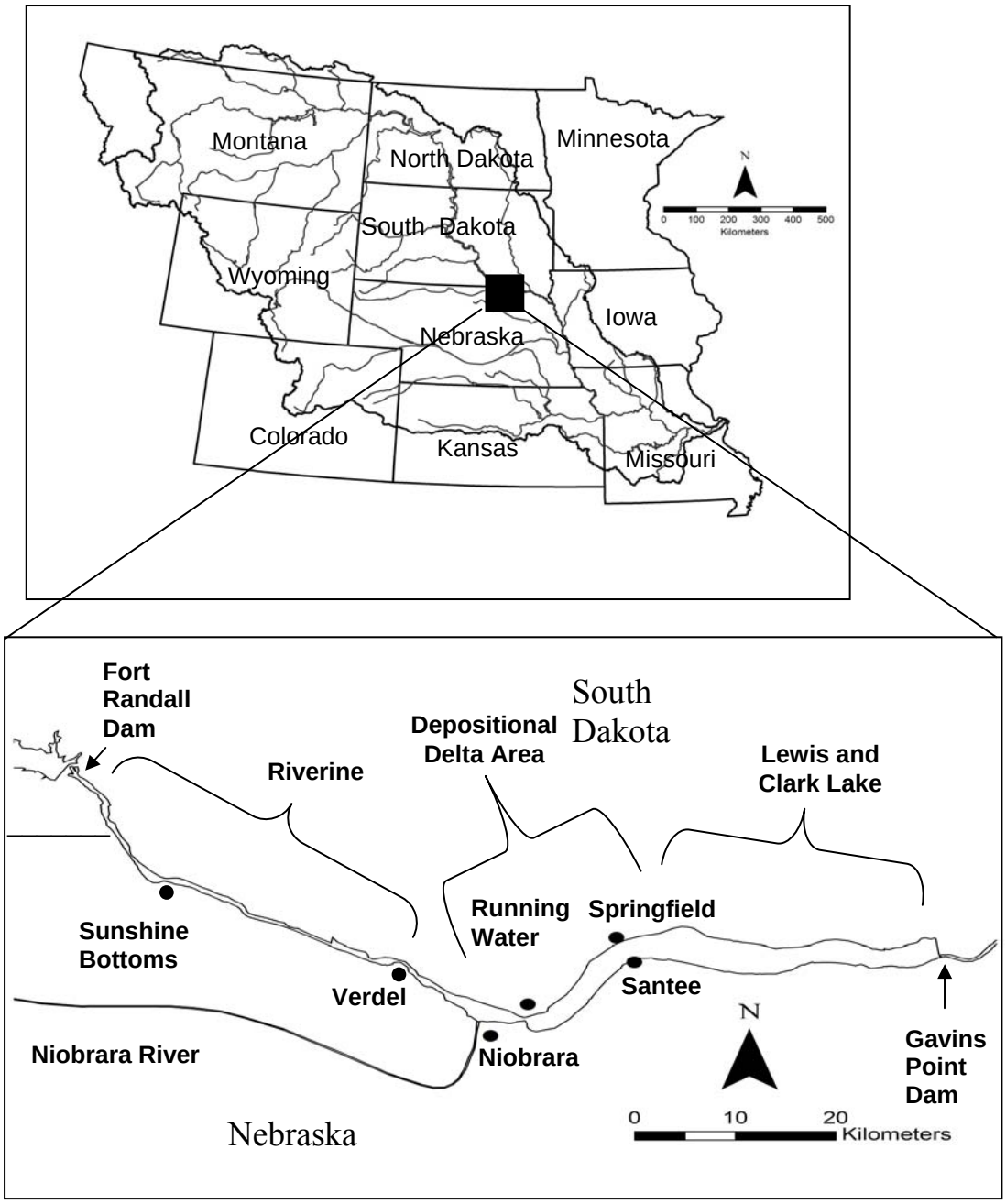


Figure 1-1. Missouri River watershed (top panel) and the Fort Randall reach located between Fort Randall and Gavin's Point dams. Study areas in 2006 for juvenile pallid sturgeon were located in the riverine and delta areas of the reach (bottom panel).

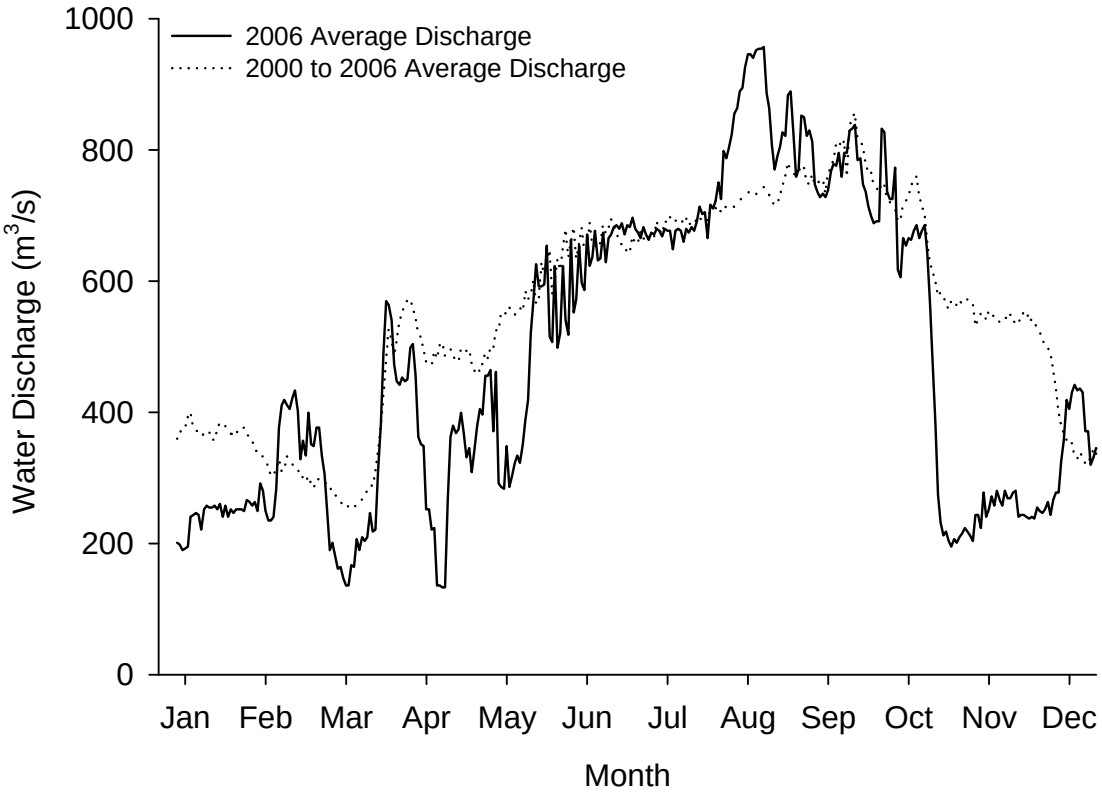


Figure 1-2. Mean daily water discharge from Fort Randall Dam, Missouri River for 2006 (solid line) and the seven year average, mean daily discharge for 2000-2006 (dotted line). Data were obtained from the U.S. Army Corps of Engineers, Northwest Division, Missouri River Basin Water Management Division, Omaha, Nebraska.

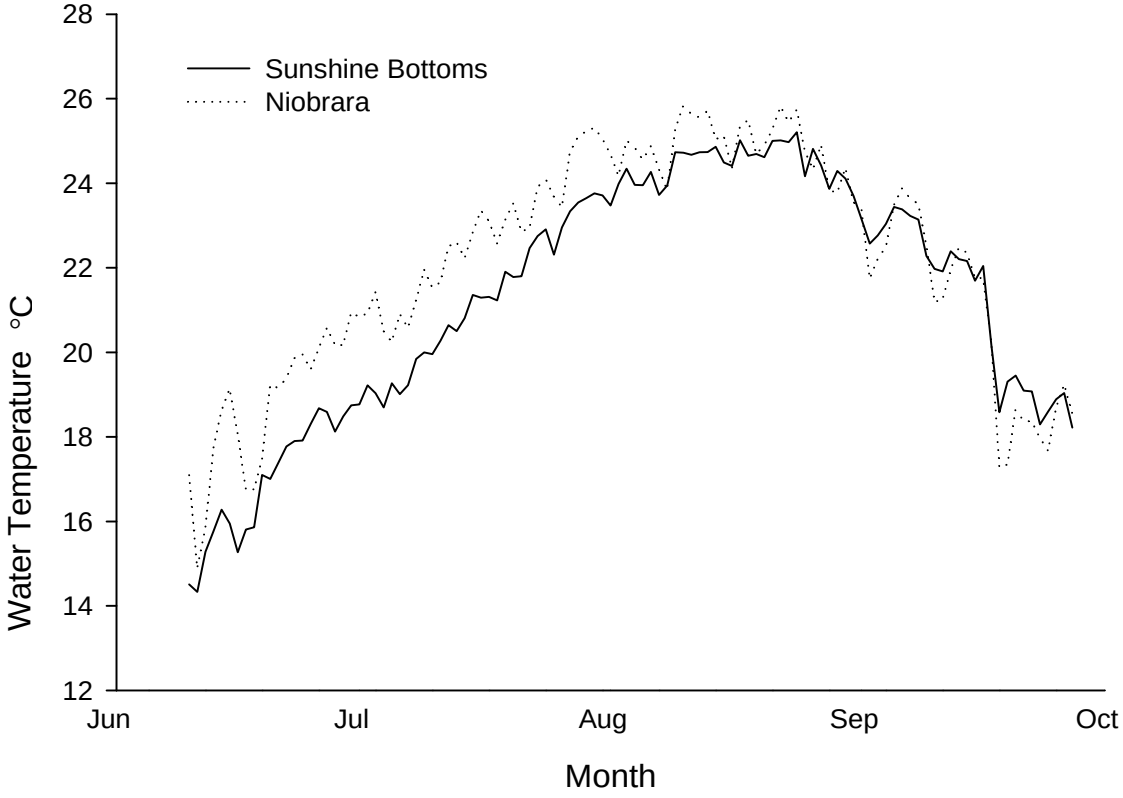


Figure 1-3. Mean daily water temperature (°C) from the Sunshine Bottoms (upstream, solid line) and Niobrara (downstream, dotted line) study locations during 2006. Data provided by R. Klumb, U.S. Fish and Wildlife Service, Great Plains Fish and Wildlife Management Assistance Office, Pierre, South Dakota.

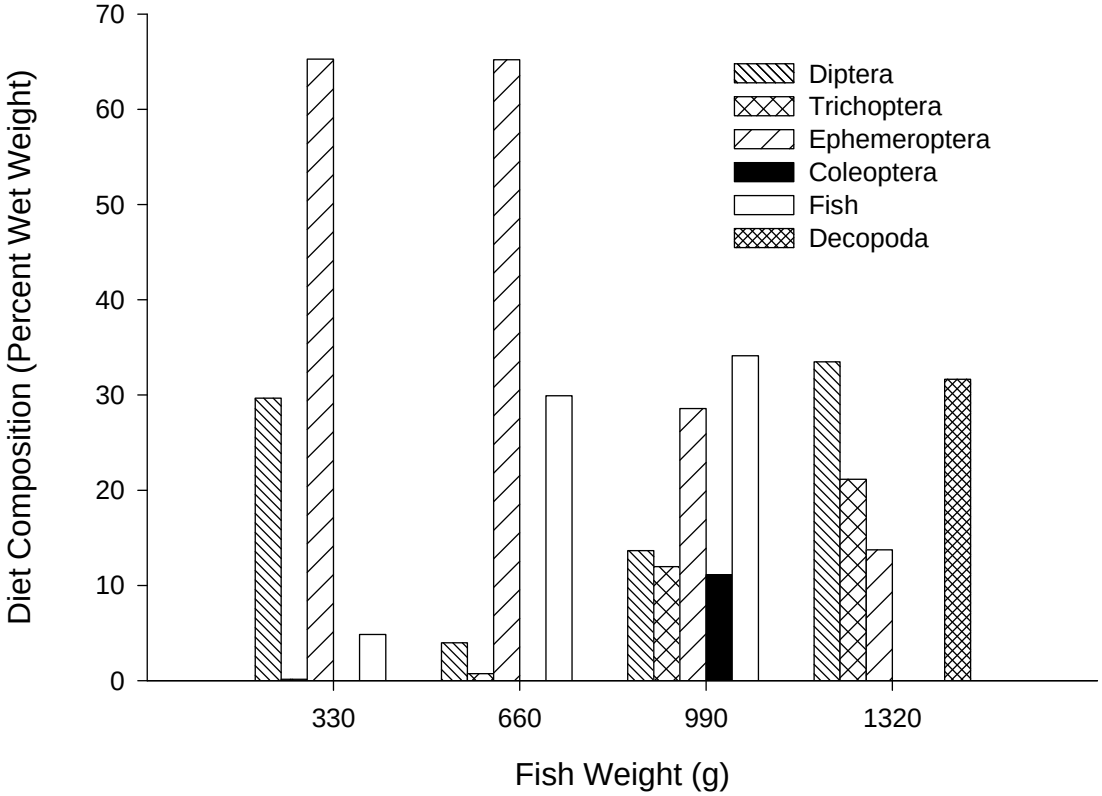


Figure 1-4. Diet composition (percent wet weight) for juvenile pallid sturgeon (90-1,320 g) collected from the Fort Randall reach of the Missouri River. Diet data were compiled from Wanner et al. (2007) and Berg (2008) based on a total of 39 stomach samples.

CHAPTER 2

SPATIAL ANALYSIS OF PALLID STURGEON *SCAPHIRHYNCHUS ALBUS* DISTRIBUTION IN THE MISSOURI RIVER, SOUTH DAKOTA

Abstract

Monitoring and assessment of the endangered pallid sturgeon *Scaphirhynchus albus* is essential to the recovery of the species. Movement and distribution of pallid sturgeon has generally been documented using radio telemetry. However, because of the time and cost involved in tracking individual fish (i.e., small samples size), it is often difficult to evaluate spatial distribution of groups of fish over long time periods (>3 years). Standardized sampling, which relies on a variety of gear types, has been conducted on the Missouri River downstream of Fort Randall Dam annually since 2003 to evaluate the pallid sturgeon population. Using long-term monitoring data from 2003 – 2006, I evaluated the spatial distribution of juvenile pallid sturgeon using spatial scan statistics. Presence and absence of pallid sturgeon was summarized from a variety of gears. Using these data, I analyzed distribution patterns based on: 1) each gear per season, 2) all gears pooled per season 3) each gear pooled across seasons, and 4) pooled data from all gears and seasons. Three significant clusters of pallid sturgeon captures were identified when all gears and years were pooled. Distribution patterns identified using data from summer trammel nets agreed well with the overall pooled dataset and could be used to identify areas with a high probability of pallid sturgeon presence. This methodology can be used to identify areas where pallid sturgeon are likely to occur, thus improving sampling efficiency for monitoring vital statistics for this endangered species.

Moreover, this approach could be applied to other reaches of the Missouri River using existing data from the Pallid Sturgeon Monitoring and Assessment Program. Once identified, these areas could then be evaluated to better understand the habitat requirements of pallid sturgeon.

Introduction

The pallid sturgeon *Scaphirhynchus albus* is a federally endangered species native to the Missouri and lower Mississippi rivers (Dryer and Sandvol 1993). Natural reproduction for this species is limited in the Missouri River and has not been able to sustain the population. As a result, pallid sturgeon are now spawned in hatcheries and juvenile fish have been stocked into many reaches of the Missouri River since 1994 as part of efforts to recover the species (Krentz et al. 2005).

Monitoring of stocked juvenile pallid sturgeon represents an essential component of the recovery effort using an adaptive management framework (Prato 2003). Standardized sampling, which relies on a variety of gear types, has been conducted since 2003 in the Missouri River downstream of Fort Randall Dam, herein called the Fort Randall reach (Shuman et al. 2007). Although information collected from the monitoring and assessment program has been useful for evaluating growth and abundance of pallid sturgeon, these data have not been used to quantify their spatial distribution in the Missouri River.

Movement and distribution of pallid sturgeon are generally documented using radio telemetry (Hurley et al 2004; Gerrity 2005; Jordan et al. 2006). However, because of the time and cost involved in tracking individual fish (i.e., small samples size), it is

often difficult to evaluate spatial distribution of groups of fish over long time periods (>3 years). Moreover, these methods do not account for other individuals (i.e., non-tagged fish) that may be in close proximity to the study fish (Kieffer and Kynard 1993, Ng et al. 2007). Understanding spatial trends in the distribution patterns of pallid sturgeon could help focus recovery efforts for the species by identifying important habitat characteristics.

One approach to evaluating the spatial distribution of fishes based on multiple years of capture data is with spatial scan statistics. This approach has received no attention in freshwater fisheries applications, but spatial scan statistics have been used in epidemiology (Dreesman and Scharlach 2004 and Kuldorff et al. 2005) and crime studies (Jeffries 1998) to evaluate the spatial distribution of these phenomenon. Results from such analyses can then be used to examine whether spatial attributes of certain areas explains clustering of the phenomenon (Brooker et al. 2004, Mostashari et al. 2003, Cousens et al. 2001).

In this study, I used spatial scan analysis to explore the distribution (clustering) of pallid sturgeon in the Fort Randall reach of the Missouri River. I used multiple years of capture data (2003-2006) from 4 different gear types (2 active, 2 passive) to evaluate spatial distribution patterns of pallid sturgeon. I discuss the usefulness of this approach for evaluating standardized monitoring data and the implications for using specific combinations of gears and seasons for documenting pallid sturgeon distribution.

Methods

Study Area

In 2003, the United States Army Corps of Engineers coordinated a multiple state and federal agency standardized sampling effort to assess the success of pallid sturgeon stocking in the Missouri River (Drobish 2006). Capture data for pallid sturgeon were obtained from the 103-km segment of the Missouri River known as the Fort Randall reach located on the border of South Dakota and Nebraska (Figure 2-1). The reach is unique in that it can be divided into riverine (~55 river km), braided depositional (~24 river km), and reservoir (~24 river km) habitat areas. The Fort Randall reach is an impounded portion of the Missouri River that is bounded upstream at Fort Randall Dam, near Pickstown, South Dakota and extends downstream to Gavins Point Dam, near Yankton, South Dakota. The depositional area is characterized by a large braided delta that is being formed by large sedimentary inputs from the Niobrara River which is the major tributary that flows into this particular reach of river. Water discharge from Fort Randall Dam is regulated by the United States Army Corps of Engineers (USACOE) for water control and hydroelectric power production.

The Fort Randall reach has a total of 27 river bends, 17 in the riverine section and 10 in the depositional delta. A river bend is comprised of an upstream channel crossover (area where the thalweg flows from one bank to the opposite bank) and the inside bend (depositional area adjacent to the thalweg), and outside bend (high velocity erosional area adjacent to the thalweg) of the main channel.

Pallid Sturgeon Sampling

The pallid sturgeon monitoring and assessment protocol established standardized sampling methods and gear specifications for both passive gears (stationary gillnets and setlines) and active gears (otter trawls and trammel nets; Drobish 2006). A minimum of ten river bends were randomly chosen for sampling each year from 2003 through 2006. All gear deployments were geospatially referenced with latitude and longitude recorded with either a WAAS enabled Garmin GPSMAP 168 echo sounder or GPSMAP 76 GPS unit (precision of 3 to 10 m). Subsequent sampling effort occurred in areas where a pallid sturgeon was captured with either otter trawls or trammel nets in order to capture more pallid sturgeon. Two subsequent sampling efforts were deployed in areas where a pallid sturgeon was captured. If another pallid sturgeon was captured during subsequent sampling, additional sampling occurred for up to nine additional gear deployments.

Gillnets were deployed as a passive gear when water temperatures were below 13 °C to minimize the chance of pallid sturgeon mortality (Drobish 2007). Each gillnet was composed of multifilament netting in mesh sizes of 2.5, 3.8, 5.1, 7.6, and 10.2 cm in five 8 m long panels for a maximum length of 38 m. These nets were anchored parallel to the current and fished overnight in the spring (March-May) and fall (October- November). On the average, 160 gillnets were deployed per year from 2003 though 2006 in the Fort Randall reach (Shuman et al. 2005, 2006, 2007).

Setlines were constructed of 2 m long, 27.2 kg-test nylon braided twine and rigged with 10/0 and 12/0 circle hooks baited with earthworms *Lumbriscus terrrestris* or leeches *Theromyzon species* (Wanner et al. 2007). The setlines were deployed overnight

and anchored by a 1.4 kg folding grapnel anchor in spring, summer (June-September), and fall. On average, over 500 setlines were deployed annually from 2003 through 2005.

Otter trawls were constructed of outer polyethylene netting consisting of 3.8 cm mesh and an inner mesh size of 0.63 mm. The trawl width was 4.8 m wide and 0.91 m high and was pulled along the bottom of the river from an upstream to downstream direction using two 33 m long tow lines for a targeted distance of 300 m and a minimum of 75 m measured with a GPS. Otter trawls were deployed in spring, summer, and fall starting in 2005, and on average 180 trawls were conducted annually.

Trammel nets were constructed of multifilament nylon netting with a 2.4-m deep inner wall and a 1.8-m deep outer wall that was 38.1 m long with the inner bar mesh of 2.5 cm and an outer mesh of 20.3 cm. Trammel nets were drifted from an upstream to downstream direction for a maximum distance of 300 m and minimum of 75 m. Distance of each drift was recorded using GPS. Trammel nets were deployed in the spring, summer, and fall seasons with an average of 296 trawls deployed annually from 2003-2006.

