Prepared in cooperation with the Missouri River Recovery—Integrated Science Program U.S. Army Corps of Engineers, Yankton, South Dakota

Ecological Requirements for Pallid Sturgeon Reproduction and Recruitment in the Lower Missouri River: Annual Report 2010

Open-File Report 2012–1009

U.S. Department of the Interior
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Cover background photograph. Approaching spring storm on the Lower Missouri River near Boonville, Missouri during spring sampling efforts for pallid sturgeon.

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U.S. Department of the Interior
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KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2012

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Suggested citation:
DeLonay, A.J., Jacobson, R. B., Papoulias, D.M., Wildhaber M.L., Chojnacki, K.A., Pherigo, E.K., Haas, J.D., and Mestl, G.E., 2012, Ecological requirements for pallid sturgeon reproduction and recruitment in the Lower Missouri River: Annual report 2010: U.S. Geological Survey Open-File Report 2012–1009, 51 p.

Contents

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Conversion Factors

Inch/Pound to SI		
Multiply	**By**	**To obtain**
	Length	
mile (mi)	1.609	kilometer (km)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

SI to Inch/Pound		
Multiply	**By**	**To obtain**
	Length	
micrometer (µm)	0.0000397	inch (in.)
millimeter (mm)	0.03937	inch (in.)
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	10.76	square foot (ft^2)
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m^3)	264.2	gallon (gal)
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	1.308	cubic yard (yd^3)
	Flow rate	
meter per second (m/s)	3.281	foot per second (ft/s)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound, avoirdupois (lb)

To communicate effectively with stakeholders, managers, and other scientists working on the Lower Missouri River, this report uses a mix of U.S. customary units and International System of Units (SI) units of measure. Distances along the Missouri River are given in river miles upstream from the junction with the Mississippi River at St. Louis, Missouri, as measured by the U.S. Army Corps of Engineers in 1960. Discharges are provided in the customary units of cubic feet per second. Reach-scale hydraulic variables depth and velocity are in SI units of meters and meters per second.

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88)

Horizontal coordinate information is referenced to the World Geodetic System of 1984 (WGS 84)

Acknowledgments

This report benefitted from technical reviews by Clayton Ridenour and Craig Paukert. Funding for this research was provided by the U.S. Army Corps of Engineers, Missouri River Recovery—Integrated Science Program and the USGS. The authors gratefully acknowledge the collaboration and cooperation in the capture, handling, culture and transport of pallid sturgeon for this study by the U.S. Fish and Wildlife Service, Columbia Fish and Wildlife Conservation Office; U.S. Fish and Wildlife Service, Gavins Point and Neosho National Fish Hatcheries; Nebraska Game and Parks Commission; South Dakota Game, Fish, and Parks; and the Missouri Department of Conservation.

Ecological Requirements for Pallid Sturgeon Reproduction and Recruitment in the Lower Missouri River: Annual Report 2010

By Aaron J. DeLonay[1], Robert B. Jacobson[1], Diana M. Papoulias[1], Mark L. Wildhaber[1], Kimberly A. Chojnacki[1], Emily K. Pherigo[2], Justin D. Haas[3], and Gerald E. Mestl[3]

Abstract

The Comprehensive Sturgeon Research Project is a multiyear, multiagency collaborative research framework developed to provide information to support pallid sturgeon recovery and Missouri River management decisions. The project strategy integrates field and laboratory studies of sturgeon reproductive ecology, early life history, habitat requirements, and physiology. The project scope of work is developed annually with cooperating research partners and in collaboration with the U.S. Army Corps of Engineers, Missouri River Recovery—Integrated Science Program. The research consists of several interdependent and complementary tasks that engage multiple disciplines. The research tasks in the 2010 scope of work primarily address spawning as a probable factor limiting pallid sturgeon survival and recovery, although limited pilot studies also have been initiated to examine the requirements of early life stages. The research is designed to inform management decisions affecting channel re-engineering, flow modification, and pallid sturgeon population augmentation on the Missouri River, and throughout the range of the species. Research and progress made through this project are reported to the U.S. Army Corps of Engineers annually. This annual report details the research effort and progress made by the Comprehensive Sturgeon Research Project during 2010.

Introduction

This report documents research activities under the Comprehensive Sturgeon Research Project (CSRP) for calendar year 2010, January1 through December 31. CSRP is an interagency collaboration of the U.S. Geological Survey (USGS), Nebraska Game and Parks Commission (NGPC), U.S. Fish and Wildlife Service (USFWS), and the U.S. Army Corps of Engineers' (USACE) Missouri River Recovery—Integrated Science Program. The goal of CSRP is to improve the fundamental understanding of the reproductive ecology of the pallid sturgeon (*Scaphirhynchus albus*) to better inform river and species management decisions. Specific objectives include:

- Determine movement, habitat use, and reproductive behavior of pallid sturgeon;
- Understand reproductive physiology of pallid sturgeon and relations to environmental conditions;
- Determine origin, transport, and fate of drifting pallid sturgeon larvae and evaluate bottlenecks for recruitment of early life stages;
- Quantify availability and dynamics of aquatic habitats needed by pallid sturgeon for all life stages; and
- Manage databases, integrate understanding, and publish relevant information into the public domain.

Management actions to increase reproductive success and survival of pallid sturgeon in the Lower Missouri River have been focused on flow regime, channel morphology, and propagation (U.S. Fish and Wildlife Service, 2003). Since 2005, scientists at the U.S. Geological Survey Columbia Environmental Research Center (CERC) have engaged in interdisciplinary sturgeon research initiated at the request of the U.S. Army Corps of Engineers. CSRP was designed to assess how different life stages and essential activities of sturgeon respond to a range of ecological factors. CSRP has evolved over time into an interagency collaboration of the U.S. Geological Survey, Nebraska Game and Parks Commission, U.S. Fish and Wildlife Service, and the U.S. Army Corps of Engineers' Missouri River Recovery—Integrated Science Program with numerous agency and university partners. CSRP research is intended to provide managers with improved understanding of linkages among flow regime, re-engineered channel morphology, and pallid sturgeon movement, habitat use, reproduction and survival.

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CSRP direction has been guided by results of sturgeon research workshops convened in 2004 (Quist and others, 2004) and 2007 (Bergman and others, 2008), by hypotheses that emerged about the role of a naturalized flow regime in pallid sturgeon reproduction during a series of workshops in 2005 (Jacobson and Galat, 2008), and by feedback from an independent science review (Sustainable Ecosystems Institute, 2008). Research objectives also have emphasized science information gaps related to priority management issues, including understanding the role of pulsed flow releases from Gavins Point Dam and Fort Peck Dam (fig. 1), and understanding of the functions of constructed shallow-water habitat in the sturgeon life cycle.

The CSRP research approach integrates opportunistic field studies, field-based experiments, and controlled laboratory studies. The field study plan is designed primarily to explore the role of flow regime and associated environmental cues in sturgeon reproduction and survival. The project uses an upstream-downstream experimental design. The design compares sturgeon reproductive behavior between an upstream section of the Lower Missouri River (fig. 1) with a highly altered flow regime and a downstream section that maintains much of its pre-regulation flow variability (Galat and Lipkin, 2000). The upstream section also has the potential for experimental flow treatments that can be used for more controlled comparisons of reproductive behavior in years with pulsed flow modifications ("spring rises") to years without pulsed flow modifications.

Scope of Work

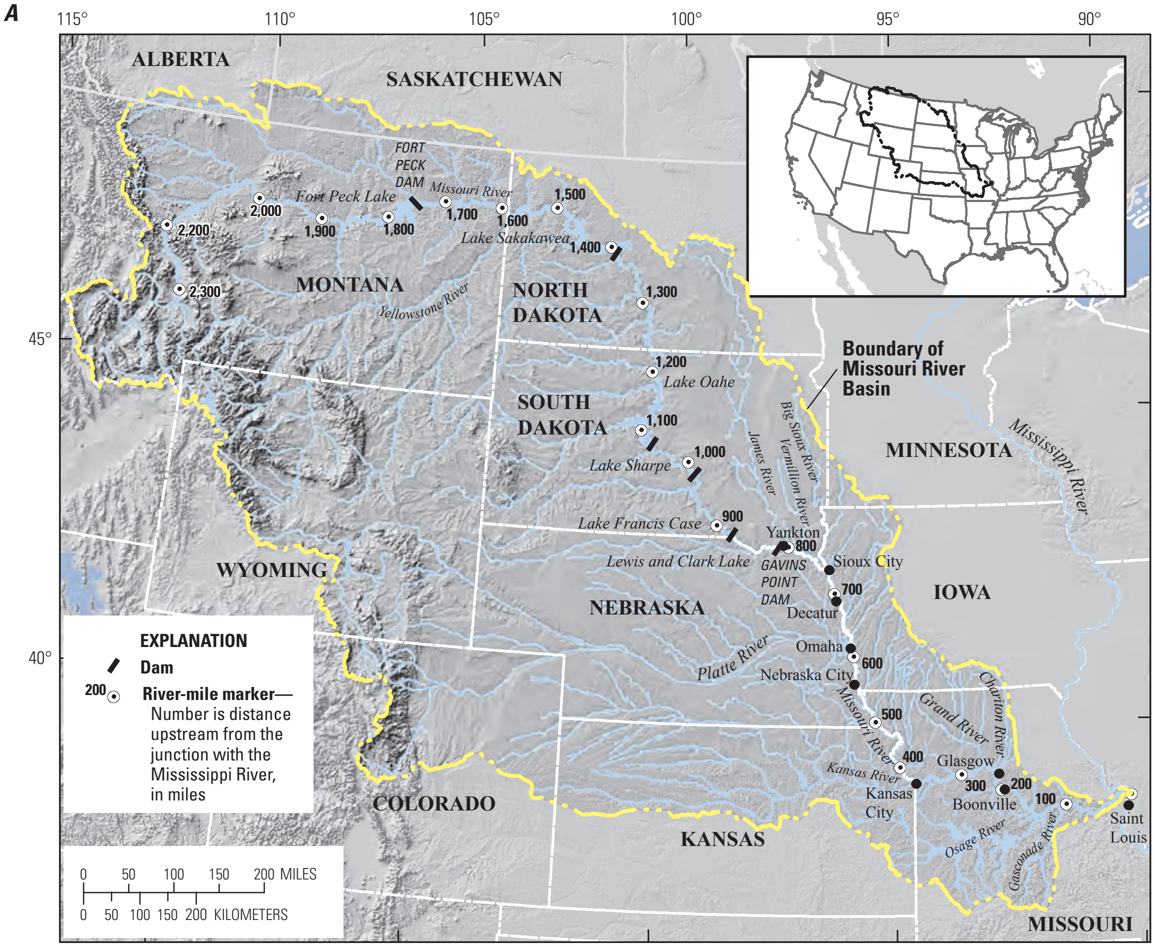
The 2010 CSRP approved scope of work included four interrelated tasks. Division of CSRP research into tasks was for convenience in understanding the relations among scientific efforts and for budgeting internal to the CSRP; the four tasks presented in 2010 were highly interdependent and designed to provide the maximum information for understanding reproductive ecology of the pallid sturgeon. Tasks for 2010 included:

1. In collaboration with Nebraska Game and Parks Commission, we proposed to track over 70 pallid sturgeon in the Lower Missouri River to determine behavior during spawning and nonspawning life stages. In addition, we proposed to do high-frequency intensive tracking on 2 to 8 reproductive pallid sturgeon in each of two river segments during the spawning season, depending on availability of reproductive fish. We proposed to increase emphasis, relative to previous years, on spawning verification through dual-frequency identification sonar (DIDSON®, Sound Metrics, Inc., Lake Forest Park, Wash.) acoustic camera deployment, and larval and egg sampling. The experimental design continues to characterize fish movement in relation to discharge characteristics, temperature, and turbidity and in using upstream and downstream sections of the river for comparison.
2. We proposed to continue coordinated physiological studies on tracked fish to develop critical links between environment (for example, flow pulses, turbidity, and temperature) and reproductive readiness. The nature of these linkages will ultimately indicate the extent to which flow management can affect reproduction of pallid sturgeon. The proposed research included developing understanding of (a) how environmental variability may act as a reproductive cue or as a source of stress that inhibits reproduction, and (b) multiyear processes that may act to set up a fish's reproductive physiology and success.
3. In coordinated habitat studies we proposed to employ a new, high-resolution mapping protocol to assess demonstrated spawning patches as well as other habitats that may be limiting to reproduction and survival of the pallid sturgeon. This research was intended to provide a uniquely detailed understanding of spawning habitat in the river and address how migration pathways may energetically limit pallid sturgeon reproduction.
4. We proposed to continue integrated database management aspects for all tasks, outreach efforts, and report production as critical aspects of the Comprehensive Sturgeon Research Project.

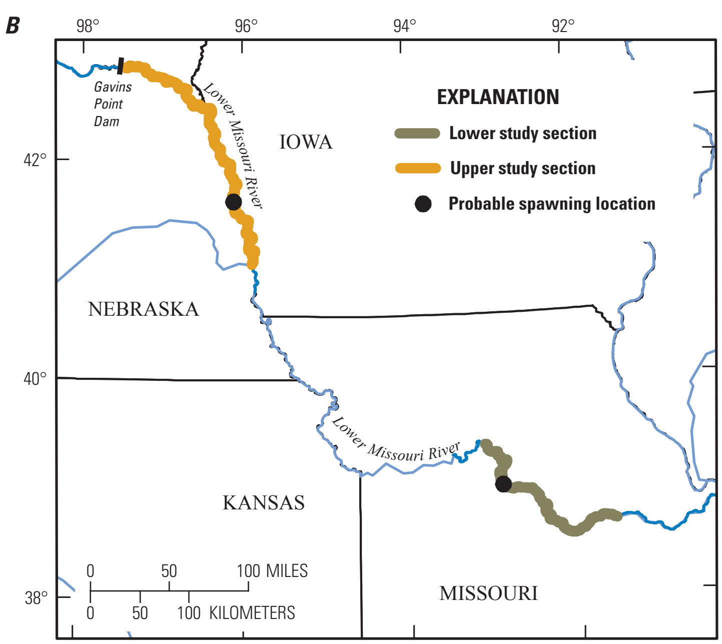
The 2010 scope of work was followed with only minor deviations, as documented in the following sections. The number of reproductive pallid sturgeon available for high-frequency intensive telemetry studies was four reproductive females and five reproductive males. Because of staffing shortages, some tagged, reproductive fish could not be intensively tracked. Opportunities to characterize habitats during spawning and migration were limited to the number of intensively tracked fish. Efforts to capture eggs and larval fish downstream from spawning patches were limited by high water and unsafe boating conditions.

Hydroclimatic Conditions During 2010 Field Work

Runoff during water year 2010 upstream from Gavins Point Dam (October 2009–September 2010) was 142 percent of average. During the March—June sturgeon migration and spawning period, daily mean discharges recorded by USGS streamgages were 127 percent of average at Sioux City, Iowa and 174 percent of average at Boonville, Missouri (Mo.). Discharges continued high through late fall upstream from Nebraska City, Nebraska because of reservoir evacuation (figs. 2, 3). Discharge and temperature data for Lower Missouri River streamgages are from the U.S. Geological Survey



Base data from the National Atlas, 2006
Universal Transverse Mercator projection
Zone 15



Base data from the National Atlas, 2006
Universal Transverse Mercator projection
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Figure 1. Missouri River Basin and major tributary rivers (*A*) with the Comprehensive Sturgeon Research Project study areas and 2010 probable spawning sites (*B*).

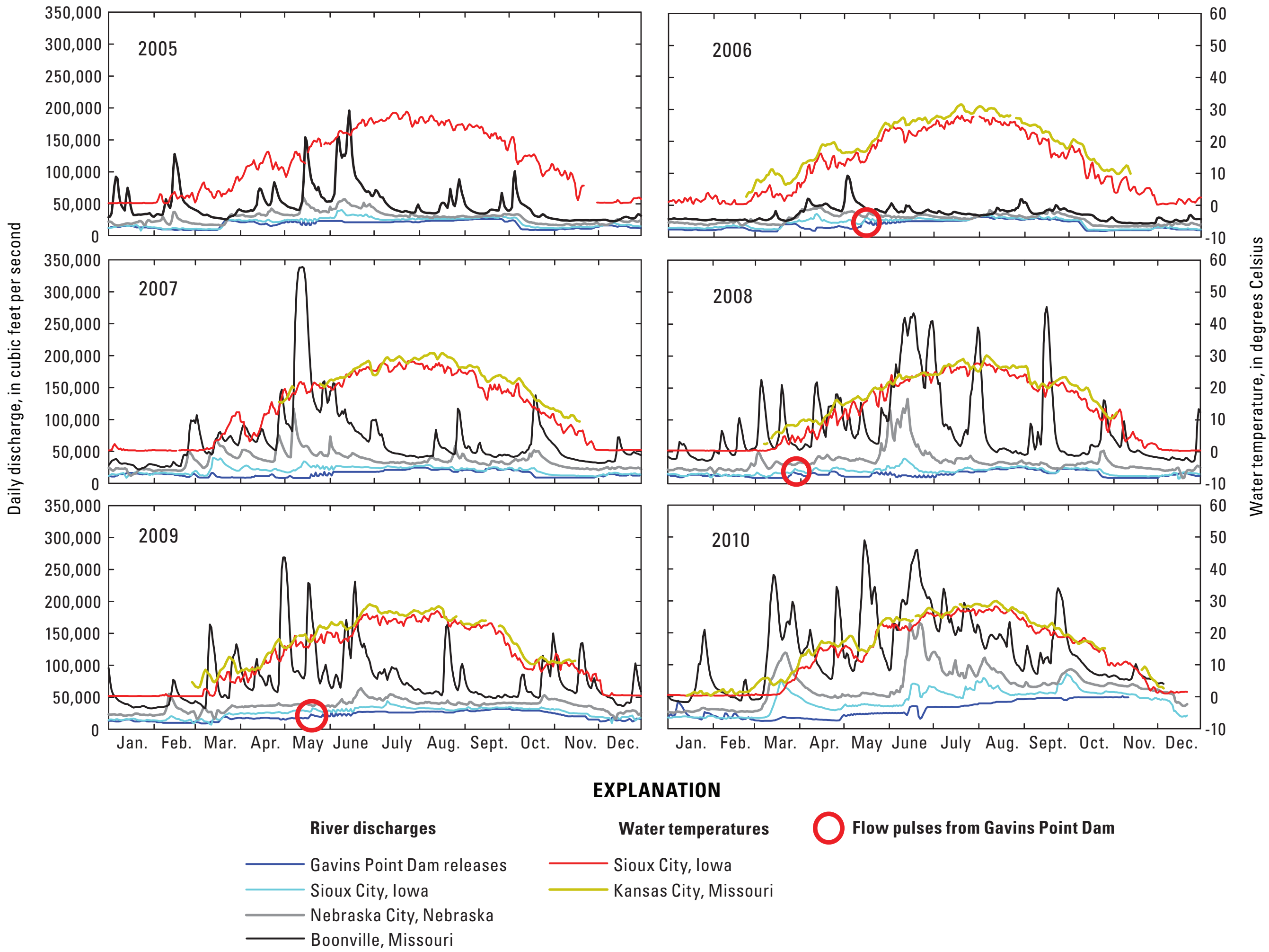


Figure 2. Hydrograph and temperature 2005–2010 for Lower Missouri River. Gavins Point Dam release data are from the U.S. Army Corps of Engineers. Discharge and temperature data at all other locations were recorded by USGS streamgages and data are available from the U.S. Geological Survey National Water Information System (NWIS), at *http://waterdata.usgs.gov/nwis*.

National Water Information System (NWIS), available at *http://waterdata.usgs.gov/nwis*.

Although reservoir levels met technical criteria for pulsed flow release from Gavins Point Dam, neither March nor May flow pulses were executed in 2010 because of excessive downstream flooding. Moreover, temperature criteria [at least 2 days when water temperature exceeds 16°Celsius (°C)] were not met because of a substantial cold snap in mid-May (figs. 2, 3). Substantial non-intentional discharge pulses occurred during 2010 including pulses in mid-March from the Vermillion and Big Sioux rivers that caused a greater than 55,000 cubic feet per second (ft^3/s) pulse in the Missouri River at Sioux City, Iowa (increase from 17,000 ft^3/s to 75,000 ft^3/s; figs. 2, 3). Downstream from the Kansas River, 2010 pulses were high and numerous, including six summer peaks in excess of a 2-year recurrence flood and two peaks at or slightly above a 5-year recurrence flood (figs. 2, 3). A pulse that peaked on March 14 at Boonville, Mo. was 195,000 ft^3/s greater than the 45,000 ft^3/s that preceded the event; a pulse that peaked May 15 at Boonville was 200,000 ft^3/s greater than the 95,000 ft^3/s that preceded the event.

The relations between pulsed flows and water-temperature fluctuations have been of particular interest on the Missouri River because of the hypothesis that discharge and water temperature may contribute to environmental cues involved with spawning (Papoulias and others, 2011; DeLonay and others, 2009; Jacobson and Galat, 2008). In addition, water-temperature decreases of as little as 2°C have been implicated in disrupted sturgeon migration patterns (DeLonay and others, 2009). Discharge and water-temperature conditions during 2010 provided some insight into possible interactions among discharge, weather patterns, and water temperature. March–June discharge and water temperature at a downstream streamgage (Glasgow, Missouri, where discharge and water temperature were recorded in 2010) are inversely related (fig. 4*A*). Pulses of cool runoff from upstream or from tributaries appear to cool the main-stem water temperature during spring months. In contrast, variations in water temperatures in the upper river (shown at Yankton, South Dakota and

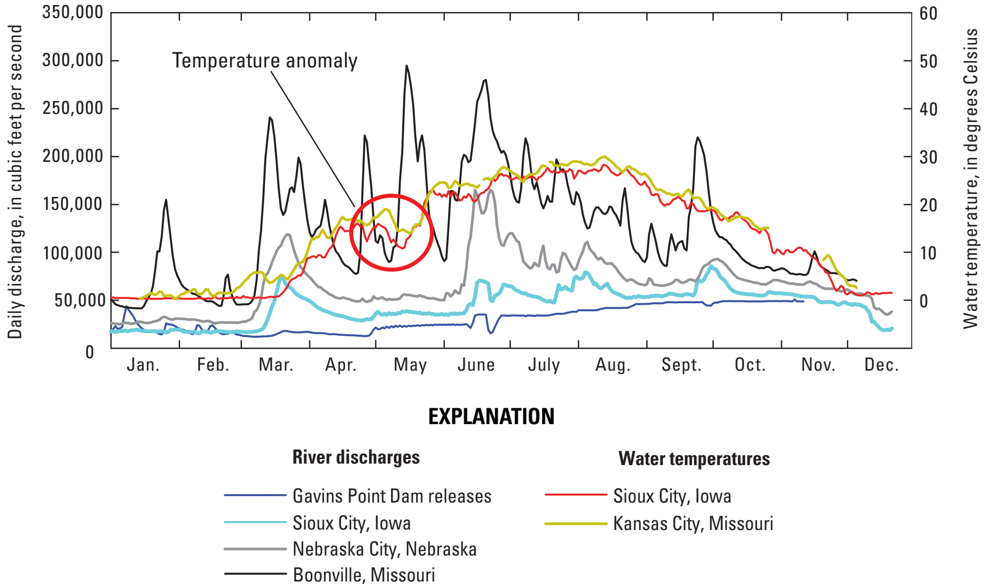


Figure 3. 2010 Lower Missouri River hydrograph with water temperature highlighting temperature anomaly. Gavins Point Dam release data are from the U.S. Army Corps of Engineers. Discharge and temperature data at all other locations were recorded by USGS streamgages and data are available from the U.S. Geological Survey National Water Information System (NWIS), at *http://waterdata.usgs.gov/nwis*.

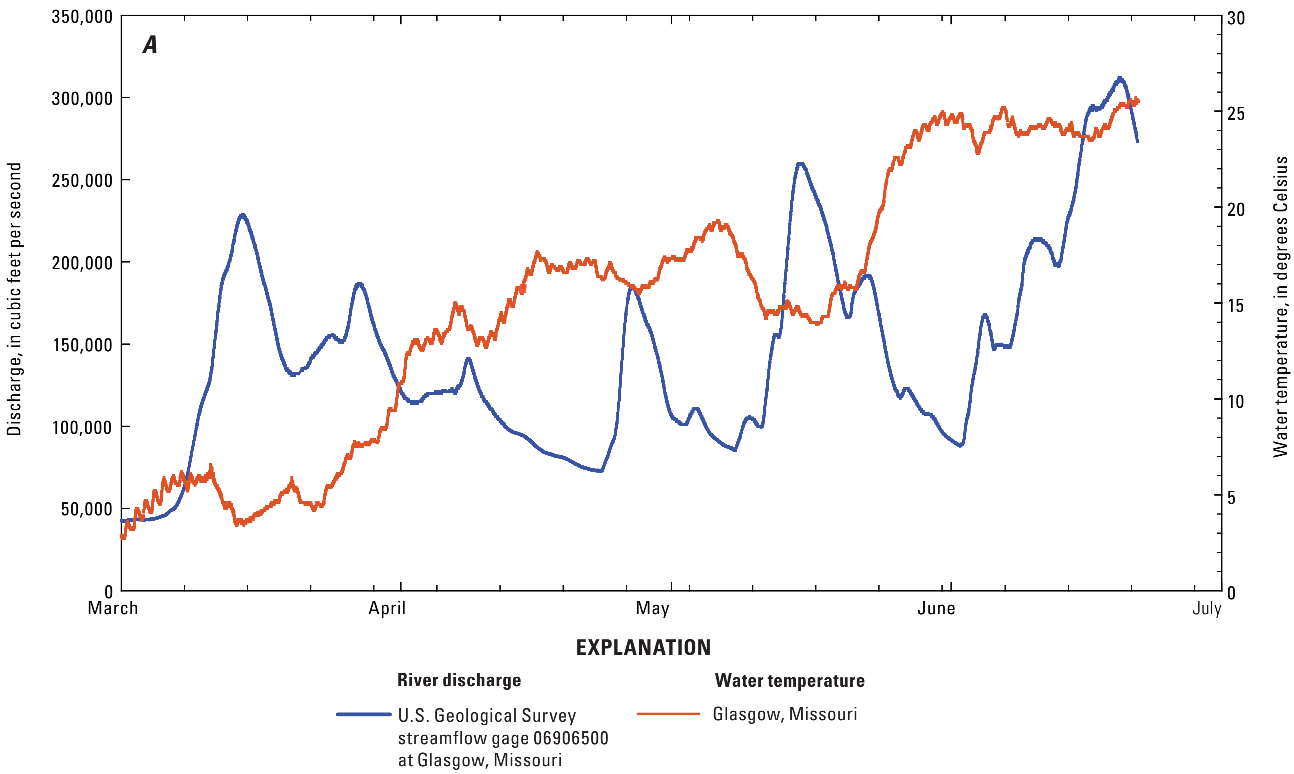
Decatur, Nebraska) did not relate to river discharge (fig. 4*B*). The 4–5°C water temperature drops in mid-May is coincident with a sudden and substantial drop in air temperature. Similar relations recorded during 2009 (DeLonay and others, 2010) indicate that spring water temperatures in the Missouri River between Gavins Point Dam and the Platte or Kansas river, may be sensitive to weather events independent of discharge.

