Using GIS to Create a Pallid Sturgeon Habitat Suitability Model in the Fort Randall Segment of the Missouri River, USA Based on Historical Habitat and Modern Telemetric Studies

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Abstract

Based on Missouri River biologists' research, this study incorporates the use of telemetry, bathymetry, and Geographic Information Systems (GIS) to identify potential pallid sturgeon (*Scaphirhynchus albus)* habitat in the Fort Randall segment of the Missouri River, USA. This habitat suitability assessment employed the use of historic and current images, bathymetry data, and data gathered from research compiled on sturgeon habitat locations during spawning periods in the Lower Missouri River. Comparisons were made between the two segments by using bathymetric data in the Fort Randall segment, historical imagery and data provided from telemetric studies downstream of the Gavins Point segment. These comparisons were used to illustrate habitat suitability within the Fort Randall segment of the Missouri River.

Introduction

Missouri River History

Prior to the 1950s, the Missouri River (USA) (referred to as "Big Muddy") was known for its forest wetlands, sediment and nutrient-rich alluvial flood plains filled with snags, whirlpools, chutes and log jams (Weeks, Vana-Miller, and Pranger, 2005).

In 1927, the United States Congress passed the River and Harbor Act (Weeks et al., 2005), which provided flood damage control with stream bank armoring. In 1944, the Flood Control Act (Weeks et al.) was passed in order to construct a six dam system on the mainstem of the Missouri River.

In 1945, an extension was passed for a nine-foot-deep channel for navigation (Weeks et al., 2005). This channel was constructed downstream of today's Gavins Point Dam. Weeks et al. report the Missouri River was dredged to provide better navigation, and this resulted in the elimination of many meanders and bends. Consequently, higher velocity and more bank erosion occurred with less deposition along the rivers banks (Weeks et al.). The last of the six dam projects was completed in 1963.

Dams located in Missouri National Recreational River (MNRR) comprise the Gavins Point Dam (completed in 1955) and the Fort Randall Dam (completed in 1956). The MNRR was established as a national recreational river under the Wild

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and Scenic Rivers Act of 1968 (Weeks et al., 2005). The 59-mile Gavins Point segment was designated in 1978 and the 39-mile Fort Randall segment was designated in 1991. Both segments were assigned to the National Parks Service (Elliot and Jacobson, 2006).

These 59-mile and the 39-mile segments are subject to a wide range of competing management objectives that include power generation, flood control, bank stabilization, endangered species management and recreation (Elliot and Jacobson, 2006). This GIS study focuses on the impacts of the river's management on the endangered pallid sturgeon (*Scaphirhynchus albus)* and its habitat.

Missouri River Ecological Impacts

According to Weeks et al. (2005), dams provide economic and social development but also impact geomorphology and river ecology. The economic and social advantages include reduced residential flooding, increased commercial barge navigation, added hydroelectric power, and water for agricultural irrigation. With respect to the dams ecological impact: the river banks are higher than pre-dam conditions and soil erosion is greater due to the steepness of the river banks. Some banks are stabilized with riprap (e.g., rocks and manmade materials like concrete slabs) to reduce bank erosion (Weeks et al., 2005).

The 59-mile Gavins Point segment of the MNRR has approximately 30 to 40% of its banks stabilized (Yager, 2008). This 59-mile segment has been impacted by the effects of bank stabilization, flow regulation and the river's sediment regime (Yager, 2008). Weeks et al. (2005) state miles of forest have been lost on the Missouri River as management of the river has stopped the meandering that created the needed periodic flooding to supply the grassland, marshland, and timber with adequate moisture and nutrients. Meandering rivers also provide available shallow water habitat (SWH) for spawning and nursery areas for fish (Price and Townsend, 2004; Stukel, Kral, and LaBay, 2009), serve as a refuge from high river velocity (Price and Townsend, 2004), and provide warmer temperature diversity (Stukel et al., 2009). Yager (2008) reports from 1941 to 2008, SWH such as backwaters and side channels have declined by 70% and 55% on the Gavins Point and Fort Randall segments respectively.