Spatial Analysis

All initial capture and non-capture locations for pallid sturgeon were entered into the spatial scan statistical program SaTScan™ version 7.0.3 (Kulldorff 2006) to identify ‘clusters’ of capture and non-capture areas. This procedure used variable-sized circular neighborhoods to test for evidence of clustering. For this purpose, I set the maximum size radius at 1.6 km based on mean daily movement rate for pallid sturgeon (Jordan et al. 2006).

A Bernoulli likelihood ratio function (Kuldorff 1997) was calculated for each neighborhood to determine the strength of the cluster as a likelihood function (L) where;

$$L = \left(\frac{c}{n}\right)^{c}\left(\frac{n-c}{n}\right)^{n-c}\left(\frac{C-c}{N-n}\right)^{C-c}\left(\frac{(N-n)-(C-c)}{N-n}\right)^{(N-n)-(C-c)},$$

C is the total number of pallid sturgeon capture locations, *c* is the number of pallid sturgeon captures within the circle (radius = 1.6 km), *N* is the sum of all captures and non-captures within the study area, and *n* is the sum of pallid sturgeon captures and non-captures within the test circle. This likelihood ratio test assumes that population densities are not constant across the study area (Kuldorff and Nagarwalla 1995). Clusters with a high calculated likelihood function are less likely to have occurred by chance, and can be tested statistically by generating a large number of Monte Carlo simulations of the dataset. A *p*-value is calculated by ranking the likelihood of the observed dataset compared to the distribution of the likelihoods resulting from the Monte Carlo simulations. A random selection of 10,000 permutations of the data points for captures and non-captures were used to identify significant non-overlapping clusters ($p < 0.05$).

Distribution of pallid sturgeon presence or absence was analyzed for 1) each gear in each season, 2) pooled gears in each season 3) each gear separately pooled for all seasons, and 4) the overall pooled dataset. Spatial scan analysis was used to identify areas of both pallid sturgeon occurrence (clustering) and absence based on presence and absence data. The analysis was performed for spring (March through May), summer (June through September), fall (October through November) and all seasons combined

for each gear type and for all gears combined. A total of 20 combinations of season and gear deployments were analyzed to determine if consistent clusters were identified across gear types and time periods. The cluster distributions of individual gear types in separate seasons were compared to the clustering patterns from the pooled dataset.

One major assumption in this model is that the data points that are entered into the spatial scan statistical model are representative of the entire population. A study of West Nile Virus occurrence indicated by the presence of dead bird reports (Mostashari et al. 2003) found that several underlying factors besides disease may influence the observed clusters of the virus such as public sighting and willingness to report sightings. Although we used multiple gears to maximize the probability of capturing pallid sturgeon, no sampling gear is 100% effective; thus, I viewed the number of clusters identified by this approach as conservative.

In this study, an important consideration is that there are no false absences in the data set. Each non-capture location should be an actual non-occurrence, and not an area where a gear deployment was unsuccessful at capturing a pallid sturgeon. The pooled dataset of pallid sturgeon capture and non-captures that has the highest sampling effort with the most efficient gear type should therefore be the best representation of the underlying population.

Spatial scan analysis is binomial and not continuous, because it is based on presence and absence data. Effort in terms of time or distance and the number of fish captured within an individual deployment, therefore, is not considered in the model. Hence, multiple pallid sturgeon captured in a single gear deployment are counted singly

as ‘present’ and the location is not weighted to account for multiple fish. In order to weight areas with multiple captures more than areas that had single captures, I adjusted the recorded fish capture locations by 1 m from of the original gear deployment location. Although this small adjustment in fish location had little effect on the actual location of captured fish, it provided more importance to areas where multiple fish were captured.

Results

Pallid Sturgeon Sampling

A total 120 pallid sturgeon were captured in 3,417 gear deployments from 2003 through 2006 (Table 2-1). Trammel nets caught the most pallid sturgeon (n=63) in the four year sample period. Otter trawls caught the fewest number of pallid sturgeon (n=11), but were only used for two years (2005-2006). Setlines were deployed the most, but caught the fewest fish (n=18). Pooled gear deployments and pallid sturgeon captures were not evenly distributed by river kilometer (Figure 2-2). More than one pallid sturgeon was captured in 13 trammel net deployments, and in 4 gillnet deployments from 2003-2006. However, we never collected more than one pallid sturgeon per trawl or setline during the two years that these gears were used (Table 2-2).

Spatial Analysis

Spatial scan analysis identified nine significant clusters of pallid sturgeon captures in the Fort Randall reach (Table 2-1). Cluster locations were identified in areas where pooled pallid sturgeon captures were high (> 1 fish) and effort was moderate (3- 10 deployments) (Figure 2-2). The total surface area of regions (i.e., clusters) characterized

by pallid sturgeon captures ranged from 0.002 to 3.60 km^2. The spatial scan analysis that included all gears and all seasons identified the most clusters (n=3) of pallid sturgeon capture, two of which were located in the same river kilometer, but in different channels of the depositional delta area of the river reach. No single subset of data found clusters of pallid sturgeon in areas where other subsets of the data did not also identify clusters. Significant clustering of pallid sturgeon was found around river kilometer 1,357 near the Ponca Creek confluence for each of the five subsets of the data where clustering was observed, and three of the five data subsets identified pallid sturgeon clustering around river kilometer 1,336 in the depositional delta area (Figure 2-2). Evidence that pallid sturgeon were significantly clustered in certain areas was obtained from fall setlines, summer trammel nets, all season trammel nets, all gears in the summer, and all gears in all seasons. Data subsets that did not identify any clusters of pallid sturgeon occurrence or non-capture were all otter trawls regardless of season, all gillnets regardless of season, all gears in the spring and fall, and all set lines in the summer, spring and combined seasons.

Four areas of pallid sturgeon absence (i.e., non-captures) were found. Non-capture clusters were identified in three subsets including summer trammel nets, all gears in all seasons, and all gears in the summer months. Clusters of non-captures were found around river kilometers 1,348 and 1,343, downstream of the confluence of the Niobrara and Missouri rivers, for more than one data subset (Figure 2-2). Cluster locations for non-captures were identified in areas where pallid sturgeon were generally not captured, despite effort being moderate (Figure 2-2). Analyses that found significant evidence of

pallid sturgeon absence were summer trammel nets, all gears in the summer, and all gears in all seasons. The total surface area of regions characterized by a high density of non-captures ranged from 0.93 to 15.95 km^2 (Table 2-1).

Discussion

One advantage of spatial scan analysis is that the locations of clusters are not limited by sample zone boundaries. Boundaries established in the standardized sampling protocol for pallid sturgeon can be hard to determine making it difficult to define exactly where a bend ends and another begins. Spatial scan analysis is not affected by boundary locations and provides a more parsimonious way to determine spatial patterns of occurrence. A study of forest fragmentation showed that clusters of fragmented forest were not limited by state (e.g., political) boundaries (Coulston and Riitters 2003). In this study, the point sample locations were analyzed for clustering and were not restricted by bend boundaries. This allowed for identification of captures areas that may have overlapped bend boundaries. These capture areas could have been composed of multiple captures of pallid sturgeon over a four year time frame that may have been sampled in two different bends.

Another benefit of the spatial scan approach was that pallid sturgeon clusters could be identified using only trammel nets in the summer. The spatial scan analysis of summer trammel nets identified clusters of pallid sturgeon occurrence in the same areas as those identified by the pooled dataset of all gears and seasons. An assessment of pallid sturgeon sampling gears in the Fort Randall reach of the Missouri River showed that trammel nets were the best gear to capture pallid sturgeon based on catch per unit effort

in the summer (Wanner et al. 2007). This evidence suggests that sampling with summer trammel nets can be used to reliably identify distribution patterns of pallid sturgeon. This may reduce the need to assess distribution patterns using multiple gears that require considerable time and effort.

There were numerous sampling locations where pallid sturgeon were not collected from 2003-2006. However, only two areas were identified that contained significant clustering of non-capture locations (near rkm 1343 and 1348). These regions were located in areas where the number of gear deployments was high enough to detect that the distribution of non-captures could not have occurred at random. There are four obvious peaks of pallid sturgeon occurrence in the histogram by rkm (Figure 2-2). Only two significant pallid sturgeon capture areas (near rkm 1336 and rkm1357) were detected in areas where the effort was higher than the other areas. Two other areas had high pallid sturgeon occurrence but significant clusters were not identified in the analysis possibly due to sample size. Sampling effort was relatively low in these areas compared to other areas where significant clusters were identified. This result points to one of the key assumptions of this type of analysis, which is that the total number of sample locations must be high enough to detect trends and depends on the size of the circular window (Kuldorff 1997). These statistics are not sensitive to uneven distributions of the data points that represent the population. Although the pooled dataset from four years of sampling was used to maximize the spatial coverage of gear deployments, some areas of the Fort Randall reach were sampled more intensively than others. Hence, the probability of detecting clusters in these areas would be higher compared to river reaches where

sampling was more sparse. For this reason, the spatial distribution of clusters identified in this study is likely conservative.

An important finding from the spatial scan analysis was that pallid sturgeon appeared to be consistently captured in similar areas. The region around river kilometer 1357 was found to be a significant area of pallid sturgeon capture in the summer and fall. Water levels are reduced during the fall each year (United States Army Corps of Engineers, 2007), thus reducing the abundance of deeper water habitats and making main channel areas even more important. More pallid sturgeon clusters likely exist in the fall than were detected by spatial scan statistics. More clusters were not detected possibly due to reduced rates of gear deployment and decreased capture efficiency of many of the gear types in the fall (Wanner et al. 2007). Setline gear deployments were the only gear type that indicated a cluster in the fall, suggesting another gear type may be needed to catch pallid sturgeon during the fall sample period.

Spatial scan analysis shows promise for assessing distribution patterns of pallid sturgeon. Once identified, these areas can provide important information about habitat use that could be extended to other segments of the Missouri River. However, there are limitations that need to be considered when applying this technique. In the present application, a circular window proved effective for identifying clusters along a single, relatively linear stretch of a large river. However, circles may not be an effective metric of spatial proximity in more complex, dendritic channel networks. Future development of the spatial scan statistic for monitoring pallid distribution should consider using linear segments of the riparian network as scanning windows (i.e., instead of circles) and

accounting for variability in sampling effort (i.e., uniform distribution of sampling effort).

The use of SaTscan analysis to identify distribution patterns of pallid sturgeon could be an effective alternative to telemetry methods in identifying important habitats for juvenile pallid sturgeon. Movement and distribution of pallid sturgeon are generally documented using radio telemetry, but because of the time and cost involved in tracking individual fish (i.e., small samples size), it is often difficult to the evaluate spatial distribution of groups of fish over long time periods (>3 years). The spatial analysis approach discussed here does identify important habitats of a larger number of fish locations over a longer time period. Identification of these areas is an essential step in aiding the recovery of the pallid sturgeon. An intensive study of these areas will lead to a better understanding of pallid sturgeon habitat requirements that will ultimately aid in the recovery of the species.

References

Brooker S, S. Clarke, J. K. Njagi, S. Polack, B. Mugo, B. Estambale, E. Muchiri, P. Magnussen, and J. Cox. 2004. Spatial clustering of malaria and associated risk factors during an epidemic in a highland area of western Kenya. Tropical Medicine and International Health, 9:757-766.

Coulston J. W. and K. H. Riitters K. H. 2003. Geographic Analysis of Forest Health Indicators Using Spatial Scan Statistics. Environmental Management, 31: 764-773.

Cousens S., P. G. Smith, H. Ward, D. Everington, R. S. G. Knight, M. Zeidler, G. Stewart, A.B. Smith-Bathgate, M.A. Macleod, J. Mackenzie, and R.G. Will. 2001. Geographical distribution of variant Creutzfeldt-Jakob disease in Great Britain, 1994-2000. The Lancet, 357:1002-1007.

Dreesman, J. and H. Scharlach 2004. Spatial-statistical analysis of infectious disease notification data in Lower Saxony. Gesundheitswesen, 66: 783-789, 2004

Drobish M., (editor) 2006. Missouri River standard operating procedures for sampling and data collection, Volume 1.1. U.S. Army Corps of Engineers, Omaha District, Yankton, SD.

Dryer M. P., and S. L. Sandvol. 1993. Pallid Sturgeon, *Scaphirhynchus albus*, recovery plan. U.S. Fish and Wildlife Service. Washington D.C.

Gerrity P. C. 2005. Habitat use diet and growth of hatchery-reared juvenile pallid sturgeon and indigenous shovelnose sturgeon in the Missouri River above Fort Peck Reservoir. Masters Thesis Montana State University.

Hurley, K. L., R. J. Sheehan, R. C. Heidinger, P. S. Wills, B. Clevenstine. 2004. Habitat use by middle Mississippi River pallid sturgeon. Transactions of the American Fisheries Society 133:1033-1044.

Jefferis, E. S. 1998. A multi-method exploration of crime hot spots: SaTScan results. National Institute of Justice, Crime Mapping Research Center.

Jordan G. R. (Editor) 2006. Pallid sturgeon range wide stocking and augmentation plan. Submitted to U.S. Fish and Wildlife Service, Billings, Montana.

Jordan G. R., R. A. Klumb, G. A. Wanner, and W. J. Stancill. 2006. Postocking movements and habitat use of hatchery-reared juvenile pallid sturgeon in the Missouri River below Fort Randall Dam, South Dakota and Nebraska. Transactions of the American Fisheries Society 135: 1499-1511.

Kieffer M. C. and Kynard B. 1993. Annual movements of shortnose and Atlantic sturgeons in the Merrimack River, Massachusetts. Transactions of the American Fisheries Society. 122:1088-1103.

Krentz, S., R. Holm, H. Bollig, J. Dean, M. Rhodes, D. Hendrix, G. Heidrich, and B. Krise. 2005. Pallid sturgeon spawning and stocking summary report. 1992-2004. United States Fish and Wildlife Service report. Bismarck, North Dakota.

Kulldorff, M, R. Heffernan, J. Hartman, R. M. Assunção, F. Mostashari. 2005. A space-time permutation scan statistic for the early detection of disease outbreaks. PLoS Medicine, 2:216-224.

Kulldorff, M. 1997. A spatial scan statistic. Communications in Statistics: Theory and Methods, 26:1481-1496.Kulldorff M. and Information Management Services, Inc.

2006. SaTScan™ v7.0: Software for the spatial and space-time scan statistics. http://www.satscan.org

Kulldorff M and N. Nagarwalla. 1995. Spatial disease clusters: Detection and Inference. Statistics in Medicine, 14:799-810.

Mostashari F., M. Kuldorff, J. J. Hartman, J. R. Miller, V. Kulasekera. 2003. Dead bird clustering: A potential early warning system for West Nile virus activity. Emerging Infectious Diseases, 9:641-646.

Ng, C. L., K. W. Able, and T. M. Grothues. 2007. Habitat use, site fidelity, and movement of adult striped bass in a southern New Jersey estuarybased on mobile acoustic telemetry. Transactions of the American Fisheries Society. 136:1344-1355.

Prato, T., 2003. Adaptive management of large river with special reference to the Missouri River. Journal of the American Water Resources Association 935-946.

Shuman D. A., G. A. Wanner, R. A. Klumb, and W. J. Stancill. 2007. 2006 Annual report for pallid sturgeon population assessment and associated fish community monitoring for the Missouri River segments 5 and 6. Prepared for the U.S. Army Corps of Engineers Missouri River Recovery Program. U.S. Fish and Wildlife Service. Great Plains Fish and Wildlife Management Assistance Office. Pierre, South Dakota.

U.S. Army Corps of Engineers, Northwestern Division, Missouri River Basin Water Management Division, Omaha, Nebraska.

Wanner, G. A., D. A. Shuman, and D. W. Willis. 2007. Food habits of juvenile pallid sturgeon and adult shovelnose sturgeon in the Missouri River downstream of Fort Randall Dam, South Dakota. Journal of Freshwater Ecology 22:81-92.

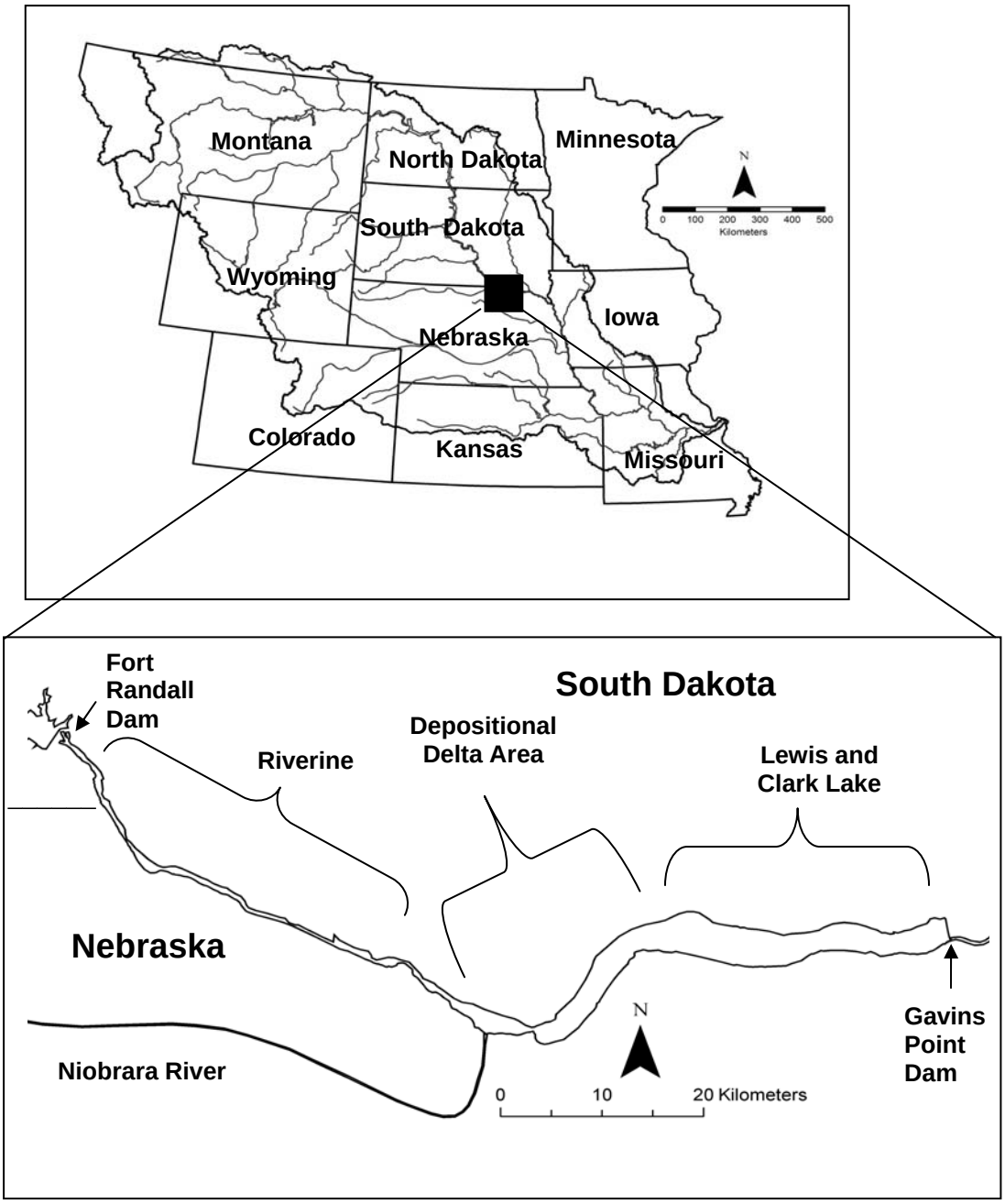


Figure 2-1. Missouri River watershed (top panel) and study area located between Fort Randall and Gavin's Point dams. Sample areas in 2003-2006 for juvenile pallid sturgeon were located in the riverine and delta areas of the reach (bottom panel).