Accomplishments and Products

A CSRP report published in 2009 synthesized 4 years of field and experimental information on sturgeon reproductive ecology (DeLonay and others, 2009). The annual report for the 2009 season provided additional information to support the 2009 synthesis (DeLonay and others, 2010). Converging lines of evidence support the hypothesis that maturation and readiness to spawn in female sturgeon is set up many months before spawning (Papoulias and others, 2011). Moreover, data collected during 2005–2009 indicated that among suspected short-term cues for ovulation—water temperature, water discharge, and day of year—only water temperature had a consistent relation to reproductive indicators and spawning behaviors. This support is based on tracking records, reproductive physiology data, and habitat-use information for hundreds of reproductive shovelnose sturgeon (*Scaphirhynchus platorynchus*), but only nine gravid pallid sturgeon that were tracked 2007–2009. Moreover, it is important to note that field studies were conducted for 5 years with extremely variable hydrology that precluded well-controlled field experiments (fig. 2). Results of reproductive pallid sturgeon tracked in 2010 tend to support the 2005–2009 results, but numbers of fish studied are relatively small, and are unlikely to be considered scientifically definitive. A combination of additional replications of detailed field studies, well-controlled field experiments (for example, pulsed flow modifications from Gavins Point Dam), and focused laboratory studies will provide increased certainty in understanding the environmental factors that support reproduction of pallid sturgeon.

These reports and our 2010 data indicate consistent patterns of upstream spawning migrations in which sturgeon appear to be spawning at many locations and over a period of 1 to 2 months. Movement patterns vary between sexes. Female sturgeon generally move upstream and spawn at the apex of their migration, whereas males choose to migrate upstream to one or several spawning locations, or remain relatively sedentary. Environmental changes such as temperature fluctuations or extreme flow events may slow or disrupt spawning migrations or inhibit spawning. Limited information indicates that patterns of migratory behavior of pallid sturgeon are similar to shovelnose sturgeon. Although information collected for 2010 is consistent with the 2005–2009 data, additional information will allow the time period, spatial extent, and range of environmental conditions associated with successful spawning to be narrowed.

Spawning habitats documented in 2010 were similar to those documented during 2005–2009. The spawning habitat patches documented in the downstream and upstream sections were on the outside of a revetted bend, with deep, relatively fast, and turbulent flow. Both patches were adjacent to a confluence channel, either from a river or from a chute.



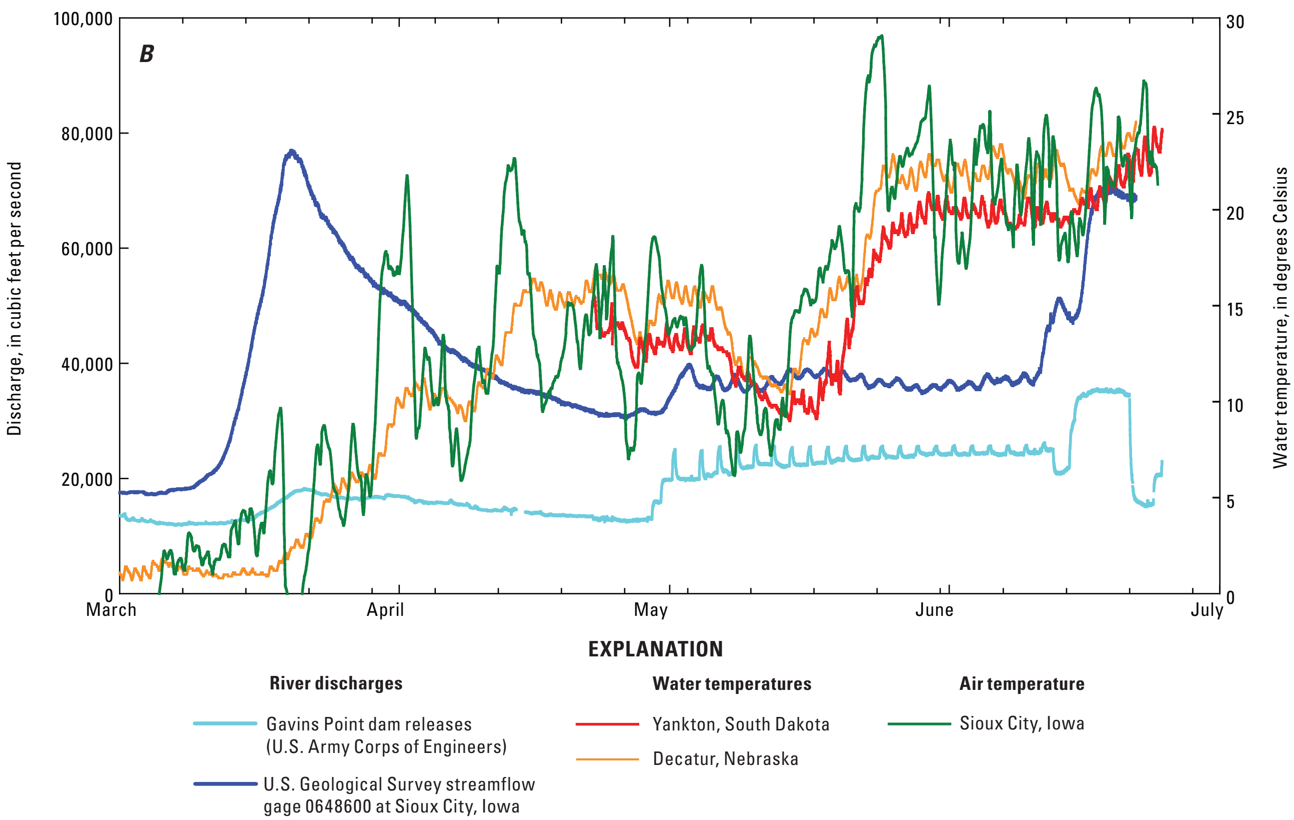


Figure 4. Interactions among discharge, weather patterns, and water temperature in two sections of the Lower Missouri River.

Table 1. Missouri River Sturgeon Project Products, U.S. Geological Survey Columbia Environmental Research Center, 2010.

Publications (alphabetical order by author last name)		
Braaten, P.J., Fuller, D.B., Lott, R.D., Ruggles, M.P., Holm, R.J., 2010.	Spatial distribution of drifting pallid sturgeon larvae in the Missouri River inferred from two net designs and multiple sampling locations.	North American Journal of Fisheries Management 30:1062–1074.
Bryan, J.L., Wildhaber M.L., and Gladish, D.W., 2010	Power to detect trends in Missouri River fish populations within the Habitat Assessment Monitoring Program	U.S. Geological Survey Open File Report 2010–1011, 42 p., *http://pubs.er.usgs.gov/usgspubs/ofr/ofr20101011*.
Bryan, J.L., Wildhaber M.L., Gladish, D.W., Holan, S., and Ellerseick, M., 2010	The power to detect trends in Missouri River fish populations within the Pallid Sturgeon Population Assessment Program	U.S. Geological Survey Open-File Report 2010–1020, 414 p., *http://pubs.usgs.gov/of/2010/1020/*.
Caitlin, D., Jacobson, R.B., Sherfy, M.H., Anteau, M.J., Felio, J., Fraser, J.D., Lott, C., Shaffer, T.L., and Stucker, J., 2010.	Discussion of "Natural hydrograph of the Missouri River near Sioux City and the least tern and piping plover" by Donald Jorgensen	Journal of Hydrologic Engineering, v. 15, no. 12, p. 1076–1078.
Candrl, J., Papoulias, D.M., Tillitt, D.E., 2010	A minimally invasive method for extraction of sturgeon oocytes.	North American Journal of Aquaculture. 72: 184–187.
DeLonay, A.J., 2010	The pallid sturgeon: scientific investigations help understand recovery needs	U.S. Geological Survey Fact Sheet 2010–3024, 4 p., *http://pubs.usgs.gov/fs/2010/3024*.
DeLonay, A., Jacobson, R., Papoulias, D., Wildhaber, M., Chojnacki, K.A., Pherigo, E.K., Bergthold, C.L., and Mestl, G.E., 2010	Ecological requirements for pallid sturgeon reproduction and recruitment in the Lower Missouri River: Annual Report 2009.	U.S. Geological Survey Open File Report 2010–1215, 64 p., *http://pubs.er.usgs.gov/publication/ofr20101215*.
Jacobson, R.B., 2010	River-corridor habitat dynamics	U.S. Geological Survey Fact Sheet 2010–3022, 2 p., *http://pubs.usgs.gov/fs/2010/3022*.
Jacobson, R.B., Elliott, C.M., and Huhmann, B.L., 2010.	Development of a channel classification to evaluate potential for cottonwood restoration, lower segments of the Middle Missouri River, South Dakota and Nebraska	U.S. Geological Survey Scientific Investigations Report 2010–5208, 38 p. *http://pubs.usgs.gov/sir/2010/5208/*.
Wildhaber, M.L., 2010	Modeling climate change and sturgeon populations in the Missouri River	U.S. Geological Survey Fact Sheet 2010–3019, 2 p., *http://pubs.usgs.gov/fs/2010/3019*.
Presentations (ordered by date with oldest first)		
DeLonay, A.J., Papoulias, D.M., Wildhaber, M.L., Jacobson, R.B., Chojnacki, K.A., Mestl, G.E., and Bergthold, C.L.	Comprehensive sturgeon research program: spawning, habitat use, and behavior of pallid sturgeon in the Lower Missouri River – update	January 26–27, 2010, Middle Basin Pallid Sturgeon Workgroup Meeting, Blue Springs, Missouri.
DeLonay, A.J., Braaten, P.J., Papoulias, D.M., Wildhaber, M.L., Jacobson, R.B., and Mestl, G.E.	Risk and uncertainty in recovery science for rare species in highly altered systems: Understanding the biology and ecology of the pallid sturgeon	February 3–5, 2010, Missouri Natural Resources Conference, Osage Beach, Missouri.
Bryan, J.L. and Wildhaber, M.L.	Use of ultrasound and endoscopic techniques in culture of sturgeon and madtoms	February 8–10, 2010, Midcontinent Warm Water Fish Culture Workshop, Independence, Missouri.
Ruskamp, R.L., Bergthold, C.L., Chojnacki, K.A., Mestl, G.E., and DeLonay, A.J.	Seasonal movements and habitat use of adult pallid sturgeon in the Lower Missouri River, USA.	February 20, 2010, Nebraska Chapter, American Fisheries Society, Ponca State Park, Ponca, Nebraska.
Papoulias, D.M.	Widespread occurrence of intersex in fishes.	March 16, 2010, Upper Mississippi River Conference, Dubuque, Iowa.
Bazzetta, L.A., Jacobson, R.B., Braaten, P.J., Elliott, C.M.	Linking river morphology to larval drift of an endangered sturgeon	March 16–19, 2010, 2010 MRNRC/BIOP meeting, Nebraska City, Nebraska.

Table 1. Missouri River Sturgeon Project Products, U.S. Geological Survey Columbia Environmental Research Center, 2010.—Continued

Presentations (ordered by date with oldest first)—Continued		
Braaten, P., Fuller, D., Lott, R., Wilson, R., Haddix, T., Jaeger, M., Holte, L., Bartron, M., Kalie, J., DeHaan, P., Ardren, W.	Recaptures and growth of pallid sturgeon early life stages in the upper Missouri River, Montana and North Dakota	March 16–19, 2010, 2010 MRNRC/BIOP meeting, Nebraska City, Nebraska.
Chojnacki, K.A., Vishy,C.J., Pherigo, E.K., and DeLonay, A.J.	Generating information from large volumes of data: Development of a sturgeon information management system (SIMS)	March 16-19, 2010, 2010 MRNRC/BIOP meeting, Nebraska City, Nebraska.
DeLonay, A.J., Jacobson, R.B., Papoulias, D.M., Wildhaber, M.L., Chojnacki, K.A., Bergthold, C.L., and Mestl, G.E.	Ecological requirements for pallid sturgeon (*Scaphirhynchus albus*) reproduction and recruitment in the Lower Missouri River	March 16–19, 2010, 2010 MRNRC/BIOP meeting, Nebraska City, Nebraska.
Haas, J.D., Mestl, G.E., Bergthold, C.L., Chojnacki, K.A., DeLonay, A.J., Bryan, J.L., Wildhaber, M.L., Bonnot, T.W., and Millspaugh, J.J.	Resource selection by adult pallid sturgeon, *Scaphirhynchus albus*, in the channelized Missouri River, USA with implications for current and planned habitat creation projects	March 16–19, 2010, 2010 MRNRC/BIOP meeting, Nebraska City, Nebraska.
Jacobson, R.B., Janke, T.P., Skold, J.	Hydrologic and geomorphic considerations in restoration of river-floodplain connectivity, Lower Missouri River	March 16–19, 2010, 2010 MRNRC/BIOP meeting, Nebraska City, Nebraska.
Papoulias, D.M., DeLonay, A.J., Annis, M.L., Nye, N., Doyle, W.J., Hill, T.D., Labay, S.	Geographic differences in reproductive synchrony of *Scaphirhynchus*: An interpretation of the data relative to genetics, cues, and reproductive behavior.	March 16–19, 2010, 2010 MRNRC/BIOP meeting, Nebraska City, Nebraska (invited).
Braaten, P.J., Fuller, D.B., Lott, R.D., and Ruggles, M.P.	Drift dynamics of larval pallid sturgeon in the mainstem Missouri River: inferences for lack of recruitment in fragmented river reaches.	May 30–June 3, 2010, 34th Annual Larval Fish Conference, Santa Fe, New Mexico.
Fuller, D.B., Lott, R.D., and Braaten, P.J.	Larval paddlefish and shovelnose sturgeon in the upper Missouri River basin including the flow-regulated Missouri River below Fort Peck Dam, Milk River, and Yellowstone River.	May 30–June 3, 2010, 34th Annual Larval Fish Conference, Santa Fe, New Mexico.
Papoulias, D.M., Tillitt, D.E., Annis, M.L., Nicks, D.K., and Schwarz, M.	Laboratory evaluation of effects of early life-stage exposure to selenium on pallid sturgeon (*Scaphirhynchus albus*) and shovelnose sturgeon (*Scaphirhynchus platorynchus*)	May 30–June 3, 2010, 34th Annual Larval Fish Conference, Santa Fe, New Mexico.
Anderson, C.J., Wildhaber, M.L., Wikle, C.K., Franz, K.J., and Holan, S.H.	Downscaling from global climate models to regional climate models for use in multi-scale modeling of riverine ecosystems and responses of fish populations	June 7–11, 2010, 3rd USGS Modeling Conference, Denver, Colorado.
Franz, K.J., Wildhaber, M.L., Wikle, C.K., Anderson, C.J., and Holan, S.H.	Downscaling from regional climate models to river hydrodynamics for use in multi-scale modeling of riverine ecosystems and responses of fish populations	June 7–11, 2010, 3rd USGS Modeling Conference, Denver, Colorado.
Holan, S.H., Wildhaber, M.L., Wikle, C.K., Anderson, C.J., and Franz, K.J.	Bayesian mark-recapture models for fish survival and population estimation for use in multi-scale modeling of riverine ecosystems and responses of fish populations	June 7–11, 2010, 3rd USGS Modeling Conference Denver, Colorado.
Wikle, C.K., Wildhaber, M.L., Anderson, C.J., Franz, K.J., and Holan, S.H.	A hierachical approach to quantify uncertainty in multi-scale modeling of riverine ecosystems and responses of fish populations	June 7–11, 2010, 3rd USGS Modeling Conference, Denver, Colorado.
Wildhaber, M.L., Wikle, C.K., Anderson, C.J., Franz, K.J., and Holan, S.H.	Multi-scale modeling of riverine ecosystems and responses of fish populations in the context of global climate change and predictive uncertainty: introduction and overview	June 7–11, 2010, 3rd USGS Modeling Conference, Denver, Colorado.

Table 1. Missouri River Sturgeon Project Products, U.S. Geological Survey Columbia Environmental Research Center, 2010.—Continued

Presentations (ordered by date with oldest first)—Continued		
Wildhaber, M.L., Wikle, C.K., Anderson, C.J., Franz, K.J., and Holan, S.H.	Translating river hydrodynamics in to fish population responses for use in multi-scale modeling of riverine ecosystems	June 7–11, 2010, 3rd USGS Modeling Conference, Denver, Colorado.
DeLonay, A.J., Jacobson, R.B., Papoulias, D.M., Braaten, P.J., Wildhaber, M.L., Chojnacki, K.A., and Mestl, G.E.	Comprehensive sturgeon research program: Update to U.S. Army Corps of Engineers Integrated Science Program	July 7, 2010, USGS Webinar, Columbia Environmental Research Center, Columbia, Missouri.
Chojnacki, K.A. and DeLonay, A.J.	Mobile mapping of fish movements in the Lower Missouri River	July 12–16, 2010, ESRI International Users Conference, San Diego, California.
Arab, A., Holan, S.H., Wildhaber, M.L. and Wikle, C.K.	A hierarchical Bayesian model for environmental correlated count processes with application to fisheries habitat management	July 31– August 5, 2010, Joint Statistical Meeting, Vancouver, British Columbia, Canada.
Jacobson, R.B.	Re-engineering the Missouri River for ecosystem recovery	August 6, 2010, Watershed Committee of the Ozarks, Springfield, Missouri.
Braaten, P.J., Lott, R.D., and Fuller, D.B.	Factors influencing recruitment of shovelnose sturgeon in the upper Missouri River basin.	September 12–16, 2010, American Fisheries Society 140th annual meeting, Pittsburgh, Pennsylvania.
DeLonay, A.J., Jacobson, R.B., Papoulias, D.M., Wildhaber, M.L., Chojnacki, K.A., Haas, J.D., and Mestl, G.E.	Progress in understanding pallid sturgeon reproductive and recruitment in the Lower Missouri River	September 20–24, 2010, Third International Symposium on Ecology and Biodiversity in Large Rivers of Northeast Asia and North America, Memphis, Tennessee.
McElroy, B.J., Jacobson, R.B., DeLonay, A.J., Vishy, C.J., Elliot, C.M., Thorsby, R., Chojnacki, K.A., and Reuter, J.M.	Multi-scale hydroacoustic remote sensing of endangered pallid sturgeon and their habitats in the Lower Missouri River	September 20–24, 2010, Third International Symposium on Ecology and Biodiversity in Large Rivers of Northeast Asia and North America, Memphis, Tennessee.
DeLonay, A.J., Jacobson, R.J., Papoulias, D.M., Wildhaber, M.L., Chojnacki, K.A., Haas, J.D, Mestl, G.E.	Progress in understanding pallid sturgeon reproduction in the Lower Missouri River	September 27–30, 2010, Pallid Sturgeon Recovery Team Meeting, Alton, Illinois.
Jacobson, R.B.	Geologic, hydrologic, and geomorphic processes and the restoration of large-river ecosystems	October 26–29, 2010, 37th Natural Areas Conference, Osage Beach, Missouri.
Jacobson, R.B.	Hydrogeomorphology and riverine habitat dynamics	October 31–November 3, 2010, Geological Society of America Annual Meeting, Denver, Colorado.
Haas, J.D., Adams, J.D., Bergthold, C.L., Chojnacki, K.A., DeLonay, A.J., and Mestl, G.E.	Use distribution of adult pallid sturgeon, *Scaphirhynchus albus*, in the Missouri River below Gavins Point Dam	December 12–15, 2010, 71st Midwest Fish and Wildlife Conference, Minneapolis, Minnesota.
Posters (ordered by date with oldest first)		
Adams, J.D., Ruskamp, R.L., Bergthold, C.L., Chojnacki, K.A., DeLonay, A.J., and Mestl, G.E.	Use distribution of adult pallid sturgeon, *Scaphirhynchus albus,* in the Missouri River below Gavins Point Dam	March 16–19, 2010, Missouri River Natural Resources Conference and BiOP Forum, Nebraska City, Nebraska.
McElroy, B., Elliott, C., Thorsby, M., and Jacobson, R.	Morphodynamic progress towards restoration of shallow water habitats in minimally engineered side-channel chutes of the Lower Missouri River: Jameson Island and North Overton Bottoms	March 16–19, 2010, Missouri River Natural Resources Conference and BiOP Forum, Nebraska City, Nebraska.
George, A.E. and Simpkins, D.G.	Spatiotemporal variation in diversity and density of larval fish in the Missouri National Recreational River, Nebraska and South Dakota.	May 30–June 3, 2010, 34th Annual Larval Fish Conference, Santa Fe, New Mexico.
Chojnacki, K.A., Vishy, C.J., Pherigo, E.K., and DeLonay, A.J.	Generating information from large volumes of data: Development of a sturgeon information management system (SIMS)	September 12–16, 2010, American Fisheries Society 140th annual meeting, Pittsburgh, Pennsylvania.

Table 1. Missouri River Sturgeon Project Products, U.S. Geological Survey Columbia Environmental Research Center, 2010. —Continued

Posters (ordered by date with oldest first)—Continued		
DeLonay, A.J., Jacobson, R.J., Papoulias, D.M., Wildhaber, M.L., Chojnacki, K.A., Bergthold, CL., Mestl, G.E.	Ecological requirements for pallid sturgeon reproduction and recruitment in the Lower Missouri River	September 12–16, 2010, American Fisheries Society 140th annual meeting, Pittsburgh, Pennsylvania.
Jacobson, R.B., Janke, T.P., Skold, J., and Chojnacki, K.A.	Hydrologic and geomorphic considerations in restoration of river-floodplain connectivity, Lower Missouri River	September 20–24, 2010, Third International Symposium on Ecology and Biodiversity in Large Rivers of Northeast Asia and North America, Memphis, Tennessee.
Chojnacki, K.A., Vishy, C.J., Pherigo, E.K., and DeLonay, A.J.	Development of a sturgeon information management system (SIMS) to support science for the recovery and management of an endangered large river species	September 20–24, 2010, Third International Symposium on Ecology and Biodiversity in Large Rivers of Northeast Asia and North America, Memphis, Tennessee.
Jacobson, R.B., Janke, T., Skold, J., and Chojnacki, K.A.	Hydrologic and geomorphic considerations in restoration of river-floodplain connectivity, Lower Missouri River	September 20–24, 2010, Third International Symposium on Ecology and Biodiversity in Large Rivers of Northeast Asia and North America, Memphis, Tennessee.
News (ordered by date with oldest first)		
Helming, J., Pherigo, E.K., and Welly, R.J.	Team busy tagging sturgeon at hatchery	August 4, 2010, Neosho Daily News *http://www.neoshodailynews.com/news/x1137372188/Team-busy-tagging-sturgeon-at-hatchery.*
DeLonay, A.J., Papoulias, D.P., Tillitt, D., Welly, R., Davenport, S.A.	Columbia researchers study intersex sturgeon in Missouri River	December 6, 2010, Columbia Missourian Newspaper *http://www.columbiamissourian.com/stories/2010/12/06/columbia-researchers-find-intersex-sturgeon-missouri-river/.*
Special Events (ordered by date with oldest first)		
Chojnacki, K.A., McLeod, R.H., and Pherigo, E.K.	USGS research on the Missouri River – a comprehensive display of research being conducted by the USGS on the Missouri River	March 16–19, 2010, Missouri River Natural Resources Conference and BiOP Forum, Nebraska City, Nebraska.
Pherigo, E.K.	USGS - CERC research on the Missouri River Display	April 24, 2010, Missouri River Festival, Washington, Missouri.
Bryan, J.L.	Ultrasound techniques to determine gender and reproductive stage in *Scaphirhynchus* sturgeon	April 28, 2010, Personalized instruction to Mark Matsche, Fish Health Biologist from the Maryland DNR provided at USGS CERC, Columbia, Missouri.
Jacobson, R.B.	Introduction to the River Studies Branch at USGS–CERC	July 19, 2010, International Association of Astacology (IAA) 18th Symposium tour of USGS-CERC, Columbia, Missouri.

If revetted outside bends are confirmed as habitats conducive to successful spawning, it would follow that spawning substrate is not a limiting factor in pallid sturgeon reproduction in the Lower Missouri River. Habitat studies in 2010 also characterized conditions during upstream fish migration. In contrast to spawning sturgeon, these data support the hypothesis that migrating sturgeon use lower velocity habitats on inside bends, presumably to minimize energy expenditure (Reuter and others, 2009). Calculations confirm that the fish use the minimum energy-expenditure path available to them. Increased energy expenditure during upstream migration may reduce a fish's reproductive capacity. Additional coordinated tracking, habitat assessments, and physiological studies would increase our understanding of how changes in flow regime or channel re-engineering of the Lower Missouri River could serve to increase low-energy migration pathways and increase reproductive success.

During 2010, project scientists published 10 articles and reports, and provided 40 presentations at regional, national, and international scientific meetings. Project scientists also provided input into Missouri River science discussions at the request of the U.S. Army Corps of Engineers, other Federal and State agencies, and stakeholders. Products delivered or published during 2010 are in table 1.

Future Research Into Reproductive Ecology of Missouri River Pallid Sturgeon

During 2010, the CSRP was successful in adding replicates and greater detail to existing understanding of pallid sturgeon reproductive ecology, especially related to spawning behavior and spawning habitat. Information on environmental conditions, migrations, and reproductive physiology added additional data points to our understanding of reproductive cues and the potential role of pulsed flow modifications to enhance reproductive success. Whereas 2010 supported the growing set of information on links between potential management actions and prospects for reproduction and survival of the species, additional information gaps have become more apparent. These information gaps could be addressed by:

- Replicating controlled and opportunistic field experiments on spawning cues to achieve credibility within the scientific community. Credibility probably will require several additional years of field studies at the current (2011) level of effort (4–8 reproductive pallid sturgeon per year) assuming good representation of years with and without flow pulses. Alternatively, fewer years would be necessary with greater numbers of tagged fish and the resources to track them. Coordinated physiological and habitat studies are needed to understand the causal links between environmental conditions and reproductive success.