Pallid Sturgeon Endangered Listing

The U.S. Fish and Wildlife Service (USFWS) listed pallid sturgeon as endangered in 1990 and has provided a biological opinion (commonly known as BiOP 2000 and 2003) that states river management practices (e.g. bank stabilization and river flow regulation) on the Missouri River have impacted spawning, growth, and survival of the fish (U.S. Fish and Wildlife Service, 2003). In response, the U.S. Army Corps of Engineers (USACE) built control structures to create shallow water habitat and undertook research studies to understand the life history of the pallid sturgeon. Pallid sturgeon are rare in the Lower Missouri River and no reliable population estimate exists (DeLonay, Papoulias, Jacobson, Wildhaber, Simpkins, Korschgen, Mestl, Everett, Annis, Tillitt, Bartholomay, Russ, Wilson, Anderson, Kopis, and Haschemeyer, 2007). Because little is known about pallid sturgeon history, recent efforts have been made to understand their habitat preferences through telemetric studies.

Pallid Sturgeon Telemetric Studies

Intensive pallid sturgeon and shovelnose sturgeon habitat studies conducted by the USFWS and the USGS, covering 811 miles of the Lower Missouri River, began in 2005 and are ongoing today. These studies show that pallid sturgeon recruitment to the adult population is limited, but some reproduction has been documented (Laustrup, Jacobson, and Simpkins, 2007). Due to the rarity of pallid sturgeon, biologists use shovelnose sturgeon as a surrogate species to model sturgeon biology and habitat use. DeLonay et al. (2007) report shovelnose sturgeon is more resilient than pallid sturgeon due to its "earlier maturity, lower trophic status, and adaptability to a broader range of environmental conditions" (e.g., ability to use clear-water habitats). Similarities between the two sturgeons include high adaptability to large, turbid, riverine environments (DeLonay et al., 2007).

Spawning of the abundant shovelnose sturgeon is believed to occur over hard substrate (i.e., rock, rubble, or gravel) in primary tributary streams or along borders of main river channels (Kynard, 1997). Some biologists believe pallid sturgeon may also spawn on hard substrate. Although actual spawning has not been observed, captures of fish in spawning condition indicates shovelnose sturgeon spawn from 14.4 °C to 24 °C (Jacobson and Galat, 2008). Similar findings were observed through telemetric studies of the pallid sturgeon by (DeLonay, Jacobson, Papoulias, Simpkins, Wildhaber, Reuter, Bonnot, Chojnacki, Korschgen, Mestl, and Mac, 2009).

Reuter, Jacobson, Elliott and DeLonay (2009) report river sturgeon select location based on habitat availability, depth, and velocity. Habitat availability refers to habitat available between river segments (i.e. minimal engineering, upstream channelized, or downstream channelized). An example of a minimally engineered segment is the river segment from Gavins Point, Yankton South Dakota, to Sioux City, Iowa. Reuter et al. (2009) report a minimally engineered segment is characterized by shallow mean depths (less than 4 meters), large widths (1,300 to 1,700 meters) and relatively low mean velocity [less than 0.6 meters/second (m/s)]. An upstream channelized segment is characterized by narrow (180 meters), deep (between 3 and 7 meters) and fast current (1 m/s) as found in the section between Sioux City, Iowa, and the Platte River in Nebraska. A downstream channelized segment is characterized by wide (300 to 400 meters), deep (between 7 and 10 meters) and fast current (greater than 1 m/s). Reuter et al. (2009) describes the section of Missouri River downstream of Kansas City, Missouri as downstream channelized.

Within each habitat, sturgeon show patterns of selection based on depth and velocity (Reuter et al., 2009). They conclude patterns of depth selection vary among segments. Sturgeon select shallower depths while in downstream channelized segments but prefer to avoid the shallowest depths while in minimal engineered segments (Reuter et al., 2009).

The telemetric study shows sturgeon were often found in one or more areas with high velocity gradient, high depth slope, low depth-averaged velocity, and low Froude number (Reuter et al., 2009).