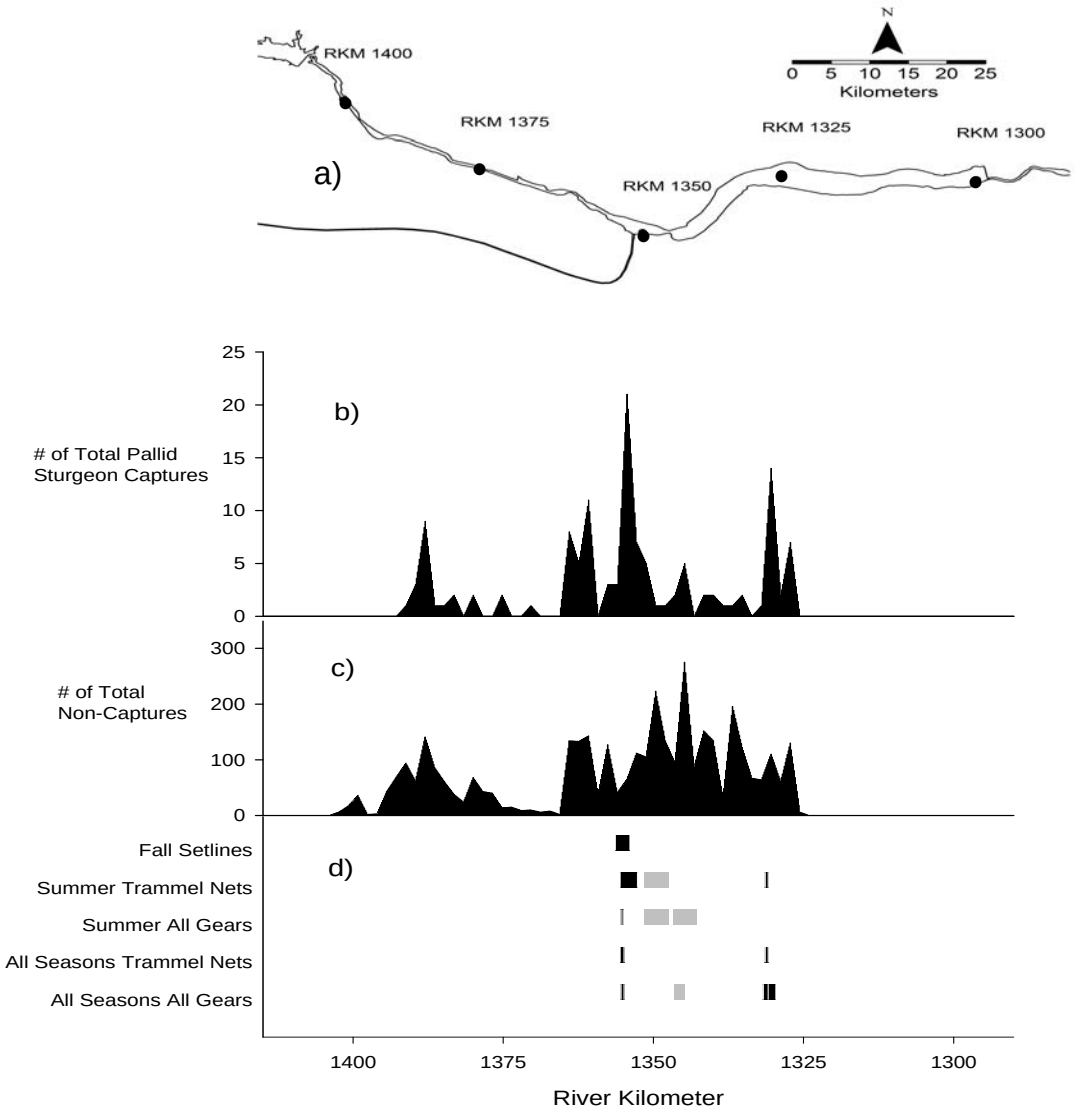


Figure 2-2. a) Map of the Fort Randall reach of the Missouri River with river kilometers (RKM). b) Plot of total pallid sturgeon captures and c) total non-captures by river kilometer from 2003-2006 that were used in the spatial scan analysis. d) River segments (RKM) where significant clustering ($p<0.05$) occurred for pallid sturgeon captures (horizontal black bars) or non-captures (horizontal gray bars) for each of the five data sets that had significant clusters (see text for details). Widths of the bars indicate approximate cluster size.

Table 2-1. Number of non-captures and captures for Summer (June-September), Fall (October-November), Spring (March-May) and all seasons of pallid sturgeon in the Missouri River downstream of Fort Randall Dam, South Dakota and Nebraska during 2003-2006 and resulting significant clusters ($p<0.05$) and total surface area from spatial scan analysis.

Season	Gear	Total Non-Captures	Initial Pallid Sturgeon Captures	Number of Clusters P< 0.05		Total Surface Area of Clusters (km^2)	
				Pallid Sturgeon	Non-Capture	Pallid Sturgeon	Non-Capture
All	All	3297	120	3	1	0.26	0.93
	Gill Nets	597	28	0	0	0	0
	Trammel Nets	1016	63	2	0	0.05	0
	Setlines	1534	18	0	0	0	0
	Otter Trawls	150	11	0	0	0	0
Summer	All	1386	58	1	2	0.002	15.95
	Trammel Nets	557	41	2	1	3.60	7.94
	Setlines	809	8	0	0	0	0
	Otter Trawls	7	7	0	0	0	0
Spring	All	1294	27	0	0	0	0
	Gill Nets	349	9	0	0	0	0
	Trammel Nets	351	13	0	0	0	0
	Setlines	519	4	0	0	0	0
	Otter Trawls	75	1	0	0	0	0
Fall	All	617	35	0	0	0	0
	Gill Nets	235	17	0	0	0	0
	Trammel Nets	108	9	0	0	0	0
	Setlines	206	6	1	0	3.06	0
	Otter Trawls	68	3	0	0	0	0

Table 2-2. Summary of number of gear deployments where multiple pallid sturgeon were captured per individual deployment during sampling for Summer (June-September), Fall (October-November) and Spring (March-May) pallid sturgeon sampling in the Missouri River downstream of Fort Randall Dam, South Dakota and Nebraska during 2003-2006.

Season	Gear	Number of Gear Deployments that Captured	
		Two Pallid Sturgeon	Three Pallid Sturgeon
Summer	Trammel Nets	8	1
	Otter Trawls	0	0
	Setlines	0	0
Spring	Trammel Nets	1	1
	Otter Trawls	0	0
	Setlines	0	0
	Gill Nets	1	0
Fall	Trammel Nets	1	1
	Otter Trawls	0	0
	Setlines	0	0
	Gill Nets	2	1

CHAPTER 3

DEVELOPMENT AND APPLICATION OF A SPATIALLY EXPLICIT HABITAT MODEL FOR JUVENILE PALLID STURGEON

Abstract

The pallid sturgeon *Scaphirhynchus albus,* is an endangered species native to the Missouri and lower Mississippi rivers. As part of a large-scale recovery effort, 361,599 juvenile pallid sturgeon have been stocked into the Missouri River since 1994 and a standardized long-term monitoring program was initiated in 2003. Understanding the distribution and habitat requirements of juvenile pallid sturgeon represents one important goal of the monitoring and assessment program. In this study, I developed a habitat assessment tool for juvenile pallid sturgeon that integrated information from known capture locations with physical habitat and macroinvertebrate abundance data. I used discriminant function analysis to assess habitat differences between capture (n=25) and non-capture (n=49) locations from 2003-2006 in the Missouri River downstream of Fort Randall Dam in South Dakota and Nebraska. Four variables successfully discriminated capture from non-capture locations: 1) water depths > 2 m, 2) proportion of sand substrate, 3) dipteran abundance and 4) ephemeropteran abundance. Classification functions were then used to predict pallid sturgeon occurrence in eight 3.2-km river segments. The discriminant function model correctly classified capture areas 88% of the time; for non-capture areas the model correctly classified sites 100% of the time for an overall classification rate of 95%. The percent of area classified as potential capture locations in each of the eight river segments ranged from 22 to 64%, indicating that

habitat and prey availability should be considered before stocking of pallid sturgeon takes place downstream of Fort Randall Dam. The model developed here illustrated that a combination of biotic and abiotic characteristics influenced juvenile pallid sturgeon occurrence. This model could be used to evaluate pallid sturgeon habitat in other areas of the Missouri River basin and help guide future pallid sturgeon stocking and habitat restoration efforts.

Introduction

The pallid sturgeon, *Scaphirhynchus albus*, a riverine species native to the Missouri and Mississippi rivers (Forbes and Richardson, 1905), has been listed as an endangered species since the fall of 1990 (Dryer and Sandvol 1993). Natural reproduction of pallid sturgeon has been negligible in many reaches of the Missouri River. The decline of pallid sturgeon populations has been associated with changes in the natural flow regime of the Missouri River due to impoundments and channelization. Immediate recovery efforts for the species have focused on stocking hatchery-reared fish to supplement the existing population (Dryer and Sandvol 1993; Krentz et al. 2007).

Annual stocking of hatchery-reared pallid sturgeon was implemented in 1994 in many segments of the lower Missouri River, and in 1998 in the upper Missouri River. A total of 361,599 juvenile pallid sturgeon have been stocked basin wide (Krentz et al. 2005), with 4,242 juvenile pallid sturgeon stocked since 2000 into the 103-km segment of the Missouri River downstream of Fort Randall Dam in South Dakota and Nebraska. This river reach was identified as a recovery priority management area (RPMA) in the original pallid sturgeon recovery plan because of existing riverine habitat that could

provide habitat for future broodstock. These broodstock could be used to supplement populations in the three other RPMAs in the Missouri River basin. Standardized sampling was started in the Fort Randall reach in 2003, and has resulted in successful capture of pallid sturgeon from all year classes stocked in that reach (Jordan 2006; Shuman et al. 2005, 2006, 2007). Pallid sturgeon captures have increased every year downstream of Fort Randall Dam since the sampling program was initiated (Shuman et al 2007).

Understanding the distribution and habitat requirements of juvenile pallid sturgeon represents an important part of the monitoring and assessment program. Efforts to better understand the habitat and prey requirements for pallid sturgeon are needed so that habitat improvements can be made in areas where sufficient habitat is lacking, and determine where potential early life history bottlenecks that prevent recruitment exist (Quist et al. 2004). As part of the monitoring and assessment program, data on water depth, water velocity and substrate composition are routinely collected in areas where pallid sturgeon are captured and for 25% of non-capture areas (Drobish 2007). Although these point measurements provide simple, baseline habitat characteristics, they have not yet been used to evaluate broad scale availability of juvenile pallid sturgeon habitat.

There have been several studies of radio-tagged juvenile and adult pallid sturgeon that have been used to evaluate movement rates, behavior, and habitat use in the Missouri River. Jordan et al. (2006) found that movement rates of juvenile pallid sturgeon were small in the first year after stocking compared to the second year, and were associated with mostly main channel habitat in the Fort Randall reach. Intensive tracking of

juvenile pallid sturgeon in the Fort Randall reach indicated that juvenile pallid sturgeon had a maximum movement rate of 270 m/hour (Jordan et al. 2006).

Results from extensive tracking studies showed that juvenile pallid sturgeon were not uniformly distributed in the river reach, implying that they preferred some areas over others (Jordan et al. 2006). Elliott et al. (2004) assessed the habitat selection of the same fish in the Jordan et al. (2006) study, and found juvenile pallid sturgeon used water depths > 1 m, bottom water velocities up to 1.0 m/s, and sandy substrates. Another tracking study of pallid sturgeon in the Missouri and Yellowstone rivers also found that adult pallid sturgeon used primarily main channel habitat and showed signs of aggregation (Bramblett and White 2001). Other pallid sturgeon habitat selection studies using radio telemetry studies (Snook et al. 2002; Hurley et al. 2006; Gerrity 2006) have found that both adult and juvenile pallid sturgeon were associated with mostly main channel habitats in deep (>1 m), and moderately fast waters (velocities up to 1.0 m/s).

Diet data for juvenile pallid sturgeon in the Fort Randall reach have shown that aquatic invertebrates, especially Ephemeroptera and Chironomidae (Diptera) comprised an important component of the diet (Wanner et al. 2007; Berg 2008). This trend was particularly apparent for small fish (≤ 330 g). Consumption of fish prey by large juvenile pallid sturgeon (>720 mm fork length [FL]) was more prevelant although aquatic invertebrates remained a substantial part of the diet. These studies have yielded valuable information regarding prey use, but as of yet there is limited knowledge of the linkage between pallid sturgeon occurrence (i.e., habitat selection) and the distribution of aquatic macroinvertebrates in the Missouri River.

Although aquatic invertebrates are very important to pallid sturgeon, previous studies of pallid sturgeon habitat use have focused exclusively on physical habitat parameters (Jordan et al. 2006; Hurley et al 2004; Elliot et al. 2007; Snook et al 2002; Gerrity 2005). Currently no tools exist to assess juvenile pallid sturgeon habitat in the Missouri River that could identify areas where restoration efforts should be focused. In this study, I developed a habitat assessment tool for juvenile pallid sturgeon that integrated information from known capture locations with physical habitat and prey availability parameters. My objectives were to 1) identify physical habitat and prey availability attributes that were related to juvenile pallid sturgeon capture, 2) develop a predictive model to identify pallid sturgeon capture and non-capture areas, and 3) apply the model to evaluate spatial variation in pallid sturgeon habitat in the Missouri River. I discuss implications for using this modeling approach to evaluate habitat availability in other river reaches, and identify potential areas to focus recovery efforts such as stocking location selection and habitat modifications by creating shallow water habitats and reconnecting side channels.

Methods

Site Selection

Pallid sturgeon habitat was studied in the 103-km segment of the Missouri River downstream of Fort Randall Dam, which forms the border between South Dakota and Nebraska (Figure 3-1), herein referred as the Fort Randall reach. The Fort Randall reach is an impounded portion of the Missouri River that begins at the Fort Randall Dam, near Pickstown, South Dakota (rkm 1402) and extends to Gavins Point Dam, near Yankton, South Dakota (rkm 1299). This reach is unique because it can be divided into riverine (~55 river km [rkm]), depositional (~24 rkm), and reservoir (~24 rkm) habitats. The depositional area is characterized by a large braided delta formed by sediment inputs from the major tributary in the reach, the Niobrara River (rkm 1350). Discharge from Fort Randall Dam is regulated by the United States Army Corps of Engineers (USACOE) for flood control and hydroelectric power production. Water levels fluctuate as much as 1 m/d due to power production demands (Klumb 2007).

Eight 3.2 km river segments representing the riverine (n=4) and depositional (n=4) habitats of the Fort Randall reach were chosen for intensive sampling. Representative river segments were chosen based on available capture data (both presence and absence) from standardized sampling in the Fort Randall reach from 2003 through 2005, and where pallid sturgeon sampling was scheduled to occur during the summer of 2006 (USFWS, Great Plains Fish and Wildlife Management Assistance Office, Pierre, South Dakota unpublished data). Upstream boundaries of the four sample segments in the riverine portion were located near Sunshine Bottoms (rkm 1390 and

1376), and Verdel, Nebraska (rkm 1361 and 1355). Study segments in the depositional area were located near the mouth of the Niobrara River (rkm 1350 and 1345), and Santee, Nebraska (rkm 1337 and 1331).

Pallid Sturgeon Sampling

Information on pallid sturgeon abundance was obtained using drifted trammel nets and otter trawls deployed during daylight hours in the summer (June through September) of 2006. Net specifications and deployments were conducted in accordance with standardized sampling protocols (Drobish 2007). Trammel nets (38.1 m length) were constructed of multifilament nylon netting with a 2.4 m deep inner wall and a 1.8 m deep outer wall with a 2.5 cm inner bar mesh and 20.3 cm outer bar mesh. Trammel nets were fished from upstream to downstream for a maximum distance of 300 m and minimum of 75 m. Otter trawls were constructed of an outer polyethylene netting consisting of 3.8 cm mesh and an inner mesh size of 0.63 mm. The trawl width was 4.8 m wide and 0.91 m high and was pulled along the bottom of the river from upstream to downstream using two 33 m tow lines for a targeted distance of 300 m and a minimum of 75 m. Global positioning system (GPS) coordinates were obtained at the start and endpoint of each deployment and sample distance using a WAAS enabled Garmin GPSMAP 168 echo sounder or Garmin GPSMAP76 GPS unit (precision of 3 to 10 m).

GIS Mapping --- Pallid Sturgeon Capture and Non-Capture Areas

Pallid sturgeon capture and non-capture areas were characterized using ArcMap 9.2 (ESRI, Redlands, California). Because it was impossible to determine the exact

locations where pallid sturgeon were captured along the actively sampled transects (trammel nets or otter trawls), I constructed a 300 m buffer that encompassed the starting location, linear sample path, and endpoint of each gear deployment. I chose 300 m because 1) it approximated the maximum hourly movement rate of juvenile pallid sturgeon as determined by radio telemetry (Jordan et al. 2006), and 2) explained where a pallid sturgeon may have been located along the transect prior to being captured by the net; that is, if it were stationary along the transect or if it was intercepted by the net while moving. Non-capture areas that overlapped with capture areas were eliminated from the analysis to prevent coding of habitat as both capture and non-capture. In cases where more than one pallid sturgeon was captured along a transect, I weighted the capture area by the number of fish caught. That is, if three pallid sturgeon were caught in a single gear deployment along the same transect, then the physical and biological habitat attributes were counted three times.

Physical Habitat

Intensive habitat sampling was conducted independent of pallid sturgeon sampling in the eight 3.2 km river segments in the Missouri river downstream of Fort Randall Dam. Water depth and water velocity were measured in July of 2006 using a boat mounted 1.5 MHz SonTek RiverCat Acoustic Doppler Profiler (ADP; SonTek/YSI, San Diego, California). Acoustic Doppler Profiler data were collected along transects perpendicular to the current sampling from bank to bank at a spacing of 100 to 150 m. Secondary channels were sampled using diagonal cross-channel transects to maximize sampling efficiency and facilitate boat navigation in the narrow side channel. The

average ping interval for water depth and water velocity measurements was set at 10 seconds. Water velocity was measured on a vertical profile with cell height set to 25 cm. For each cell the ADP measured the direction of flow in degrees from true north. Simultaneous GPS position was obtained for each point using a real-time differentially corrected Trimble GPS receiver (Trimble Corporation, Sunnyvale, California) linked to the unit (precision < 1 m).

Sediment was collected using a 0.3 m long x 10.8 cm diameter Hesse sampler. Substrate particle size was qualitatively estimated for percent substrate size classification according to Wentworth (1922) and Threader et al. (1998). Sediment samples were collected at three locations on transects spaced 300 m apart at 25% of the channel width near the left bank and right bank, and in the center of the main channel. Sediment samples were collected in the center of the secondary channels every 300 m. GPS latitude and longitude were obtained using a WAAS enabled Garmin GPSMAP 76.

Macroinvertebrate Composition and Abundance

Aquatic macroinvertebrate abundance was measured in June and August of 2006 using a 0.5 m diameter, 3 m long, 500 µm mesh conical-shaped drift net (Cummins 1962) attached to a 22.7 kg weight. The net was deployed near the river bottom for 2 to 8 minutes depending upon the suspended detritus loads. The volume of water sampled was measured by a flowmeter that was fixed to the center of the net mouth. Drift nets were deployed along transects spaced 300 m apart at points near 25% of the channel width near the left bank and right bank, and in the middle of the main river channel. Drift net samples in secondary channels were collected in the middle of the channel every 300 m.

Sample contents were rinsed into sampling bottles and preserved in 90% ethanol with rose bengal dye. In the laboratory, aquatic invertebrates were sorted, enumerated, and identified to family (Merrit and Cummins 1996, Pennak 1978). Abundance estimates were expressed as volumetrical density as number of individuals/m^3.

GIS Mapping – Habitat, Prey Abundance, Pallid Sturgeon Occurrence

A geographic information system (GIS) was used to create maps for each river segment from measured habitat and prey variables with ArcMap 9.2 software (ESRI, Redlands, California). Shoreline boundaries for each river segment were digitized using simplified contours derived from 2006 light detection and ranging (LIDAR) elevation data (USACOE), and the mean summer gauge height of the nearest stream gauge (near Greenwood, South Dakota for the riverine section or Springfield, South Dakota for the delta section). Point sample locations of all physical habitat and aquatic invertebrate data were plotted in each sample segment. Maps were corrected for missing data by eliminating shallow water areas less than 0.5 m deep that prohibited boat navigation and sampling.

Interpolated maps of each measured physical habitat and prey variable were calculated from measured field point data by ordinary kriging (Krige 1966) with anisotropy or inverse distance weighting methods using the Geostatistical Analyst Tool in ArcMap 9.2. A 20 m grid cell size was chosen because it maximized processing efficiency and resolution. The best prediction map for each variable was chosen based on the interpolation method that had the smallest mean square error from cross-validation calculated by comparing the predicted to observed values. The ADP data and ordinary

kriging with anisotropy were used to create maps for water depth, near bottom water velocity, the directional variation in near-bottom water flow, and bottom slope (see Appendix B1-B4). I used an approach similar to that for calculating directional variation in wind velocity (Yamartino 1984) to derive directional variation (DV) in near-bottom water flow. Directional variation in bottom water flow was calculated at 20 m grid cell resolution by first developing a circular sampling window (radius = 3 grid cells) around each target grid cell (Figure 3-2). Then, the x and y directional components of bottom flow were calculated by obtaining the sine and cosine values (in radians) for the directional flow in each of the grid cells within the sampling window. Variation in direction flow (DV), was then calculated for each target grid cell as,

$$DV = SD_{sine\ n} + SD_{cosine\ n}\ ,$$

where $SD_{sine\ n}$ is the standard deviation of sine values for grid cells in the sampling window and $SD_{cosine\ n}$ is the standard deviation of cosine values for grid cells in the sampling window (Figure 3-2).

The bottom slope map was created using the interpolated water depth map, and then using the slope calculation tool in ArcMap 9.2. Latitude and longitude coordinates of drift sample locations and inverse distance weighting were used to create interpolated maps of invertebrate abundance (Appendix B5-B6) and sand substrate composition (Appendix B7). Maps for invertebrate abundance were averaged for June and August after interpolation.

Pallid sturgeon capture and non-capture areas were then layered on top of physical habitat and invertebrate abundance grid maps. Mean values for habitat and

invertebrate data were calculated for each capture and non-capture area. In addition, the proportional availability of several habitat attributes were calculated for capture and non-capture locations. Water depth availability was calculated as percent area with depths greater than 2, 3, 4, 5, 6, 7, or 8 m. Similarly, near-bottom water velocity availability was calculated as percent area greater than 20, 40, 60, 80, 100, or 120, cm/s. Substrate availability was also calculated as percent area that had substrate that was greater than 50% or 75% sand. Bottom slope was calculated as percent area greater than 1.5, 3, 4.5, or 6% slope.