- Increasing efforts in addressing spawning success criteria. In addition to demonstrating that eggs have been released, indicators of spawning success are a presence of males, observations of fish interactions, observations or sampling of fertile eggs, sampling of larvae downstream from demonstrated spawning patches, and sampling of larvae of a developmental stage consistent with the observed spawning event or linked by genetic analysis.

- Understanding where pallid sturgeon go and what habitats they use between reproductive seasons. Pallid sturgeon females become reproductive once every 2–5 years, and environmental conditions—food availability, water temperature, physical habitat quality and quantity, biotic interactions—between spawning events may be critical to spawning success (Wildhaber and others, 2011a). Understanding the role of nonspawning years will require additional year-round tracking and may require expansion of telemetry efforts into the Mississippi River. Such efforts also will help define the extent of habitat used by these fish and may provide insight into genetic structure of the population.

- Understanding the roles of intersex and reproductive tumors (DeLonay and others, 2009) in pallid sturgeon to determine whether contaminants in the environment contribute to lack of reproduction or recruitment, in whole or in part.

- Quantifying habitat selection during nonreproductive seasons and for juvenile fish to determine if various habitats (for example, migration, over-wintering, or young-of-the-year feeding habitats) may be bottlenecks to reproduction and recruitment. This can be approached through a combination of detailed field studies and controlled laboratory experiments on young fish.

- Understanding transport and fate of pallid sturgeon larvae to determine if they successfully drift into supportive habitats. Previously presented calculations have indicated that mean velocities in the Lower Missouri River are sufficient to transport larvae hatched over much of its length into the Middle Mississippi River (DeLonay and others, 2009). Improved understanding of drift dynamics will document whether channel re-engineering that decreases mean velocity and increases drift retention would be effective in increasing recruitment.

Detailed Research Task Activities and Progress

Task 1. Movement, Habitat Use, and Reproductive Behavior of Shovelnose Sturgeon and Pallid Sturgeon in the Lower Missouri River

Background

Adult pallid sturgeon in reproductive condition are rare on the Lower Missouri River and evidence of successful reproduction and survival of young suggest that any reproduction that may be occurring is insufficient to sustain a viable population (U.S. Fish and Wildlife Service, 2007). Although harvest and habitat fragmentation by reservoirs may limit pallid sturgeon populations in parts of its range, limited numbers of adults and poor reproduction have been recognized among the greatest threats to pallid sturgeon in the Lower Missouri River. Management agencies consistently have identified the need to (1) characterize and quantify spawning habitats; (2) develop a better understanding of environmental factors that affect maturation and spawning movements, including homing; and (3) quantify spawning success and failure based on collections of eggs, larvae and young-of-year, and relate reproductive success to environmental conditions as priority information necessary to recover the species (U.S. Fish and Wildlife Service, 2007; Bergman and others, 2008). Many studies have examined habitat use and movement by adult *Scaphirhynchus* sturgeon (Hurley and others, 1987; Latka and others, 1995; Quist and others, 1999; DeLonay and others, 2000; Bramblett and White, 2001; Snook and Peters, 2002; Hurley and others, 2004; Garvey and others, 2009). Few studies have attempted to study reproductive migrations, characterize spawning behavior and habitat, assess spawning success, or examine long-term reproductive cycles or patterns of habitat use by pallid sturgeon. Before this study, none have precisely documented where pallid sturgeon spawn or provided information necessary to link pallid sturgeon migration, spawning, or reproductive success to large river management. Until recently (2004) none have specifically focused on reproductively mature fish before and during the spawning season.

During 2004–2009, CSRP employed telemetry to relocate individual sturgeon for long periods to collect information on movement, habitat use, behavior, and response to environmental cues or habitat manipulations (DeLonay and others, 2007b; DeLonay and others, 2009). Previous experience with telemetry provided opportunities to recollect, reassess, and re-implant individual sturgeon to monitor changes in growth, condition, and reproductive status through multiple years. This information is not available using traditional fisheries sampling techniques, especially in large systems where all habitats cannot be sampled or sampled throughout all time periods. Telemetry data provides a means for defining characteristic migration patterns of reproductive fish and identifying spawning locations (DeLonay and others, 2009). Deployment of environmental data collection tags in telemetered fish provides unprecedented direct and quantitative understanding of a fish's environment (DeLonay and others 2007a; Holan and others 2009). CSRP has used telemetry as part of a unique multidisciplinary approach in which telemetry is coordinated with physiological assessments of reproductive behavior (Task 2) and hydroacoustic habitat assessments (Task 3) (DeLonay and others, 2007b; DeLonay and others, 2009; Papoulias and others, 2011). The physiologic context provides an understanding of the reproductive state of a tagged fish, and thereby provides interpretation of why the fish behaves as it does (Wildhaber and others, 2007). Similarly, detailed habitat mapping around tagged fish places the behavior of individuals within a larger spatial context that allows researchers to characterize habitat availability and selection, and thereby understand how channel morphology and flow regime can be managed to maximize reproduction and survival (Reuter and others, 2008; DeLonay and others, 2009; Jacobson and others, 2009; Reuter and others, 2009; Bonnot and others, 2011).

CSRP has emphasized tagging male and female sturgeon in reproductive condition in order to focus on spawning cues, behaviors, and habitat. Although CSRP has gained useful information from shovelnose and pallid sturgeon, tagging for the last 3 years has emphasized pallid sturgeon. Generally, fish have been captured in the spring, assessed for reproductive condition, and if reproductive, they have been implanted and tracked throughout the spring and summer. After a spawning migration or at the end of the season, the fish are targeted for recapture to extract data storage tags (DST) and re-implant with long-lived telemetry tags. For the last 4 years the approach has resulted in an at-large population of about 80 adult, male and female pallid sturgeon at various reproductive stages. This at-large population is an investment with the potential to yield an important understanding of pallid sturgeon reproductive cycles.

Scope and Objectives

This task is a continuation of work initiated in 2005 in collaboration with NGPC. The objectives of this work are to (1) identify pre-spawning habitat; (2) determine the direction and magnitude of spawning movements, (3) characterize patterns of habitat use during spawning migrations, (4) determine where and under what conditions sturgeon spawn, (5) verify and validate spawning behavior, (6) assess the relative success of spawning related to status and environmental conditions, including natural and augmented spring flows, and (7) determine and characterize post-spawn and nonreproductive habitat.

Methods

Task 1 focused exclusively on pallid sturgeon in 2010. The work was again conducted within two geographically and hydrologically distinct reaches of the Lower Missouri River to take advantage of the longitudinal variability in the system for comparative purposes. The lower, downstream section is located on the Lower Missouri River between the Osage River and Grand River (river miles 130–250, fig. 1). The upstream section is located between the Platte River in Nebraska and the Big Sioux River (river miles 595–734). The general approach entailed capturing pallid sturgeon from the Missouri River, intensively evaluating the reproductive status of individuals, implanting each with transmitters and data storage tags (DST), tracking their movements, and characterizing habitat use through migration and spawning (DeLonay and others, 2007b). Tagged pallid sturgeon were tracked to their spawning locations and recaptured as soon as possible after spawning to evaluate their reproductive success and recover the implanted DST. The assessment of reproductive status and spawning success is coordinated with Task 2.

In 2010, USGS and NGPC planned to implant and track female and male pallid sturgeon meeting established implantation criteria (appropriate size and reproductive status) in each of the two study sections with 2-year acoustic transmitters and DSTs recording depth and temperature at 30-minute intervals. At least one, but no more than four gravid females were targeted for implantation within each study section. At least one, but no more than three ripe males also were targeted for implantation within each study section. Throughout the study concerted efforts were made to re-collect, re-evaluate, and re-implant pallid sturgeon tagged in previous years. Sturgeon collected by other agencies for use as broodstock in the pallid sturgeon hatchery propagation program also were implanted opportunistically with transmitters before release back into the

Missouri River near the site of capture. The long-term goal of the study is to retain more than 80 adult sturgeon with active transmitters and with known reproductive histories for long-term analyses of patterns of migration, spawning site selection and fidelity, and reproductive frequency and success.

Following implantation, USGS and NGPC crews located and tracked individual telemetered fish to record habitat use and seasonal movements (DeLonay and others, 2007b). Fish were tracked extensively (located every few days) during pre- and post-spawn periods. Fish in reproductive condition were tracked intensively (located daily or several times daily) from April through June, or until re-collection indicated that spawning was complete. Sturgeon in reproductive condition were prioritized for tracking to better allocate crew resources and to increase the likelihood of documenting spawning events. Gravid females were given priority over males, and migrating gravid females with low polarity indices (PI) were given the highest priority. The goal for reproductive female pallid sturgeon was to determine their location daily in early spring and more frequently when water temperatures reach 16°C or when the movement or behavior of the females indicated that spawning was imminent. During high-frequency intensive tracking, sturgeon are located several times daily to determine direction and rate of movement. Migrating females that pause or stop for more than 6 hours are targeted for continuous monitoring and habitat characterization. Continuous tracking of rapidly migrating sturgeon is not possible during hours of darkness in the lower study section because of safety concerns, but continuous tracking of stationary sturgeon or sturgeon at spawning locations is possible. The goal for nonreproductive pallid sturgeon was to determine their location one to three times monthly.

Measurements of water conditions (for example, temperature, conductivity, dissolved oxygen, and turbidity) and habitat characteristics (for example, depth and substrate) were recorded at each location to qualitatively and quantitatively describe habitat used by sturgeon during nonspawning, prespawning, and spawning periods. Detailed mapping of migration pathways and spawning habitat locations were coordinated with Task 3. Suspected spawning sites of tagged sturgeon were assessed through a combination of sampling for eggs or larvae, capture of adult pallid sturgeon in reproductive condition, or dual-frequency identification sonar (DIDSON®) imagery. Not all assessment methods were employed at each spawning site. Assessment methods used at each site were determined by resource availability, river conditions, and safety considerations.

Results

USGS and NGPC began recollecting and re-implanting tagged pallid sturgeon in September 2009 in anticipation of 2010 studies. Tagged pallid sturgeon females and males were identified as candidates for recapture using the Sturgeon Information Management System (SIMS) (see Task 4) based upon sex, reproductive history, and recent movement. All sturgeon used in the tracking studies are given a unique database identifier, implanted with a transmitter with a unique acoustic code, and tagged with a passive integrated transponder (PIT). Candidate sturgeon were located and re-collected using drifted trammel nets as described by DeLonay and others (2007b). Re-collection efforts continued from September through November of 2009 and from February through November of 2010. Trotline and gill net sampling for new, untagged reproductive adults began in February and continued through April 2010.

Winter and spring capture efforts were hampered by cold weather, ice and high water. The combination of adverse environmental conditions made sampling for adult pallid sturgeon difficult to nearly impossible for a substantial portion of the spring sampling season. The composition of pallid sturgeon captured was similar to that reported in previous years though numbers of sturgeon captured declined (fig. 5). Likewise tracking efforts and recapture efforts were hampered by extreme high water in the lower study section. Sampling crews adjusted to adverse environmental conditions by relying less on the collection of new fish and actively seeking and recapturing previously tracked fish for re-evaluation and re-implantation.

In 2010, 57 adult pallid sturgeon were captured, assessed, implanted and released as part of the telemetry tracking program. Of those, 20 were previously tracked fish that were recaptured using targeted recapture methods and re-implanted for long-term monitoring, including one gravid female and four ripe males. Spring sampling with gill nets and trotlines yielded only one additional male and one female in reproductive condition. The program also opportunistically took advantage of fish collected by the propagation and broodstock collection program. Fish released by the propagation program for telemetry included 2 reproductive females, 5 reproductive males, as well as 4 spent females, 3 probable atretic females, and 1 intersex reproductive male. As a result the average size and age of adults, as well as the number of fish in the research portfolio that are known to have spawned or previously been reproductive has increased substantially.

Four gravid females were intensively tracked during spring 2010 to determine spawning location and success. One gravid female was tracked in the lower section, and three were intensively tracked in the upstream section. During intensive pallid sturgeon tracking in spring 2010, two of four female pallid sturgeon were tracked to their likely spawning locations, subsequently recaptured and determined to have spawned. This triggered larval sampling at two locations. One spawning site was located for a female pallid sturgeon in the upper study section and one in the lower.

Female pallid sturgeon PLS10-013 in the upper study section was captured on April 12, 2010, and sent to Blind Pony State Fish Hatchery in Sweet Springs, Mo (not shown). Genetic analyses indicated a probability that PLS10-013 may be the progeny of the hatchery program and therefore unsuitable for broodstock. PLS10-013 was released to CSRP on April 21, 2010, implanted with a transmitter, and released

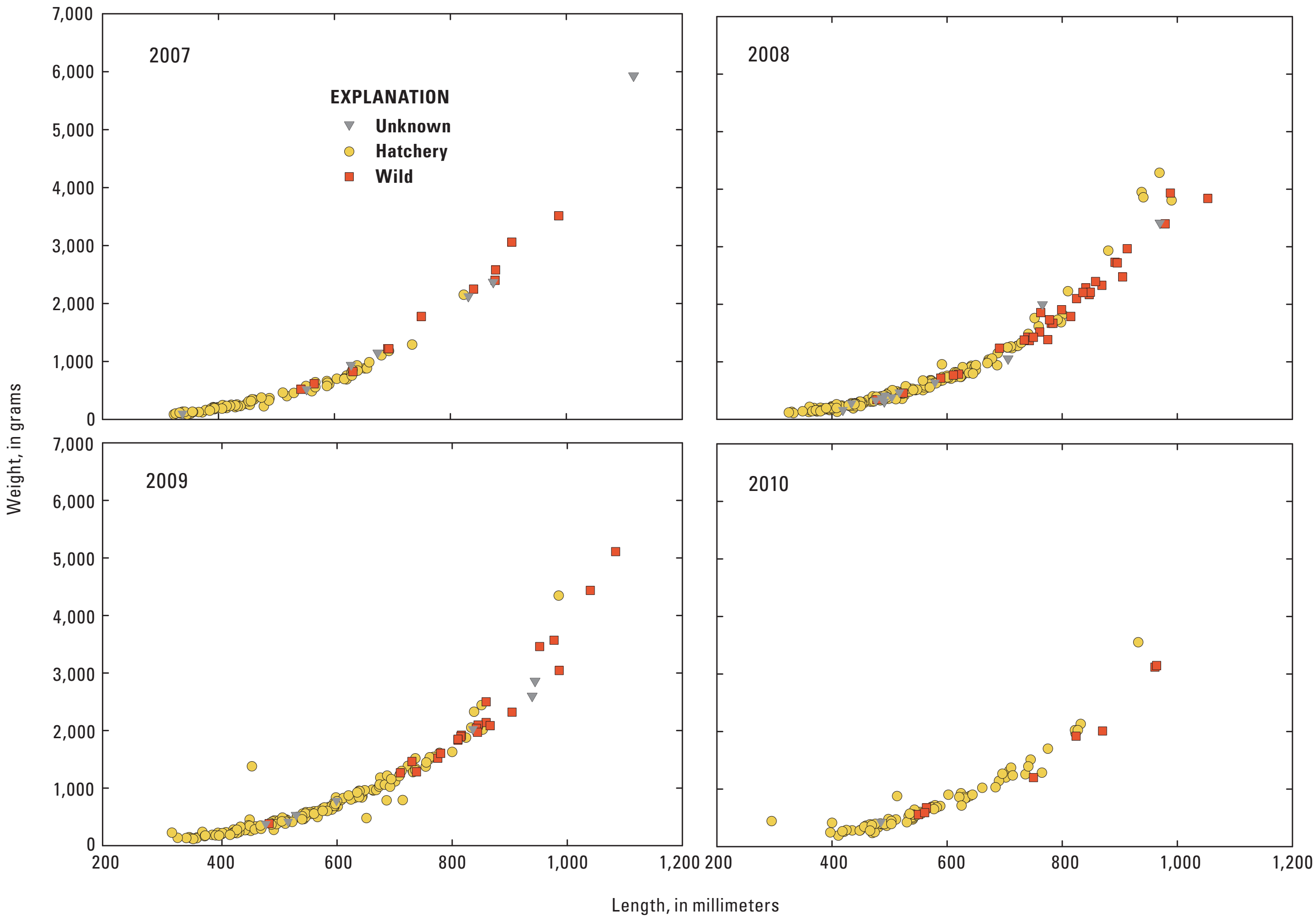


Figure 5. Length-weight relation of hatchery-released, unknown and wild pallid sturgeon collected during 2007–2010 spring sampling efforts in the upper and lower study sections. Pallid sturgeon of unknown origin did not bear hatchery marks and samples have not been tested to determine genetic parentage. Pallid sturgeon are presumed wild if genetic testing did not assign them to known broodstock parents. Not all parents used in the propagation program are present in the genetic database; therefore, sturgeon presumed to be wild may be over-represented in the actual totals.

upstream from its original capture location. The upstream release was designed to account for migration that could have occurred during the 9 days the fish was held in captivity. After release PLS10-013 moved rapidly upstream and is presumed to have spawned in the main-stem Missouri River on April 28–29, 2010, on an outside revetted bend between river mile 633.7–634.2 adjacent to the Boyer Chute National Wildlife Refuge (fig. 6). Crews sampled for larvae during the time when eggs were likely to hatch based upon calculated developmental times at ambient river temperatures. No *Scaphirhynchus* larvae were collected at the probable spawning site of PLS10-013, though paddlefish larvae of various ages were collected.

The intensively tracked reproductive female pallid sturgeon in the lower study section (PLS10-006) moved upstream and is presumed to have spawned on April 30–May 1, 2010, in the main-stem Missouri River between river miles 202.0–202.4 on an outside revetted bend immediately downstream from the confluence with the Lamine River (not shown); a small tributary (fig. 7). The upstream spawning movement was interrupted briefly by a discharge event exceeding 195,000 ft^3/s and a temperature drop of greater than 3°C. Migration resumed as discharge declined and temperatures increased. Spawning occurred at the apex of migration on the descending limb of the hydrograph as water temperatures warmed from 15 to 17°C. This female sturgeon possessed a coded wire tag and was therefore of known hatchery-origin. DIDSON® was deployed at the spawning site in an attempt to observe spawning aggregations and behavior. A minimal number of active large sturgeon were observed at the site. The amount and quality of the imagery was limited because of deep water, fast current and the presence of bedrock. Crews sampled for larvae during the time when eggs were likely to hatch based on calculated developmental times at ambient river temperatures. Water temperatures following spawning suggested a 6–8 day incubation period. Two early stage *Scaphirhynchus* larvae and one egg were collected immediately downstream from the probable spawning site of PLS10-006 on May 7, 2010. The larvae were early protolarvae collected soon after hatch. Subsequent genetic analyses by Dr. Edward Heist indicated that the larvae were shovelnose

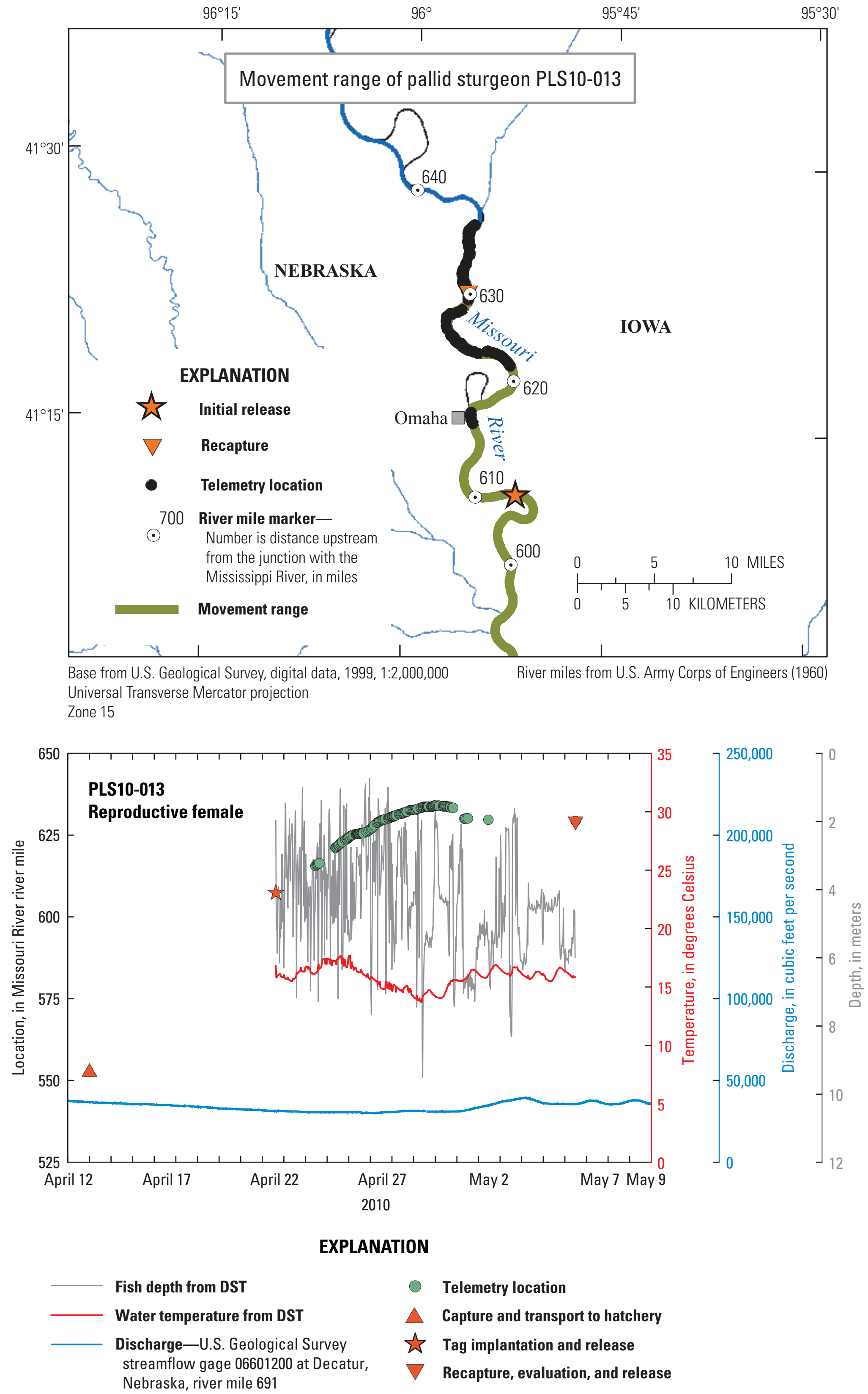


Figure 6. Movement range of female pallid sturgeon PLS10-013. Depth and temperature recorded from data storage tag (DST), discharge from the nearest streamgage at Decatur, Nebraska, and telemetry locations for implanted gravid pallid sturgeon PLS10-013. Fish was implanted in reproductive condition, later recaptured, and determined to have spawned.

sturgeon (Heist and others, University of Illinois, Carbondale, Ill., written commun., 2010).

The two remaining females, both tracked in the upper study section, exhibited complex migratory patterns; either not spawning at the apex of their migration (PLS10-023), or demonstrating multiple upstream and downstream movements (PLS08-014). PLS10-23 was captured on April 14, 2010, and sent to Blind Pony State Fish Hatchery as potential broodstock. Subsequent genetic analyses rejected this sturgeon as parental broodstock based on results of NEWHYBRIDS analysis that suggest the possibility of some shovelnose sturgeon introgression one or more generations removed from this female's parents (0.871 pallid sturgeon) (Heist and others, University of Illinois, Carbondale, Ill., written commun., 2010). The NEWHYBRIDS analysis is a probability model that calculates the likelihood that an individual may be identified as either one of two parental species, in this case a pallid sturgeon or a shovelnose sturgeon, or one of various classes of hybrids (F1s, F2s, or various backcrosses) (Anderson and Thompson, 2002). The model suggests that PLS10-23 was the product of a pure pallid sturgeon backcrossing (spawning) with a shovelnose *x* pallid sturgeon hybrid. PLS10-023 was released to CSRP on April 28, 2010, implanted with a transmitter and released upstream from its capture location. The upstream release was to account for migration that could have occurred during the 14 days the fish was held in captivity. PLS10-023 moved upstream and reached its migration apex on May 6, 2010, at river mile 659.9 (fig 8). Within hours PLS10-023 began to move back downstream and was targeted for recapture. It was recaptured on May 13, 2010, at river mile 642.7. Reproductive evaluation in the field revealed that it had not spawned and still possessed viable ova. Because of limited crews, intensive tracking of PLS10-023 was abandoned in favor of PLS08-014, which had begun to move rapidly upstream. Extensive tracking efforts later located the stationary PLS10-023 more than 147 miles downstream at the confluence with the Big Nemaha River (not shown) at river mile 495.1. It was recaptured on June 9, 2010. Field evaluations revealed that the female had spawned completely.

PLS08-14 was first captured as a presumed-wild, gravid female on April 11, 2008. She was implanted with a transmitter and DST and intensively tracked though the spawning period. Its movement patterns in 2008 were highly irregular and disjointed (fig. 9). Disrupted migration movement by PLS08-014 in 2008 appeared to be related to sudden drops in water temperature that caused it to pause its upstream migration or to move downstream (DeLonay and others, 2009). PLS08-014 was recaptured in early June 2008 and field evaluations indicated that the female had spawned, although the location of spawning could not be determined from movement or behavior. PLS08-014 was targeted for recapture in the fall of 2009. Evaluations of reproductive readiness on October 27, 2009, and again on March 9, 2010, indicated that PLS08-014 would be ready to spawn in the spring of 2010, 2 years after its last spawning event. Examination of movement among years indicates strikingly similar patterns (figs. 9, 10). PLS08-014 began its spring migration from almost exactly the same location and at nearly the same time in 2008 and 2010. In each year the upstream migration pattern is complex and disrupted. PLS08-014 was recaptured on May 26, 2010, after multiple upstream and downstream movements. At recapture it had not yet spawned and field biopsies of ovaries determined that the ova were still viable (fig. 10). On June 4, 2010, it was again recaptured after a pronounced downstream movement and the ova had gone atretic. In contrast to 2008, PLS08-014 was unable to spawn in 2010.

Five pallid sturgeon males known to be in reproductive condition were available for intensive tracking at the start of the season. Two were captured and evaluated in the lower section and three in the upper section. Midway into the spawning season, the hatchery propagation program released five additional males to CSRP for telemetry that originally were captured in the upper section, transported to the hatchery, and used as broodstock. The males were implanted with transmitters and released in the upper study section to increase the likelihood of documenting spawning aggregations with tagged females. Although the males had been artificially induced to release sperm in the hatchery for propagation, inspection of the testes during implantation on April 29, 2010, indicated that these males were still ripe and likely capable of spawning in the Missouri River.

