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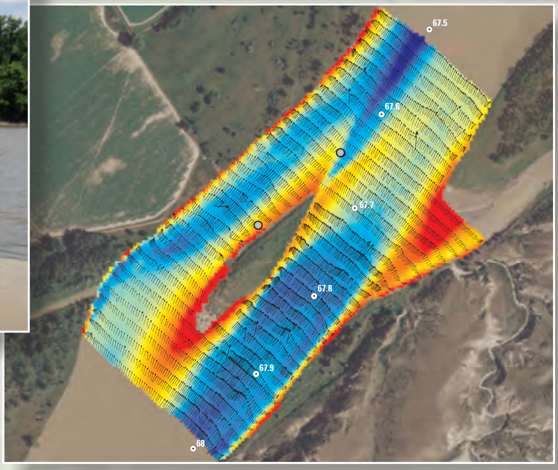
Prepared in cooperation with the Missouri River Recovery–Integrated Science Program
U.S. Army Corps of Engineers, Yankton, South Dakota

Ecological Requirements for Pallid Sturgeon Reproduction and Recruitment in the Missouri River—Annual Report 2011



Open-File Report 2014–1106

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Cover photographs. Microscopic image of a newly hatched pallid sturgeon free embryo (upper left). Hydrographic survey data collection on the Lower Missouri River (lower left, photograph by Chad Vishy, Five Rivers Services, LLC, May 2011). LANDSAT TM image of the area around the confluence of the James and Missouri Rivers on September 25, 2011 (upper right). High resolution multibeam depth and velocity map characterizing the habitat of pallid sturgeon telemetry locations in the Yellowstone River (lower right).

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Volume	
acre-foot (acre-ft)	1233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
million acre-feet (maf)	1233	cubic hectometer (hm^3)
	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	
millimeter (mm)	0.03937	inch (in)
centimeter (cm)	0.3937	inch (in)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	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	
milliliter (mL)	0.03382	ounce, fluid (fl. oz)
cubic meter (m^3)	264.2	gallon (gal)
cubic meter (m^3)	35.31	cubic foot (ft^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	
milligram (mg)	0.00003527	ounce, avoirdupois (oz)
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).

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Abstract

The Comprehensive Sturgeon Research Project is a multi-year, 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 2011 scope of work emphasized understanding of reproductive migrations and spawning of adult sturgeon, and hatch and drift of larvae. These tasks were addressed in three hydrologically and geomorphologically distinct parts of the Missouri River Basin: the Lower Missouri River downstream from Gavins Point Dam, the Upper Missouri River downstream from Fort Peck Dam and including downstream reaches of the Milk River, and the Lower Yellowstone River. The research is designed to inform management decisions related to 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 2011.

Introduction

This report documents research activities under the Comprehensive Sturgeon Research Project (CSRP) for calendar year 2011, January 1 through December 31. The 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), Montana Fish Wildlife and Parks (MTWFP) 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. The following specific objectives were included:

- 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 information relevant to management decisions into the public domain.

Management actions to increase reproductive success and survival of pallid sturgeon in the Missouri River have been focused on re-naturalizing the flow regime, re-engineering 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) and various participating partner agencies have engaged in interdisciplinary research to provide the fundamental information necessary to understand linkages between management actions and sturgeon responses.