Model Development and Cross-Validation

I used forward stepwise discriminant function analysis (DFA) to identify physical habitat and macroinvertebrate parameters that best distinguished pallid sturgeon capture areas from non-capture areas (McGarigal et al. 2000). A total of 26 variables were initially screened using t-tests ($p < 0.1$) to identify candidate metrics for input in the DFA analysis. I chose one candidate variable from each of the seven variable categories (i.e., water depth, bottom water velocity, macroinvertebrate abundance) that had the lowest (most significant) p-value from the t-tests. Candidate variables were then entered into forward stepwise DFA (Statistica 6, Stat Soft Inc., Tulsa, Oklahoma). Tolerance values were calculated to test for the amount of variance that is unique to the individual variables in the model. Classification functions were then derived for capture and non-capture areas from the DFA and used to classify sites as capture or non-capture areas. Actual classification rates were cross-validated against predicted classification values for each area to evaluate model performance.

Modeling of Potential Capture Areas

Classification of sites as either capture or non-capture areas was determined at 20 m grid cell resolution for each of the eight 3.2-km river segments using the derived classification functions generated from DFA. Pallid sturgeon capture was assigned to grid cells that had a capture classification value that was higher than the non-capture classification value. Conversely, non-capture classification was assigned to grid cells that had higher non-capture values than that predicted by capture classification values. In each of the 3.2 km river segments, I calculated the proportion of area that was characterized as a potential capture location, based on the physical habitat and prey availability parameters in the DFA model.

Results

Pallid Sturgeon Captures

A total of 25 pallid sturgeon (FL 330 to 711 mm) were captured in 142 gear deployments in the eight 3.2 km river segments during the summer of 2006 (Table 3-1, and Table 3-2). Multiple pallid sturgeon were captured in the same location on five instances. Pallid sturgeon were captured with both trammel nets and otter trawls in only two of the eight study segments, and no pallid sturgeon were captured in two of the sample segments where both gears were deployed. A total of seven pallid sturgeon were captured in 59 gear deployments in the riverine habitats. Eighteen pallid sturgeon were captured in 83 gear deployments in the depositional delta habitat.

Capture rates varied for trammel nets and otter trawls in the riverine and delta habitats during the sampling period. Trammel net catch per unit effort (CPUE) in riverine reaches ranged from 0 to 0.12 fish •100 m^{-1} whereas catch rates using otter trawls in riverine habitats were lower ranging from 0 to 0.06 fish •100 m^{-1}. In depositional habitats, CPUE for trammel nets ranged from 0 to 0.08 fish •100 m^{-1}; catch rates using otter trawls ranged from 0 to 0.25 •100 m^{-1}. Multiple captures of pallid sturgeon (>1 pallids/area) occurred in 20% of the sampling areas (n=5). On one occasion 12 fish were captured from the same location; this site was located in the depositional area of the Fort Randall reach.

Mapping Cross-Validation

Mean square error (MSE) values from cross-validation of actual versus predicted values for physical habitat and macroinvertebrate abundance maps varied from 0 to 40.07 (Table 3-3). June ephemeropteran abundance had the least amount of mapping error (MSE = 0 to 0.09), while near bottom water velocity had the highest amount of error in the maps (MSE = 26.47 to 40.07). Overall MSE values were relatively low for all macroinvertebrate maps, water depths, and flow direction variability. Bottom water velocity, and sand substrates had the highest MSE values for the sites.

Physical Habitat Associations

A total of 25 pallid sturgeon capture areas and 49 non-capture areas were used in the DFA. Comparisons between capture and non-capture locations revealed significant differences (p<0.10) in each of the five physical habitat and prey variable categories

(Table 3-3). Physical habitat variables associated with capture areas indicated that captures were more likely in areas with deep water (> 2 m) and moderate near bottom flow velocity (<120 cm/s). Bottom water flow direction was more variable in pallid sturgeon capture areas versus non-capture areas. High composition of sand substrate (91%) and steep bottom slopes (>3%) were also associated with pallid sturgeon capture areas. Proportional availability of water depths >2 m, proportional availability of bottom water velocities greater than 120 cm/s, proportional availability of areas that had bottom slope >3%, mean percent sand composition in substrate, and mean near bottom flow direction variability were chosen as physical habitat metrics to enter into the DFA.

Macroinvertebrate Associations

Pallid sturgeon captures were positively associated with abundance of aquatic macroinvertebrate drift (Table 3-4). Larval dipteran abundance was higher in pallid sturgeon capture areas (3.28 / m^3) versus non-capture areas (1.81 / m^3). Similarly, mean ephemeropteran abundance was higher in pallid sturgeon capture areas (0.58/ m^3) compared to non-capture areas (0.37 / m^3). Therefore, mean abundance of ephemeropterans and dipterans were chosen as candidate prey variables to enter into the DFA analysis.

Model Development and Cross-Validation

Seven candidate variables were used as input in DFA to discriminate between areas where pallid sturgeon were present or absent. Two physical habitat, and two prey abundance variables successfully discriminated between capture and non-capture areas

(discriminant function; $F_{4,69}$= 27.141, Wilks' Lamda = 0.388; P< 0.0001; Table 3.4). Classification functions derived from DFA for pallid sturgeon capture (PSCA) and non-capture (NCA) areas were given by:

$$PSCA = -85.2372 + 67.0676(a) + 0.8885(b) + 83.2562(c) + 8.4009(d)$$

$$NCA = -55.9216 + 67.0676(a) + 0.7546(b) + 62.7260(c) + -4.5995(d),$$

where *a, b, c,* and *d* represent values for percent area > 2 m water depth, mean percent sand, and mean diptera and ephemeroptera abundance, respectively (Table 3-4). Tolerance values ranged from 0.67 (dipteran abundance) to 0.88 (percent area with bottom velocity > 120 cm/s) indicating that redundancy among variables (i.e. 33-12%) was low. Cross-validation of pallid sturgeon capture areas yielded 22 of 25 cases being correctly classified as a capture area (88%). All 49 non-capture areas were correctly classified (100%). Overall, the apparent classification rate by the model was 95% for capture and non-capture locations.

Spatial Distribution of Potential Capture Areas

Areas classified as juvenile pallid sturgeon capture or non-capture locations were spatially modeled in each of the eight 3.2-km sample reaches (Figures 3.2 and 3.3) using the DFA classification functions. Areas classified as potential pallid sturgeon capture locations were not evenly distributed throughout the Missouri River downstream of Fort Randall Dam. Areal estimates of predicted capture locations ranged from 22 - 64% within the riverine habitats, and 39 to 56% within the depositional habitats. The proportion of locations classified as potential capture areas was not significantly different between the

depositional habitats (n=4, mean = 47.75%) and riverine habitats (n=4, mean = 40.75%; t = -0.73, p=0.49).

Discussion

This spatial habitat assessment for juvenile pallid sturgeon is unique in that it is the first attempt to develop a habitat assessment tool for juvenile pallid sturgeon using biotic and abiotic variables. This type of approach is an improvement over previous habitat studies based on collected physical habitat attributes at relocations that focused only on telemetry (Hurley et al. 2004; Elliot et al. 2004; Jordan et al. 2006), or spatially explicit bioenergetics modeling studies that focus solely on prey availability alone (Niklitschek and Secor 2005). This study found that juvenile pallid sturgeon habitat use was strongly associated with invertebrate abundance as well as deep water and sandy substrates.

Juvenile pallid sturgeon capture was less likely if invertebrate abundance was low even though water depths and substrates were suitable. Physical habitat and prey availability parameters should therefore be integrated to model habitat use for juvenile pallid sturgeon. The food habits of juvenile pallid sturgeon (< 330 g) show that larval dipterans, principally chironomids and ceratopagonidae, as well as ephemeropterans composed 90% of the diet and are therefore important for juvenile pallid sturgeon in the first few years after stocking (Wanner et al. 2006; Berg 2008). Aquatic invertebrates have also been observed in the diets of pallid sturgeon in the lower Mississippi River basin (Hoover et al. 2007) and in the Missouri River upstream of Fort Peck in Montana (Gerrity et al. 2006).

Prey fish are known to be an important component of the diets of larger juvenile pallid sturgeon in the Missouri River in Montana (Gerrity et al. 2006). Diets of larger juvenile pallid sturgeon in the Fort Randall reach also contained prey fish (mainly silver chubs *Macrhybopsis storeriana*, emerald shiners *Notropis atherinoides*, and johnny darters *Etheostoma nigrum*) (Wanner et al. 2006; Berg 2008). However, they were not measured in this study because I wanted to predict juvenile pallid sturgeon capture of stocking size (less than 330g, Jordan 2007) because they feed almost exclusively on invertebrates (Wanner et al 2007; Berg 2008), and sampling of small fish was not feasible. In the future, a habitat model for larger pallid sturgeon that contains prey fish abundance as a variable may be necessary to measure habitat availability for this lifestage. Prey fish abundance should be studied further in the Missouri River because they could be a competitor for the same macroinvertebrate resources and could be prey species that older juvenile pallid sturgeon need for growth (Klumb 2007).

One main objective of DFA is that it can be used to parsimoniously predict group membership (i.e. pallid sturgeon capture or non-capture) for potential sampling areas using classification functions (McGarigal et al. 2000). These classification functions efficiently predict capture and non-capture areas for pallid sturgeon based on water depth, substrate, and macroinvertebrate abundance measured from the field. This habitat assessment tool could potentially be used to measure juvenile pallid sturgeon habitat elsewhere on the Missouri River because pallid sturgeon are known to use these physical habitat and prey variables.

Water depths > 2 m (deep water) and sandy substrates were the physical habitat attributes that were associated to pallid sturgeon capture. Previous studies have shown that these variables are positively associated with pallid sturgeon habitat selection in the Missouri River in Montana and North Dakota (Bramblett and White 2001; Hurley et al. 2004). Pallid sturgeon selected sandy substrates over gravel and cobble substrate types, and water depths ranging from 0.6-14.5 m, but selected deeper water more often than what was available (Bramblett and White 2001). In the middle Mississippi River, pallid sturgeon selected deep main channel habitat frequently (Hurley et al. 2004). In laboratory studies, juvenile pallid sturgeon selected sand substrates and deep water depth compared to what was proportionally available (Allen et al. 2007). Concordance of this study to the other studies of juvenile and adult pallid sturgeon indicates that water depths > 2 m and sand substrate represent important habitat features for pallid sturgeon.

Moderate bottom water velocity (< 120 cm/s), variable bottom flow direction (i.e., turbulence), and bottom slope were all significantly higher in capture areas compared to non-capture areas, but were not found to be discriminators of pallid sturgeon capture compared to other variables in the DFA. Bottom water velocity magnitude and flow direction variability, and bottom slope were not used in the final DFA model possibly because they were highly variable among capture and non-capture areas. Water turbulence and velocity have been observed to affect fish behavior (Pavlov et al. 2000) so it is likely that this metric is also important to juvenile pallid sturgeon, but may not have been detectable at the resolution I sampled (e.g., transects). Elliot et al. (2004) used an ADP with 5 m transect spacing and were able to detect that juvenile pallid sturgeon were

selecting moderate water column velocities, but did not examine near bottom water velocities. This may indicate that transect spacing used in this study (100-150 m) may have been too large to capture spatial resolution in water velocity differences between capture and non-capture locations.

Pallid sturgeon capture areas mapped using the DFA classification functions showed that availability of potential capture areas for juvenile pallid sturgeon in a 3.2-km study segments was variable (22 to 64%). Maps of predicted pallid sturgeon capture are likely conservative and may underestimate the areas of capture based on a classification rate of 88% from cross-validation analysis. Therefore, it is possible that there are more areas where pallid sturgeon capture is likely than what my model identified as a non-capture area.

Gear deployments and pallid sturgeon captures occurred primarily in the main channel areas and secondary channels of the river where sample gears were able to be deployed successfully (Drobish 2007). The spatially explicit habitat model identified areas where pallid sturgeon capture is likely but have yet to be sampled due to the random placement of sample gears. Gear deployment sample area coverage was approximately 35% of each 3.2-km habitat sample river segment, therefore, I recommend that future gear deployments of sampling effort should be focused on areas where my model predicted pallid sturgeon capture was likely but not sampled within 3 to 5 years of this study to account for the constantly changing conditions of this river reach.

This type of non-random sampling effort could be used to corroborate the model. Site classifications derived from the model could be used to efficiently target areas for

pallid sturgeon capture so that monitoring efforts are more efficient. A targeted non-random sampling approach that focuses on areas classified as capture locations may improve the probability of capturing pallid sturgeon, thus improving our ability to monitor growth, survival and population estimates (e.g., increased sample size).

Current and future random sampling could be used to evaluate the model developed here by overlaying capture areas onto predicted use maps and measure the percent of the area that is classified as capture locations. If potential capture areas do not coincide with actual pallid sturgeon capture this may indicate that river conditions have changed. This type of analysis could be particularly useful in measuring rates of change in both the riverine and depositonal delta habitats. Although this habitat assessment approach may be viewed as cumbersome (i.e. considerable effort to process samples), the same results may be achieved with wider transect spacing.

Stocking efforts for juvenile pallid sturgeon are often based on accessibility to the river. Boat ramp locations are common sites of stocking because fish hauling trucks can easily access the river. Some of these stocking locations appear to have a high abundance of areas likely to hold pallid sturgeon habitat, while some of these stocking areas appear to be lacking suitable habitat. Based on this study, I recommend that juvenile pallid sturgeon should continue to be stocked at the boat ramp locations near Sunshine Bottoms and Verdel because modeling results showed a high percentage of pallid sturgeon capture locations at these areas. Stocking locations near Running Water, South Dakota should be moved slightly downstream into more of the depositional habitat areas to capitalize on the high abundance of classified pallid sturgeon capture areas compared to the areas

directly adjacent to the boat ramp. Juvenile pallid sturgeon should also be stocked upstream of the boat ramp at Santee, Nebraska as this area also has a high abundance of locations classified as pallid sturgeon capture locations. According to my model all of these suggested stocking locations contained deep water (> 2 m), sandy substrates, and a high abundance of macroinvertebrate prey.

These drifting invertebrates likely came from areas upstream, but from this study, actual upstream origin for drifting invertebrates was unknown. High invertebrate production areas should be incorporated into focused habitat restoration efforts so that physical habitat and prey availability could be supplemented in areas that are lacking suitable pallid sturgeon habitat in the Missouri River basin. The integrated biotic and abiotic juvenile pallid sturgeon habitat assessment tool developed in this study shows promise to be able to efficiently identify restoration and sampling areas where focused effort could take place. These focused restoration and sampling efforts would ultimately allow managers to monitor populations and guide management efforts so that stocked juvenile pallid sturgeon have the best chance of survival.

References

Allen, T. C., Q. E. Phelps, R. D. Davinroy, and D. M. Lamm. 2007. A laboratory examination of substrate, water depth, and light use at two water velocity levels by individual juvenile pallid (*Scaphirhynchus albus*) and shovelnose (*Scaphirhynchus platorynchus*) sturgeon. Journal of Applied Ichthyology 23:375-381.

Berg, K. L. 2008. Relative prey use by juvenile pallid sturgeon, and longitudinal distribution of macroinvertebrates in the Missouri River below Fort Randall and Gavins Point Dams, South Dakota and Nebraska, Masters Thesis, South Dakota State University.

Bramblett, R. G. and R. G. White. 2001. Habitat use and movements of pallid and shovelnose sturgeon in the Yellowstone and Missouri Rivers in Montana and North Dakota. Transactions of the American Fisheries Society 130:1006-1025.

Cummins, K. W. 1962. An evaluation of some techniques for the collection and analysis of benthic samples with special emphasis on lotic waters. American Midland Naturalist 67:477-504.

Drobish M. (editor) 2007. Missouri River standard operating procedures for sampling and data collection, Volume 1.1. U.S. Army Corps of Engineers, Omaha District, Yankton, SD.

Dryer, M. P., and A. J. Sandvol. 1993. Pallid sturgeon, *Scaphirhynchus albus*, recovery plan.Department of the Interior. U.S. Fish and Wildlife Service. Washington, D.C.

Elliott, C. E., R. B. Jacobson, and A. J. DeLonay. 2004. Aquatic habitat assessment, Fort Randall segment of the Missouri River, Nebraska and South Dakota. USGS Report.

Forbes, S. A. and R. E. Richardson. 1905. On a new shovelnose sturgeon from the Mississippi River. Bulletin of the Illinois State Laboratory of Natural History 7:39-44.

Gerrity P. C. 2005. Habitat use diet and growth of hatchery-reared juvenile pallid sturgeon and indigenous shovelnose sturgeon in the Missouri River above Fort Peck Reservoir. Masters Thesis Montana State University.

Gerrity, P. C., C. S. Guy, W. M. Gardner. 2006. Juvenile pallid sturgeon are piscivorous: a call for conserving native cyprinids. Transactions of the American Fisheries 135:604-609

Hoover J. J., S. G. George, and K. J. Killgore. 2007. Diet of shovelnose sturgeon and pallid sturgeon in the free-flowing Mississippi River. Journal of Applied Ichthyology 23:494-499.

Hurley K. L., R.J. Sheehan, R. C. Heidinger, P. S. Wills, and B. Clevenstine.2004. Habitat Use by Middle Mississippi River Pallid Sturgeon. Transactions of the American Fisheries Society 133:1033–1041.

Jordan, G. R. 2006. Pallid sturgeon (*Scaphirhynchus albus*) range-wide stocking and augmentation plan. Pallid Sturgeon Recovery Team plan submitted to U.S. Fish and Wildlife Service. Billings, Montana.

Jordan, G. R., R. A. Klumb, G. A. Wanner, and W.J. Stancill.2006. Poststocking movements and habitat use of hatchery-reared juvenile pallid sturgeon in the Missouri River below Fort Randall Dam, South Dakota and Nebraska Transactions of the American Fisheries Society 135:1499-1511.

Klumb R. A. 2007. Shallow water fish communities in the Missouri River downstream of Fort Randall and Gavins Point dams in 2003 and 2004 with emphasis on Asian carps. Prepared for the Aquatic Nuisance Species Coordinator, U.S. Fish and

Wildlife Service –Region 6, 134 Union Boulevard, Lakewood, Colorado 80228. USFWS Great Plains Fish and Wildlife Management Assistance Office, Pierre, South Dakota.

Krentz S., R. Holm, H. Bollig, J. Dean, M. Rhodes, D. Hendrix, G. Heidrich, and B. Krise. 2005. Pallid sturgeon spawning and stocking summary report. 1992-2004. United States Fish and Wildlife Service report. Bismarck, North Dakota.

Krige, D. G. 1966. Two-dimensional weighted moving average trend surfaces for ore valuation. Journal of the South African Institute of Mining and Metallurgy: 13-38.

McGarigal, K., S. Cushman, and S. Stafford. 2000. Multivariate statistics for wildlife research. Springer press.

Merritt R. W. and K. W. Cummins. 1996. An introduction to the aquatic insects of North America, Third edition. Kendall Publishing company.

Niklitschek, E. J. and D. H. Secor. 2005.Modeling spatial and temporal variation of suitable nursery habitats for Atlantic sturgeon in the Chesapeake Bay. Estuarine coastal and shelf science 64:135-148.

Pavlov, D. S., A. I. Lupandin, and M. A.Skorobogatov. 2000. The effects of flow turbulence on the behavior and distribution of fish. Journal of Ichthyology 40:S232-S261.

Pennak R. W. 1972. Fresh-water invertebrates of the United States, second edition. Wiley interscience publishing company.

Quist, M. C., and 12 coathors. 2004. Research and Assessment Needs for Pallid Sturgeon Recovery in the Missouri River. Final report to the U.S. Geological Survey.

Shuman D. A., G. A. Wanner, R. A. Klumb, and W. J. Stancill. 2007. 2006 Annual report for pallid sturgeon population assessment and associated fish community monitoring for the Missouri River segments 5 and 6. Prepared for the U.S. Army Corps of Engineers Missouri River Recovery Program. U.S. Fish and Wildlife Service. Great Plains Fish and Wildlife Management Assistance Office. Pierre, South Dakota.

Shuman, D. A., G. A. Wanner, R. A. Klumb, and W. J. Stancill. 2006. 2005 Pallid sturgeon population assessment project and associated fish community monintoring for the Missouri River: segments 5 and 6. Prepared for the U. S. Army Corps of Engineers-Northwest Division. U. S. Fish and Wildlife Service, Pierre, South Dakota.

Shuman D. A., G. A. Wanner, R. A. Klumb, and S. T. McAlpin. 2005. 2004 Annual report for pallid sturgeon population assessment and associated fish community monitoring for the Missouri River segments 5 and 6. Prepared for the U.S. Army Corps of Engineers Missouri River Recovery Program. U.S. Fish and Wildlife Service, Great Plains Fish and Wildlife Management Assistance Office, Pierre, South Dakota.

Snook, V. A., E. J. Peters, and L. J. Young. 2002. Movements and habitat use by hatchery-reared pallid sturgeon in the lower Platte River, Nebraska. In W. Van Winkleeditor. Biology, management, and protection of North American sturgeon. American Fisheries Society, Symposium 28:161-174.

Threader, R. W., R. J. Pope, and P. R. H. Schaap. 1998. Development of a habitat suitability index model for lake sturgeon (*Acipenser fulvescens*). Report number H-07015.01-0012. Ontario Hydro, Toronto, Ontario.