Because of the disparate locations of the males and females in the lower section intensive tracking of males logistically was not possible with the crew resources available. No aggregations of tagged males and females were observed in the lower section. Males were not tracked intensively in the upper section because of the numbers of prioritized gravid females available. Gravid female pallid sturgeon PLS08-014 was found in close association with three males on several occasions during her upstream migration (fig. 11). Male pallid sturgeon PLS08-019 and PLS10-014 were known to be in reproductive condition and each briefly encountered PLS08-014. Male pallid sturgeon PLS08-031 closely tracked the upstream migration of PLS08-014 for nearly a week in mid-May, but its reproductive status was not evaluated.

Intensive and extensive tracking of pallid sturgeon between 2007 and 2010 has resulted in the documentation of spawning by 12 individual females in the Lower Missouri River (table 2). The precision with which it is possible to estimate when and where spawning has taken place varies. Descriptions of spawning events by some intensively tracked and recaptured females has defined spawning as occurring over a few hundred meters of an outside bend of the river in a 24–36 hour period. Estimates of the timing and location of spawning of other tagged females may be more broadly defined, especially if the migration pattern of intensively tracked females was complex and disrupted without any clear observation of spawning behavior, or if only the females were tracked extensively and had only a few observations between the initial reproductive evaluation and the post-spawn recapture.

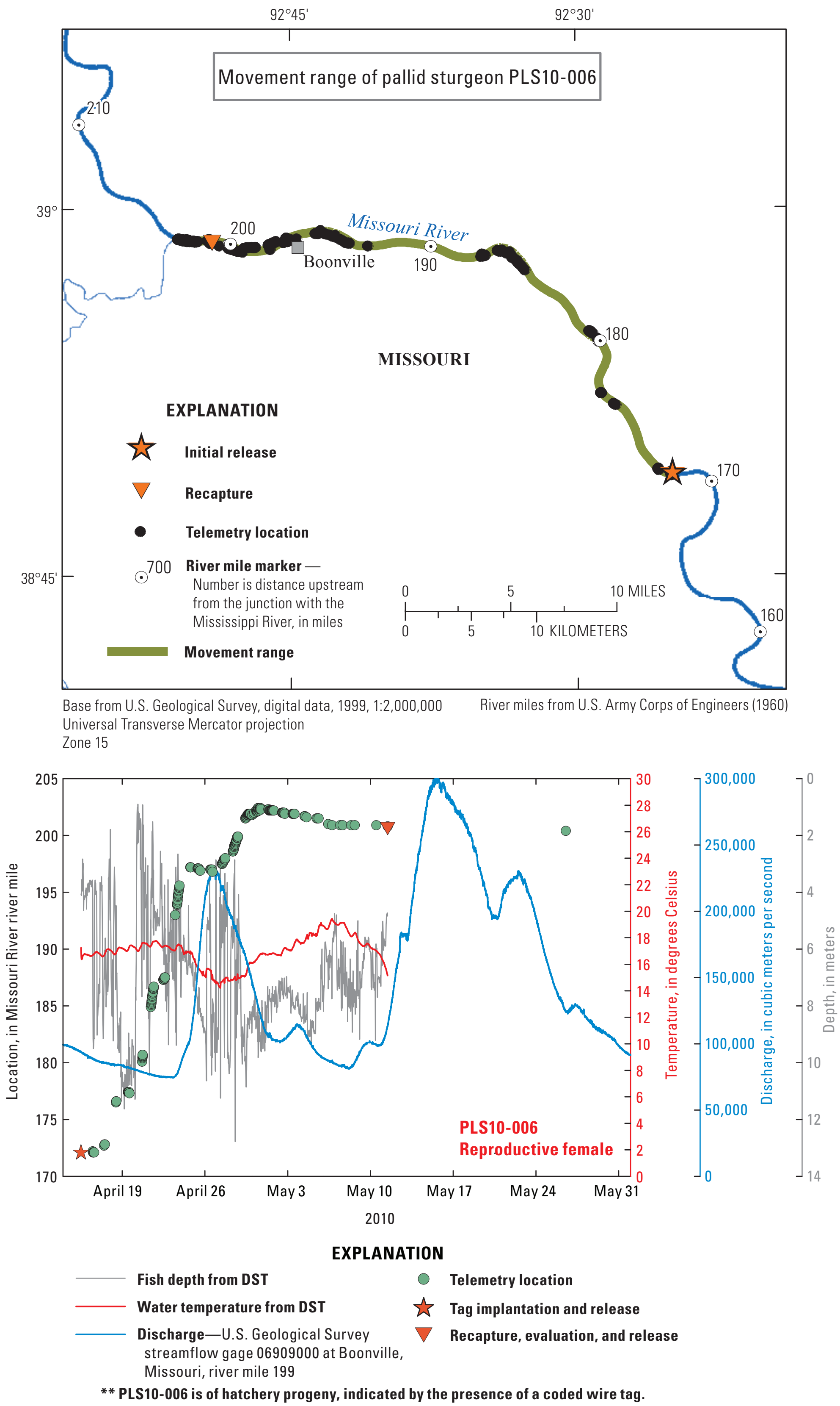


Figure 7. Movement range of female pallid sturgeon PLS10-006. Depth and temperature recorded from data storage tag (DST), discharge from the nearest streamgage at Boonville, Missouri, and telemetry locations for implanted gravid pallid sturgeon PLS010-006. Fish was implanted in reproductive condition, later recaptured, and determined to have spawned.

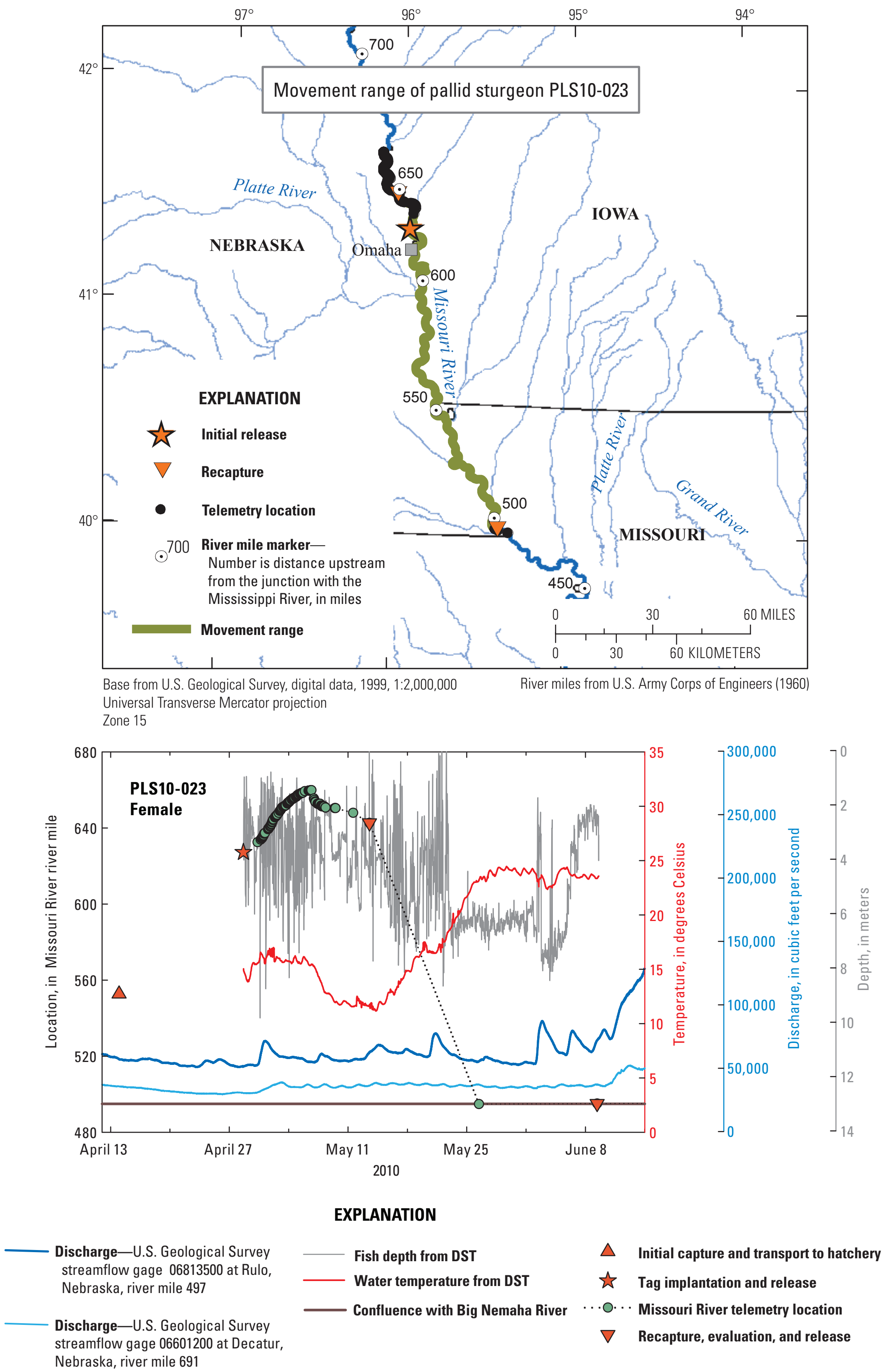


Figure 8. Movement range of female pallid sturgeon PLS10-023. Depth and temperature recorded from data storage tag (DST), discharges from the nearest streamgages, and telemetry locations for implanted gravid pallid sturgeon PLS10-023. Fish was implanted in reproductive condition, later recaptured, and determined to have spawned.

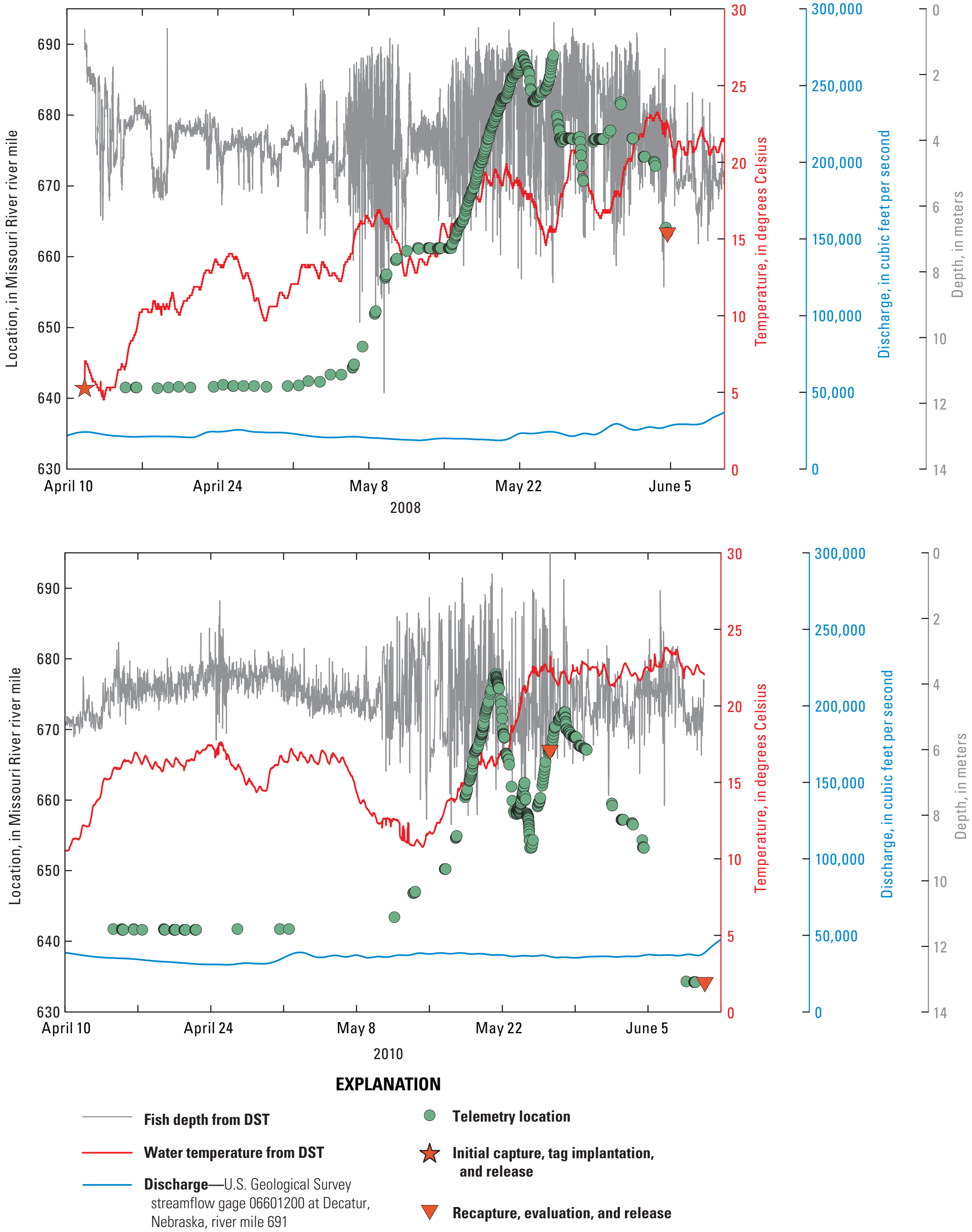


Figure 9. Comparison of telemetry locations of pallid sturgeon PLS08-014 in 2008 and 2010. Depth and temperature recorded from data storage tags (DST), discharge from the Decatur, Nebraska, streamgage, and telemetry locations for implanted gravid pallid sturgeon PLS08-014. Fish was implanted in reproductive condition, later recaptured, and determined to have spawned in 2008, but not to have spawned in 2010.

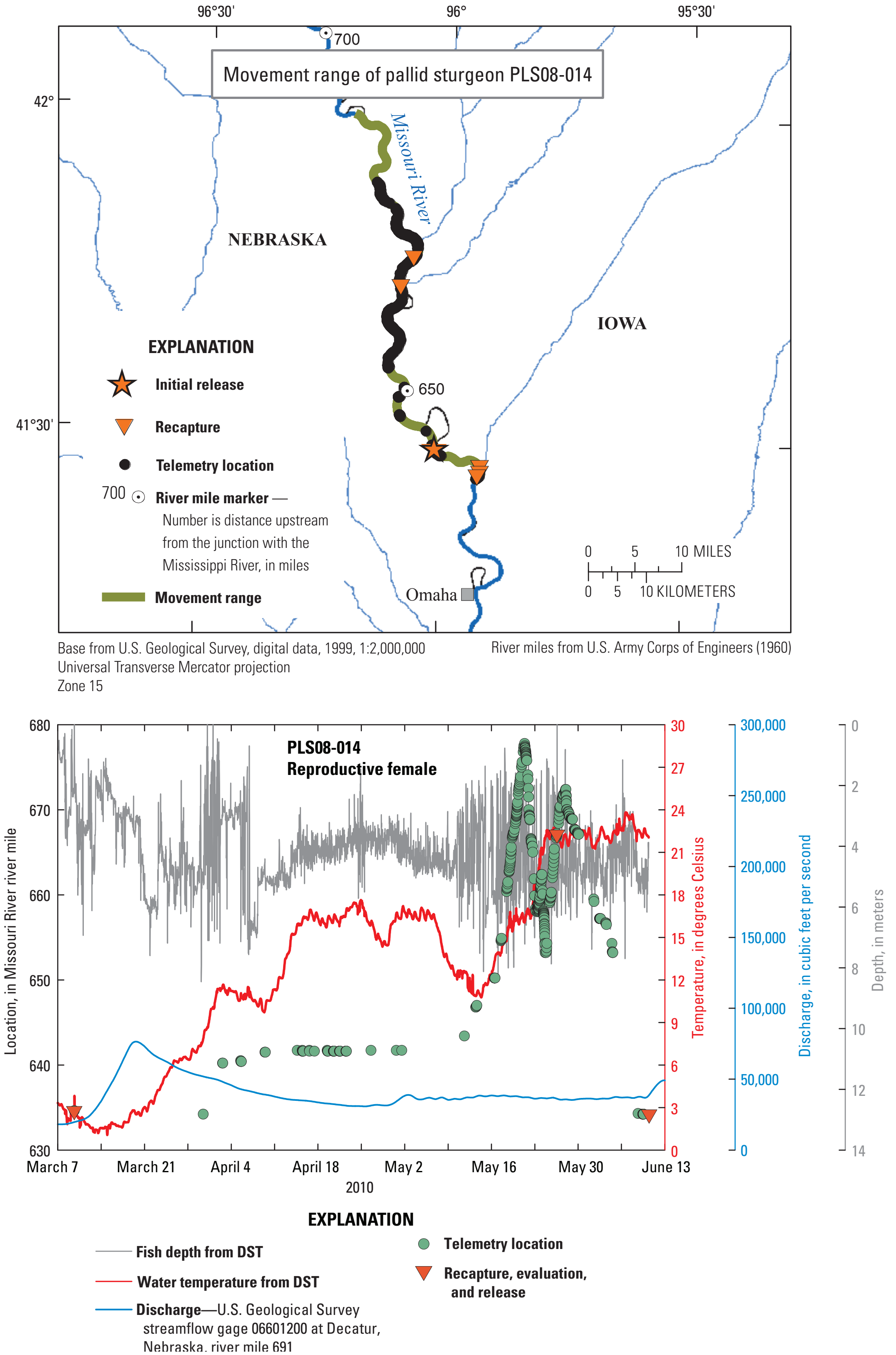


Figure 10. Movement range of female pallid sturgeon PLS08-014. Depth and temperature recorded from data storage tag (DST), discharge from the nearest streamgage at Decatur, Nebraska, and telemetry locations for implanted gravid pallid sturgeon PLS08-014. Fish was implanted in reproductive condition, later recaptured, and determined not to have spawned.

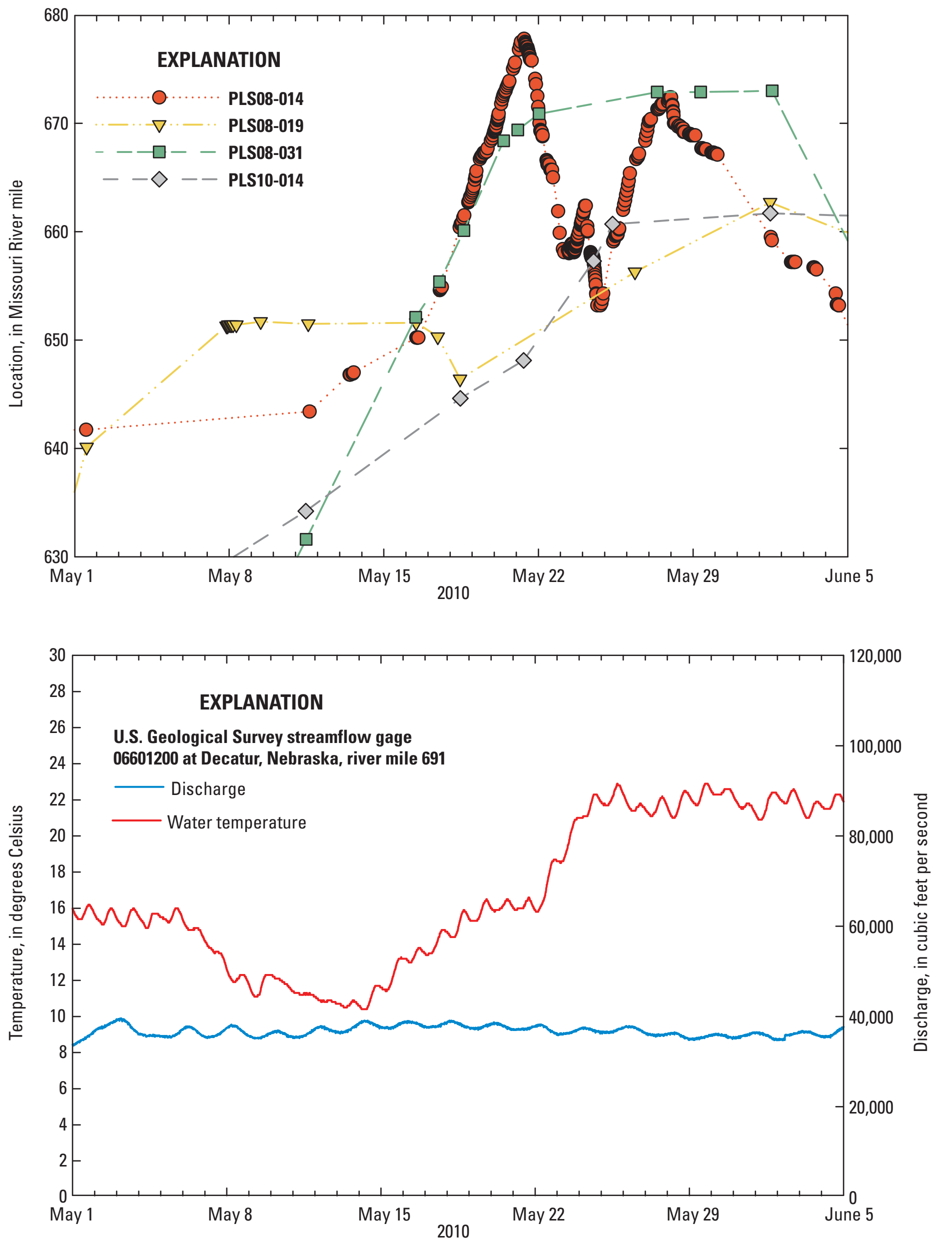


Figure 11. Telemetry locations of reproductive male pallid sturgeons PLS08-019 and PLS10-014 as well as male PLS08-031 indicating possible aggregations with gravid female PLS08-014 in the upper study section. Discharge and temperature from the nearest upstream streamgage at Decatur, Nebraska.

Despite the relatively low number of documented spawning events, a number of trends are evident (table 2). Pallid sturgeon are capable of spawning in most reaches of the main-stem Missouri River under a wide variety of conditions (fig. 12). Compared to shovelnose sturgeon, which may spawn from mid-April to July, pallid sturgeon females in the Lower Missouri River are spawning from the end of April through May. Female sturgeon that have complex or disrupted patterns of upstream migration spawn later than females that exhibit the more typical characteristic rapid upstream movement pattern with spawning occurring at the most-upstream location, or apex of the spawning migration. Female pallid sturgeon with the typical single-apex pattern spawn from the end of April through the first two weeks of May. Sturgeon with complex, disrupted patterns and sturgeon nearer the dam typically spawn later; from the middle to the end of May.

Spawning success for sturgeon may be measured by the number of fertilized eggs that hatch, or the documentation of free-swimming embryos that disperse from the spawning location to larval rearing habitat. Whereas this study has yet to collect fertilized pallid sturgeon eggs or dispersing free-embryos at documented spawning sites, the numbers of eggs deposited by each female at the spawning sites can be estimated and compared among study sections. Comparisons of the amount

Table 2. Probable spawning locations of telemetry tracked reproductive female pallid sturgeon, 2007–10.

[Fish ID, Fish identification code; >, greater than; <, less than; NA, not available]

Spawning site confidence score[1]	Fish ID	Spawning period[2]			Boundary of probable spawning extent[3]			Tracking details[4]			Notes
		Spawning year	Spawning begin date (month/day/year)	Spawning end date (month/day/year)	Upstream extent	Downstream extent	Center of spawning site	Prespawn evaluation	Tracking	Spawning confirmed	
3	PLS07-004	2007	5/17/2007	5/23/2007	>768.7	756.3	NA	Yes	Intensive	Yes	Spawning occurred in unchannelized river. Tracking boats could not follow fish at night and lost contact. Complete migration and spawning not observed.
3	PLS07-007	2007	4/29/2007	5/8/2007	>694.9	681.1	NA	Yes	Intensive	Yes	Intensive tracking interupted by lethal tornado. Complete migration and spawning not documented.
1	PLS08-004	2008	5/4/2008	5/5/2008	230.7	230.0	230.4	Yes	Intensive	Yes	Intensive tracking to spawning location. Complete migration and spawning behavior documented.
1	PLS08-008	2008	5/8/2008	5/9/2008	366.8	366.1	366.4	Yes	Intensive	Yes	Intensive tracking to spawning location. Complete migration and spawning behavior documented.
1	PLS08-009	2008	5/7/2008	5/8/2008	369.7	369.3	369.5	Yes	Intensive	Yes	Intensive tracking to spawning location. Complete migration and spawning behavior documented.
3	PLS08-014	2008	5/22/2008	5/31/2008	688.4	670.7	NA	Yes	Intensive	Yes	Intensviely tracked female showed complex distrupted pattern. Complete migration pattern documented, but spawning behavior difficult to discern.
3	PLS07-001	2008	NA	6/3/2008	811.0	790.7	NA	No	Extensive	Yes	Female not intensively tracked. Recovered in July after spawning season with spent ovaries indicating she had spawned that spring, most likely prior to downstream movement. What few observations exist suggest that this fish most likely spawned in the unchannelized reach above 790.
1	PLS09-007	2009	4/25/2009	4/26/2009	206.1	206.5	206.3	Yes	Intensive	Yes	Intensive tracking to spawning location. Complete migration and spawning behavior documented.

Table 2. Probable spawning locations of telemetry tracked reproductive female pallid sturgeon, 2007–10.—Continued

[Fish ID, fish identification code; >, greater than; <, less than; NA, not available]

Spawning site confidence score[1]	Fish ID	Spawning period[2]			Boundary of probable spawning extent[3]			Tracking details[4]			Notes
		Spawning year	Spawning begin date (month/day/year)	Spawning end date (month/day/year)	Upstream extent	Downstream extent	Center of spawning site	Prespawn evaluation	Tracking	Spawning confirmed	
2	PLS09-009	2009	5/7/2009	5/11/2009	659.8	650.3	NA	Yes	Intensive	No	Female intensively tracked and aggregations with males documented, but female not recovered. Spawning not verified.
1	PLS10-006	2010	4/30/2010	5/1/2010	202.4	202.0	202.2	Yes	Intensive	Yes	Intensive tracking to spawning location. Complete migration and spawning behavior documented.
1	PLS10-013	2010	4/28/2010	4/29/2010	634.2	633.7	633.9	Yes	Intensive	Yes	Intensive tracking to spawning location. Complete migration and spawning behavior documented.
5	PLS10-023	2010	5/13/2010	5/26/2010	642.7	494.9	NA	Yes	Intensive	Yes	Translocated fish from propagation program. Intially intensively tracked as it moved upstream to spawn. It reached its upstream apex and began moving downstream. It was recovered on May 13 after its intial downstream movement and it had not yet spawned. It was recovered again June 9 more than nearly 150 miles downstream and it had spawned.