The 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 of 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 approach integrates field-based experiments and controlled laboratory studies. The field study plan is designed primarily to explore the roles of flow regime and associated environmental cues in sturgeon reproduction and survival. The design compares sturgeon reproductive behavior among four study sections, which comprise four hydrologic regimes in three segments of the Missouri River system: a Yellowstone River study section, an Upper Missouri River study section, and an upper and lower study section in the Lower Missouri River downstream from Gavins Point Dam. The Yellowstone River study section provides a nearly unaltered flow regime (fig. 2*A*) and channel morphology (fig. 3*A*) that is relatively natural and complex as compared to other sections studied, with the exception of a weir that presumably limits fish passage at Intake, Montana. The Upper Missouri River section has a highly altered flow and temperature regime (fig. 2*B*) because of its location downstream of Fort Peck Dam, and a relatively natural and complex channel morphology (fig. 3*B*). The Upper Missouri River also offers the opportunity to evaluate sturgeon selection of the Milk River, a tributary with relatively high temperature and increased turbidity relative to that available in the main-stem Upper Missouri River. The Lower Missouri River is subdivided into an upper and a lower study section to incorporate an upstream-downstream experimental design approach. The upstream study section of the Lower Missouri River has a highly altered flow regime (fig. 2*C)* and channel morphology that varies between a nonchannelized segment immediately downstream of Gavins Point Dam to the confluence with the Big Sioux River (Gavins segment, fig. 3*C*) and a narrow channelized segment from the Big Sioux River downstream to the confluence with the Platte River (Big Sioux segment, fig. 3*D*). 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. The lower study section of the Lower Missouri River has a flow regime that has recovered some of the natural variability (fig. 2*D*), thereby providing flow pulses in most years. This section also has been channelized, but it has greater width and somewhat greater complexity compared to the Big Sioux segment (fig. 3*E*).

River miles (RM) are the customary linear units of measurement along the Missouri River and are retained in this report for their use in communicating to managers and stakeholders. RM are measured along the Lower Missouri River from 0 at St. Louis. RM along the tributary rivers are measured from 0 at their confluence with the Missouri River.

Scope of Work

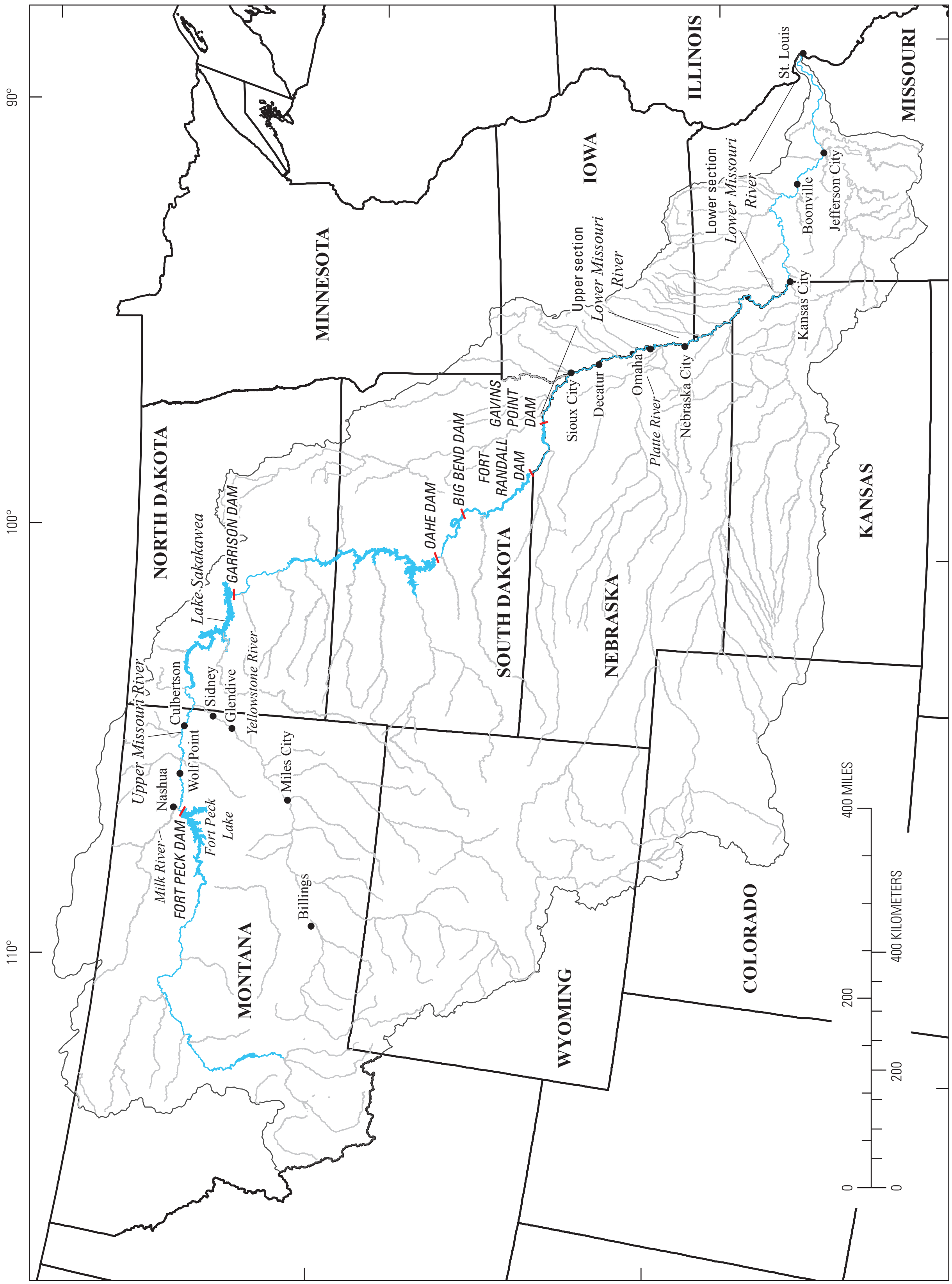
The 2011 scope of work originally was developed around three tasks, but subsequently was amended during April 2011 and expanded to five tasks. These tasks were highly interdependent and designed to provide complementary information for understanding reproductive ecology of the pallid sturgeon. Tasks for 2011 included:

- Task 1 continued previous years' interdisciplinary approach to understanding reproductive ecology of pallid sturgeon emphasizing, and as river conditions permit, documentation of spawning events.
- Task 2 extended this interdisciplinary approach to the Yellowstone River as a pilot project to examine migrations and reproductive ecology in a system characterized by nearly natural flow and thermal regimes.
- Task 3 started research into physiological understanding of the reproductive cycle of pallid sturgeon males to address possible constraints on sturgeon reproduction in the field and in hatcheries.
- Task 4 added a study to integrate and assess data from the Pallid Sturgeon Population Assessment Monitoring Program 2005–10.
- Task 5 started research to examine migrations and reproductive ecology of pallid sturgeon on the Upper Missouri River downstream from Fort Peck Dam to assess effects of high flows from the Milk River, and potentially releases from Fort Peck Dam, on pallid sturgeon reproductive behaviors and migration.

Extreme hydroclimatic conditions during 2011 presented challenges to our ability to follow the scope of work, but also provided opportunities to document fish responses to rare flooding events. The following section of this report documents the hydroclimatic conditions of 2011 and compares them to conditions recorded in previous years of CSRP study.

Hydroclimatic Conditions During 2011

Large amounts of snowpack and heavy spring rainfall produced an unprecedented quantity of runoff in the Missouri River Basin in 2011. During calendar year 2011, runoff was estimated at 60.8 million acre feet (maf) upstream from Sioux City, Iowa, the largest annual runoff in 112 years of record (Missouri River Flood Independent Review Panel, 2011) (fig. 4). Although the reservoir system stored some of this runoff, releases from main-stem dams were at record levels (table 1). These releases led to the highest post-dam discharges on record for main-stem streamflow-gaging stations in the Upper Missouri River and uppermost segments of the Lower Missouri River (table 2). Downstream of Omaha, Nebraska, flooding was not as severe because tributaries



Base from the U.S. Geological Survey digital data, 1:2,000,000, 2012
Albers Equal Area projection

Figure 1. Missouri River Basin and major tributary rivers with the Comprehensive Sturgeon Research Project study areas.