Wanner, G. A., D. A. Shuman, and D. W. Willis. 2007. Food habits of juvenile pallid sturgeon and adult shovelnose sturgeon in the Missouri River downstream of Fort Randall Dam, South Dakota. Journal of Freshwater Ecology 22:81-92.

Wentworth, C. K. 1922. A scale of grade and class terms for cladistic sediments. Journal of Geology 30:377-392.

Yamartino R. J. 1984. A comparison of several “single pass” estimators of the standard deviation of wind direction. Journal of Climate and Applied Meteorology 22:1362-1366.

Table 3-1. Summary of pallid sturgeon captures, deployments by gear, and catch per unit effort (CPUE).River km indicates the upstream start of each 3.2 km sample area.

		Otter trawls			Trammel nets		
Area	River km	Deployments (n)	Pallid sturgeon captures (n)	CPUE (Sturgeon · $100m^{-1}$)	Deployments (n)	Pallid sturgeon Captures (n)	CPUE (Sturgeon · $100m^{-1}$)
A	1390	16	3	0.06	10	0	0
B	1376	5	0	0	5	0	0
C	1361	8	0	0	9	2	0.09
D	1355	–	–	–	6	2	0.12
E	1350	8	0	0	8	0	0
F	1345	–	–	–	11	0	0
G	1337	10	0	0	12	2	0.06
H	1331	16	12	0.25	18	4	0.08

Table 3-2. Summary of juvenile pallid sturgeon capture and stocking information for individual pallid sturgeon captured during the summer of 2006 by otter trawls (OT) and trammel nets (TN). Juvenile pallid sturgeon were either stocked from Garrison (GAR) or Gavins Point (GP) National Fish Hatcheries at boat ramps near Running Water (RWT), Standing Bear (SBR), Verdel (VDL) or Sunshine Bottoms (SBT).

Set Date	Gear	Capture Length FL mm	Capture Weight g	Tag #	Stock Length FL mm	Stock Weight g	Hatchery	Stocking Site	Spawn Date	Stock Date
6/28	OT	356	120	46264B5C5C	290	101	GP	RWT	7/11/2004	8/30/2005
6/28	OT	356	120	46264B5C5C	290	101	GP	RWT	7/12/2004	8/30/2005
6/29	OT	600	710	460D416213						
6/29	OT	402	200	4443430D34	259	56	GP	SBR	6/24/2003	10/7/2004
6/29	OT	545	560	432355121E	190		GAR	VDL	6/26/2001	4/21/2002
6/29	OT	460	270	460E553F18						
6/29	OT	575	580	46277B5D60						
6/29	OT	665	1000	406E65467A	526	538	GP	VDL	6/17/1997	6/6/2000
6/29	OT	382	170	4624146A5D	268	81	GP	SBR	6/24/2003	10/7/2004
6/29	OT	711	1200	411B6E3866	567	800	GP	VDL	6/17/1997	6/6/2000
6/29	OT	509	420	42561D5112	272	81	GP	SBR	6/22/2002	7/26/2003
6/29	OT	595	680	460E4B2B2C						
6/29	OT	606	710	424D4F3527	393	200	GP	SBT	6/14/1999	4/27/2002
6/29	OT	403	180	4626014C73	296	99	GP	RWT	7/13/2004	8/30/2005
7/19	TN	350	145	46257E300A	225	37	GP	RWT	7/14/2004	8/30/2005
7/19	TN	412	250	4256526126	218	40	GP	SBT	6/22/2002	7/26/2003
7/21	TN	452	350	435E200C34						
7/21	TN	510	420	431C2B0062	230		GAR	VDL	6/26/2001	4/21/2002
7/27	TN	702	1015	406E523F1F	582	869	GP	VDL	6/17/1997	6/6/2000
7/27	TN	670	940	406E630351	390	163	GP	VDL	6/17/1997	6/6/2000
7/27	TN	720	1320	411A7C0B63	414	344	GP	VDL	6/17/1997	6/6/2000
8/7	OT	330	90	4626721356						
9/7	TN	533	495	4443170D35	226	47	GP	SBR	6/22/2002	7/26/2003
9/8	TN	438	268	435E112709	245	57	GP	SBT	6/22/2002	7/26/2003

Table 3-3. Mean square error calculations for actual versus predicted points from interpolated physical habitat and prey maps for each 3.2-km site. Inverse distance weighting was used to interpolate sand and invertebrate sample locations. Ordinary kriging with anisotropy was used to create maps for water velocity, flow direction, and water depth.

Site	June Dipterans	August Dipterans	June Ephemeropterans	August Ephemeropterans	Water Depth	Water Velocity	Sand	X Flow Direction	Y Flow Direction
A	0.29	0.39	0.02	0.03	0.34	30.03	19.51	0.25	0.38
B	0.21	0.19	0	0.02	0.19	31.98	35.27	0.21	0.37
C	3.31	1.3	0.08	0.02	0.74	29.85	39.19	0.37	0.47
D	0.56	0.79	0	0.19	0.62	26.47	32.3	0.48	0.50
E	0.18	0.52	0.08	0.68	1.04	38.52	13.88	0.37	0.44
F	0.18	0.25	0.08	0.28	0.97	38.13	29.58	0.34	0.38
G	0.14	0.22	0.07	0.12	0.91	32.24	22.12	0.31	0.27
H	0.09	1.63	0.05	0.22	0.92	40.07	24.94	0.70	0.72

Table 3-4. Mean (standard deviation), t-value, and significance level (p-value) for physical habitat and prey variables that were compared between pallid sturgeon capture areas (PSCA, n=25) and non-capture areas (NCA, n=49) for pooled gears. Candidate variables used as input in discriminant function analysis are indicated by an asterisk. Significant variables identified by DFA are signified by letters (Wilks' Lambda = 0.38, Metricapprox. F (4, 69) = 27.14, and P< 0.00001.

Metric	NCA		PSCA		t-value	p-value
Water Depth (m)						
Mean	2.7	(0.46)	3.2	(0.62)	-3.689	<0.001
Percent Area > 2 * (*a*)	72.9	(0.14)	88.1	(0.10)	-4.679	<0.001
Percent Area > 3	53.3	(0.33)	74.9	(0.23)	-2.930	0.005
Percent Area > 4	11.4	(0.13)	16.1	(0.19)	-1.265	0.210
Percent Area > 5	3.1	(0.06)	8.7	(0.14)	-2.406	0.019
Percent Area > 6	1.1	(0.03)	3.0	(0.08)	-1.423	0.159
Percent Area > 7	0.3	(0.01)	1.6	(0.05)	-1.689	0.095
Percent Area > 8	0.0	(0.00)	0.5	(0.02)	-2.036	0.045
Water Bottom Velocity (cm/s)						
Mean	88.4	(12.7)	89.4	(6.80)	-0.372	0.711
Percent Area > 20	99.6	(0.01)	99.9	(0.00)	-0.932	0.354
Percent Area > 40	98.5	(0.04)	99.6	(0.01)	-1.429	0.157
Percent Area > 60	93.0	(0.09)	97.5	(0.04)	-2.451	0.017
Percent Area > 80	66.1	(0.24)	78.8	(0.22)	-2.201	0.031
Percent Area > 100	31.5	(0.29)	20.4	(0.11)	1.861	0.067
Percent Area > 120*	4.9	(0.08)	0.1	(0.00)	3.022	0.003
Flow Direction Variability Index						
Mean*	0.171	(0.07)	0.228	(0.05)	-3.421	<0.001
Percent Bottom Slope						
Mean	1.25	(0.52)	1.4	(0.66)	-1.111	0.270
Percent Area > 1.5	29.0	(0.16)	31.8	(0.16)	-0.679	0.500
Percent Area > 3.0*	7.8	(0.09)	12.5	(0.13)	-1.836	0.071
Percent Area > 4.5	2.2	(0.05)	4.2	(0.07)	-1.387	0.170
Percent Area > 6.0	0.8	(0.03)	1.2	(0.04)	-0.493	0.623
Percent Sand Substrate						
Mean*(*b*)	80	(14.2)	91	(7.87)	-3.459	0.001
Percent Area > 50	88.8	(0.17)	96.8	(0.05)	-2.260	0.027
Percent Area > 75	72.4	(0.24)	88.1	(0.15)	-2.997	0.004
Larval Dipteran Drift Abundance (No. / m^{-3})						
Mean*(*c*)	1.81	(0.11)	3.29	(0.17)	-4.518	<0.001
Ephemeropteran Drift Abundance (No. / m^{-3})						
Mean*(*d*)	0.37	(0.05)	0.58	(0.04)	-1.908	0.060

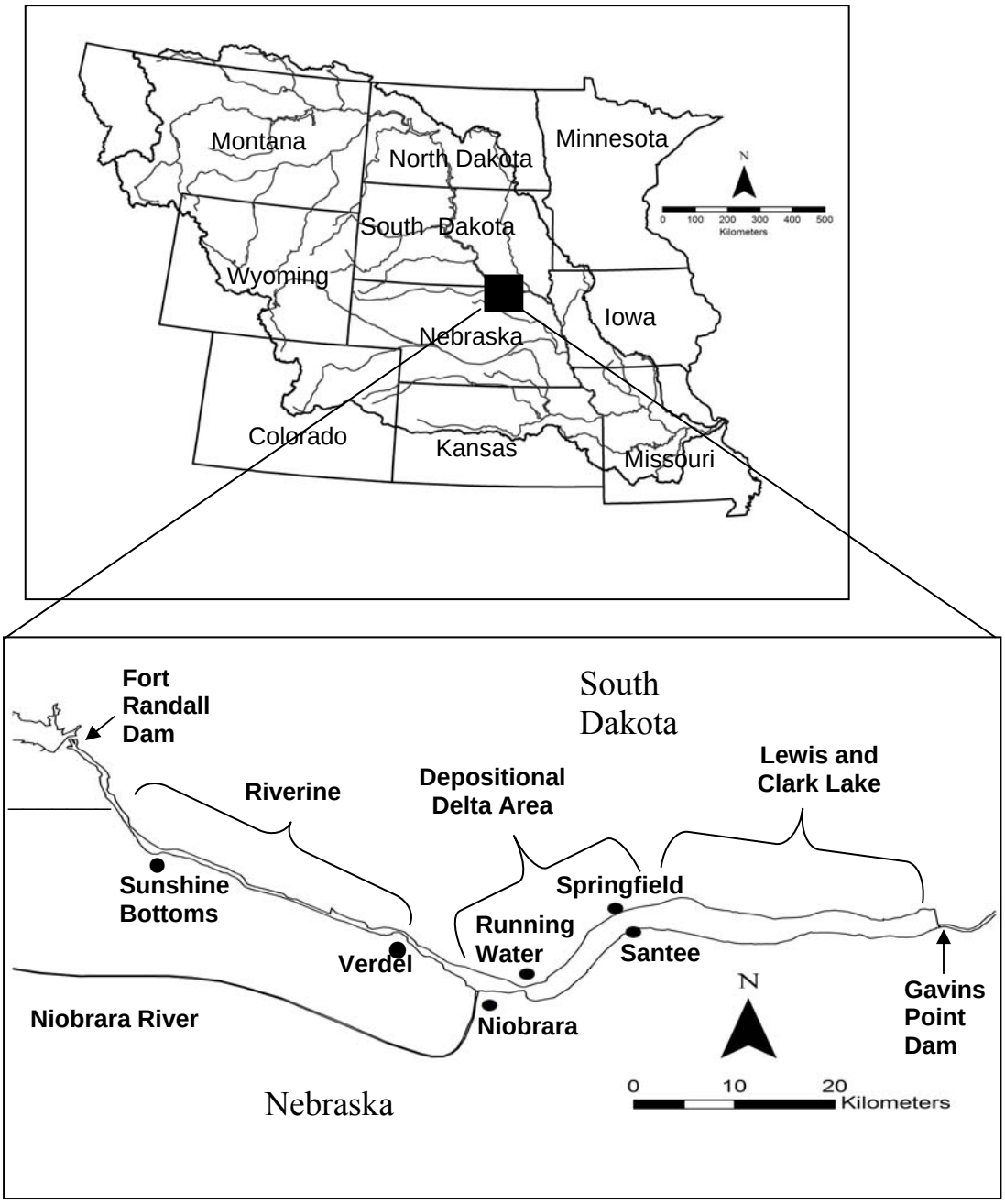


Figure 3-1. Missouri River watershed (top panel) and study area reach located between Fort Randall and Gavins Point Dams. Sample areas in 2006 for juvenile pallid sturgeon were located in the riverine and delta areas of the reach (bottom panel).

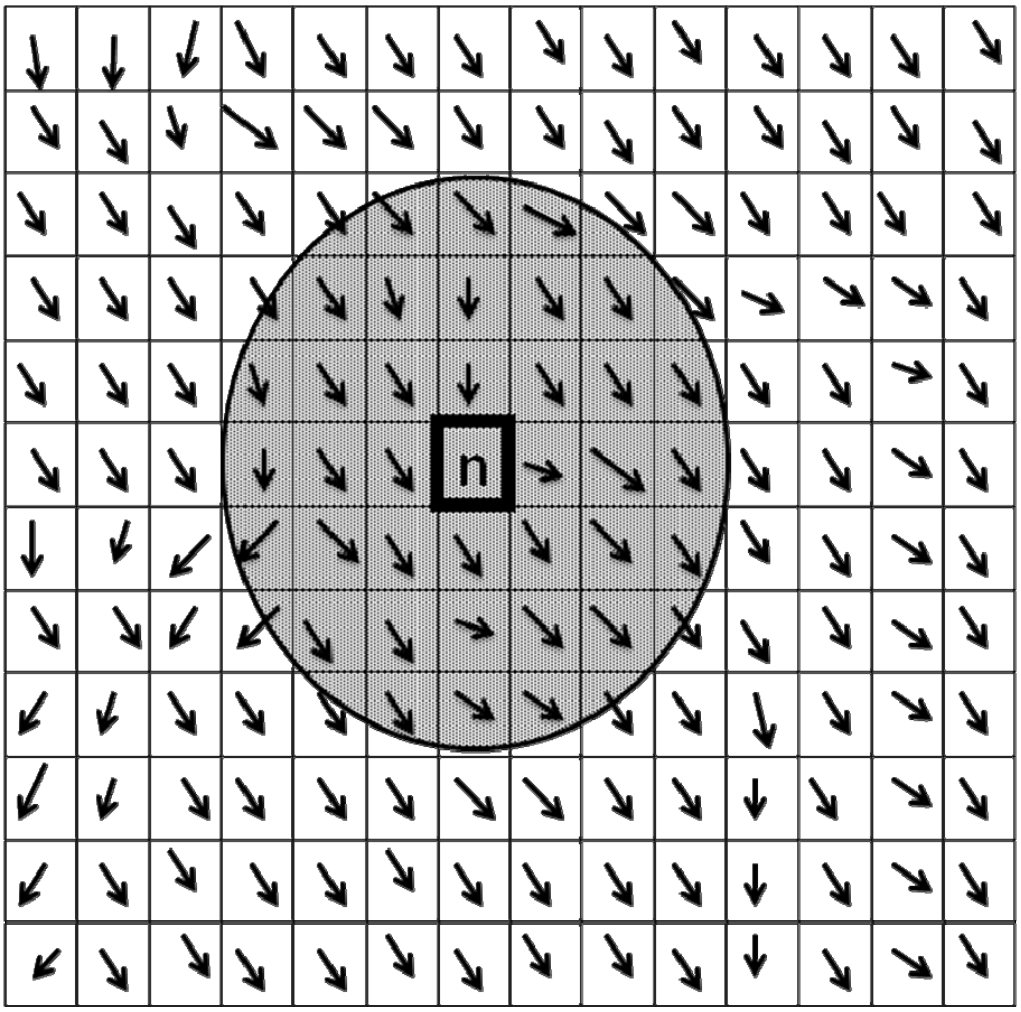


Figure 3-2. Schematic of circular neighborhood (radius = 3 grid cells) delineation around a target grid cell (n) used for calculating the neighborhood standard deviation of flow. Black arrows display hypothetical near bottom flow direction for each 20 m grid cell.

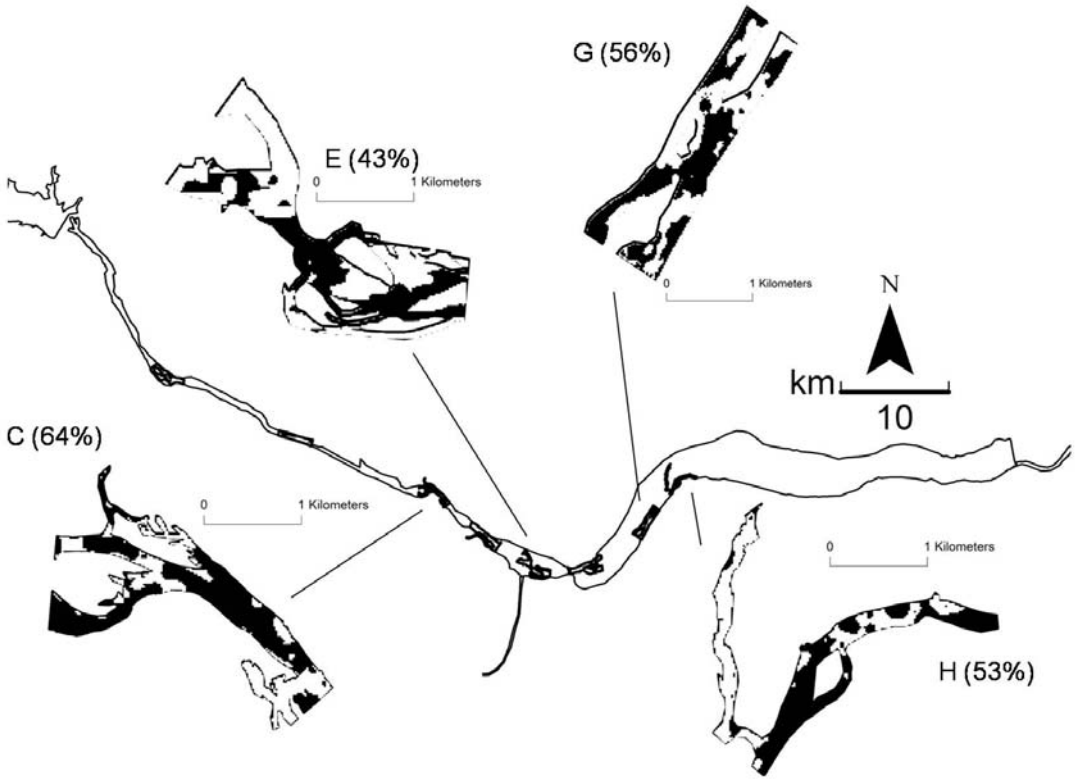


Figure 3-3. Map of the four 3.2 km sample areas in the Fort Randall Reach of the Missouri River that had the highest proportion of area classified as potential pallid sturgeon capture locations (areas in black). Discriminant function analysis was used to classify areas as capture or non-capture locations at 20 x 20 m resolution. Values in parentheses represent the percent of total river area that is classified as potential capture area.

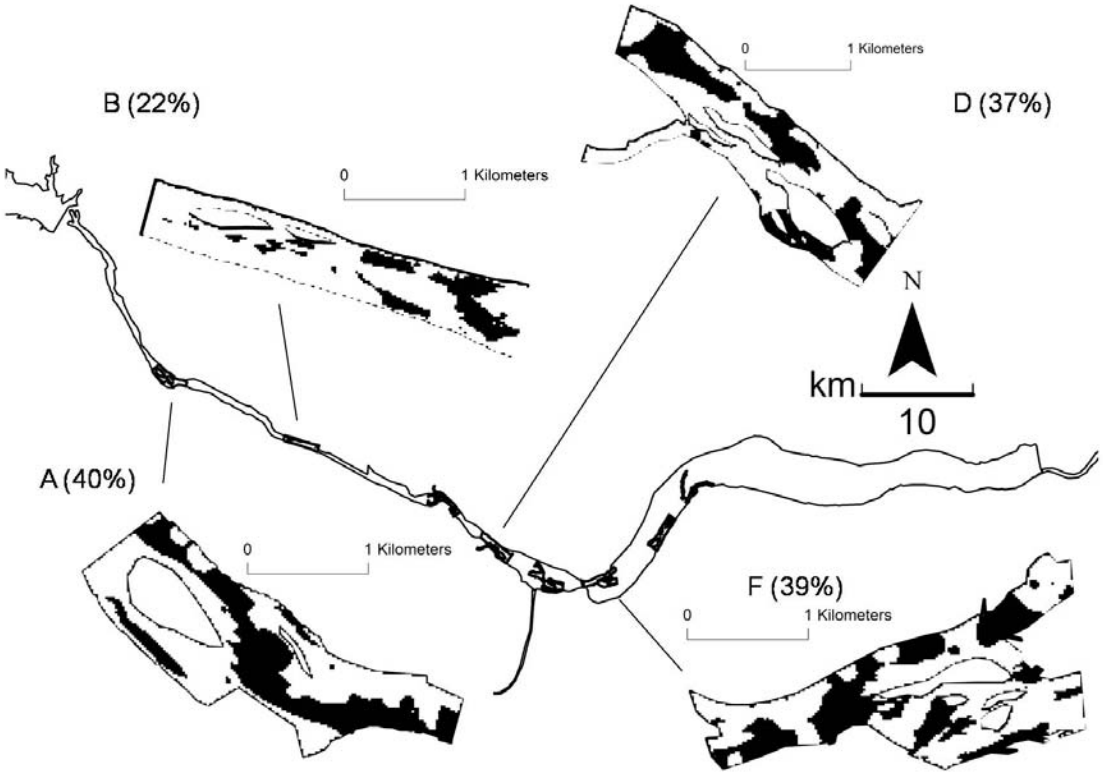


Figure 3-4. Map of the four 3.2 km sample areas in the Fort Randall Reach of the Missouri River that had the lowest proportion of area classified as potential pallid sturgeon capture locations (areas in black). Discriminant function analysis was used to classify areas as capture or non-capture locations at 20 x 20 m resolution. Values in parentheses represent the percent of total river area that is classified as potential capture area.