[1]1=Probable spawning site located within < 1 rivermiles; 2=Probable Spawning site located within 1–10 miles; 3=Probable spawning site located within 10–25 miles; 4=Probable spawning site located within 25–100 miles; 5=Probable spawning site located within >100 miles.

[2]The act of spawning by a female sturgeon may take from 8 to 24 hours. The spawning begin and end dates indicate the time during which spawning may have occurred for an individual fish. The time period reported reflects the uncertainty surrounding the actual timing of the spawning event, not the actual time spent spawning by an individual.

[3]The spawning of an individual sturgeon occurs over a fairly limited area. As we understand it, spawning by pallid sturgeon may occur over a patch of spawning habitat ranging from 0.3 to 0.7 rivermiles in length. The upstream and downstream extents reported reflect the uncertainty surrounding where the patch of spawning habitat is located, not the extent over which the individual actually deposited eggs. It some instances the female sturgeon was tracked to the probable spawning site and spawning behavior was documented. In this case a river mile for the center of the spawning habitat patch is reported.

[4]The tracking details indicate whether the female sturgeon was evaluated for reproductive condition in the months just prior to spawning, if the sturgeon was targetted for intensive tracking (daily) or extensively tracked as resources allowed, and if the female sturgeon was recaptured following spawning to confirm that eggs had been released successfully.

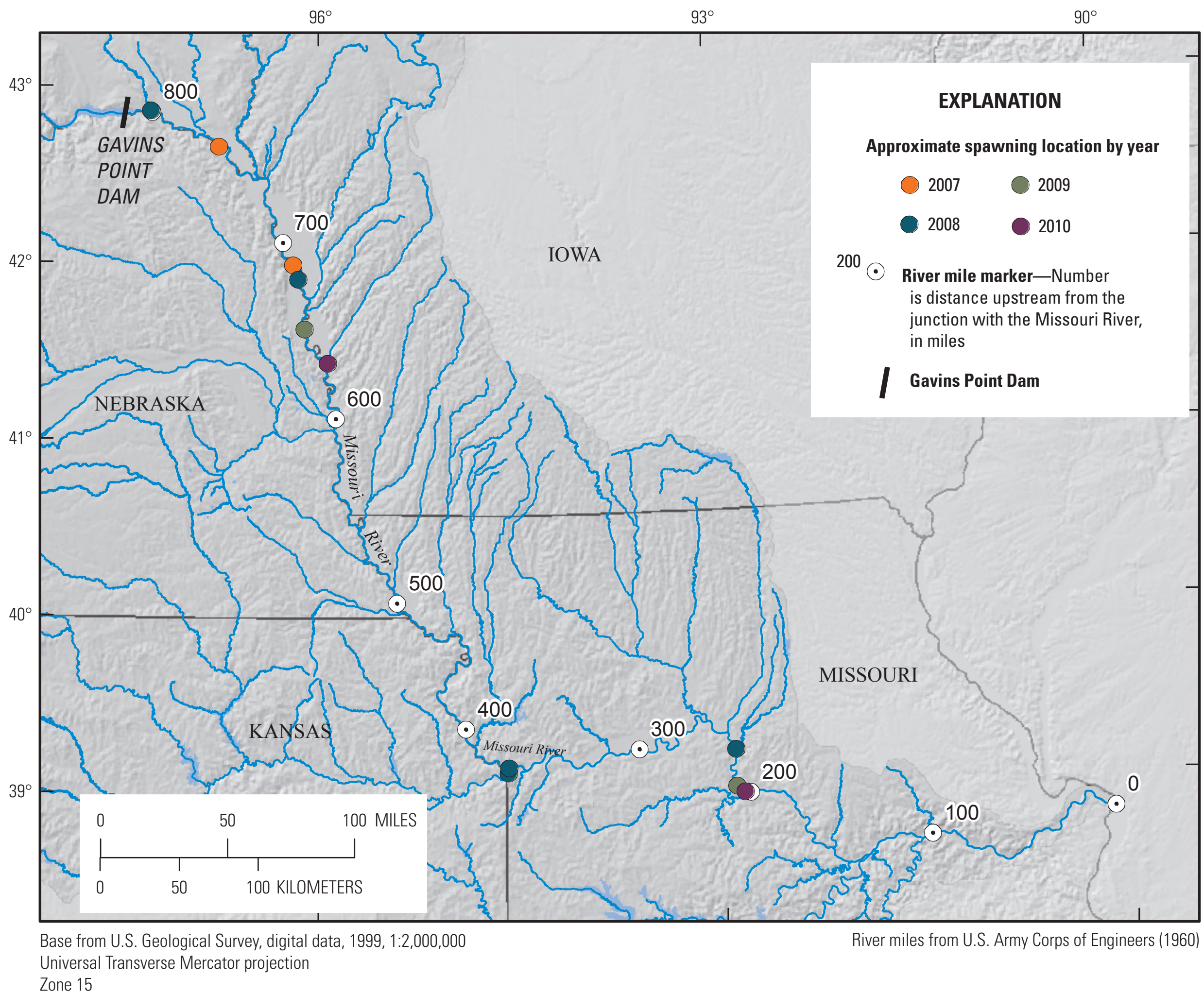


Figure 12. Spawning locations of pallid sturgeon in the lower Missouri River.

of body mass lost through spawning measured as the difference in weight at implantation just before spawning and at recapture immediately following spawning indicate large differences between study sections (fig. 13). Female pallid sturgeon in the lower study section lost on average 21.2 percent of their body weight through spawning, whereas females in the upper study section lost less than 9.3 percent. Mean egg diameters among sites did not differ and ranged from 2.4 to 3.2 millimeters. Therefore, based on the limited data from spawning studies it appears that pallid sturgeon females nearest the dam are on average 56 percent less fecund than pallid sturgeon females tracked in the lower study section. Although the age of females tracked in the study is unknown, all females in the lower study section were hatchery progeny and could not be older than 10–18 years old at the time of spawning. The age at first spawning for female pallid sturgeon in the lower Missouri River is approximately 10–12 years (DeLonay and others, 2009).

The number of pallid sturgeon tracked by CSRP has grown steadily since 2007. As more of tagged sturgeon with known reproductive histories are recaptured, re-implanted and tracked for three or more years, more instances of complex or repeated behavior are documented. PLS07-020, for example, is a male pallid sturgeon that was captured in reproductive condition and sent to the hatchery on April 3, 2007, for use as hatchery broodstock (fig. 14). It was implanted with a transmitter and released near its capture location. PLS07-020 has since been recaptured and its reproductive status reevaluated twice. For more than 3 years it has made repeated upstream movements in the fall and in the spring during the spawning season. After spawning is complete, PLS07-20 returns downstream to nearly the same location it occupied the previous summer, river mile 566 (fig. 15). Long-term repeated patterns and instances of site fidelity have been documented with increasing regularity for males and females in this study (DeLonay and others, 2010).

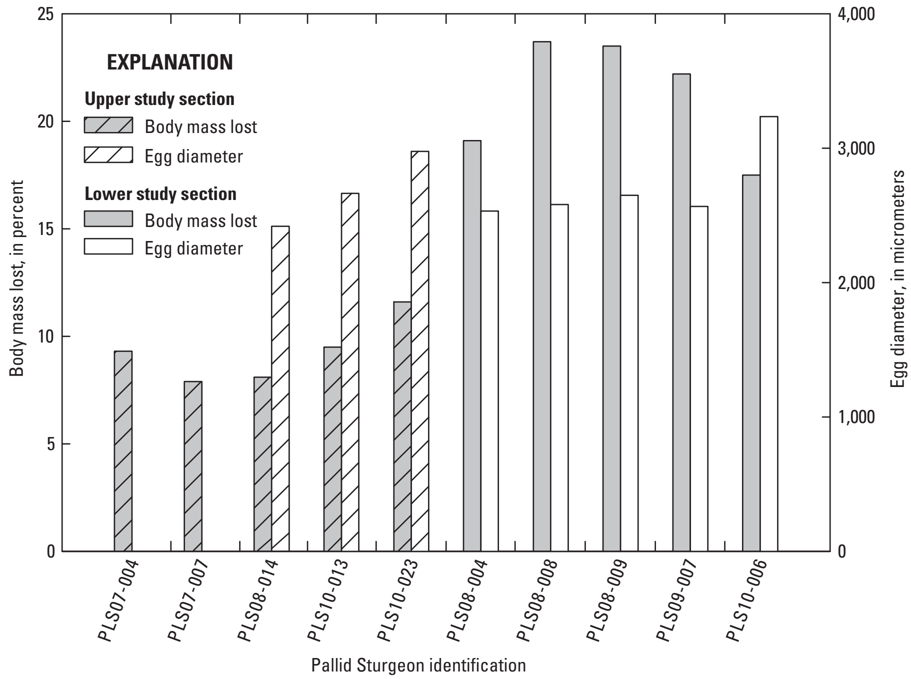


Figure 13. Comparison of egg diameter and body mass lost at spawning of telemetry tracked pallid sturgeon in the upper and lower study sections.

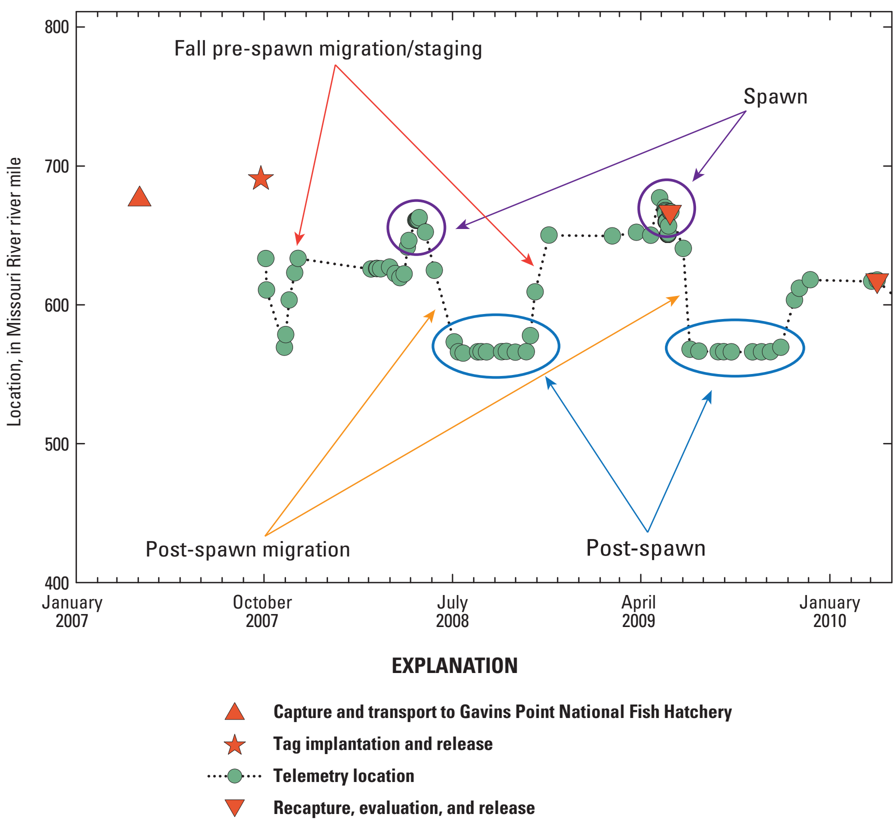


Figure 14. Telemetry locations for implanted pallid male sturgeon PLS07-020 in the lower Missouri River.

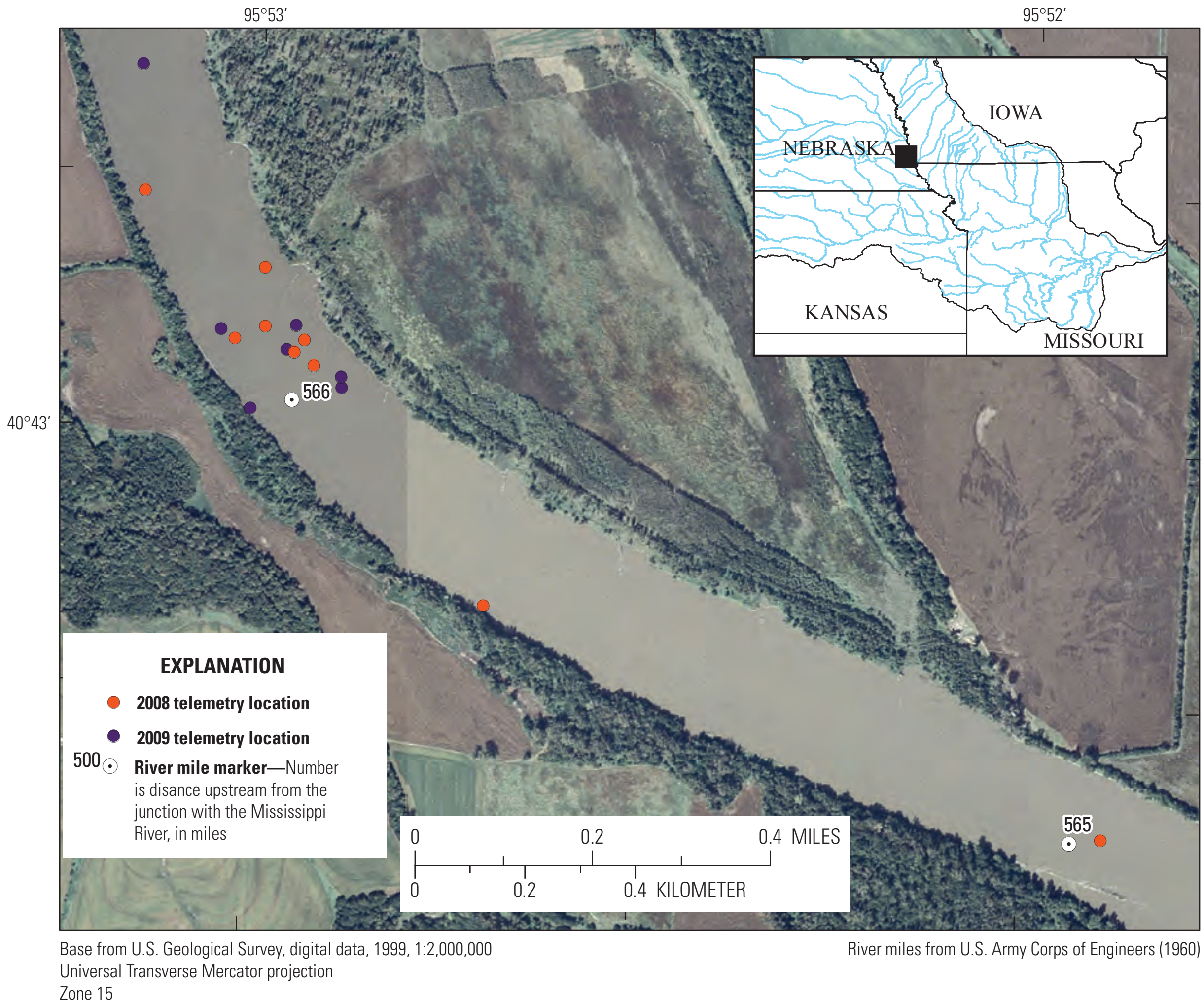


Figure 15. Telemetry locations recorded July through September 2008 and 2009 for implanted pallid male sturgeon PLS07-020 in the lower Missouri River.

Task 2. Reproductive Physiology to Support Assessment of the Importance of Spring Flows, Temperature, and Photoperiod to Successful Pallid Sturgeon Spawning in the Missouri River

Background

An important contributor to fish reproductive success is synchronization of the reproductive cycle with seasonal environmental conditions. Photoperiod, water temperature, and in some environments, discharge are the primary factors thought to cue the reproductive physiology of most fishes to provide this seasonal synchronization and the greatest chance for offspring survival (Lam, 1983; Ims, 1990). Physiological and morphological measurements allow scientists to evaluate the direct biological responses of sturgeon to such environmental conditions. Responses may be general, such as stress, or may be specific, such as indicating how close a sturgeon is to ovulation. For the last several years, we have demonstrated that we can assess the reproductive condition of shovelnose sturgeon before their spawning migration, regularly during their migration, and then again upon recapture (as soon after spawning as possible) and relate the readiness to spawn and success in spawning to location, discharge, water temperature, and day length (DeLonay and others, 2009). During the last few years, this approach has been successfully applied to pallid sturgeon.

CERC cumulative research indicates that the physiological data collected during telemetry studies provide an understanding of the motivational biology behind observed sturgeon behaviors during the reproductive cycle. Determining physiological readiness provides information for determining approximately ‘when’ an individual sturgeon should spawn. This information can be combined with tracking and capture information (location, speed, pattern and direction of movement) to determine ‘where’ the sturgeon spawn. Physiological measurements on fish captured through time in a specific location can reveal whether a group of fish are synchronized and, therefore, are likely responding to the same environmental cues, or if they are aggregating at a particular site to spawn.

A complete understanding of the relations between environmental conditions and reproductive physiology of pallid sturgeon and shovelnose sturgeon in the Missouri River has been hampered by the difficulties of working in a large river system. For this reason, and because of iterative improvements to tracking study designs in the past 5 years, the question of when sturgeon spawn has been fairly well answered, and an initial understanding of where sturgeon spawn has been made, but only modest progress has been made in trying to answer the question ‘what combination of environmental conditions is necessary or sufficient for successful pallid sturgeon spawning?’. Sound data are available to make predictions about pallid behaviors, but additional observations on many more individuals are needed to create a scientifically robust dataset with which to identify the controlling biotic and abiotic factors for the various stages of the reproductive cycle. The reproductive cycle in sturgeon begins months before spawning at a time when the fish may be hundreds of miles from the spawning location. Therefore, in order to fully understand the effect of the cues at spawning, it is important to understand the relative importance of environmental conditions in the months before spawning. In addition to collection of field data, experimental manipulations of sturgeon under controlled and semi-controlled situations may provide additional insights for answering these questions. Moreover, new techniques are now available that allow quick assessments of hundreds of biochemical pathways in order to identify those that are key for the appropriate physiological and behavioral responses to occur. For example, collaborative work between CERC and the University of Florida has resulted in the development of a *Scaphirhynchus* microarray, or gene chip, that can be used to evaluate the change in gene expression of 25,000 genes in a single experiment.

Scope and Objectives

This task provides the necessary supporting data and analyses to evaluate the biological response of pallid sturgeon to spring pulsed flows in the Missouri River. This task also continues to develop tools and acquire multiyear geographic and condition-specific data from the field and the laboratory to answer questions about when, where, and what environmental conditions are necessary for pallid sturgeon to spawn. In 2010, there were three specific objectives:

Objective 1. Use physiological measurements to provide sex identification, assess reproductive readiness, and evaluate success of spawning for tracked sturgeon.

Objective 2. Expand dataset of pallid sturgeon physiological endpoints coincident with environmental data through the addition of observations during the 2010 spring-rise period in order to increase sample size for identification of likely environmental cues associated with key stages in the reproductive cycle.

Objective 3. Support development of tools and assays to measure and analyze specific pallid reproductive hormones important in cueing migration, gamete maturation and release, and spawning success.

Methods

For the first objective, field crews were supplied with tissue collection materials in support of Task 1 to determine readiness to spawn. Blood plasma was collected at implantation of transmitters and upon each recapture for measurement of sex hormones. Eggs were collected into formalin for measurement of polarization index (PI) or into Ringers solution for progesterone assay to determine germinal vesicle breakdown (GVBD). All tissues were returned to the CERC laboratory for analyses. Spawning success was evaluated based on visual inspection of gonads and blood reproductive hormones.

Research was conducted to better define the environmental factors (including natural spring pulses and pulsed-flow releases) necessary for completion of the reproductive cycle and successful spawning in the Lower Missouri River. The approach for this second objective was to assess the reproductive condition of sturgeon before spawning migration, during the migration, as soon after spawning as possible, and to relate the readiness to spawn and success in spawning to discharge characteristics, temperature, and day length. Data were collected from fish used in telemetry Task 1 and on pallid sturgeon used in the propagation program with funding through a U.S. Geological Survey–U.S. Fish and Wildlife Service (USGS–USFWS) grants program. Temperature and flow data were obtained from streamgages, deployed data loggers, and data collected by field crews.

The third objective extends ongoing work conducted at USGS to develop tools and assays to measure gonadotropin II (GtH II) and maturation-inducing hormone (MIH). For the last few years, several approaches (biochemical and molecular) were attempted to isolate the *Scaphirhynchus* GtH II protein in order to develop GtH II-specific antibody or probe that is necessary to measure GtH II in blood plasma of the sturgeon. Protein was obtained during fall 2010 and an antibody was produced. Activity this year was to develop an appropriate enzyme-linked immunosorbent assay (ELISA); this work is on-going. Chromatographic methods were used in past years to identify the composition of the *Scaphirhynchus* MIH. Validation that the putative MIH is the *Scaphirhynchus* MIH is necessary before a radioimmunoassay (RIA) can be developed to measure MIH in plasma of wild sturgeon. Validation requires use of fresh oocytes from a gravid female in spring for the necessary bioassay. Validation was accomplished for two individuals previously and a third was attempted in 2010.

Genomics and molecular techniques are additional tools that are being developed for use with sturgeon to identify indicators diagnostic of the sturgeon’s response to environmental stimuli during the spawning period. A *Scaphirhynchus*-specific 15,000-gene microarray developed by CERC is being used with tissue samples collected during the 2010 field season.

Figure 16. Water columns (4.0 meters) used to determine vertical distribution of free embryos and their ability to fill their swim bladders.

Figure 17. Water columns (2.4 meters) containing turbid water used to evaluate egg adhesion.

Fin, barbel, and gonad tissue were collected from various individuals and frozen at -80°C. Two experiments will be conducted in December 2010 to include (1) a time course of gene expression in an ovary for a reproductive season, and (2) sex and reproductive stage differences in gene expression in a barbel.

Laboratory studies used pallid sturgeon eggs from a captive population. Two experiments were conducted in the laboratory to attempt to deduce the depth at which pallid sturgeon are spawning. In the first experiment, examination of whether there was a limit to the depth at which embryos could hatch and still swim to the surface to fill the swim bladder. On the median hatch date, 24 embryos were placed in the bottom of a column of water just prior to hatch. The water column was initially 2.4 meters (m) deep and subsequently extended to 4.0 m deep (fig. 16). Hatch and free embryo behavior was monitored at intervals for 2 days. Water in the column was periodically replaced to maintain temperature and the column was kept in the dark to simulate low-light river conditions. There was no flow in the column. Positions of the free embryos were noted during 5-minute observation periods conducted periodically throughout the course of 2 days. In the second experiment, the effect of varying turbidities on adhesion of pallid eggs to surfaces and the rate at which they fell through a column of water was investigated. Freshly fertilized pallid sturgeon eggs were released at the top of a 2.4 m column of water of varying turbidities and a recording was made of the time it took to reach the bottom of the column (fig. 17). Turbidity was created by mixing creek mud into well water and measured using a Hach 2100P turbidimeter. Four turbid (100, 200, 400, and 800 Nephelometric Turbidity Units (NTU)) and one clear water conditions were tested in triplicate.

Results

Physiological data were collected for 58 fish in 2010. Blood only was collected for 46 fish (17 females and 29 males, including 4 intensively tracked males) that were captured and released. Blood and an ovarian biopsy were collected for 12 females, including 7 females that were tracked for all or part of the reproductive season.

In 2010 seven females were tracked. PLS10-012, a hybrid gravid female implanted with a transmitter on April 20, 2010 (water temperature 17.3°C), had a PI of 0.13 and oocytes completed GVBD in the progesterone assay. Estradiol (E2) and testosterone (T) were slightly elevated for a fish at this stage of readiness (tables 2 and 3). After 7 days of tracking

Table 3. Mean polarization index of gravid female pallid sturgeon collected during 2010.

[Fish ID, fish identification code; PI, polarization index; Std, standard deviation; GVBD, germinal vesicle breakdown; --, no data]

Fish ID	Date (month/day/year)	Mean PI	Std	GVBD?	Disposition
PLS08-014	3/9/2010	0.24	0.07	--	Tracked.
PLS08-014	5/26/2010	.05	- -	--	Tracked.
PLS10-006	4/15/2010	.12	.02	Yes	Tracked.
PLS10-012	4/20/2010	.13	.03	Yes	Tracked.
PLS10-013	4/14/2010	.16	.02	--	Tracked.
PLS10-013	4/21/2010	.08	.01	--	Tracked.
PLS10-015	4/14/2010	.13	.05	--	Hatchery.
PLS10-015	4/22/2010	.12	.01	--	Hatchery.
PLS10-016	4/14/2010	.17	.02	--	Hatchery.
PLS10-016	4/22/2010	.11	.02	--	Hatchery.
PLS10-017	4/14/2010	.15	.02	--	Hatchery.
PLS10-017	4/22/2010	.11	.03	--	Hatchery.
PLS10-018	4/22/2010	.11	.02	--	Tracked.
PLS10-018	4/14/2010	.15	.02	--	Tracked.
PLS10-019	4/14/2010	.12	.02	--	Hatchery.
PLS10-019	4/22/2010	.13	.04	--	Hatchery.
PLS10-019	4/29/2010	.10	.03	--	Hatchery.
PLS10-023	4/22/2010	.10	.01	--	Tracked.
PLS10-023	4/28/2010	.15	.03	--	Tracked.
PLS10-023	5/13/2010	.10	.02	Yes	Tracked.
PLS10-029	5/7/2010	.11	.03	--	Hatchery.
PLS10-031	3/15/2010	.17	- -	No	Tracked.
PLS10-031	4/7/2010	.17	- -	No	Tracked.

upstream about 20 miles, PLS10-012 disappeared and was not seen again. PLS08-014, a wild gravid female evaluated on March 3, 2010 (water temperature 2.7°C), at which time she had a PI of 0.24 and elevated E2, T, and 11-ketotestosterone (11KT) compared to what would be expected for a reproductive female a couple of months before spawning (tables 3 and 4). On May 26, 2010, she was recaptured with a PI of 0.05; her E2 had decreased but T was still elevated, indicating that she would spawn soon. On June 10, 2010, PLS08-014 was again captured but had not spawned; her eggs were breaking down and all hormones had decreased. It is unknown why PLS08-014 did not spawn.