Froude number is a dimensionless parameter derived from depth, velocity, and gravitational constant. Velocity gradient represents the amount of spatial change in velocity. High velocity gradient (1 to 3 m/s) produces a violently rotating column of water, which often forms bedrock pits in the river bottom. Depth slope is the topographic slope (measured in degrees) of the river bed. The Reuter et al. (2009) study indicates sturgeons were often found in areas with higher depth slopes (greater than 1 to 2 degrees). Depth-averaged velocity was based on Doppler readings from the MNRR sonar equipment. The best available way to pinpoint the sturgeon location was to use average-depth velocity, because interference signals occur near river bottom. Froude number is often used in habitat characterization studies and quantifies the river environment's energy.

Other studies considered water temperature and river flow as factors that drive reproductive development and spawning migration (Lucas and Baras, 2001; Jacobson and Galat, 2008).

The goal of this research was to examine existing pallid sturgeon habitat data from telemetric studies and to establish and isolate potential suitable habitat based on this and other data that encompass pallid sturgeon studies of the Missouri River Basin. Other information used for this research included bathymetric data provided by the USGS and current and historical images.

Sturgeon data collected from various river segments within the Missouri River were used for this study; however the study area was narrowed to within the Missouri National Recreational River (MNRR) boundaries comprising the 39-mile Fort Randall Dam and the 59-mile Gavins Point Dam.

Study Area

Two stretches of the Missouri River, comprising 98 river miles, are protected in northeast Nebraska and southeast South Dakota. This protected area includes a 39-mile section from Fort Randall Dam near Pickstown, South Dakota, to Lewis and Clark Lake; and a 59-mile section from Gavins Point Dam near Yankton, South Dakota, to Ponca, Nebraska (Figure 1).

The study area was narrowed further to the 39-mile Fort Randall segment for three reasons: time constraints for this project; few pallid sturgeon studies have been conducted within the 39-mile segment; and because of the known competitive invasive Asian carp in the 59-mile segment. The two main invasive carp known in this segment are the big head (*Hypophthalmichthys nobilis*) and the silver (*Hypophthalmichthys molitrix*) carp.

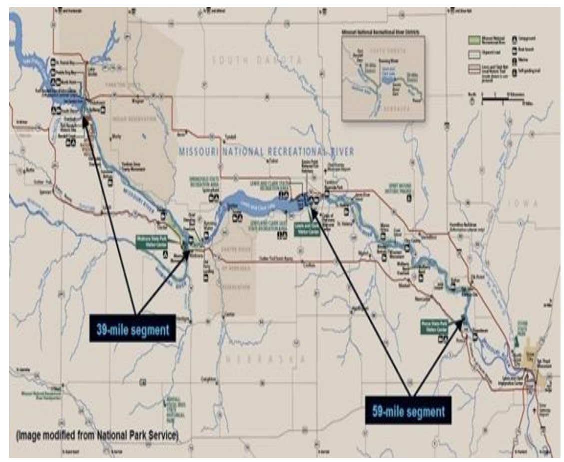

Figure 1. Missouri National Recreational River illustrated with the 39-mile segment defined by the black text box on the left and the 59-mile segment depicted by the black text box on the right. Modified from National Park Service (Yager, 2008).

Asian carp are estimated in the thousands in the Lower Missouri River and are very competitive for food with the pallid sturgeon (USGS, Duane Chapman, Missouri River Biologist, pers. comm., 2010).

Methods

Telemetric Data

Telemetric data was used to understand pallid sturgeon habitat preference during the spawning migration period, which begins the end of March and extends through May (DeLonay et al., 2009).

Discharge, depth, and temperature data from each of the six pallid sturgeon graphs, provided by DeLonay et al. (2009), were used to examine relationships that cue the pallid sturgeon river migration and spawning. The extent of Delonay and others' telemetric study included approximately 811 miles of the Lower Missouri River covering segments below Gavins Point Dam to Saint Louis, Missouri. The time frame of their study encompassed March through April of 2007 and 2008.

Discharge, depth, and temperature were entered into Excel tables. River mile marker (RM) locations for each pallid sturgeon were also used to indicate distance traveled. The spreadsheet tables were used to create graphs and tables that illustrate depth preferences and distance traveled (Figures 3-8, Table 1). These data were then used in GIS for spatial analysis.