CHAPTER 4

SUMMARY AND MANAGEMENT IMPLICATIONS

A tool that measures available suitable juvenile pallid sturgeon habitat in river segments would be valuable because it would enable managers to focus habitat restoration efforts on river segments that lack important habitat and prey availability. This tool could also focus stocking efforts into areas where pallid sturgeon survival would be highest. The habitat assessment tool developed here could also be used to target areas where pallid sturgeon are likely to occur for more efficient sampling to evaluate growth and condition. As of yet no such tool exists.

SaTscan analysis identified three significant areas, characterized by 'clusters' of pallid sturgeon captures, using existing data from the monitoring and assessment program. Results from this analysis also showed that distribution patterns of juvenile pallid sturgeon could be reliably identified using summer trammel net sampling. Thus, this gear/season combination could be used to identify areas where pallid sturgeon congregate, thus improving our ability to monitor growth, survival and abundance.

It is important to note that distribution patterns identified in this study may change with changing habitat conditions in the Fort Randall reach. For this reason, I recommend that spatial analysis of presence and absence data be evaluated at 3-5 year intervals if using standardized data obtained from the monitoring and assessment program. Snapshots of pooled presence and absence from five year time frames could be compared to see how pallid sturgeon location and therefore how habitat location has changed over time. Changes in pallid sturgeon habitat use could be used as a surrogate measure to

quantify changes in habitat conditions over time if current monitoring strategies are sustained over a long time period (30 years).

Understanding the habitat requirements of juvenile pallid sturgeon represents an important part of the monitoring and assessment program. In this study, I developed a spatially explicit habitat assessment tool to predict pallid sturgeon capture that integrated physical habitat, and aquatic invertebrate prey parameters related to pallid sturgeon capture. The model that I developed is the first multivariate model that integrated both habitat and prey parameters in predicting pallid sturgeon capture (i.e. occurrence). This study is an improvement over previous studies of juvenile pallid sturgeon habitat because it indicates that juvenile pallid sturgeon habitat use is dependent upon both physical habitat and prey availability attributes and showed that macroinvertebrate abundance was an important parameter associated to pallid sturgeon occurrence.

Juvenile pallid sturgeon have been stocked at boat ramps where fish hauling trucks can easily access the river, but without regard for habitat in these areas. According to my model, some of these stocking locations appear to have a high abundance of areas likely to have an abundance of suitable pallid sturgeon habitat, but some of these stocking areas do not. Therefore, some of these stocking locations should be moved to capitalize on a high abundance of locations where suitable habitat is present. Based on both the spatial analysis and habitat assessment tool, I recommend that juvenile pallid sturgeon should continue to be stocked at the boat ramps near Verdel and upstream of the boat ramp at Santee. Spatial scan analysis identified that pallid sturgeon capture was high in these areas, and my habitat assessment model classified a high abundance of locations

where pallid sturgeon capture is likely to occur. Both of these areas were characterized by a high macroinvertebrates, deep water, and sandy substrates.

Juvenile pallid sturgeon stocking near the Sunshine Bottoms boat ramp should also be continued even though it was not identified as high density area from spatial analysis because my habitat assessment tool indicated that there was a moderate abundance (40%) of areas where pallid sturgeon capture was likely. This area could be a a good secondary stocking location for juvenile pallid sturgeon because of the moderate water depths high dipteran abundance in this area. This could be stocked to alleviate over -crowding concerns if pallid sturgeon stocking rates remain high. The stocking location of juvenile pallid sturgeon at the boat ramp near Running Water, South Dakota could also be another good secondary stocking location if it is moved slightly downstream of the boat or upstream to near the confluence of the Niobrara River where deep water is more abundant. These areas also were found to contain a fair amount of suitable habitat especially in the main channel areas of these segments and also had and abundance of macroinvertebrates.

Spatial analysis and habitat assessment modeling showed that the depositional habitat areas are used by juvenile pallid sturgeon. Three of the four sample depositional habitat areas had the highest abundance of classified pallid sturgeon capture locations. This indicates that this unique habitat contains about the same if not more suitable habitat for pallid sturgeon than that in upstream, riverine habitats. These areas should therefore be considered as important rearing areas for juvenile pallid sturgeon in the Fort Randall Reach of the Missouri River.

APPENDIX A - TABLES

Appendix A-1. Mean (standard deviation), t-value, and p-values for all physical habitat and prey variables screened for pallid sturgeon capture areas (PSCA, n=25) versus non-capture areas (NCA, n=49) considering both trammel net, and otter trawl gear deployments. Candidate variables used to discriminate PSCA versus NCA in Discriminant Function Analysis are indicated by an asterisk. Identified discriminating variables from DFA are identified by a double asterisk.

Metric	NCA		PCSA		t-value	p-value
Water Depth (m)						
Minimum	1.17	(0.36)	1.21	(0.26)	-0.490	0.625
Maximum	5.04	(1.29)	6.03	(1.45)	-2.963	0.004
Range	3.87	(1.35)	4.81	(1.47)	-2.754	0.007
Mean	2.73	(0.46)	3.20	(0.62)	-3.689	<0.001
Standard Deviation	0.89	(0.35)	0.96	(0.44)	-0.646	0.520
Proportion Area > 1	0.98	(0.04)	0.993	(0.01)	-1.260	0.212
Proportion Area > 2 **	0.73	(0.14)	0.881	(0.10)	-4.679	0.000
Proportion Area > 3	0.53	(0.33)	0.749	(0.23)	-2.930	0.005
Proportion Area > 4	0.11	(0.13)	0.161	(0.19)	-1.265	0.210
Proportion Area > 5	0.03	(0.06)	0.087	(0.14)	-2.406	0.019
Proportion Area > 6	0.01	(0.03)	0.030	(0.08)	-1.423	0.159
Proportion Area > 7	0.003	(0.01)	0.016	(0.05)	-1.689	0.095
Proportion Area > 8	0.000	(0.00)	0.005	(0.02)	-2.036	0.045
Water Bottom Velocity (cm/s)						
Minimum	48.43	(22.4)	51.09	(14.18)	-0.539	0.591
Maximum	120.83	(13.8)	115.82	(10.00)	1.603	0.113
Range	72.39	(22.5)	64.718	(20.13)	1.436	0.155
Mean	88.42	(12.6)	89.434	(6.80)	-0.372	0.711
Standard Deviation	14.89	(5.10)	10.921	(3.18)	3.557	0.001
Proportion Area > 20	0.99	(0.01)	0.999	(0.00)	-0.932	0.354
Proportion Area > 40	0.99	(0.04)	0.996	(0.01)	-1.429	0.157
Proportion Area > 60	0.93	(0.09)	0.975	(0.04)	-2.451	0.017
Proportion Area > 80	0.66	(0.24)	0.788	(0.22)	-2.201	0.031
Proportion Area > 100	0.32	(0.29)	0.204	(0.11)	1.861	0.067
Proportion Area > 120**	0.049	(0.08)	0.001	(0.00)	3.022	0.003
Proportion Area > 140	0.000	(0.00)	0.000	(0.00)	0.000	1.000
Flow Direction Variability Index						
Minimum	0.045	(0.03)	0.112	(0.06)	-6.258	<0.001
Maximum	0.430	(0.17)	0.454	(0.05)	-0.674	0.502
Range	0.385	(0.17)	0.341	(0.08)	1.251	0.215
Mean*	0.171	(0.07)	0.228	(0.05)	-3.421	0.001
Standard Deviation	0.083	(0.04)	0.068	(0.03)	1.567	0.122

Appendix A-1 continued. Mean (standard deviation), t-value, and p-values for all physical habitat and prey variables screened for pallid sturgeon capture areas (PSCA, n=25) versus non-capture areas (NCA,n=49) considering both trammel net, and otter trawl gear deployments. Candidate variables used to discriminate PSCA versus NCA in Discriminant Function Analysis are indicated by an asterisk. Identified discriminating variables from DFA are identified by a double asterisk.

Metric	NCA		PSCA		t-value	p-value
Percent Bottom Slope						
Minimum	0.02	(0.02)	0.041	(0.02)	-3.566	0.001
Maximum	4.7	(2.12)	5.563	(1.90)	-1.685	0.096
Range	4.7	(2.11)	5.521	(1.90)	-1.655	0.102
Mean	1.25	(0.52)	1.404	(0.66)	-1.111	0.270
Standard Deviation	0.94	(0.46)	1.137	(0.43)	-1.767	0.081
Proportion Area > 1.5	0.29	(0.16)	0.318	(0.16)	-0.679	0.500
Proportion Area > 3.0*	0.08	(0.09)	0.125	(0.13)	-1.836	0.071
Proportion Area > 4.5	0.02	(0.05)	0.042	(0.07)	-1.387	0.170
Proportion Area > 6.0	0.01	(0.03)	0.012	(0.04)	-0.493	0.623
Percent Sand Substrate						
Minimum	26.132	(26.12)	30.997	(28.75)	-0.732	0.466
Maximum	99.969	(0.06)	99.988	(0.04)	-1.470	0.146
Range	73.837	(26.12)	68.991	(28.74)	0.730	0.468
Mean*	80.982	(14.20)	91.570	(7.87)	-3.459	0.001
Standard Deviation	15.973	(7.92)	11.573	(5.93)	2.448	0.017
Proportion Area > 50	0.888	(0.17)	0.968	(0.05)	-2.260	0.027
Proportion Area > 75	0.724	(0.24)	0.881	(0.15)	-2.997	0.004
Larval Dipteran Drift Abundance (No. / L)						
Minimum	0.06	(0.03)	0.04	(0.08)	1.521	0.133
Maximum	0.43	(0.37)	3.70	(2.14)	-10.457	<0.01
Range	0.38	(0.37)	3.67	(2.18)	-10.349	<0.01
Mean**	0.18	(0.11)	0.33	(0.17)	-4.518	<0.01
Standard Deviation	0.08	(0.08)	0.49	(0.27)	-10.063	<0.01
Ephemeropteran Drift Abundance (No. / L)						
Minimum	0.002	(0.00)	0.01	(0.01)	-3.077	0.003
Maximum	0.17	(0.33)	0.33	(0.17)	-2.274	0.026
Range	0.17	(0.33)	0.32	(0.17)	-2.199	0.031
Mean**	0.04	(0.05)	0.05	(0.04)	-1.908	0.060
Standard Deviation	0.03	(0.06)	0.06	(0.02)	-1.763	0.082

Appendix A-2. Mean (standard deviation), t-value, and p-values for all physical habitat and prey variables screened for pallid sturgeon capture areas (PSCA, n=15) versus non-capture areas (NCA, n=17) considering trammel net gear deployments.

Metric	NCA		PSCA		t-value	p-value
Water Depth (m)						
Minimum	1.22	(0.37)	1.05	(0.24)	-1.410	0.166
Maximum	5.05	(1.23)	6.69	(2.05)	3.109	0.003
Range	3.82	(1.28)	5.64	(2.06)	3.366	0.002
Mean	2.79	(0.48)	3.46	(0.88)	3.132	0.003
Standard Deviation	0.88	(0.33)	1.19	(0.64)	2.006	0.052
Proportion Area > 1	0.99	(0.03)	0.99	(0.01)	0.186	0.853
Proportion Area > 2	0.74	(0.15)	0.86	(0.10)	2.316	0.026
Proportion Area > 3	0.63	(0.34)	0.94	(0.17)	2.744	0.009
Proportion Area > 4	0.13	(0.14)	0.27	(0.27)	2.306	0.026
Proportion Area > 5	0.03	(0.06)	0.16	(0.20)	3.384	0.002
Proportion Area > 6	0.01	(0.03)	0.08	(0.12)	2.823	0.007
Proportion Area > 7	0	(0.01)	0.04	(0.08)	2.647	0.012
Proportion Area > 8	0	(0.00)	0.01	(0.03)	2.760	0.009
Water Bottom Velocity (cm/s)						
Minimum	49.47	(19.8)	39.63	(15.9)	-1.428	0.161
Maximum	121.8	(14.5)	116.68	(14.7)	-0.988	0.329
Range	72.42	(21.9)	77.06	(26.6)	0.554	0.583
Mean	88.42	(12.1)	85.72	(7.56)	-0.660	0.513
Standard Deviation	14.67	(4.87)	13.54	(3.56)	-0.674	0.504
Proportion Area > 20	1	(0.01)	1	(0.01)	0.192	0.849
Proportion Area > 40	0.99	(0.03)	0.99	(0.02)	-0.157	0.876
Proportion Area > 60	0.94	(0.07)	0.94	(0.05)	0.102	0.919
Proportion Area > 80	0.65	(0.23)	0.67	(0.23)	0.232	0.818
Proportion Area > 100	0.3	(0.29)	0.18	(0.12)	-1.307	0.199
Proportion Area > 120	0.05	(0.09)	0	(0.01)	-1.858	0.071
Proportion Area > 140	0	(0.00)	0	(0.00)	0.315	0.754
Flow Direction Variability Index						
Minimum	0.05	(0.04)	0.08	(0.06)	2.335	0.025
Maximum	0.42	(0.15)	0.45	(0.08)	0.465	0.644
Range	0.37	(0.14)	0.36	(0.11)	-0.270	0.788
Mean*	0.17	(0.07)	0.22	(0.05)	2.002	0.052
Standard Deviation	0.08	(0.03)	0.08	(0.04)	0.089	0.930

Appendix A-2 continued. Mean (standard deviation), t-value, and p-values for all physical habitat and prey variables screened for pallid sturgeon capture areas (PSCA, n=15) versus non-capture areas (NCA, n=17) considering trammel net gear deployments.

Metric	NCA		PSCA		t-value	p-value
Percent Bottom Slope						
Minimum	0.02	(0.02)	0.03	(0.04)	1.104	0.276
Maximum	4.46	(1.97)	6.05	(2.89)	1.988	0.054
Range	4.43	(1.96)	6.02	(2.89)	1.981	0.055
Mean	1.21	(0.53)	1.66	(1.02)	1.856	0.071
Standard Deviation	0.88	(0.44)	1.23	(0.66)	1.955	0.058
Proportion Area > 1.5	0.28	(0.17)	0.38	(0.26)	1.376	0.177
Proportion Area > 3.0	0.07	(0.09)	0.18	(0.19)	2.459	0.018
Proportion Area > 4.5	0.02	(0.05)	0.07	(0.11)	2.316	0.026
Proportion Area > 6.0	0.01	(0.03)	0.03	(0.06)	1.725	0.092
Percent Sand Substrate						
Minimum	25.63	(25.99)	25.08	(33.46)	-0.055	0.956
Maximum	99.97	(0.06)	99.97	(0.05)	0.017	0.987
Range	74.34	(25.99)	74.89	(33.44)	0.055	0.956
Mean	81.97	(12.87)	87.3	(11.24)	1.175	0.247
Standard Deviation	15.66	(7.38)	13.72	(7.98)	-0.713	0.480
Proportion Area > 50	0.9	(0.16)	0.94	(0.07)	0.784	0.438
Proportion Area > 75	0.74	(0.22)	0.8	(0.21)	0.693	0.492
Larval Dipteran Drift Abundance (No. / L)						
Minimum	0.05	(0.03)	0.04	(0.04)	-1.300	0.201
Maximum	0.43	(0.35)	2.9	(2.31)	6.011	<0.001
Range	0.37	(0.35)	2.86	(2.32)	6.012	<0.001
Mean	0.18	(0.10)	0.4	(0.21)	4.652	<0.001
Standard Deviation	0.07	(0.08)	0.46	(0.33)	6.359	<0.001
Ephemeropteran Drift Abundance (No. / L)						
Minimum	0	(0.01)	0.01	(0.02)	1.924	0.062
Maximum	0.17	(0.23)	0.38	(0.20)	2.516	0.016
Range	0.17	(0.23)	0.37	(0.21)	2.428	0.020
Mean	0.04	(0.05)	0.07	(0.05)	1.394	0.171
Standard Deviation	0.03	(0.04)	0.06	(0.02)	1.799	0.080

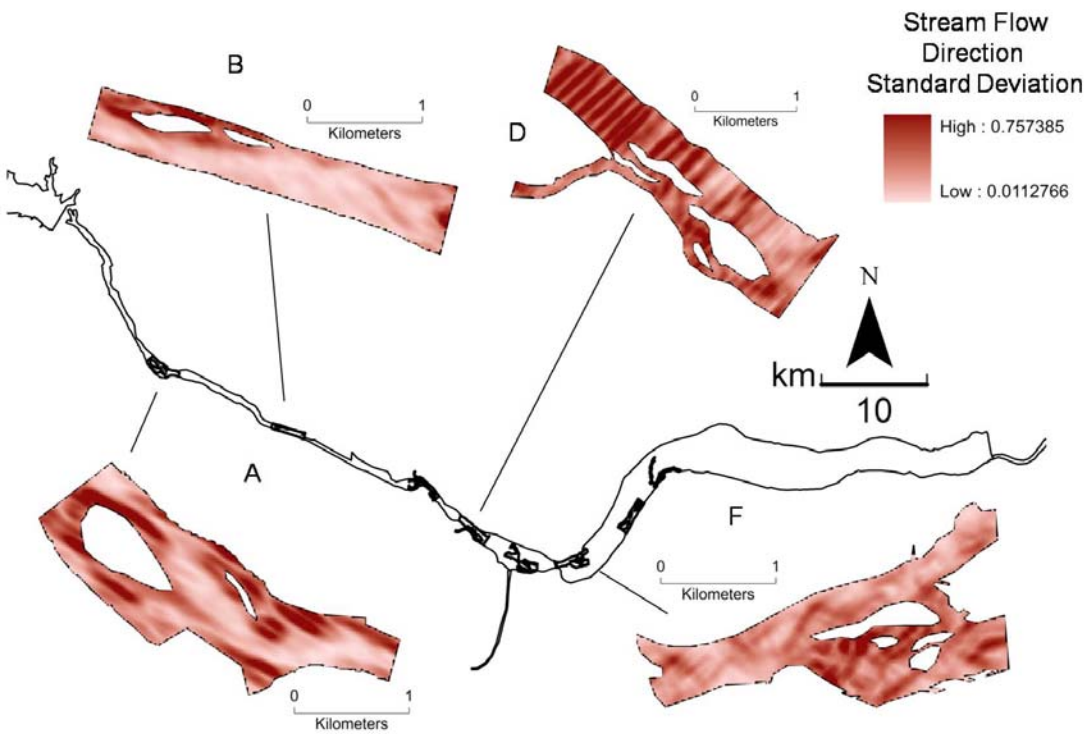
Appendix A-3. Mean (standard deviation), t-value, and p-values for all physical habitat and prey variables screened for pallid sturgeon capture areas (PSCA, n=10) versus non-capture areas (NCA, n=32) considering otter trawl gear deployments.