Gravid female PLS10-006 was implanted with a transmitter on April 15, 2010, at which time water temperature was 15.8°C and her PI was 0.12, oocytes completed GVBD in the progesterone assay, and hormones were as expected for a prespawn female a month or less before spawning (tables 3 and 4). Upon recapture May 11, 2010, she had spawned and hormone levels had decreased appropriately to less than 10 percent of pre-spawn levels. PLS10-013, was collected on April 14, 2010, with a PI of 0.16 and originally brought to the hatchery, but then released when it was determined she was hatchery progeny. When released to the river on April 21, 2010, her PI had decreased to 0.08 (table 3). Estradiol was low, but T was similar to PLS10-006 pre-spawn (table 4). On May 5, 2010, she was recaptured and determined to have spawned; her testosterone level had decreased to 10 percent of prespawn level.

Gravid female PLS10-019 was captured on April 8, 2010, and delivered to the hatchery for broodstock. On April 14, 2010, her PI was 0.12; a week later the PI had not changed (0.13; table 3). She was induced to spawn in the hatchery, but never ovulated. On April 29, 2010, her PI was still elevated (0.10). Estradiol had decreased, probably in response to induction, but T remained higher than expected for a prespawn female presumably ready to spawn (table 4). She was released in the Missouri River and although not recaptured, her hormone levels and PI suggest that her eggs became atretic. It is not known why PLS10-019 did not ovulate. A progesterone assay was not conducted on her eggs.

Female PLS10-023 was captured for broodstock on April 14, 2010, however, genetic tests identified her as a pallid

Table 4. Plasma hormone values for female pallid sturgeon collected in 2010. Upper limits of detection are estradiol=734, testosterone=686, 11-ketotestosterone=496. Lower limits of detection are estradiol=5, testosterone=4, 11-ketotestosterone=3.

[Fish ID, fish identification code; pg/mL, picograms per milliliter; --, no data; <, less than; >, greater than; LOD, limit of detection]

Fish ID	Date (month/day/year)	Estradiol (pg/mL)	Testosterone (pg/mL)	11-Ketotestosterone (pg/mL)
PLS06-003	3/4/2010	36	722	--
PLS06-003	9/8/2010	25	215	--
PLS07-001	9/21/2010	2,971	10,317	--
PLS07-007	4/7/2010	<LOD	1239	--
PLS07-007	10/14/2010	28	202	--
PLS08-006	10/13/2010	84	10,516	--
PLS08-014	3/9/2010	1,304	7,290	--
PLS08-014	5/26/2010	229	10,122	--
PLS08-014	6/10/2010	26	323	--
PLS08-027	9/3/2010	64	177	--
PLS08-035	9/8/2010	48	1,048	--
PLS08-058	9/3/2010	41	195	--
PLS10-002	3/2/2010	60	1,641	--
PLS10-003	3/9/2010	114	1,841	--
PLS10-003	9/14/2010	38	1,474	--
PLS10-004	4/14/2010	61	501	--
PLS10-006	4/15/2010	864	3,044	--
PLS10-006	5/11/2010	35	117	--
PLS10-010	4/8/2010	55	2,216	--
PLS10-010	10/14/2010	66	682	--
PLS10-011	4/14/2010	43	4,135	--
PLS10-012	4/20/2010	4,711	14,801	--
PLS10-013	4/21/2010	<LOD	3,361	--
PLS10-013	5/5/2010	14	218	--
PLS10-015	4/29/2010	27	3,571	--
PLS10-016	4/29/2010	37	>LOD	--
PLS10-017	4/22/2010	5	2,878	--
PLS10-018	4/29/2010	<LOD	1,177	--
PLS10-019	4/29/2010	78	12,102	--
PLS10-023	4/28/2010	172	7,014	--
PLS10-023	5/13/2010	166	12,941	--
PLS10-023	6/9/2010	28	978	--
PLS10-025	4/30/2010	30	1,568	--
PLS10-026	4/30/2010	<LOD	1,043	--
PLS10-029	5/7/2010	9	1,800	--
PLS10-031	3/15/2010	285	19,182	1,413
PLS10-031	4/7/2010	246	15,925	--

sturgeon, but further analyses eliminated her from consideration as broodstock because of the possibility of genetic introgression with shovelnose sturgeon one or more generations removed. Her PI on April 22, 2010, was 0.10 and it increased to 0.15 a week later when she was returned to the Missouri River (table 3). At that time, hormone levels were appropriate for a prespawn female with this PI (table 4). On May 13, 2010, she was recaptured with a PI again of 0.10 and the oocytes completed GVBD in the progesterone assay. Estradiol was the same, but testosterone had increased slightly as was observed for PLS08-014. However, unlike PLS08-014, when PLS10-023 was recaptured for a third time on June 9, 2010, she had spawned and all hormones had decreased approximately 10-fold.

PLS10-031 had been held at the Neosho National Fish Hatchery in Neosho, Mo. (not shown), for broodstock since fall 2008. In October 2009, endoscopy and an egg biopsy indicated she had black eggs with PI of 0.14 and hormones were elevated to levels greater than values measured in springtime prespawn females. On March 15, 2010, her PI had increased to 0.17, but no GVBD could be induced in vitro; her E2 had decreased and both androgens were elevated. On April 7, 2010, her PI was still 0.17 and there was no GVBD in the progesterone assay (tables 3 and 4). She was induced to spawn, but did not ovulate and was returned to the Missouri River on May 7, 2010. She was not recaptured; therefore, it is not known whether or not she spawned.

Of the remaining females for which blood plasma was analyzed, all but two had low hormone levels consistent with a nonreproductive state (table 4). Female PLS07-001 was evaluated on September 21, 2010, when water temperature was 19.7°C and found to have black eggs. No sample was obtained for PI, however, hormone levels were similar to those measured for pallid female PLS10-031 in the fall of 2009 and believed to be normal for this reproductive condition and date. Based on this profile PLS10-031 would be expected to spawn in spring 2011. The hormone and reproductive stage profile for female PLS08-006 is inconsistent because it was assessed as non-reproductive yet movement patterns and locations from 2007 to 2008, 2008 to 2009, and from 2009 to 2010 were identical and reminiscent of spawning pattern. Blood collected on October 13, 2010, also was uncharacteristic of a nonreproductive female, with low E2 and high T. Hormones and behavior appear more consistent with this fish being a male.

Six males provided to the broodstock program and successfully induced for milt collection were implanted with transmitters before their return to the Missouri River. Plasma hormone analysis of these individuals upon release from the hatchery in late April and early May indicated all had low E2 and elevated androgens consistent with their reproductive state (spermiating; table 5). Five males were tracked through the spawning period. PLS08-002, PLS08-019, and PLS09-013 in late March and early April had high androgen levels with low E2 and when recaptured in the fall androgens had greatly decreased indicating the fish had cycled and likely spawned. Similarly, PLS08-039 and PLS10-005 had low E2 and high androgen levels early to mid-April. Although not recaptured in the fall, their hormonal indicators in spring suggested they could have cycled and could have spawned. At this time, there is insufficient information on male hormonal and reproductive status throughout its cycle to fully interpret these reproductive indicators.

Of the remaining 18 fish, only two individuals collected between March and early June may have been reproductive based on hormone levels (table 5). Plasma hormones for an intersex pallid, PLS10-028, which was induced to spawn, were analyzed on May 6, 2010. These hormones had low E2 and moderate levels of androgens. Whereas induced male brood fish at about the same time of year (PLS08-042, PLS10-014, PLS10-020, PLS10-021, PLS10-022, PLS10-030) had higher levels of T or 11KT. All other fish had low E2 and low androgens and were non-reproductive. Hormone levels of three males captured and evaluated only in the fall (PLS08-015, PLS08-053, PLS09-005) suggest they may have spawned in spring 2010.

Objective 2: Identification of likely environmental cues associated with key stages in the reproductive cycle.

In the experiment to characterize the ability of free embryos to fill the swim bladder, hatching began at 0900 hours on Day 1 of the observations. Hatching was complete after 3900 hours. Because of the length of the water columns temperature control was difficult to maintain, and mortality was observed between hours 4000 and 5000. Within 1.5 hours of the initiation of hatch three free embryos had swum to the top of the 2.4-meter section of pipe, therefore, another 1.6-meter section was added. During the 2 days, some free embryos were always observed near the top of the 4.0-meter column and, in general, the free embryos used the upper one-half of the column (fig. 18). However after 50 hours, all free embryos were found in the lower one-half of the column. The experiment was ended at that time; therefore, it is not known how long the free embryos remained in this position. One conclusion from this experiment is that the free embryos are able to get to the water surface, at least under conditions similar to those provided in the experiment, to fill the swim bladder. Therefore, pallid sturgeon likely do not have to deposit eggs at shallow depths (less than 4 meters) to ensure that free embryos are able to access the water surface to fill their swim bladders.

In the second experiment, the effect of varying turbidities on adhesion of pallid eggs to surfaces and the rate they fell through a 2.4 m column of water (fig. 17) was investigated. Eggs tested at all turbidities failed to adhere to rocks at the bottom of the column. However, eggs that passed through clear water did adhere to the rocks at the bottom of the 2.4 m column. Limited numbers of eggs prevented testing egg adherence at different turbidities and depths. Qualitative observations during the present studies suggest that eggs lose their adherence within 0.3 to 0.6 m below the surface after release into the turbid water. Fall rate of the eggs increased slightly at greater than or equal to 200 NTU (nominal) to an average of 1.98 m/sec (table 6). This information together with water

Table 5. Plasma hormone values for male pallid sturgeon collected 2010. Upper limits of detection are estradiol=734, testosterone=686, and 11-Ketotestosterone=496. Lower limits of detection are estradiol=5, testosterone=4, 11-ketotestosterone=3.

[Fish ID, fish identification code; pg/mL, picograms per milliliter; >, greater than; <, less than; LOD, limit of detection]

Fish ID	Date (month/day/year)	Estradiol (pg/mL)	Testosterone (pg/mL)	11-Ketotestosterone (pg/mL)
PLS07-020	3/10/2010	45	1,087	43
PLS08-002	4/1/2010	55	14,731	>LOD
PLS08-002	9/22/2010	25	4,152	443
PLS08-015	10/15/2010	84	11,952	7,171
PLS08-019	3/31/2010	22	13,323	>LOD
PLS08-019	9/20/2010	93	5,744	2,371
PLS08-039	4/2/2010	90	>LOD	>LOD
PLS08-042	4/29/2010	33	>LOD	3,673
PLS08-043	6/8/2010	<LOD	306	27
PLS08-053	9/15/2010	88	5,639	1,356
PLS09-002	3/5/2010	19	2,117	88
PLS09-005	9/22/2010	69	5,240	610
PLS09-013	4/15/2010	<LOD	>LOD	2,399
PLS09-013	9/8/2010	<LOD	4,424	422
PLS10-001	3/2/2010	86	1,092	33
PLS10-005	4/15/2010	3	>LOD	>LOD
PLS10-009	4/8/2010	83	3,039	93
PLS10-014	4/29/2010	<LOD	6,730	>LOD
PLS10-020	4/29/2010	<LOD	5,075	>LOD
PLS10-021	4/29/2010	<LOD	10,600	>LOD
PLS10-022	4/29/2010	52	>LOD	>LOD
PLS10-024	4/28/2010	88	1,657	91
PLS10-027	5/5/2010	7	1,103	107
PLS10-028	5/6/2010	26	7,917	1,976
PLS10-030	5/7/2010	<LOD	11,389	8,425

velocity can be used to estimate where eggs ovulated at a given depth could be deposited.

Studies at CERC in previous years (DeLonay and others, 2010) have tentatively identified the MIH (maturation inducing hormone) for *Scaphirhynchus* sturgeon; however, validation testing is incomplete. Therefore, in 2010 eggs were collected from a shovelnose sturgeon to perform a bioassay with extracts of ovarian tissues believed to contain MIH that were collected and prepared in spring 2009. Unfortunately, the only available eggs were of poor quality and the bioassay failed. The bioassay will be repeated again in 2011.

Tissues from 53 fish were collected for future analysis of gene expression using the sturgeon microarray (table 7). The experiment to assess the genes expressed in the ovary for the reproductive season will include two time points before spawning and one time point post spawn (March, April, and May) and use four replicate females for each time point. The second experiment to identify sex and reproductive stage differences in gene expression in the barbel will use four replicate individuals of males and females in reproductive and nonreproductive condition. Fish used in these experiments can be found in table 8.

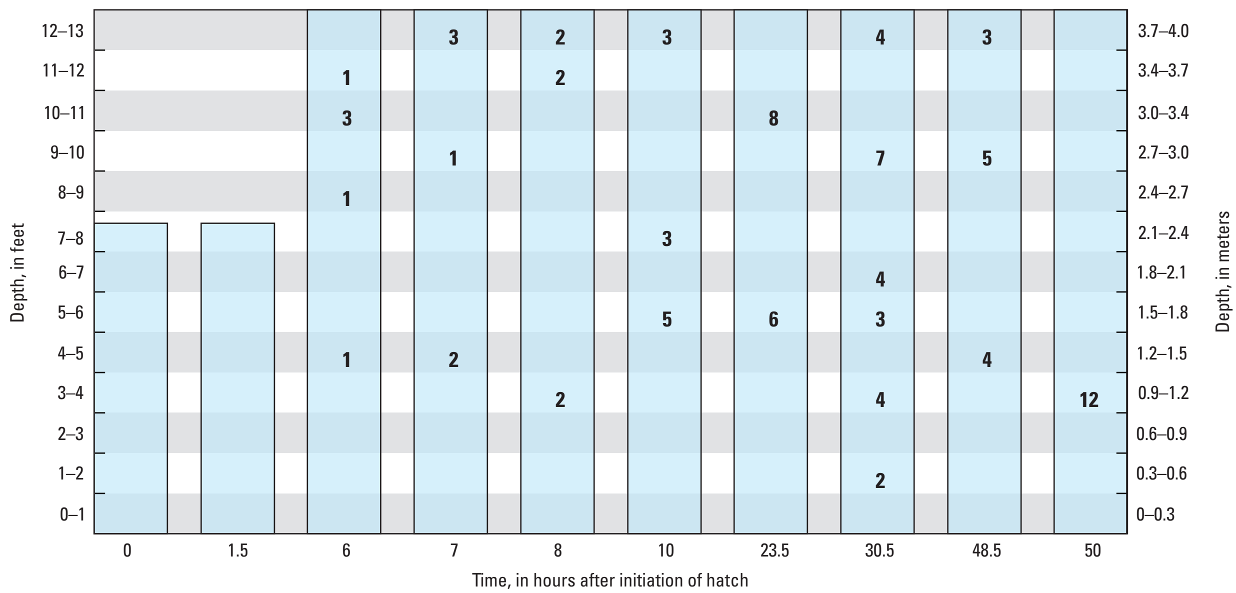


Figure 18. Depth distribution of free embryos observed during 5-minute periods at various times for a 50-hour time span after the initiation of hatch. Observations began at hatch (at 0900 hours on the first day) and continued until 1100 hours on the third day of the experiment. Blue bars indicate the depth of the water column at that time during the experiment. Numbers in bold indicate the number of free embryos observed at that depth strata during an observation.

Table 6. Test results for the fall rate of freshly fertilized pallid sturgeon eggs in four turbid conditions.

[NTU, nephelometric units; m/sec, meters per second]

Nominal (NTU)	Actual (NTU)	Average (m/sec)
0	1	1.90
100	97	1.91
200	280	1.95
400	355	2.04
800	689	1.95

Table 7. Tissues collected from pallid sturgeon in 2010 for genomics analysis.

Sex	Reproductive status	Tissue		
		Barbel	Gonad	Fin
Female	Non-reproductive	16	0	16
Female	Reproductive	6	18	6
Male	Non-reproductive	7	0	7
Male	Reproductive	11	0	11
Intersex	Reproductive	1	1	1

Table 8. List of fish used in the genomics experiments.

[Fish ID, fish identification code]

Fish ID	Experiment
PLS08-014	2
PLS10-006	1
PLS10-007	2
PLS10-012	1 and 2
PLS10-013	1 and 2
PLS10-014	1 and 2
PLS10-015	2
PLS10-016	2
PLS10-017	2
PLS10-018	2
PLS10-019	2
PLS10-020	2
PLS10-021	2
PLS10-022	2
PLS10-023	2
PLS10-024	2
PLS10-029	1
PLS10-031	1
PLS08-042	2
PLS11-007	1

Task 3. Quantify Pallid Sturgeon Migration and Spawning Habitat

Background

In 2010 as in previous years, hydroacoustic assessments were used to quantify habitat used by pallid sturgeon and habitat that were available but not used in order to understand habitat selection. By coordinating with studies of reproductive movements and physiology, patterns of habitat selection can indicate whether specific habitats are limiting in the reproduction and survival of pallid sturgeon. Because of the fundamental role of spawning in population dynamics (Quist and others, 2004; Bajer and Wildhaber, 2007; Wildhaber and others, 2007), definition and quantification of spawning habitat was emphasized in 2010 as in previous years. Recognizing that previous information supports the hypothesis that spawning substrate itself may not be limiting for pallid sturgeon on the Lower Missouri River (DeLonay and others, 2009; DeLonay and others, 2010), assessments also were conducted of habitats used by upstream migrating reproductive sturgeon.

Scope and Objectives

The first project objective for Task 3 was to survey spawning habitats in order to replicate assessments conducted in previous years and to continue increasing understanding of the role of habitat that has been a subject of previous reports (Reuter and others, 2008; Elliott and others, 2009; Jacobson and others, 2009; Reuter and others, 2009). The goal of this objective is to distinguish those environments that pallid sturgeon occupy during spawning from those that they avoid. For these assessments, an enhanced, high-resolution habitat-mapping protocol was deployed as described below (and as used in previous years) around fish locations identified by telemetry crews.

The second objective was to survey habitats associated with upstream-migrating reproductive pallid sturgeon. These surveys were designed to test the hypothesis that migrating fish take paths that minimize the energetic expenditure necessary to arrive at spawning sites. Understanding of migration paths, and the energetic costs involved in navigating them, may lead to channel re-engineering designs that increase fecundity of reproductive fish. This work began in 2010 and will help provide an understanding of the effects of spawning migrations on reproductive success.

Methods

Habitat survey methods employed in 2010 replicated those used in 2008 and 2009; detailed documentation of methods are on file at USGS-CERC. For spawning habitat objective, fish locations were selected based on their likelihood as spawning sites as documented by telemetric data. The R/V Brush hydroacoustic survey boat was deployed to a fish location for high-resolution multibeam bathymetry and acoustic Doppler current profiler surveys within 10 percent of the discharge that existed when the fish was located. An additional goal was to survey the reach within 24 hours of when the fish was located, but this was not always possible. For the second objective of mapping migration habitats, the R/V Brush carried out hydroacoustic surveys over fish locations as it followed the upstream movements of tagged fish. Some of these surveys occurred in near real-time with the survey vessel following as closely as 15 minutes behind the fish. All surveys were completed within 10 percent of discharge that existed when the fish were located.

The R/V Brush is equipped with a dual-receiver Global positioning system (GPS) and inertial motion-sensing system, a multibeam echosounder for detailed mapping of the riverbed, and an acoustic Doppler current profiler (ADCP) for mapping current-velocity fields. GPS base-stations were used to obtain real-time kinematic (RTK) positioning with nominal positioning errors of +/- 0.02 m horizontal and +/- 0.1 m vertical. The multibeam system is a RESON SeaBat® 7125 (RESON, Inc., Slangerup, Denmark) operating at 455 kilohertz (kHz). The transducer and receiver arrays are mounted on the front of the survey vessel on a tilt-up mount. The multibeam system collects data from 512 beams at 0.25 degree spacing and is capable of mapping depths of approximately 1–200 m. The geometry allows a 128° swath covering a width of approximately four times the water depth. Positioning and motion sensing data were acquired using an Applanix POS-MV Wavemaster® system receiving broadcast RTK corrections from the base station. This unit also provides corrections for vessel heading, pitch, roll, and heave that are used to calculate sounding locations in conjunction with the multibeam sonar.

The multibeam system and boat mount were calibrated with a “patch” test that corrects for internal geometry of the boat, transducer/receiver, and GPS receiver. Patch test results were used to update geometry files used by the data acquisition software. In addition, sound-velocity profiles were collected to assess stratification of sound-velocity with depth. HYPACK/HYSWEEP® software (Hypack, Inc., Middletown, Conn.) was used to acquire, compile, correct, and edit GPS and multibeam data. Hypack and RESON provide real-time quality-control displays that are monitored to ensure quality data are collected. Total propagated vertical errors have been estimated at 0.06–0.15 m (Huizinga and others, 2010).

For high-resolution surveys, longitudinal survey lines were laid out in Hypack at intervals to assure at least 50-percent overlap in multibeam coverage. The lines were parallel to the flow of the river and centered over the chosen fish location. A helm display showed the boat pilot the boat position and the quality and extent of incoming data.

Multibeam files were edited in the office to remove erroneous data. These data were subsequently exported from the Hypack environment and imported into ArcMap (ESRI, Redlands, Calif.) where the data were gridded for analysis and display.

Current velocity fields were mapped using either a 600 kHz or a 1,200 kHz acoustic Doppler current profiler (Teledyne RD Instruments, Poway, Calif.). During high water discharge and high turbidity conditions, the lower frequency unit was required to achieve acoustic penetration to full river depth. When possible, the higher frequency unit was used because its measurements are made at a finer vertical resolution. ADCP data were logged simultaneously with GPS data on a laptop computer running WinRiver® (version 10.06, Teledyne RD Instruments, Poway, Calif.). Magnetic variation was set for each reach mapped by using GeoMagix® software (Interpex, Ltd., Golden, Colo.). Mapping crews performed the “Method 3” compass calibration procedure at each site by rotating the boat in a tight circle (RD Instruments, 2003). This procedure corrects for one-cycle compass errors. The procedure was repeated until the total error reading was less than 1 degree. Configuration settings for ADCP data have a vertical resolution of 0.25 m (1,200 kHz) or 0.50 m (600 kHz) and a blanking distance of 0.50 m below the transducer head. ADCP data were collected using water mode 1 with six water pings and bottom mode 5 with one bottom ping.

For spawning habitat surveys (objective one), channel cross-section lines for the ADCP survey were laid out in a grid with 20 m spacing in the direction of water flow over an area that equally covered the multibeam survey, approximately twice the width of the river. For migration habitat surveys (objective two), channel cross-section lines were laid out orthogonally to the local flow direction through the points where the fish was located. The spacing of these lines was determined by the rate of movement of the fish upstream and the rate at which a single cross-section could be surveyed or the fish could be relocated.

Velocity data were edited in the office and exported from WinRiver into generic text files. These data were subsequently imported into ArcMap or MATLAB (The Mathworks, Natick, Mass.) for further processing and gridding.

Results

Four locations (two spawning locations and two migration locations) were mapped (table 9) using the high-resolution multibeam habitat protocol. This totals approximately 3 miles of channel. One spawning reach was located in the upstream segment near the outlet of the Boyer Chute (not shown) (PLS10-013, fig.19, 20), and one spawning reach was located in the downstream segment near the confluence of the Lamine (not shown) and Missouri Rivers (PLS10-006, fig. 21, 22). The number of spawning sites mapped was limited by the number of sites documented by tracking crews; tracking crews were not able to track all tagged, reproductive fish intensively to spawning sites because of a shortage of crews when fish were spawning simultaneously, at multiple sites. Seven independent migration pathways were surveyed (table 9) covering approximately 50 miles of the paths of four fish (males, PLS09-013 and PLS10-023, and females, PLS10-006 and PLS08-014). Four of the pathways were located in the lower river segments and three were located in the upper river segments (fig.1).

Spawning by sturgeon PLS10-006 was confirmed to have occurred between river mile 202.0 and river mile 202.4 (fig. 19, 20). Spawning by sturgeon PLS10-013 was confirmed to have occurred between river mile 633.7 and river mile 634.2 (fig. 21, 22). Habitat surveys at both of these locations indicate spawning could have occurred in a variety of

Table 9. Summary data for habitat assessment efforts in 2010. Habitat Surveyed denotes habitat type. River mile location gives the upstream and downstream extent of each survey. Discharge is reported as the mean discharge through the course of the survey at the streamgage given in the nearest streamgage column. Survey Type denotes the methods used for each survey as described in the Task 3 methods section.

[Fish ID, fish identification code; ft^3/s, cubic feet per second; ADCP, acoustic doppler current profiler]

Habitat surveyed	Fish ID	Date (month/day/year)	River mile location	Nearest streamgage (fig. 1)	Discharge ft.^{3}/s	Survey type
Migration	PLS09-013	4/21/2010	266.3–269.3	Waverly, Missouri	73,100	ADCP.
Migration	PLS10-006	4/22/2010	185.1–186.6	Boonville, Missouri	77,300	ADCP.
Migration	PLS10-006	4/28/2010	198.6–199.6	Boonville, Missouri	191,000	ADCP.
Migration	PLS10-006	4/29/2010	201.5–201.7	Boonville, Missouri.	168,000	ADCP.
Spawning	PLS10-006	5/1/2010	201.8–202.5	Boonville, Missouri	112,000	ADCP & Multibeam.
Spawning	PLS10-013	5/5/2010	633.3–633.8	Omaha, Nebraska.	40,500	ADCP & Multibeam.
Migration	PLS10-023	5/19/2010–5/20/2010	632.6–660.0	Omaha, Nebraska	44,600	ADCP.
Migration	PLS08-014	5/24/2010–5/26/2010	663.6–675.5	Decatur, Nebraska	36,700	ADCP & Multibeam.
Migration	PLS08-014	5/26/2010–5/27/2010	658.1–662.4	Decatur, Nebraska	36,300	ADCP & Multibeam.
Migration	PLS10-006	7/23/2010	198.7–199.7	Boonville, Missouri	192,000	Multibeam.
Migration	PLS09-013	8/31/2010–9/1/2010	231.9–232.5	Glasgow, Missouri	91,500	Multibeam.