Table 1. Maximum and minimum depth (feet) locations and total distance (mi) traveled per pallid sturgeon.

Discharge Location	Max Depth	Min Depth	Total Distance
Yankton, SD	46	7	95
Decatur, NE	33	16	30
Glaskow, MO	49	3	85
KC, MO	49	7	170
KC, MO	49	7	175
Decatur, NE	39	10	22
Average	44	8	96

Bathymetric Data

Data provided by U.S. Army Corps of Engineers (USACE) (2008) was used for bathymetric data in the Fort Randall segment. Figure 2 illustrates water surface changes and river bed changes between 1975 and 1995.

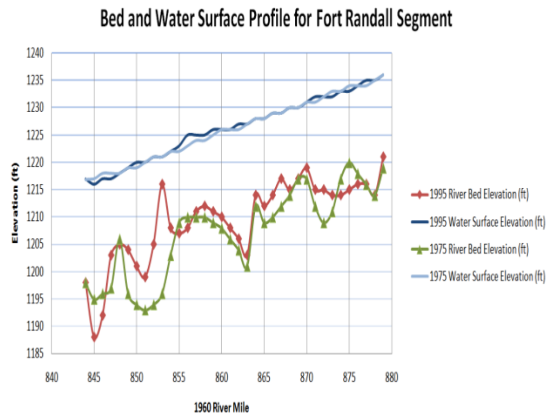

Figure 2. Bed and water surface profile for the Fort Randall study area with a discharge of 25,100 cubic feet per second (cfs) (Recreated from USACE, 2008).

The red line in Figure 2 is the 1995 river bed elevation (ft); the green line is the 1975 river bed elevation (ft) and the dark blue and light blue lines are 1995 and 1975 water surface elevations (ft), respectively. Elevation is represented on the y-axis and 1960 river mile on the x-axis.

A depth table was created using this data. Both telemetric and bathymetric data were used in GIS to show potential pallid sturgeon habitat.

GIS Data

NAD 83 UTM 14N was the coordinate system of the aerial imagery. All base data were provided by the MNRR staff and the USGS river biologists.

According to collective research conducted by professionals across the United States, the NAD 83 datum is very similar to WGS 84 in the two coordinate systems are within one to two meters of each other and still have essentially the same elevations above MSL (Ferris Education, 2010).

Although there are minimal differences between NAD 83 and WGS 84, this GIS assessment focuses on the habitat loss and availability. To reflect changes in habitat availability, appropriate transformations were made (WGS 84 to NAD 83 UTM 14N) while importing ESRI World Imagery into the GIS project.

Base data included park boundaries for the 39-mile and 59-mile segments, Indian Reservations, DEM data, county lines, wetlands, transportation routes, mine locations and landfill locations. Other data included: locations for river mile markers, hydrology, bank stabilization, sandbars, and historical images (1956 and 1984) for both segments.

Aerial photographs were used to see historical impacts of flow regulation on habitat in MNRR. Current ESRI orthophoto imagery was used to digitize the 39-mile Fort Randall and 59-mile Gavins Point riverbank polyline-shapefiles. A scale of 1:5,000 was used to digitize the river segments. Side channels were kept as part of the mainstem as sturgeon may still have access to these sections. Backwaters were not included in the riverbank polyline-shapefiles.

Polylines were converted to polygons and later converted into rasters for statistical analysis. All polylines had to be cleaned of topology errors (dangles, intersecting lines, and overlaps) prior to conversion to polygons. The 59-mile segment was completed by hand. The 39-mile segment was completed by constructing topology rules. The steps involved the following: (1) create a new geodatabase in order to run topology; (2) create a new dataset in the geodatabase; (3) create new topology within that dataset; (4) within the topology create topology rules: must not overlap, must not have dangles, and must not intersect; (5) drag the newly created topology rules into the map session; (6) validate and fix topology errors; and (7) convert polylines to polygons.