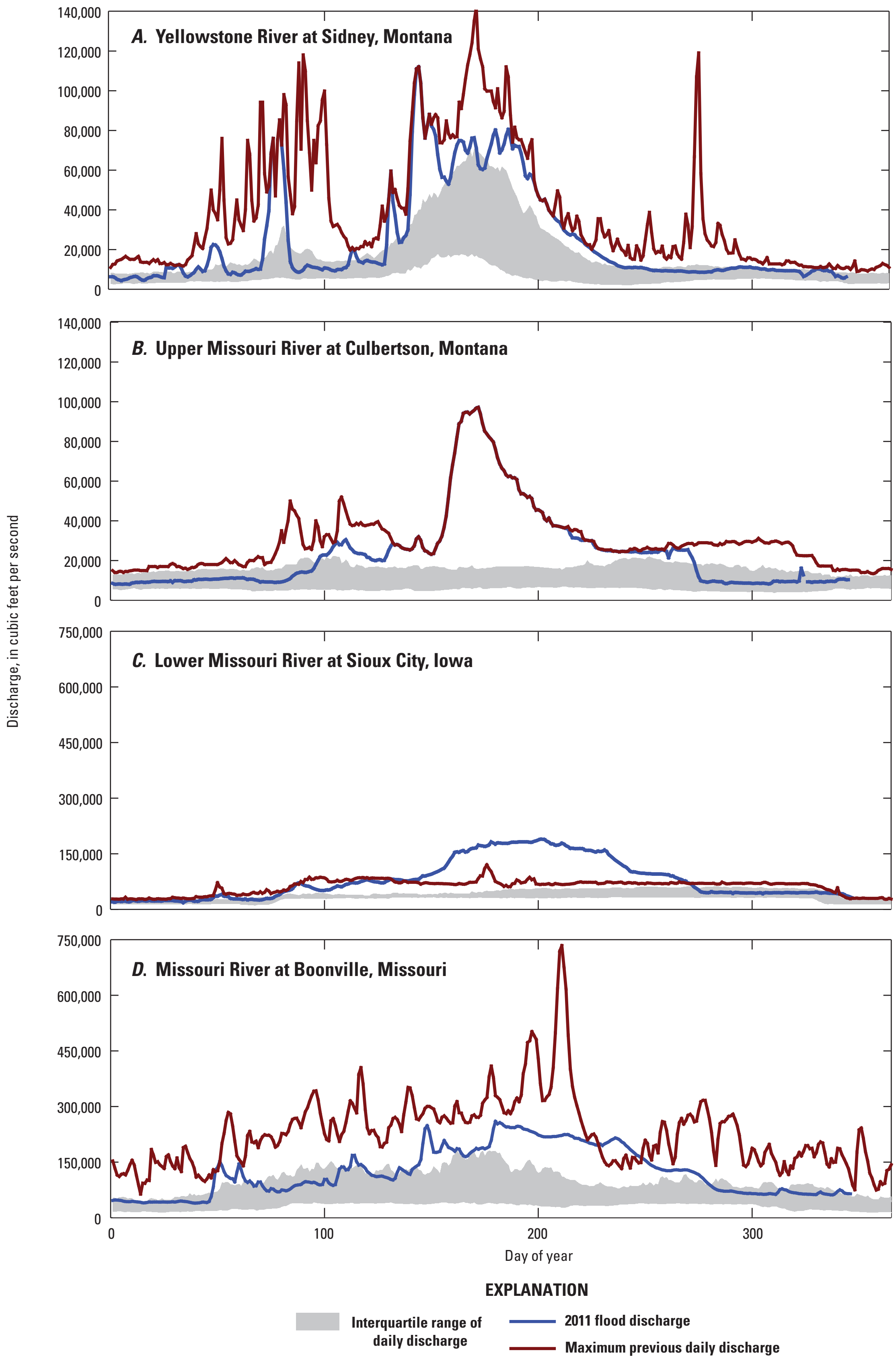


Figure 2. Interquartile range of daily flows, maximum daily discharges, and 2011 hydrographs for *A*, Yellowstone River at Sidney, Montana; *B*, Upper Missouri River at Culbertson, Montana; *C*, Lower Missouri River at Sioux City, Iowa; and *D*, Lower Missouri River at Boonville, Missouri.