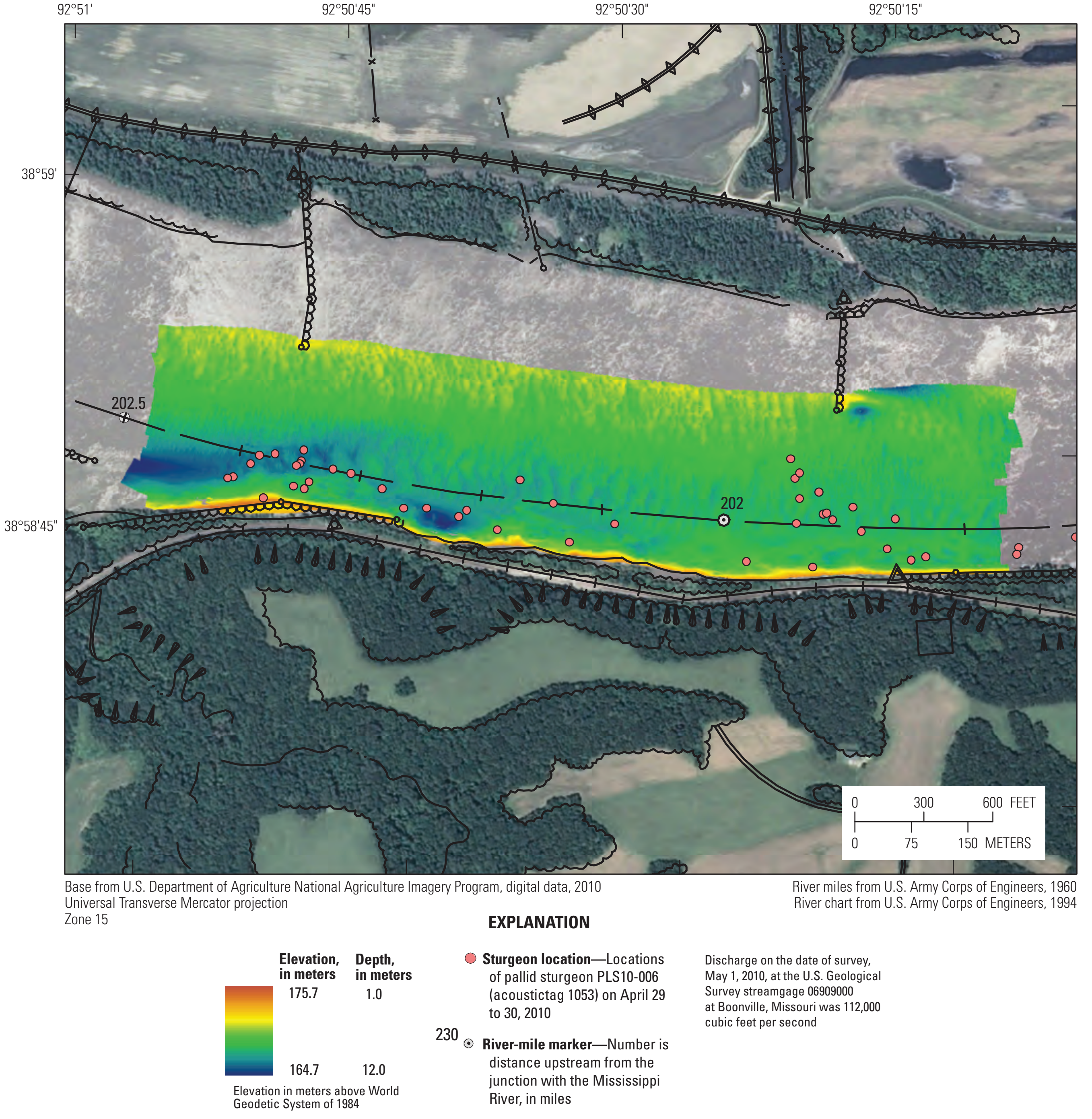
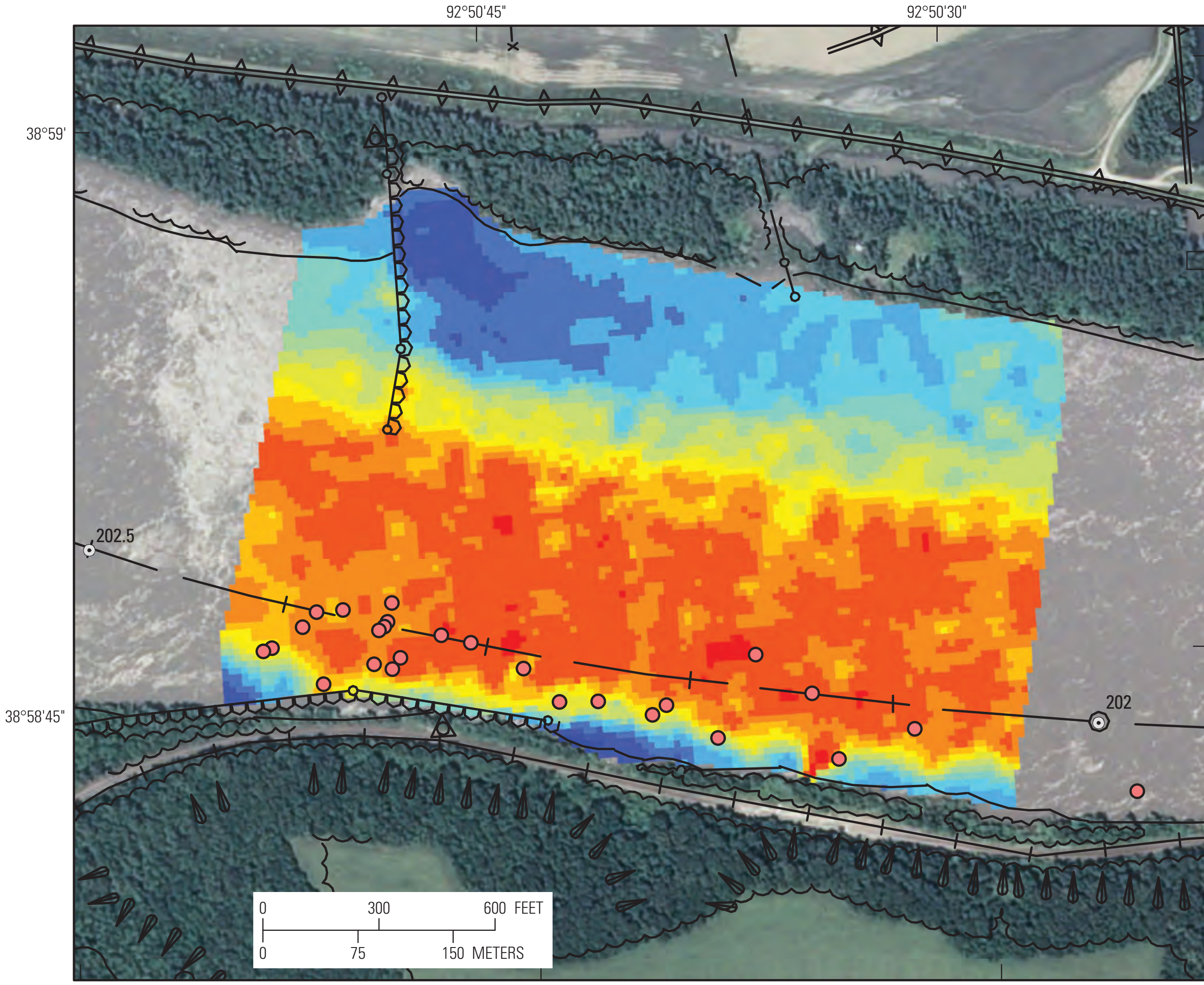


Figure 19. Multibeam bathymetric map of reproductive female pallid sturgeon PLS10-006 spawning site. Mapped May 1, 2010.



Base from U.S. Department of Agriculture National Agriculture Imagery Program, digital data, 2010
Universal Transverse Mercator projection
Zone 15

River miles from U.S. Army Corps of Engineers, 1960
River chart from U.S. Army Corps of Engineers, 1994

EXPLANATION

Depth-averaged velocity, in meters per second

- 0 to 0.2
- Greater than 0.2 to 0.4
- Greater than 0.4 to 0.6
- Greater than 0.6 to 0.8
- Greater than 0.8 to 0.9
- Greater than 0.9 to 1.0
- Greater than 1.0 to 1.1
- Greater than 1.1 to 1.2
- Greater than 1.2 to 1.3
- Greater than 1.3 to 1.4
- Greater than 1.4 to 1.5
- Greater than 1.5 to 1.6
- Greater than 1.6 to 1.8
- Greater than 1.8 to 2.0

Sturgeon location—Locations of pallid sturgeon PLS10-006 (acoustic tag 1053) on April 29 to 30, 2010

230 **River-mile marker**—Number is distance upstream from the junction with the Mississippi River, in miles

Discharge on the date of survey, May 1, 2010, at U.S. Geological Survey streamgage 06909000 at Boonville, Missouri was 112,000 cubic feet per second

Figure 20. Acoustic Doppler current profiler velocity map of reproductive female pallid sturgeon PLS10-006 spawning site. Mapped May 1, 2010.

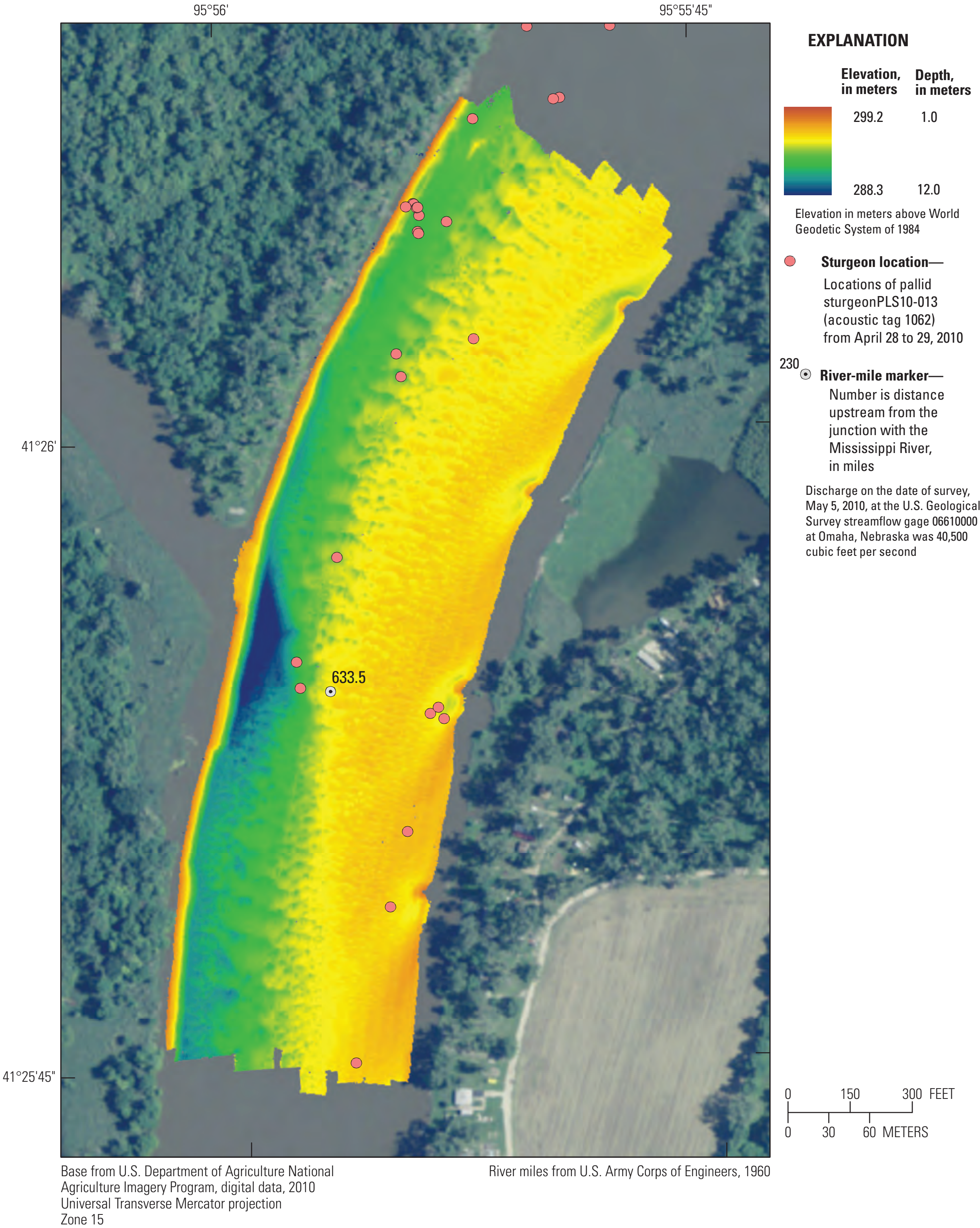


Figure 21. Multibeam bathymetric map of reproductive female pallid sturgeon PLS10-013 spawning site. Mapped May 5, 2010.

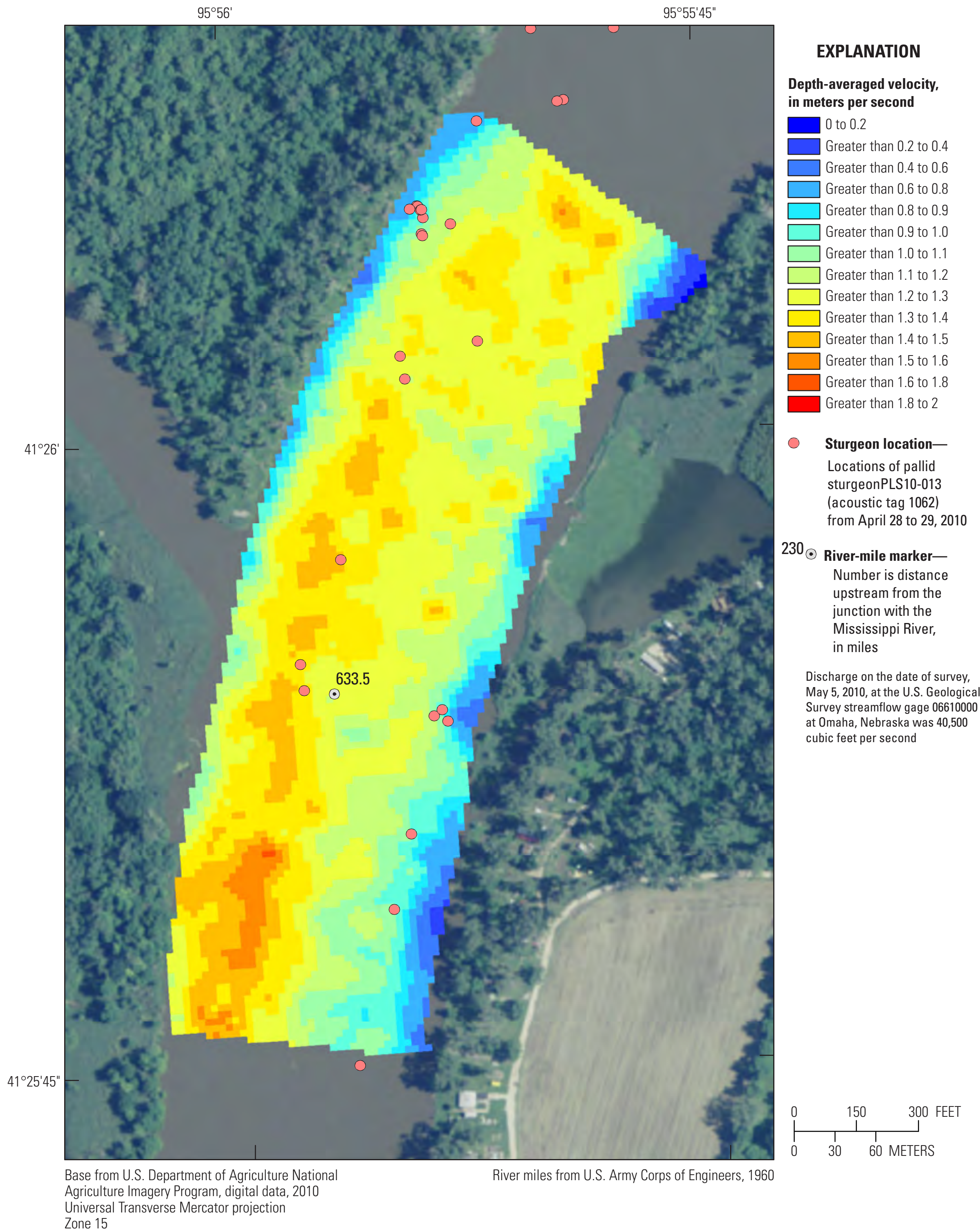


Figure 22. Acoustic Doppler current profiler velocity map of reproductive female pallid sturgeon PLS10-013 spawning site. Mapped May 5, 2010.

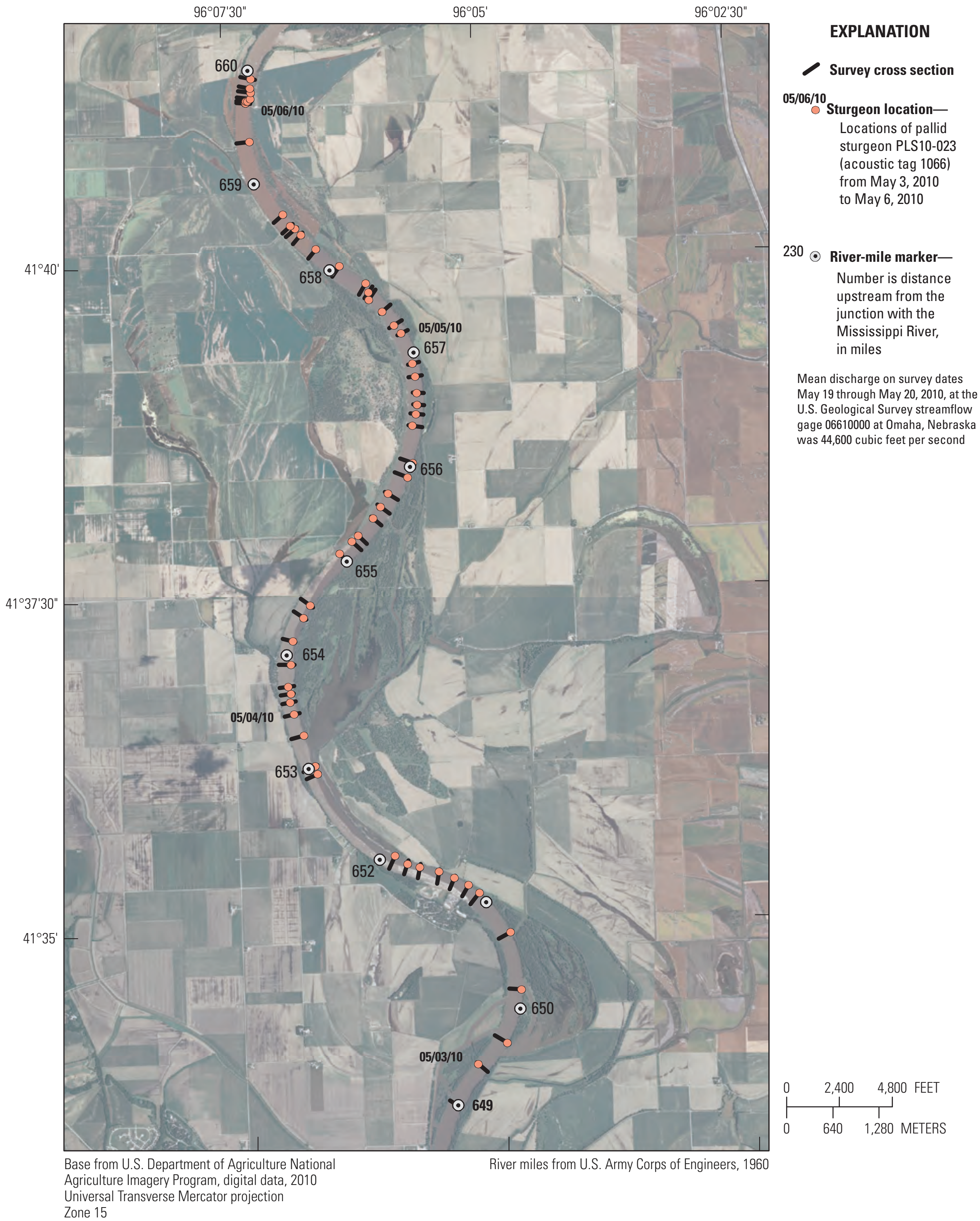


Figure 23. PLS10-023 migration pathway between river mile 651 and river mile 656, May 3 through May 6, 2010.

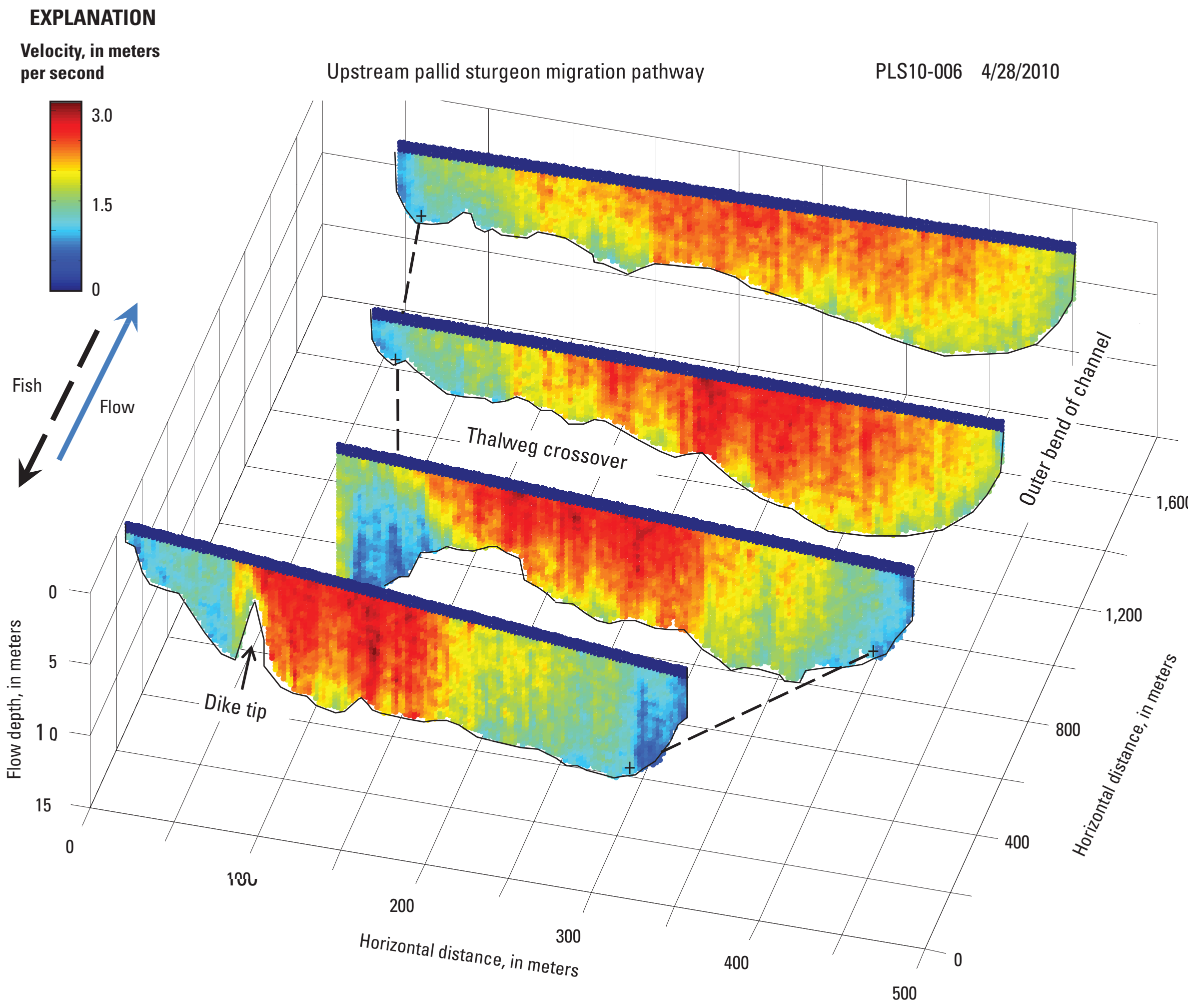


Figure 24. Perspective view of reproductive female pallid sturgeon PLS10-006 traversing flow velocity field through a bend-crossover-bend reach between river mile 198.7 and river mile 199.

substrates along the outer banks of channel bends in some of the deepest and fastest waters locally available.

During upstream migration all tracked fish were observed to follow a general path that follows the inside bank of a channel bend, crosses the river where the navigation channel crosses in the opposite direction, and continues up the inside bank of the subsequent channel bend (fig. 23). Combining DST depth estimates from individual fish with ADCP survey channel depths indicates that the tracked sturgeon generally migrate upstream maintaining vertical positions near the bottom of the water column (fig. 24). The pathways selected are distinguished from the multitude of unselected pathways by relatively slower flow velocities.

Spawning was observed to occur near the outer banks or generally within deep, fast-moving water. Hence, near the end of their migrations, sturgeon must move away from the inner bends of the channel (relatively slower, shallower waters) to the fast, deep spawning habitat. This was observed to occur in close proximity to both spawning locations (for example, fig. 19, 21).

Task 4. Provide Database Integration, GIS Support, and Report Coordination

Background

The research activities of CSRP generate large volumes of data about the physiology, ecology, and habitat requirements of pallid and shovelnose sturgeons. These data may be useful in addressing management needs if they are properly organized, effectively displayed, carefully interpreted, and expeditiously published. In recognition of the critical role of information management CSRP has developed a robust platform for data collection, integration, maintenance, analysis, visualization, and distribution of project data.

Scope and Objectives

The general objectives of Task 4 have been to (1) develop and maintain a standardized mobile mapping and electronic data-collection framework to support simultaneous data collection from multiple field crews, (2) compile and maintain data collected for CSRP, and (3) develop and maintain near real-time data reporting.

Methods

The Sturgeon Information Management System (SIMS) was developed as a central platform for data collection, maintenance, and exploration of the large volumes of data generated by CSRP. SIMS was developed using a variety of products to accommodate the types of data and the demand for near real-time updates. ArcPad® and ArcGIS® (ESRI, Redlands, Calif.) have been used to collect and manage the geospatial data (such as telemetry locations for all individual sturgeon). SQL Server 2008® (Microsoft Inc., Seattle, Wash.) is used to manage tabular data (including gender, length, and weight for example). In addition, a custom SIMS user interface has been developed in Microsoft Access® (Microsoft Inc., Seattle, Wash.) to allow quick access to near real-time reports that incorporate information from spatial and tabular data (DeLonay and others, 2010).

Results

The SIMS platform continued to record and maintains geospatial data detailing all sturgeon telemetry locations and search-effort location data from the CSRP tracking efforts during 2010. Since 2004, more than 12,500 pallid and shovelnose sturgeon locations have been recorded and archived using SIMS. During 2010, USGS and NGPC field crews recorded more than 1,875 pallid sturgeon locations during more than 450 search efforts. Additionally, SIMS has recorded and archived 32 initial telemetry device implantations and 35 evaluations and re-implantations of pallid sturgeon during 2010. These data are linked to other morphological, physiological, and environmental data within the SIMS database framework, making it possible to maintain data and reports in a near real-time environment (DeLonay and others, 2010).