Sandbar data were previously created by the MNRR staff in 2004. This sandbar data appeared to match the current 2010 orthophoto imagery provided by ESRI, therefore this data was used in this analysis. Note, the sandbar data includes both sandbars and vegetated islands (also referred to as bar habitat) and for the purpose of this project both are referred to as sandbars.

All polygons used for analysis were converted to raster with a 5 m grid cell size. The 1941, 1999, and 2004 bar vector shapefiles were converted to raster shapefiles for habitat-change analysis and to illustrate available pallid sturgeon habitat.

Within each raster's attribute table, an additional acreage field was created to show each corresponding acreage amounts. A formula was applied to each Acreage field by using ArcMap's field calculator. Acreage calculations for each polygon raster = [count * 5 * 5 (grid size that was set) * 0.0002471044 (m^2 conversion to acres)].

Total sandbar loss and habitat available were calculated using cell statistics. Average sandbar acreage loss and standard deviations were calculated using GIS statistics calculator. Sandbar statistics were run for the 1941 and 2004 Gavins Point 59-mile segment to show impacts on sandbar habitat.

Bathymetric data was joined to the existing 39-mile RMs shapefiles and only matching data were kept for further analysis. Telemetric data was used to search within the 39-mile bathymetric data attributes table. The search was conducted by using corresponding telemetric data (Table 1), bathymetric shapefiles, and attribute tables.

Simple field calculations were performed in this search for appropriate depth and spatial locations. Calculations were based on findings in Table 1. A search was conducted in the attributes table of the 39-mile segment for depths between 3 and 8 feet and greater than 20 feet. And point shapefiles were created to illustrate the corresponding depth ranges.

Results

Telemetric Data

Figures 3-8 were created from data provided by DeLonay et al. (2009). Each graph illustrates individual pallid sturgeon ranges in depth and temperature recorded from data storage tags and discharge from the closest discharge location. Discharge locations depicted in each graph represent the nearest town, not necessarily the location of sturgeon release point. The left of each graph represents late March release of each pallid sturgeon and the right represents the capture of each sturgeon in post-spawn condition.

Based on the telemetric data (converted from meters to feet), the pre-migration depths of the sturgeon ranged from 33 to 49 feet with an average of 44 feet. Table 1 depicts spawn and post-spawn data, which show sturgeon located in a range from 3 to 16 feet with an average of 8 feet.

Neither the river mile (RM) locations nor time frame were depicted in Figures 3-8. Data collected from Delonay et al. (2009) illustrate pallid sturgeon can migrate up to 180 miles, based on RM release and capture locations. Distance traveled from the time of release to time of capture ranged between 22 miles and 175 miles over an approximately two month time span.

Figures 3-8 were used to derive maximum and minimum depth preferences shown in Table 1.

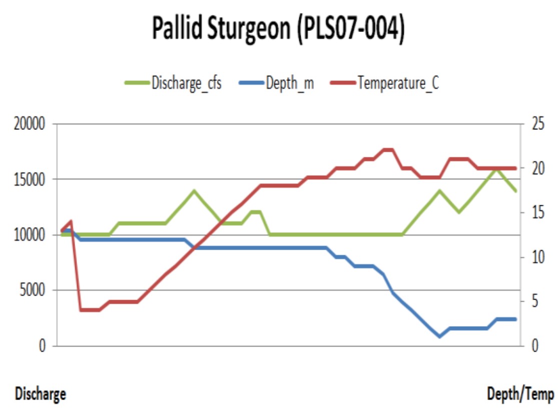

Figure 3. Yankton, SD, near RM 811, and telemetric data from implanted reproductive pallid sturgeon PLS07-004.

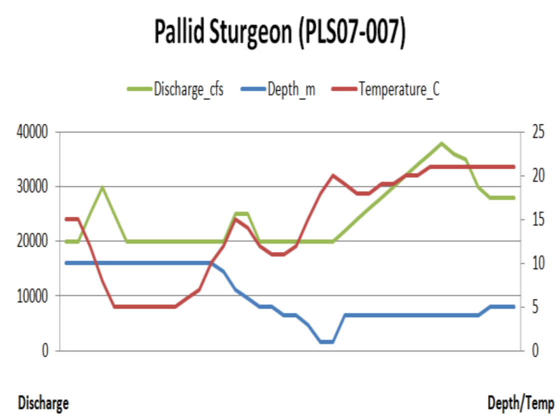

Figure 4. Decatur, NE, near RM 691, and telemetric data from implanted reproductive pallid sturgeon PLS07-007.