Figure 3. Aerial photographs showing representative channel morphologies of four study sections of the Missouri River. *A*, Yellowstone River; *B*, Upper Missouri River; *C*, upper study section, Lower Missouri River, nonchannelized Gavins segment; *D*, upper study section, Lower Missouri River, channelized Big Sioux segment; and *E*, lower study section, Lower Missouri River.

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Imagery from U.S. Department of Agriculture
National Agriculture Imagery Program, 2010
Albers Equal Area projection

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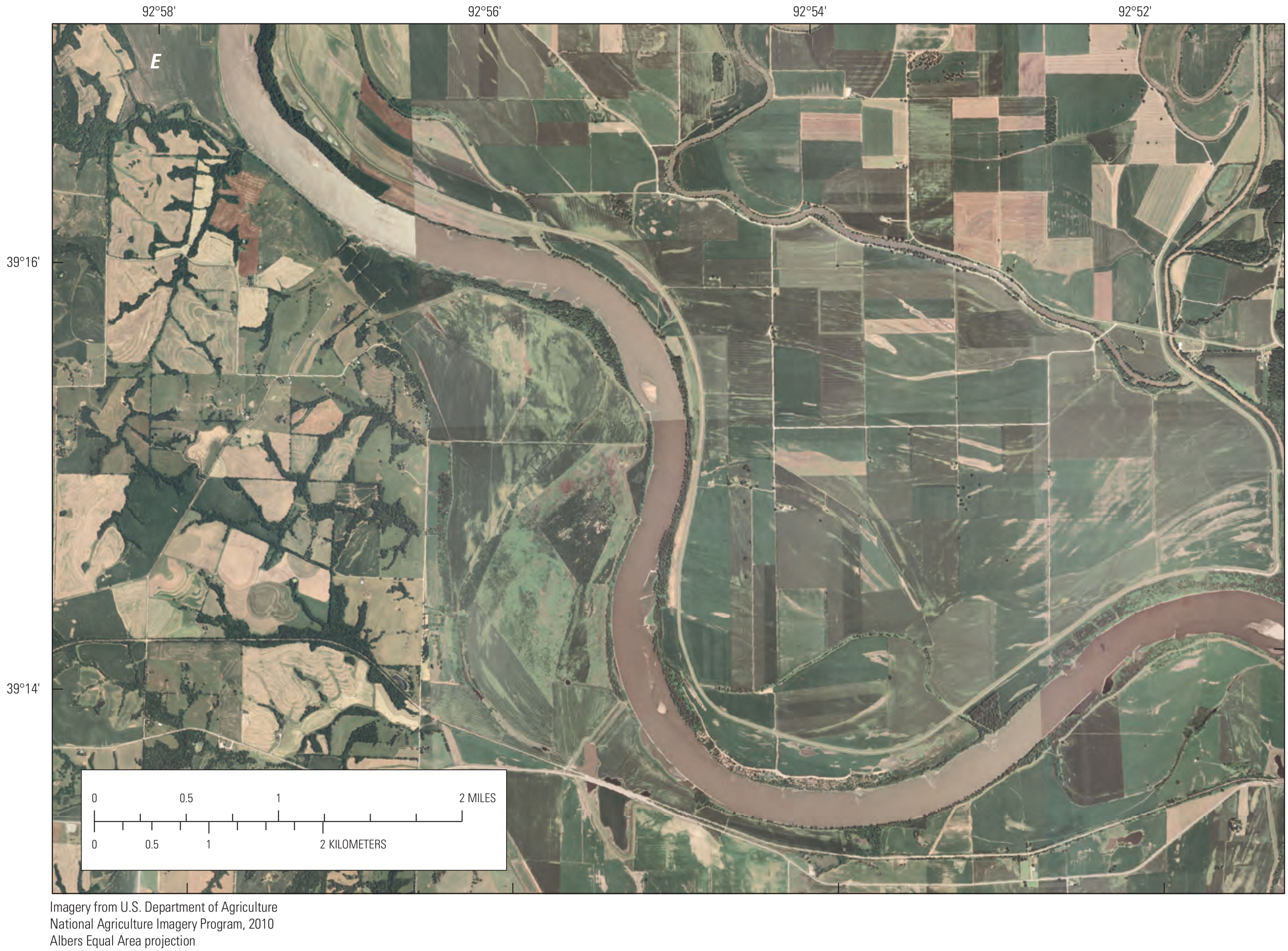