Metric	NCA		PCSA		t-value	p-value
Water Depth (m)						
Minimum	1.08	(0.32)	1.33	(0.20)	-2.526	0.017
Maximum	5.04	(1.44)	5.59	(0.63)	-1.352	0.186
Range	3.96	(1.51)	4.26	(0.42)	-0.746	0.461
Mean	2.63	(0.40)	3.03	(0.27)	-3.203	0.003
Standard Deviation	0.93	(0.40)	0.81	(0.04)	1.177	0.248
Proportion Area > 1	0.97	(0.05)	0.99	(0.02)	-1.708	0.098
Proportion Area > 2	0.7	(0.13)	0.89	(0.11)	-4.454	<0.001
Proportion Area > 3	0.35	(0.22)	0.62	(0.18)	-3.809	0.001
Proportion Area > 4	0.09	(0.11)	0.09	(0.03)	0.203	0.841
Proportion Area > 5	0.03	(0.06)	0.03	(0.02)	-0.266	0.792
Proportion Area > 6	0.01	(0.03)	0	(0.00)	1.579	0.125
Proportion Area > 7	0	(0.01)	0	(0.00)	1.358	0.185
Proportion Area > 8	0	(0.00)	0	(0.00)		
Water Bottom Velocity (cm/s)						
Minimum	46.47	(27.3)	58.74	(5.05)	-1.709	0.098
Maximum	118.82	(12.8)	115.24	(5.54)	1.002	0.324
Range	72.35	(24.2)	56.49	(7.65)	2.423	0.022
Mean	88.42	(13.9)	91.91	(5.10)	-0.915	0.367
Standard Deviation	15.33	(5.63)	9.17	(1.01)	4.168	<0.001
Proportion Area > 20	1	(0.02)	1	(0.00)	-1.015	0.318
Proportion Area > 40	0.97	(0.05)	1	(0.00)	-1.995	0.055
Proportion Area > 60	0.91	(0.11)	1	(0.01)	-3.030	0.005
Proportion Area > 80	0.69	(0.27)	0.87	(0.16)	-2.273	0.030
Proportion Area > 100	0.34	(0.29)	0.22	(0.10)	1.503	0.143
Proportion Area > 120	0.04	(0.07)	0	(0.00)	2.415	0.022
Proportion Area > 140	0	(0.00)	0	(0.00)		
Flow Direction Variability Index						
Minimum	0.04	(0.02)	0.13	(0.06)	-6.326	<0.001
Maximum	0.44	(0.21)	0.46	(0.02)	-0.275	0.785
Range	0.41	(0.21)	0.33	(0.04)	1.424	0.165
Mean	0.17	(0.07)	0.23	(0.05)	-2.726	0.011
Standard Deviation	0.09	(0.06)	0.06	(0.02)	1.980	0.057

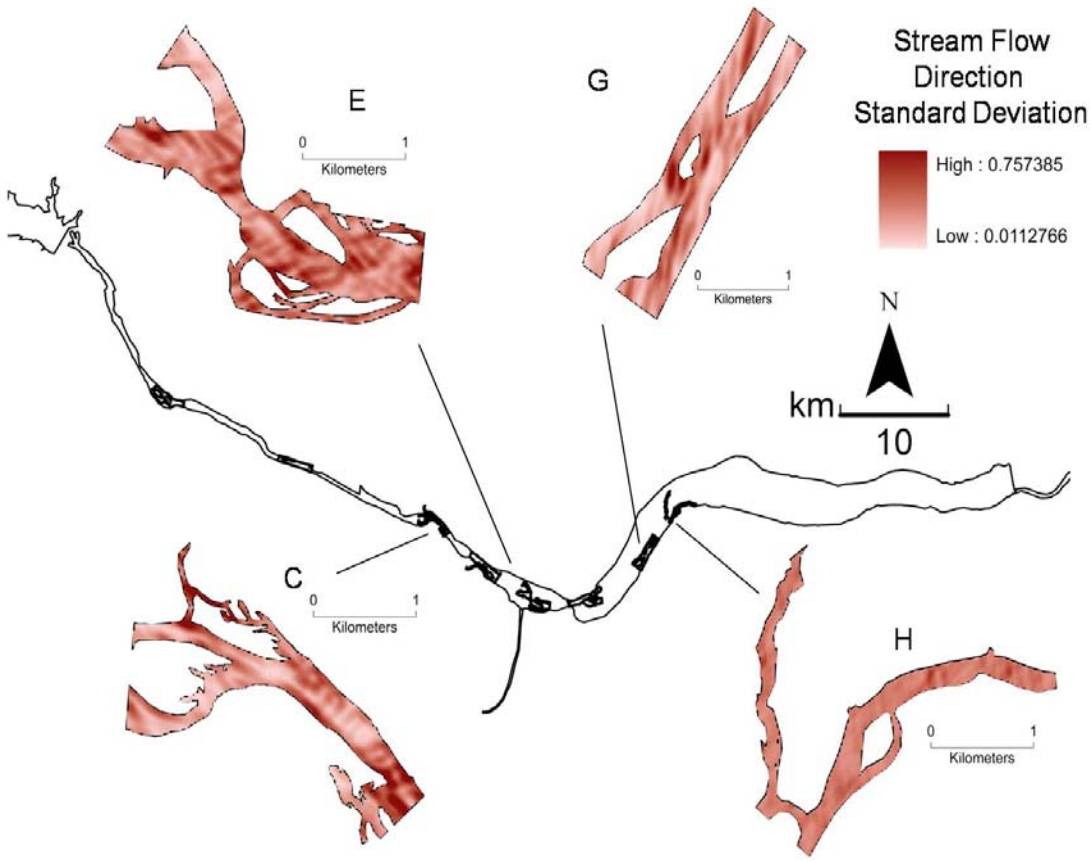
Appendix A-3 continued. Mean (standard deviation), t-value, and p-values for all physical habitat and prey variables screened for pallid sturgeon capture areas (PSCA, n=10) versus non-capture areas (NCA, n=32) considering otter trawl gear deployments.

Metric	NCA		PSCA		t-value	p-value
Percent Bottom Slope						
Minimum	0.02	(0.02)	0.05	(0.01)	-4.517	<0.001
Maximum	5.2	(2.36)	5.24	(0.73)	-0.061	0.952
Range	5.18	(2.35)	5.19	(0.73)	-0.026	0.980
Mean	1.31	(0.51)	1.23	(0.09)	0.610	0.547
Standard Deviation	1.06	(0.50)	1.08	(0.14)	-0.104	0.918
Proportion Area > 1.5	0.31	(0.15)	0.28	(0.03)	0.873	0.389
Proportion Area > 3.0	0.09	(0.09)	0.09	(0.03)	0.143	0.887
Proportion Area > 4.5	0.03	(0.05)	0.02	(0.01)	0.664	0.512
Proportion Area > 6.0	0.01	(0.03)	0	(0.00)	1.307	0.201
Percent Sand Substrate						
Minimum	27.07	(27.13)	34.94	(25.61)	-0.841	0.407
Maximum	99.97	(0.07)	100	(0.00)	-1.891	0.068
Range	72.89	(27.13)	65.06	(25.61)	0.837	0.409
Mean	79.12	(16.68)	94.41	(1.83)	-3.526	0.001
Standard Deviation	16.56	(9.04)	10.14	(3.73)	2.558	0.016
Proportion Area > 50	0.86	(0.20)	0.98	(0.01)	-2.387	0.023
Proportion Area > 75	0.69	(0.28)	0.94	(0.03)	-3.457	0.002
Larval Dipteran Drift Abundance (No. / L)						
Minimum	0.06	(0.03)	0.04	(0.10)	1.008	0.322
Maximum	0.44	(0.43)	4.24	(1.91)	-7.966	<0.001
Range	0.38	(0.42)	4.2	(1.98)	-7.794	<0.001
Mean	0.19	(0.13)	0.28	(0.12)	-2.043	0.050
Standard Deviation	0.08	(0.10)	0.52	(0.23)	-7.102	<0.001
Ephemeropteran Drift Abundance (No. / L)						
Minimum	0	(0.00)	0.01	(0.00)	-6.740	<0.001
Maximum	0.16	(0.48)	0.3	(0.14)	-1.067	0.295
Range	0.16	(0.47)	0.29	(0.13)	-1.027	0.313
Mean	0.03	(0.05)	0.05	(0.02)	-1.854	0.074
Standard Deviation	0.03	(0.09)	0.05	(0.02)	-0.887	0.382

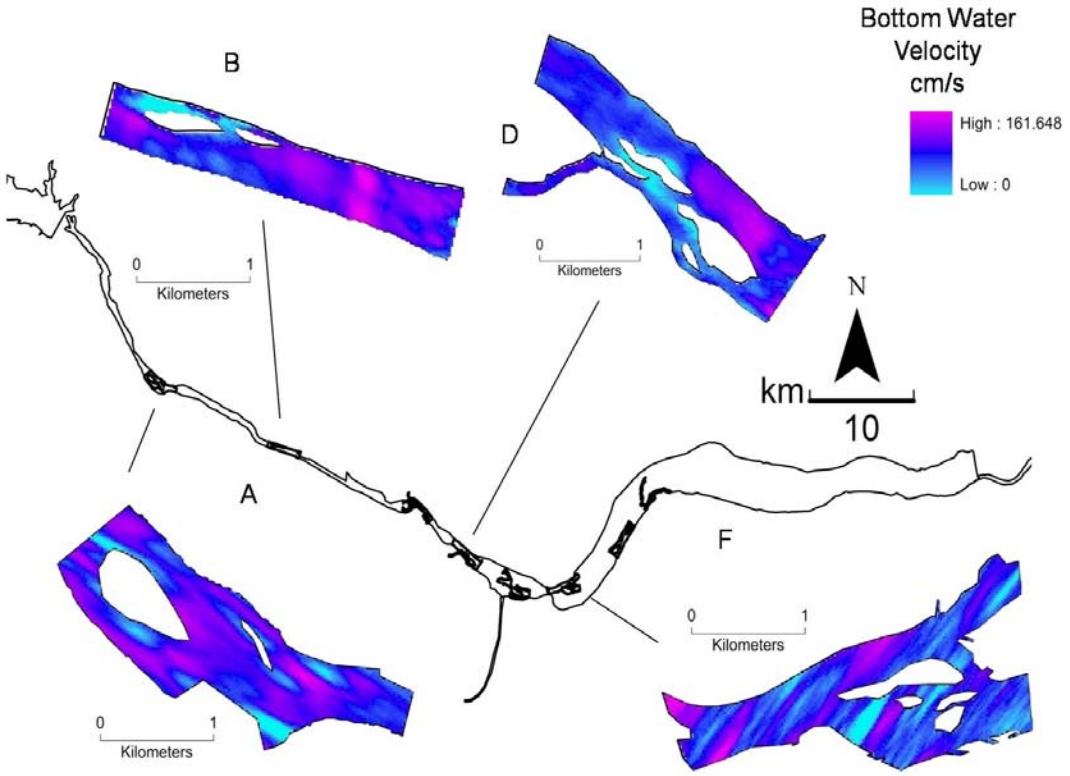
APPENDIX B - FIGURES



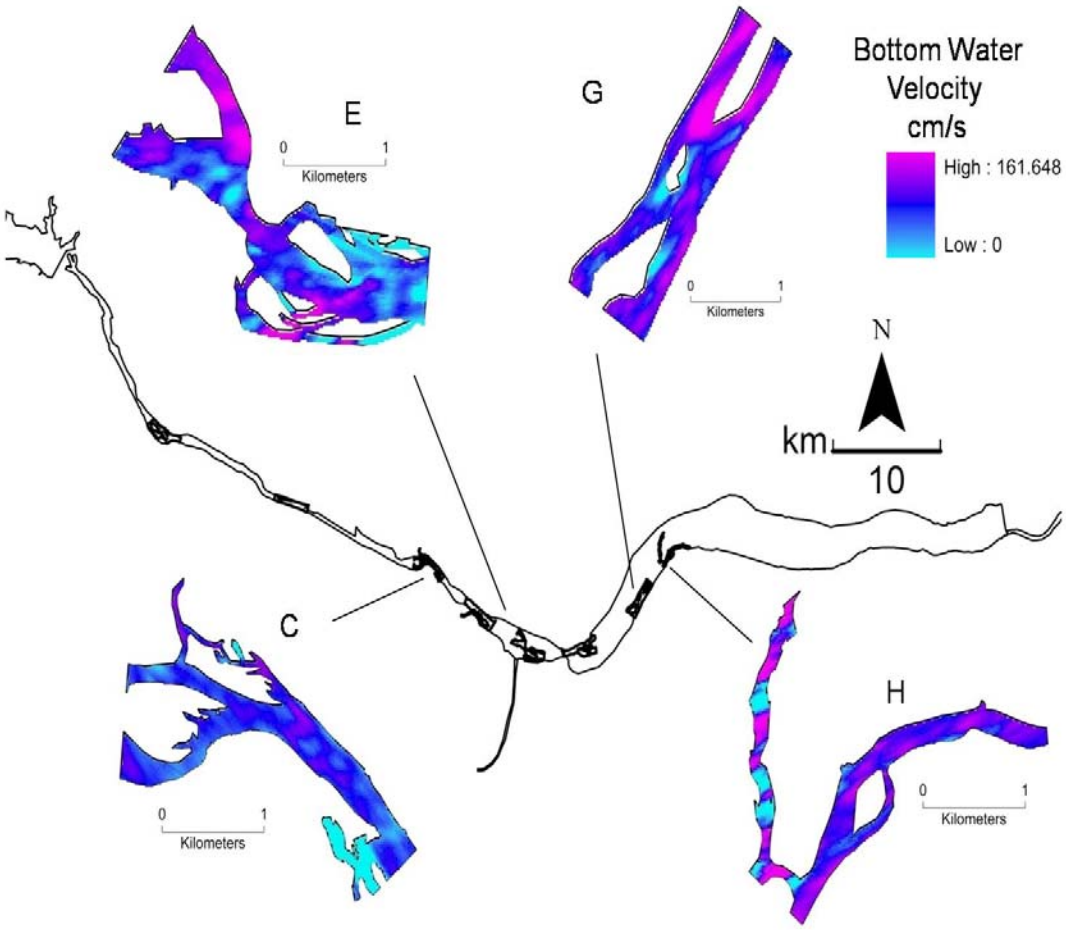
Appendix B-1. Stream flow direction standard deviation maps for the four 3.2-km sample areas that had the lowest proportion of predicted area of pallid sturgeon capture.



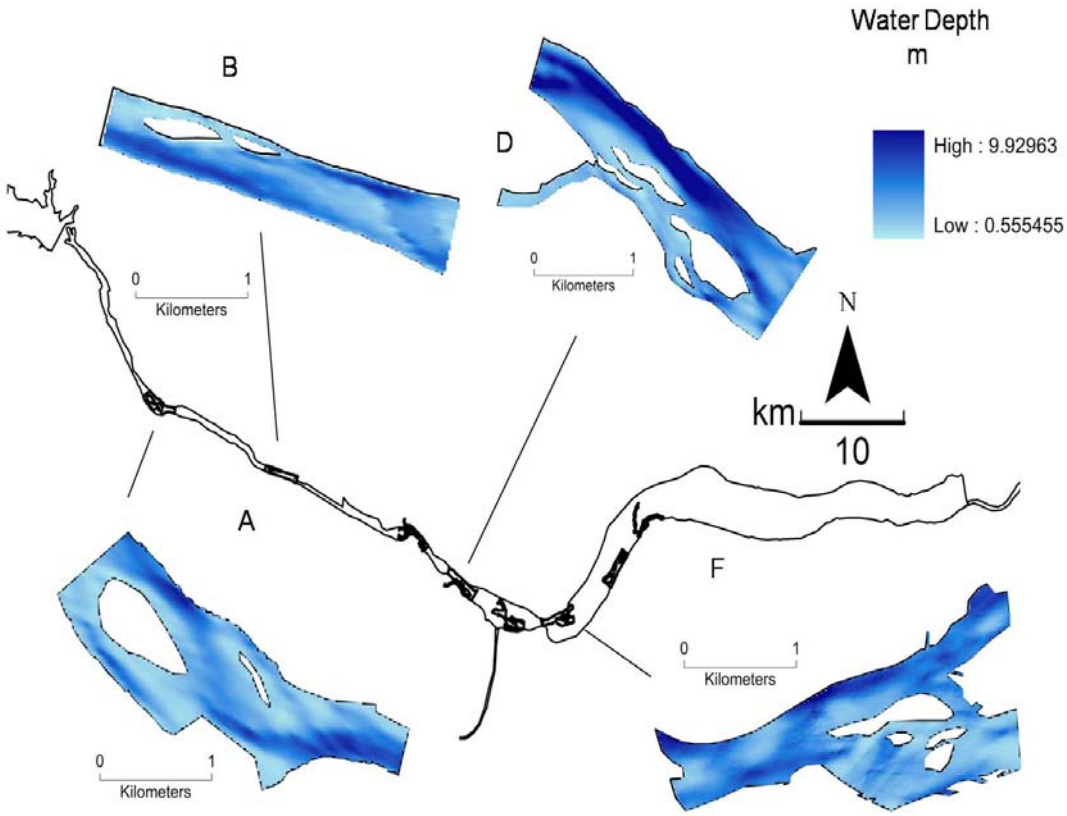
Appendix B-1 continued. Stream flow direction standard deviation maps for the four 3.2-km sample areas that had the highest proportion of predicted area of pallid sturgeon capture.



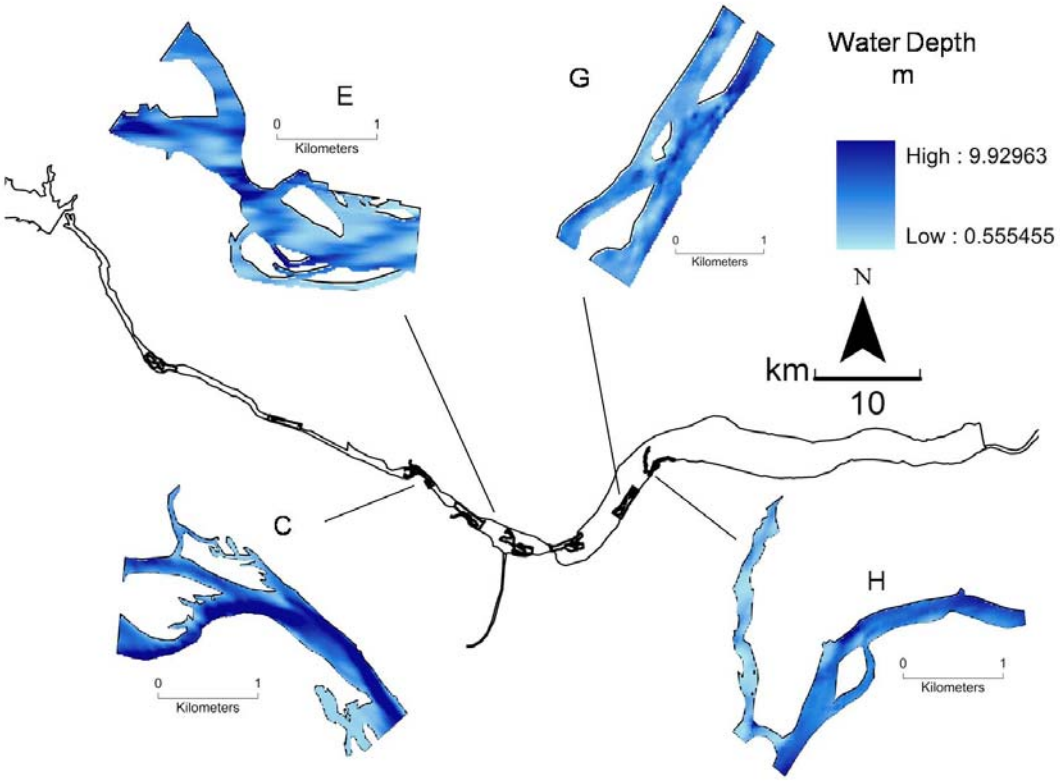
Appendix B-2. Bottom water velocity maps for the four 3.2-km sample areas that had the lowest proportion of predicted area of pallid sturgeon capture.



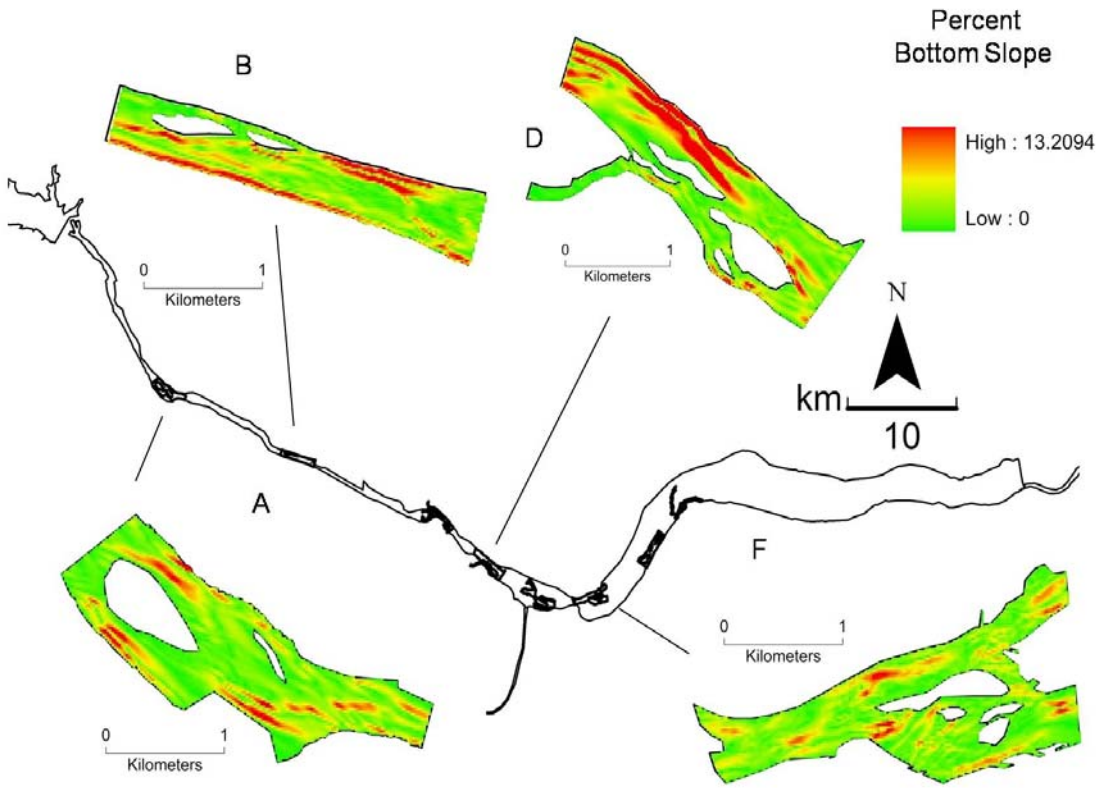
Appendix B-2 continued. Bottom water velocity maps for the four 3.2-km sample areas that had the highest proportion of predicted area of pallid sturgeon capture.