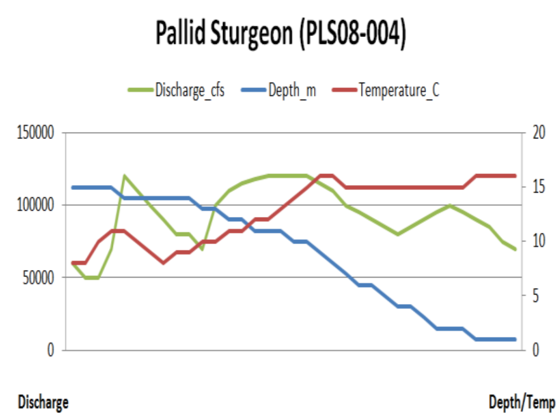

Figure 5. Glaskow, MO, near RM 199, and telemetric data from implanted reproductive pallid sturgeon PLS08-004.

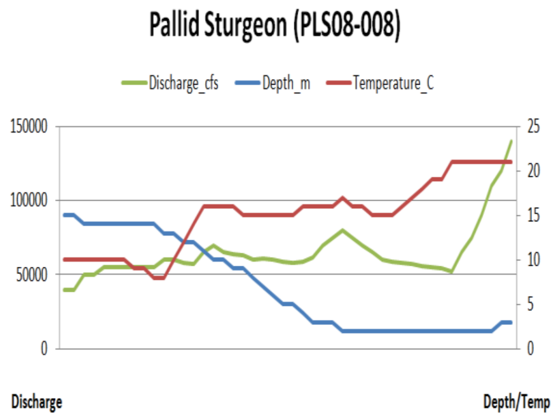

Figure 6. Kansas City, MO, near RM 366, and telemetric data from implanted reproductive pallid sturgeon PLS08-008.

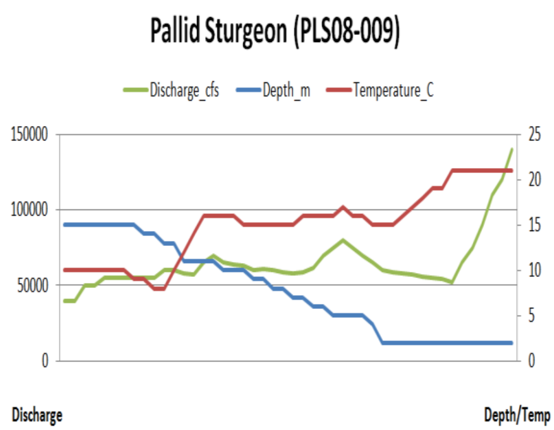

Figure 7. Kansas City, MO, near RM 366, and telemetric data from implanted reproductive pallid sturgeon PLS08-009.

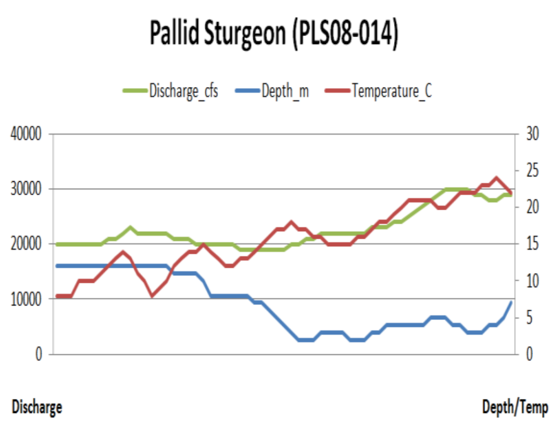

Figure 8. Decatur, NE, near RM 691, and telemetric data from implanted reproductive pallid sturgeon PLS08-014.