During 2010 the SIMS relational database was converted to a 64-bit server and SQL Server 2008® (64-bit compatible) to provide a faster and more stable platform. During this upgrade, the near real-time linkages between the geospatial telemetry data and the database were upgraded to virtual tables, which provide increased user performance. The Microsoft Access® based SIMS user interface also required additional programming to meet SQL Server 2008® standards. The reprogramming of numerous reports and data entry forms to ensure 64-bit compliance also allowed further streamlining of the user interface and improved functionality. For example, the Individual Fish Summary page illustrates many of the improvements made possible by transitioning to a 64-bit platform (fig. 25). In addition, a mapping functionality was added to the Individual Fish Summary page allowing a user to obtain a near real-time ArcGIS map of all the telemetry locations for an individual fish. This functionality opens an ArcGIS map, which allows a user to interact with the data and is preformatted to USGS standards for export to a document or presentation (fig. 26). Other additions to the Individual Fish Summary page allow a user to obtain DST data within a formatted chart in SigmaPlot® (Systat, Inc., Chicago, Ill.), view any DIDSON® video footage that may exist for an individual fish and export pertinent information about particular fish directly to a crew member in the field by way of SMS (Short Message Service) text message (fig. 27). The improved Individual Fish Summary Report allows scientists to access all available information quickly and easily, compressing decision cycles.

The existing SIMS framework was used to incorporate and leverage an increasing amount of ancillary data. In 2010, additional tables were created to maintain data storage tag (DST) records, hatchery and broodstock information, temperature logger data, and a digital chain of custody for tissue samples. More than 1.7 million records obtained from DST devices recovered from 62 telemetered pallid sturgeon have been imported into the SIMS database framework. The SIMS user interface also allows a user to quickly filter and display these records graphically, within the SIMS user interface or by opening preformatted charts within SigmaPlot®. Information regarding the capture, reproductive condition, and use of the nearly 80 fish received from the broodstock propagation program and implanted with transmitters was added to SIMS. This information is included on the Individual Fish Summary page. Additionally, more than 300,000 temperature logger data records at 28 locations from 2002 to 2010 have been incorporated into the SIMS database. The SIMS user interface allows a user to interactively select and chart the temperature data at any number of these stations (fig. 28). Tables and reports also have been developed within SIMS to provide a digital chain of custody detailing the location and status of genetics and physiology tissue samples collected by field crews and analyzed by laboratory staff or partnering agencies.

During 2010, reporting process for Federal and several State endangered species collectors permits were streamlined substantially by automating the compilation of information necessary to reapply for multiple permits, each with various data reporting requirements. The resulting automated reports provide more efficient data reporting to permit-granting agencies. Reports also were developed to increase efficiency of the data-verification process. These verification reports highlight possible inconsistencies within the database, thereby enabling the data reviewer to quickly discover discrepancies within the data.

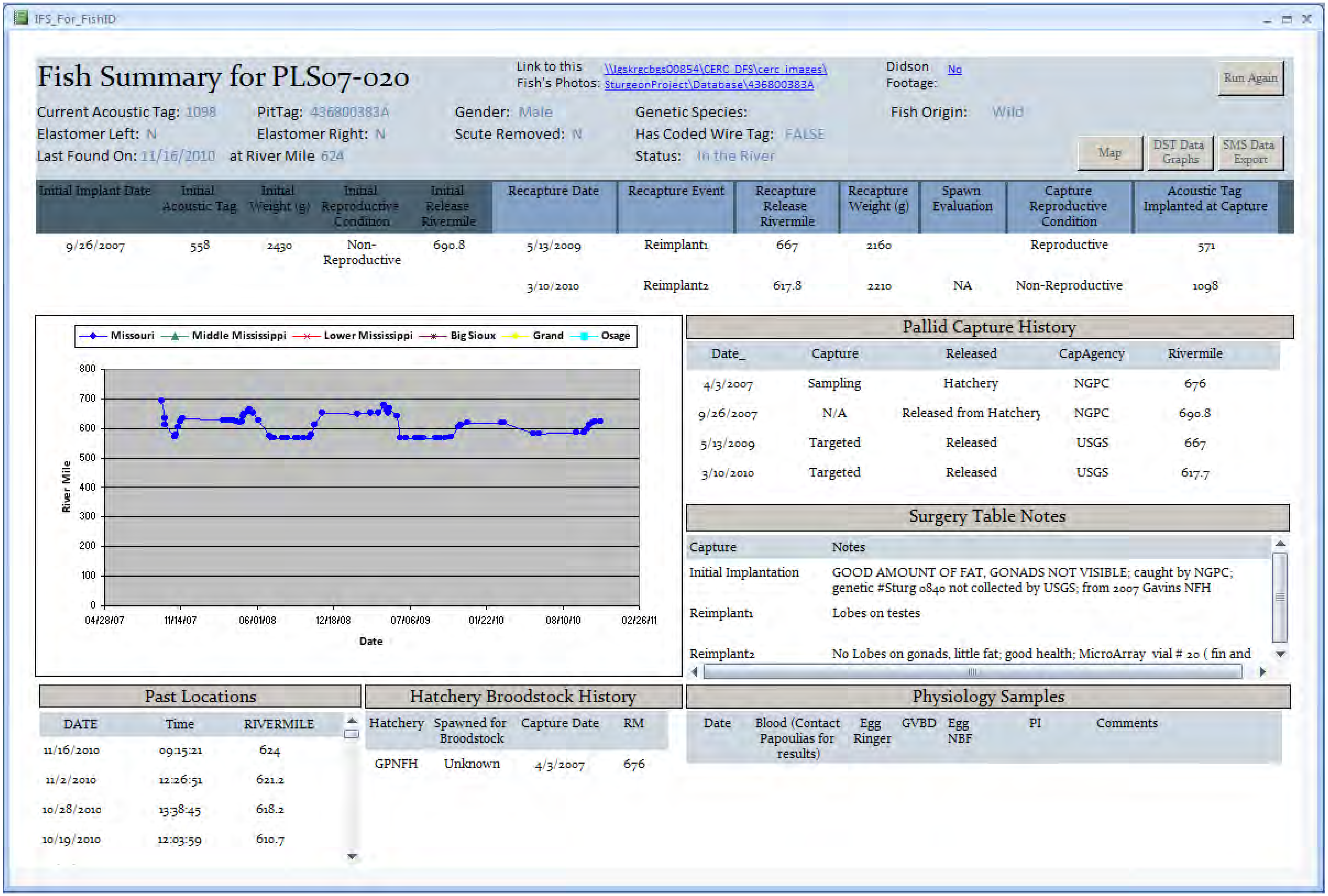


Figure 25. Example of the Individual Fish Summary page generated by the user interface.

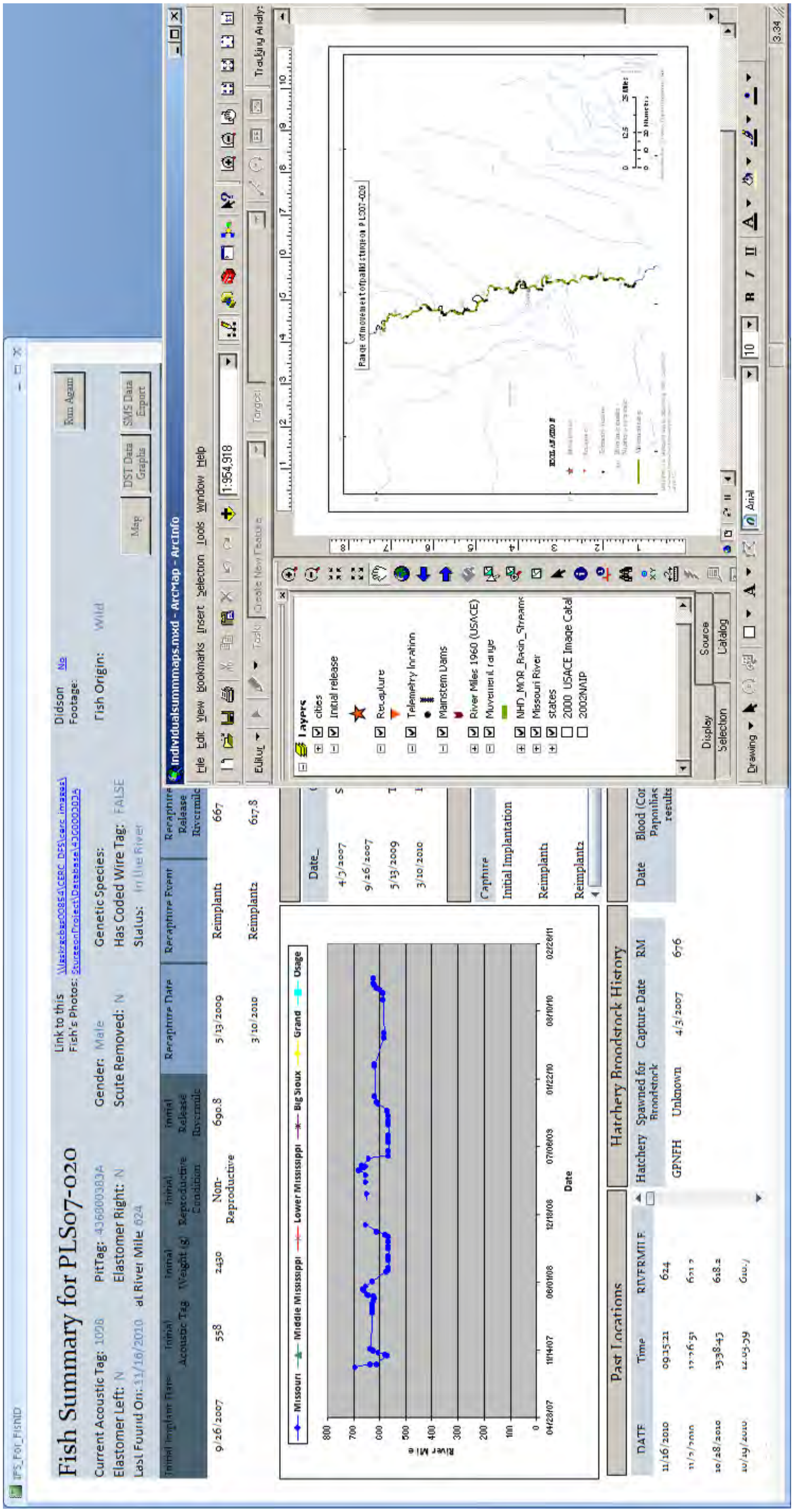


Figure 26. The Individual fish Summary Report links to a preformatted map ready for export.

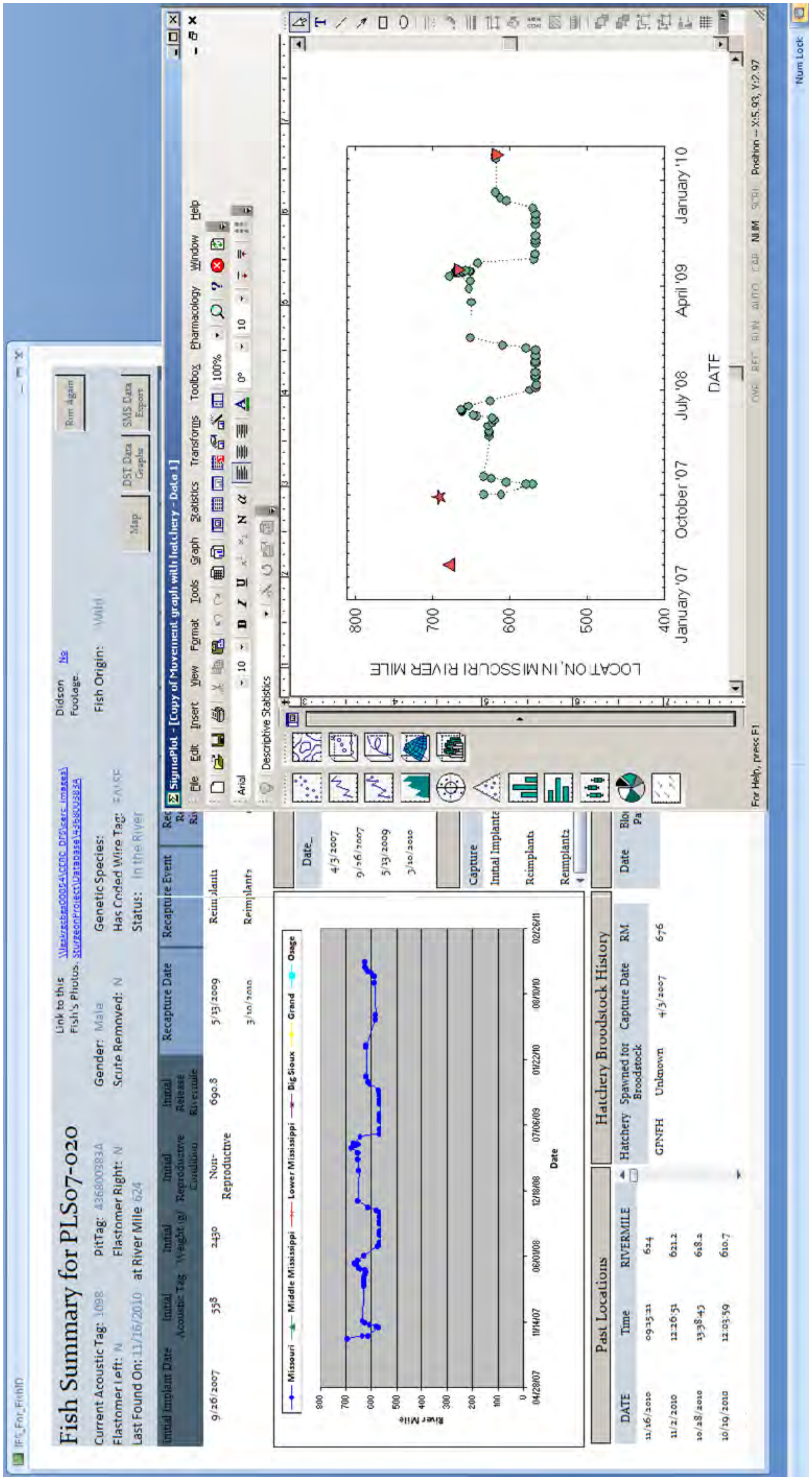


Figure 27. The Individual Fish Summary Page provides access to DST data graphed and formatted for USGS publications.

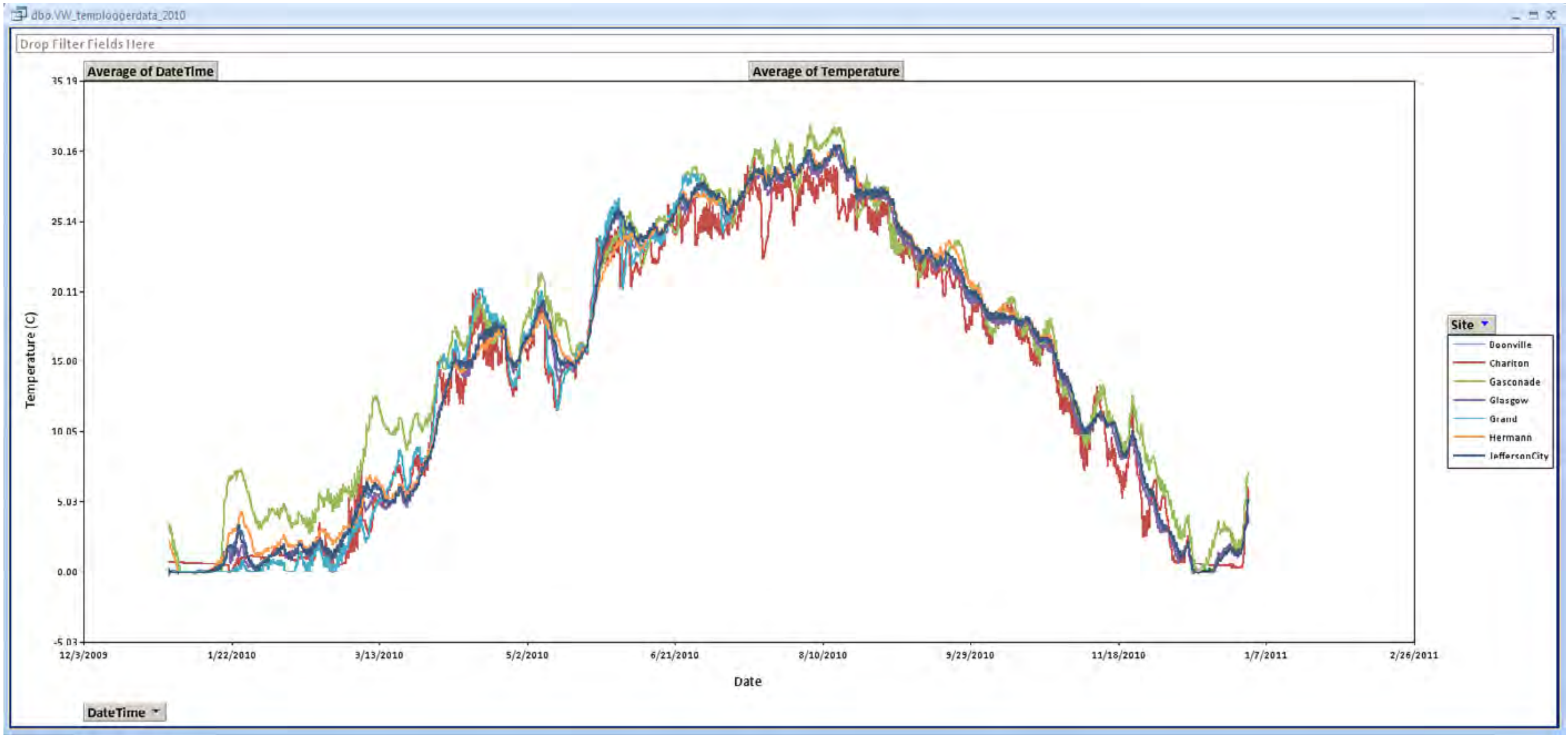


Figure 28. Temperature logger data from approximately 32 different locations for the last 8 years was added to SIMS for storage and exploration.

Incremental Progress in Understanding Pallid Sturgeon Reproduction and Survival

CSRP accomplishments in 2010 added a substantial amount of knowledge about pallid sturgeon reproductive biology by increasing documented migration and spawning events, increasing understanding of how environmental conditions might "cue" reproduction, and adding information on habitats used by reproductive pallid sturgeon in upstream migrations and spawning. This information contributes to the growing knowledge available to decision makers and serves to generate additional hypotheses about constraints on pallid sturgeon reproduction and survival.

Reproductive Movements and Spawning Cues

Migration patterns of reproductive pallid sturgeon documented on the Lower Missouri River in 2010 were similar to those documented in previous years. Females tend to migrate rapidly upstream in mid-April, pause to spawn at an upstream apex, and then drift slowly downstream for weeks to months. Male patterns are less regular and frequently include upstream and downstream movements, giving the impression that they are using multiple strategies to actively search for mates.

Spawning locations documented in 2010 confirm that pallid sturgeon are spawning in multiple places along the Lower Missouri River (fig. 12), similar to previous results from reproductive shovelnose sturgeon (DeLonay and others, 2009). Because this study's sampling design is based on an upstream sample and a downstream sample, the gap in spawning locations between Kansas City and Omaha is to some extent an artifact. The distribution of spawning sites indicates that sturgeon are not limited to spawning at a few specific reaches or patches for spawning. This observation supports a hypothesis that multiple locations exist within the Lower Missouri River with suitable combinations of environmental conditions, including, but not limited to: depth, velocity, substrate, water temperature, and presence of mates. Selection of a location may not indicate that the location is optimal for spawning success, only that it represents a combination of conditions that the fish perceives to be reasonably suitable for spawning at a time when the fish's reproductive system has advanced to a state when gametes need to be released.

Spawning migrations during 2010 indicated no clear, consistent linkages to discharge conditions or flow pulses. Lack of clear linkages does not mean that discharge is not an important variable in sturgeon reproduction, but it does indicate that discharge in the regulated Lower Missouri River does not exert an overwhelming control or may interact with other variables in complex ways. Migration patterns did show relations to water temperature fluctuations, similar to previously documented effects (DeLonay and others, 2009). Temperature effects seem to fall into two categories. The first is a temperature threshold for spawning at 16–18˚C. Water temperatures above this threshold seem to be necessary for spawning, but temperature alone is not sufficient to insure successful spawning because other conditions (presence of mates, substrate, local flow conditions, for example) may not be appropriate. The other effect is a notable relation between changes in water temperature and migration direction or speed. In 2010 documentation was collected of repeat episodes of cold water that were associated with stopping (fig. 7, PLS10-006) or reversing (fig. 9, PLS08-14 in 2008) upstream migration.

Relations between water discharge and water temperature are complex and variable along the Lower Missouri River. The episode of low water temperature during late April 2010 that stopped upstream migration of PLS10-006 was associated with a discharge pulse originating in local tributaries. Similarly, episodes of low water temperature in early April and mid-May were associated with local discharge pulses in the lower section of the river (fig. 4*A*), suggesting an inverse relation between discharge and water temperature in the lower section during spring. In contrast, water temperature variation in the upper section of the river occurred without association with discharge pulses (figs. 6, 8, 9, and 10). Comparison to air temperatures indicates that water temperatures in the upper section of the river may be controlled directly by air temperature (fig. 4*B*). Importantly, these data indicate that water temperatures can vary substantially, and within a range that is effective in affecting sturgeon migrations, independent of discharge pulses. Understanding the different relations between the upstream and downstream sections will require additional analysis of historical temperature records, which may provide important information on the predictability of water temperature and discharge cues in pallid sturgeon reproduction.

Shorter, less-systematic migration patterns also have been observed for upper-section shovelnose sturgeon compared to lower section shovelnose sturgeon on the Lower Missouri River (Wildhaber and others, 2011b). This study was carried out 2004–2007, a period characterized by high upstream to downstream and within-year hydrologic variability. Despite variability in flow the authors did not detect differences in migration pattern by year. The causes for differences in migration pattern remain unknown, but may relate to as-yet unidentified environmental conditions that differ from upstream to downstream. Such conditions may include variation of discharge, availability of tributaries, temperature, turbidity, or other water-quality properties.

Fecundity data developed during 2010 also contributed to hypotheses for an upstream/downstream variation in reproductive potential of pallid sturgeon. This study documents that reproductive females in the upstream section lose substantially less body mass between pre-spawn and post-spawn evaluations compared to downstream females (fig. 13). Lower fecundity of upstream females could relate to lowered reproductive success and may be attributed to various causes including insufficient diet, non-optimal water temperatures, habitat availability, or genetic differentiation among metapopulations.

Multiyear tracking of individual fish has documented examples of geographic fidelity within the Lower Missouri River. PLS07-020, for example, apparently has migrated upstream to spawn twice within a reach of about 10 miles and has returned after spawning to nearly the same location at river mile 566 (fig. 14). If geographic fidelity like this can be confirmed for substantial portions of the pallid sturgeon population, it may be possible to focus channel re-engineering for specific habitats in specific reaches, or to tailor propagation approaches to address specific metapopulations.

Blood hormone profiles of female pallid sturgeon documented in 2010 and in previous years show consistent patterns through time in relation to reproductive cycles, similar to those documented for shovelnose sturgeon (Papoulias and others, 2011). Recognition of these cycles and their timeframes provides a basis for evaluating links to external conditions (or "cues") responsible for initiating or continuing reproductive cycles. In particular, estradiol and 11-ketotestosterone are associated with oocyte growth weeks to months before spawning, whereas gonadotrophic and maturation inducing hormones peak within hours of ovulation and spawning (DeLonay and others, 2009). Hence, blood hormone levels assessed during 2010 helped quantify reproductive readiness of pallid sturgeon, their susceptibility to environmental cues, and their reproductive behaviors.

Potential Habitat Limitations

Migration paths mapped during 2010 confirm that the path followed by the observed migrating sturgeon is, in general, the geographically shortest path to upstream destinations and the least-cost path from an energetic perspective. Because the distance along the inner banks of channel bends is shorter than that along the outer banks, traversal of each bend occurs approximately through the shortest geographic path for that bend. As a fish migrates from bend to bend and upstream their path is less sinuous than the overall path of the channel, and the result is a path that is shorter in distance than the path of the channel centerline (fig. 23). These observations support the previous findings of Reuter and others (2008 and 2009), DeLonay and others (2009). Energetic expenditure during migration is a function of the velocities available to sturgeon along their upstream directed paths. Combining the ADCP surveyed velocities with the DST fish depths and locations during telemetry, the tracked sturgeon were observed to select paths that minimize the energy necessary to arrive at their upstream destination (fig. 24). This hypothesis is not yet supported by enough independent observations to be statistically significant. Because migration difficulty is demonstrated to be related to fecundity in a number of large river fishes (Kinnison and others, 2001; Kinnison and others, 2003; Crossin and others, 2004; Jonsson and Jonsson, 2006), this could have implications for managing fecundity through flow or channel modifications. Similarly, Ridenour and others (2009) found that adult *Macrhybopsis* spp. chubs (makes up 79 percent of juvenile pallid sturgeon diet) were most associated with habitats consistent with the minimal energy expenditure pathway identified in this study, suggesting that pallid sturgeon foraging behavior also may be affected by energetic considerations.

As in previous years, flow and channel morphology data were collected at spawning sites. Results from 2010 support previous interpretations that sturgeon select deep (greater than 3 meters), fast (greater than 1 meter per second), and turbulent flow on the revetted outer banks of channel bends (DeLonay and others, 2010). However, this contrasts slightly with the spawning sites surveyed in the upper river section in 2009. At those sites the sturgeon were spread over a broader area, whereas fish locations within the 2010 site in the upper management unit were concentrated between 10 meters and 12 meters water depth. Additionally, both spawning sites surveyed in 2010 are located adjacent to confluences (Boyer Chute at river mile 633.5; Lamine River at river mile 202.5). The form of channel bottom topography at both spawning sites indicates that revetted rock banks or exposed bedrock or both was readily available for the deposition of eggs as well as large sandy bed forms (that is greater than 30 meters in length) as adjacent flow refugia. These observations also corroborate previous characterization of spawning areas (DeLonay and others, 2009; DeLonay and others, 2010).

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