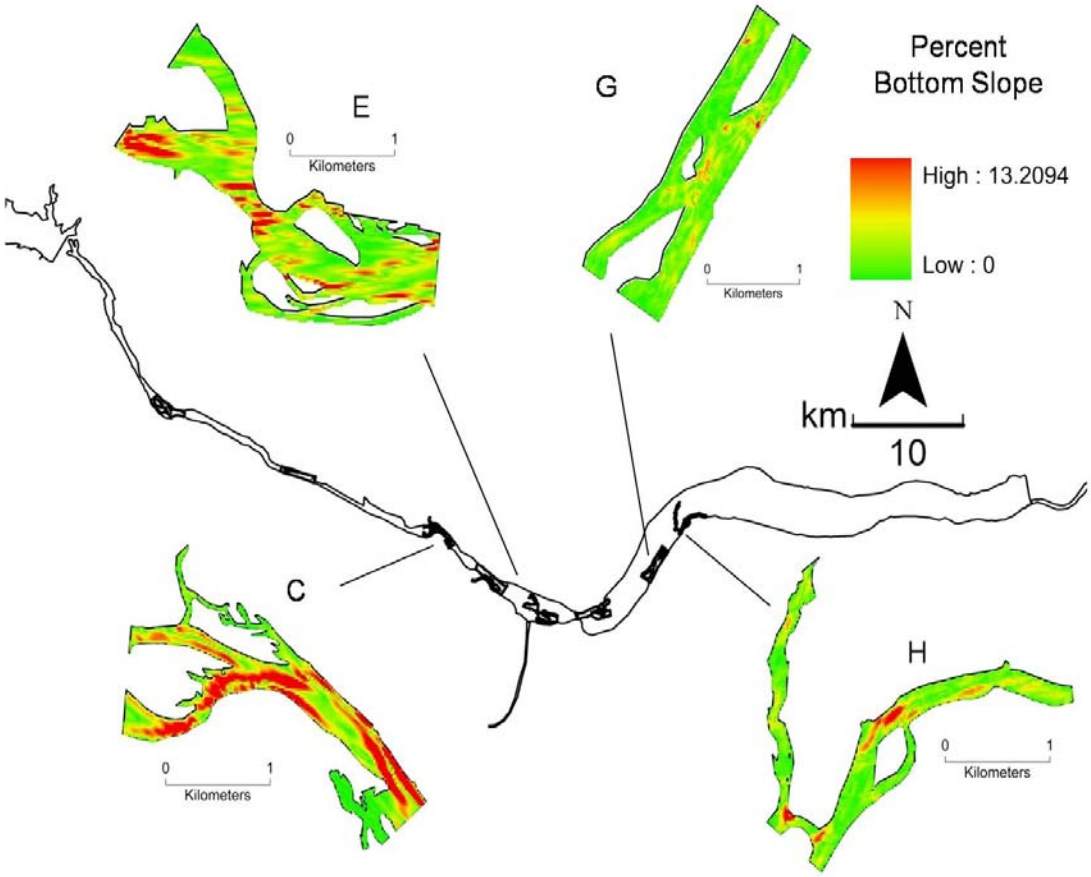
Appendix B-3. Water depth maps for the four 3.2-km sample areas that had the lowest proportion of predicted area of pallid sturgeon capture.



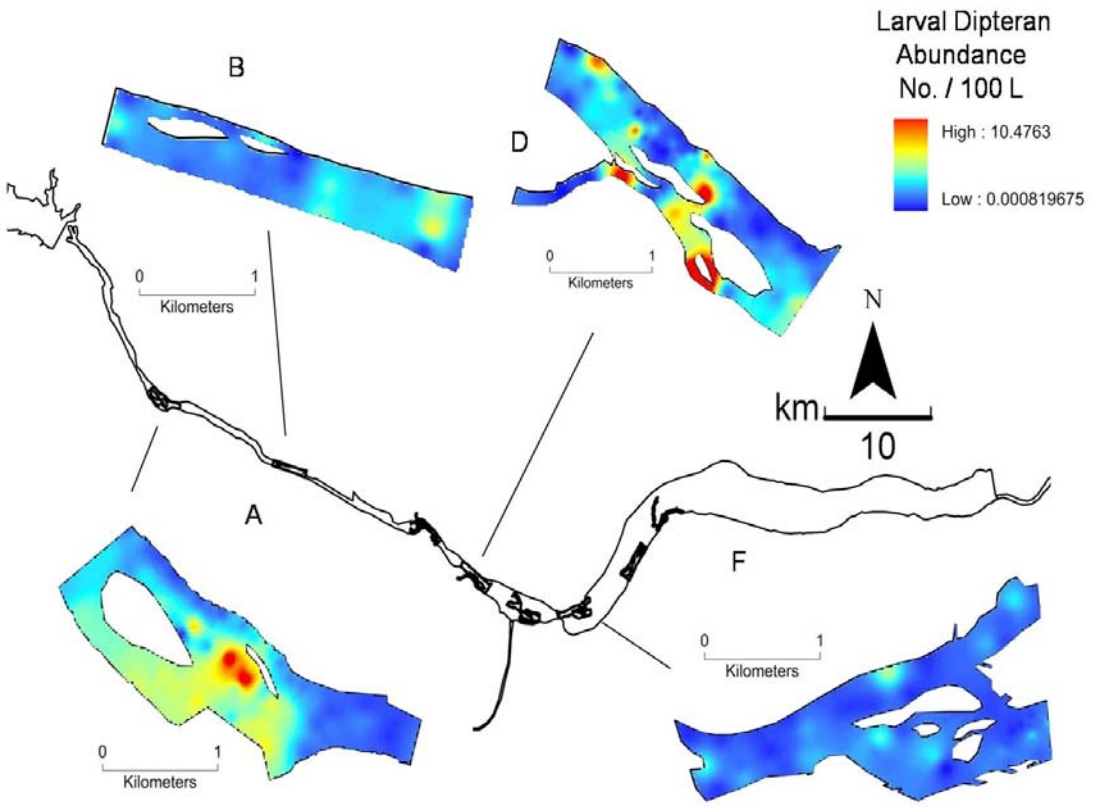
Appendix B-3 continued. Water depth maps for the four 3.2-km sample areas that had the highest proportion of predicted area of pallid sturgeon capture.



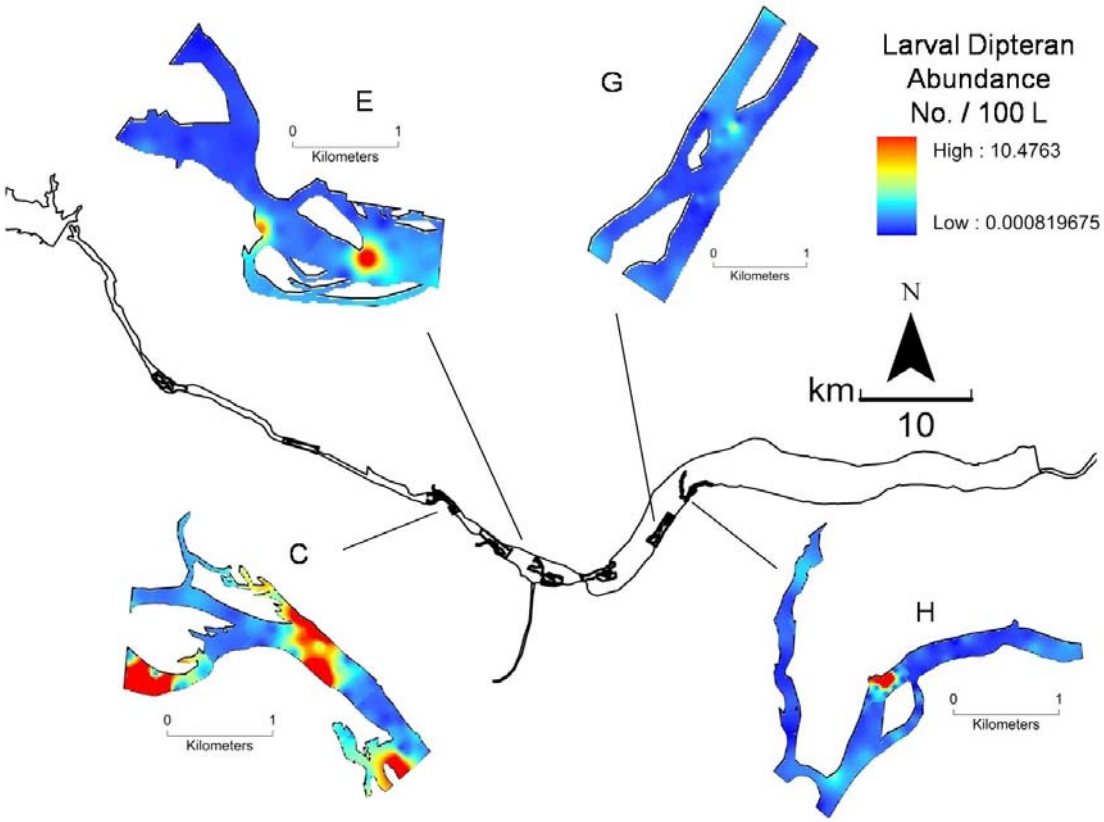
Appendix B-4. Percent bottom slope maps for the four 3.2 km sample areas that had the lowest proportion of predicted area of pallid sturgeon capture.



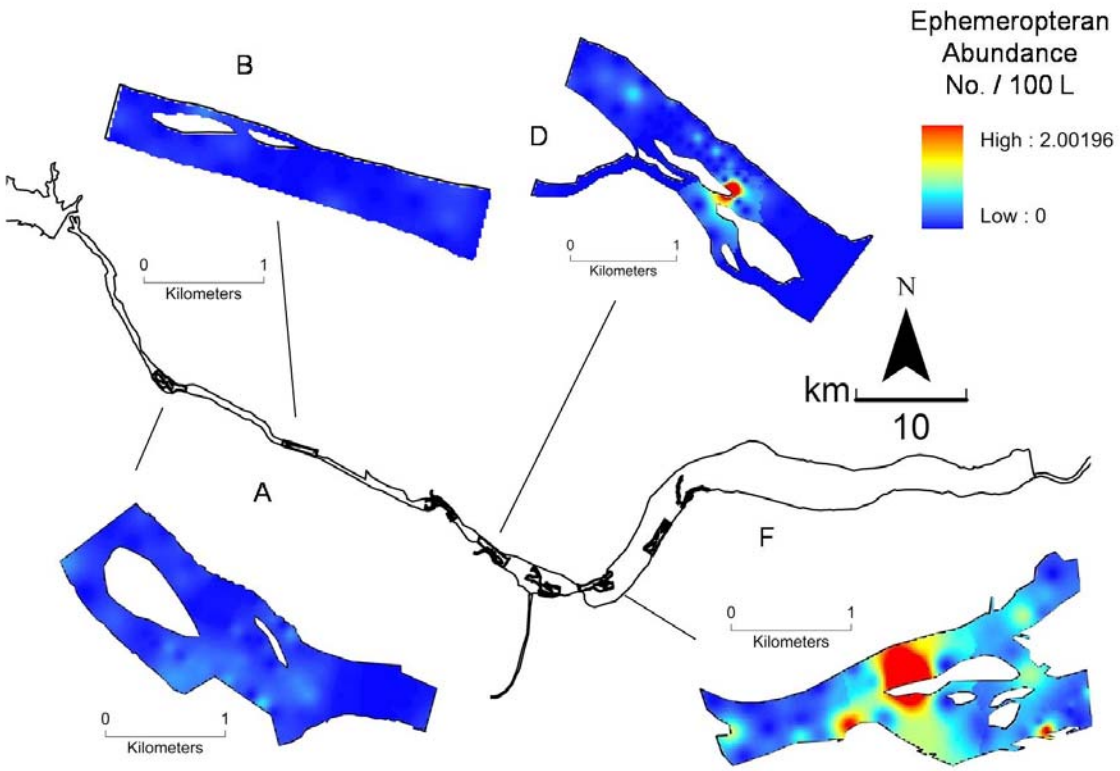
Appendix B-4 continued. Percent bottom slope maps for the four 3.2-km sample areas that had the highest proportion of predicted area of pallid sturgeon capture.



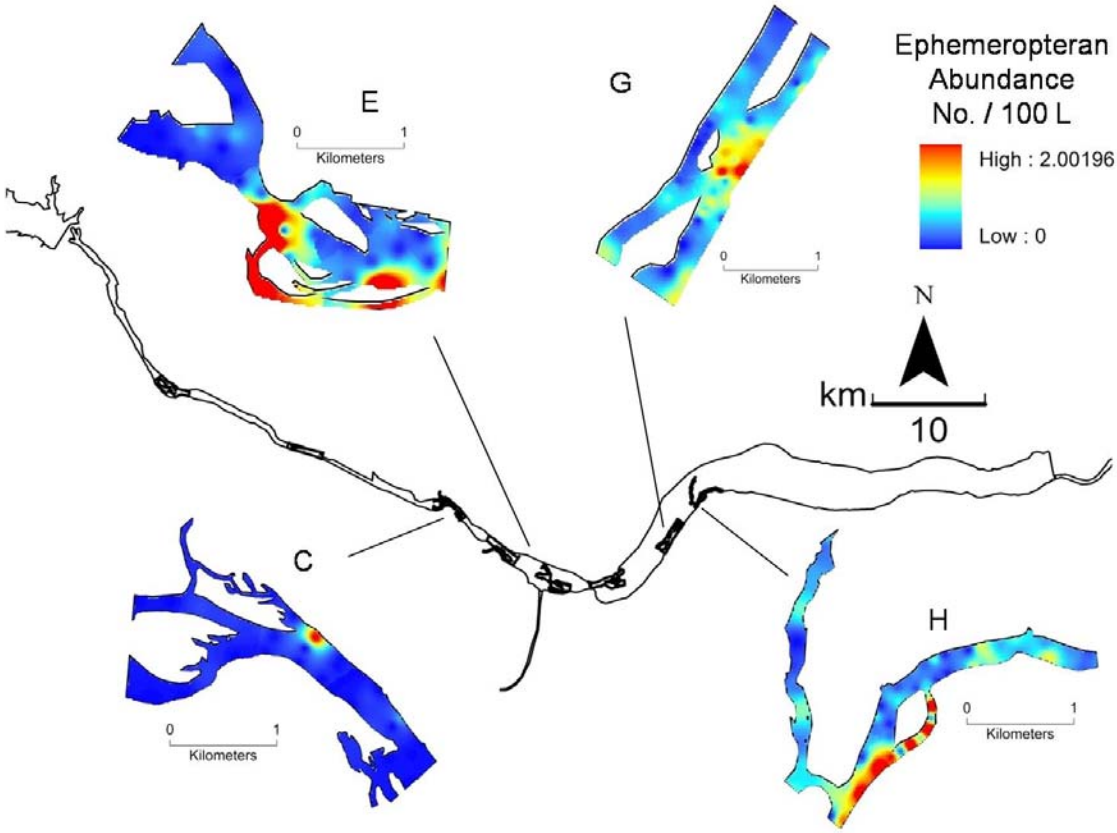
Appendix B-5. Drifting larval dipteran abundance maps for the four 3.2-km sample areas that had the lowest proportion of predicted area of pallid sturgeon capture.



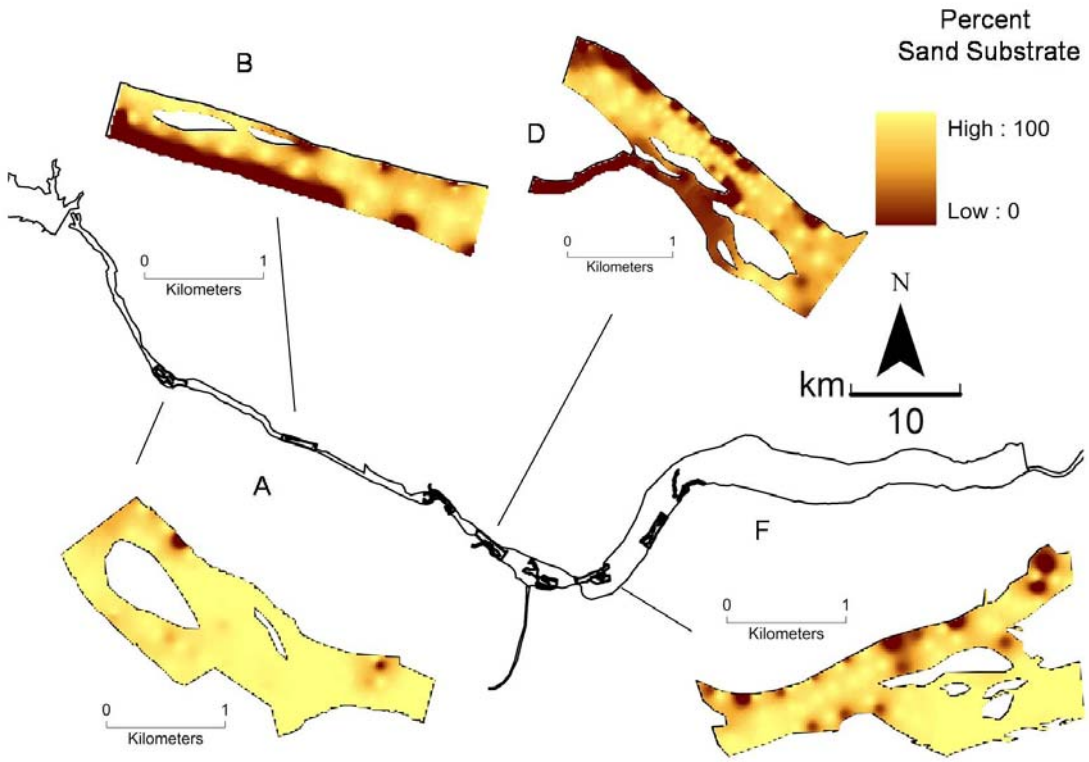
Appendix B-5 continued. Drifting larval dipteran abundance maps for the four 3.2-km sample areas that had the highest proportion of predicted area of pallid sturgeon capture.



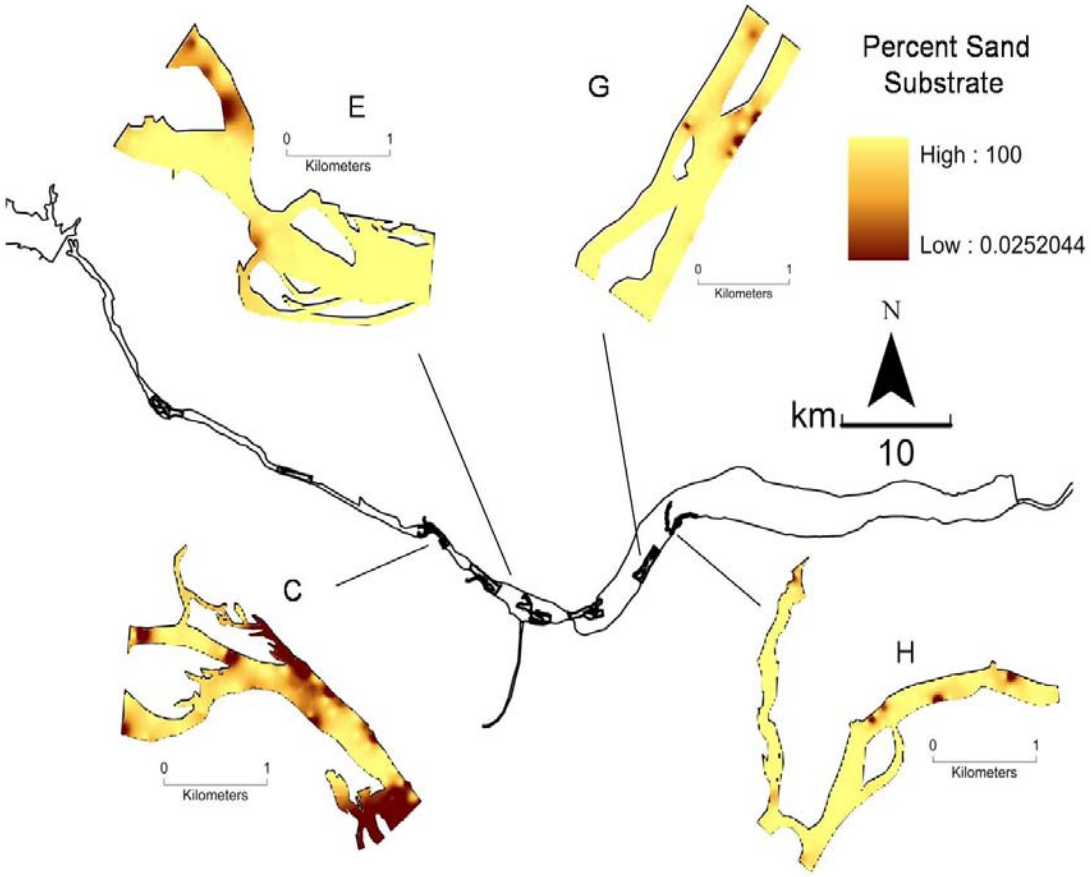
Appendix B-6. Drifting ephemeropteran abundance maps for the four 3.2-km sample areas that had the lowest proportion of predicted area of pallid sturgeon capture.



Appendix B-6 continued. Drifting ephemeropteran abundance maps for the four 3.2-km sample areas that had the highest proportion of predicted area of pallid sturgeon capture.



Appendix B-7. Percent sand substrate maps for the four 3.2-km sample areas that had the lowest proportion of predicted area of pallid sturgeon capture.



Appendix B-7 continued. Percent sand substrate maps for the four 3.2-km sample areas that had the highest proportion of predicted area of pallid sturgeon capture.