Bathymetric Data

Historic bathymetric data were used to illustrate changes in river dynamics. USACE (2008) provided water surface elevation and bed elevation to indicate patterns of aggradation (sediment deposition) and degradation (sediment erosion) from 1975 to 1995. As Figure 9 illustrates, a majority (61%) of the Fort Randall segment is in its aggradation stage and 39% is in the degradation stage.

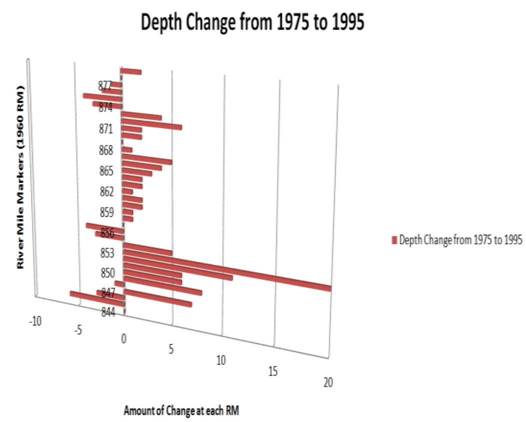

Figure 9. Changes in depth of the Fort Randall 39-mile segment from 1975 to 1995 (calculated from data provided by USACE, 2008). Data to the left of the origin represents river bed degradation and to the right represents river bed aggradation. The x-axis is the depth changes (increments of 5ft) and the y-axis is the river mile locations.

The major peaks shown in Figure 9 indicate areas of aggradation from the Niobrara River tributary and Lewis and Clark Lake Reservoir held by Gavins Point Dam (USACE, 2008).

GIS Data

The GIS analysis depicted ranges available to the pallid sturgeon within the 39-mile segment. The twenty years of historical bathymetry data were very useful in quickly determining if and where potential locations might be found. The result, as depicted in Table 2 and Table 3, illustrates habitat changes from 1941 to 2004 and river habitat availability. The star (*) in Table 3 signifies habitat changes were calculated by two different sets of years. That is, the habitat change for the 59-mile segment was from 1941 and 2004 bar habitats and the habitat change for the 39-mile segment was from 1999 and 2004 bar habitats. The reason for the difference was data availability.

Table 2. GIS data results depicting bank line acreage for MNRR and 1941 and 1999 data. ND = no data available.

MNRR Segments	Bank Waterline (Acre)	Bar Habitat 1941 (Acre)	Bar Habitat 1999 (Acre)
Gavins Point 59-mile	16,656	15,663	ND
Fort Randall 39-mile	42,040	ND	10,630

Table 3. GIS data results depicting 2004 bar habitat, percentage change in habitat and river habitat available.

MNRR Segments	Bar Habitat 2004 (Acre)	*Percent Habitat Change	River Habitat (Acre)
Gavins Point 59-mile	5,963	-61.9	10,693
Fort Randall 39-mile	16,466	54.9	25,573

Figure 10 illustrates river mile segments shallow and deep water habitat locations based on the criteria obtained from telemetric data. Out of 36 river mile locations, only one river depth was between 3 and 8 feet located at RM 853. There were 6 locations greater than or equal to 20 feet (RMs 845, 846, 851, 862, 863, and 878).

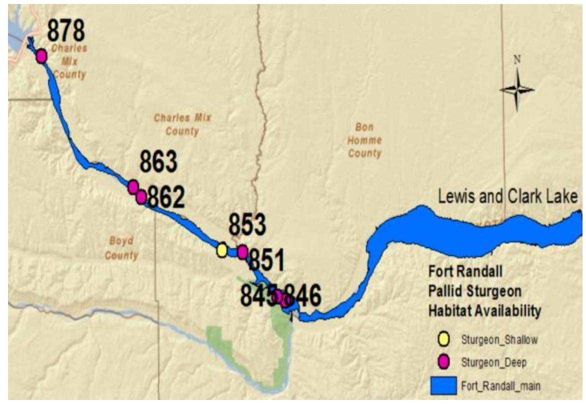

Figure 10. Fort Randall segment illustrating RM locations of potential shallow and deep water pallid sturgeon habitat locations.

Discussion

Because pallid sturgeon are rare and there is no established pallid sturgeon baseline (no numbers to show decline), this GIS pallid sturgeon habitat assessment was challenging. Therefore present telemetric, bathymetric data, and historical data were used to illustrate potential suitable habitat. To gauge potential habitat, it was helpful to understand past available habitat prior to Fort Randall Dam and Gavins Point Dam.

The graphs in Figures 3-8 appear to show a closer inverse relationship of pallid sturgeon depth to temperature change than to discharge rate, with exception to the Gavins Point segment. As the temperature rose above 15 degrees Celsius, the pallid sturgeon showed a migration pattern toward shallower depths and several miles upstream.

Pallid sturgeon preferred depth ranges between 8 feet (minimum) and 49 feet (maximum) depending on the temperature variable. Figures 3-8 illustrate on the right side of the graph (capture post-spawn) the tagged pallid sturgeon spawned in depth ranges between 3 and 15 feet. The Lewis and Clark Lake Reservoir was not included in the bathymetric data, however online research indicated the lake's maximum depth is 45 feet. Because none of the depth in the mainstem Fort Randall segment had depths reaching 44 feet, an alternative search criterion was made for that segment which included: maximum depths greater than 20 feet and between 3 and 15 feet.

The USACE (2008) state the degradation stages are contributing to the continued adjustments of the river channel moving as it moves towards dynamic equilibrium. This continued adjustment impacts habitat availability and is suggested as one reason for the pallid sturgeon decline (Weeks et al., 2005).

Because none of the depth in the mainstem Fort Randall segment had depths reaching 44 feet, an alternative search criterion was made for that segment, which included: maximum depths greater than 20 feet and between 3 and 15 feet.

Possible errors posed limitations in this study including: onscreen digitizing of the Fort Randall and Gavins Point segments which may affect total acreage accuracy; using imagery that may have been taken at peak-flood or low-flow parts of the season which could misrepresent total sandbar habitat and thus alter the river habitat availability; using outdated bathymetry data, but 1995 was the only year available. An improvement in the analysis could have been achieved had a current complete bathymetry data existed, which would have aided in creation of water contours.

Habitat history and current correlations were helpful to predict future impacts to the MNRR segments. Data comparisons and GIS were used to illustrate habitat suitability within the Fort Randall segment of the Missouri River. Some locations based on depth preference were identified. However, one major criterion that (pallid sturgeons select hard substrates) was not analyzed during this study due to lack of data. Some studies conducted by the USFWS and the USACE have suggested the placing of hard substrate mats in the river bottoms aid in sturgeon reproduction.

There are several mines and dump sites in the tributaries leading to the Missouri River and this may contribute to the decline of the pallid sturgeon. Further studies are recommended to analyze water quality and effects that the highly competitive invasive big head carp and silver carp have on the pallid sturgeon in the Lower Missouri River.

Conclusion

River biologists have suggested the pallid sturgeons are impacted by reservoir dams that regulate the Missouri River. It is true dams have impacted sandbar habitat in both Fort Randall Dam and Gavins Point Dam areas. The Fort Randall 39-mile segment has had a 55% increase in sandbar and island habitat and the 59-mile Gavins Point segment has shown a 62% decrease in sandbar and island habitat. Data suggests for the pallid sturgeon habitat, it would have a 55% decrease in water habitat for the 39-mile segment and would have a 62% increase in water habitat in the 59-mile segment. One would think this increase in water habitat would be advantageous. However, the presence of the invasive Asian carp interferes with benthic fish which includes the pallid sturgeon.

Other studies conducted by the USFWS and the USACE suggest the loss of sandbar habitat affects avian species in the area but according to telemetric studies pallid sturgeon select habitat based on availability. Additionally, pallid sturgeons select hard substrate and the loss of sandbars downstream of Gavins Point should not adversely affect them with respect to river habitat. Therefore there is a possibility the reason for the pallid sturgeon's rarity is biological competition or potential river contaminants and not the changes in habitat. It would be interesting to learn if the pallid sturgeon could survive in the Fort Randall segment if they were reared there.

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