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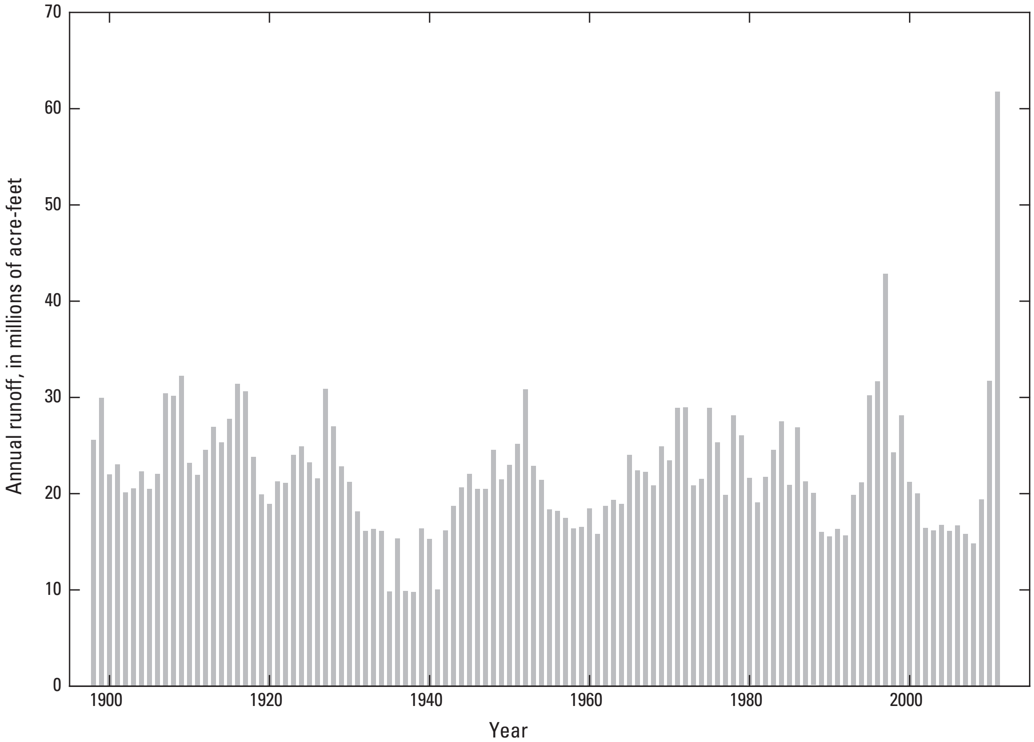


Figure 4. Time series of annual runoff in the Missouri River Basin upstream from Gavins Point Dam.

were not in flood. Estimated flood recurrence intervals for 2011 peak discharges decreased from a 200–500-year event (0.5 to 0.2 annual percent exceedance probability) at Omaha, Nebr., to between 2- and 5-year event (50 to 20 annual percent exceedance probability) at Boonville, Missouri. No intentional pulsed flow release was attempted in 2011 because of flood risk.

The 2011 flood also was notable for its duration. On the Yellowstone and Upper Missouri River, discharges were in excess of the 1-percent daily flow exceedance for 52 and 77 days, respectively. Downstream from the reservoir system, sustained releases of runoff increased the number of days in excess of the 1-percent daily flow exceedance to 122 days at Sioux City, Iowa, and 118 days at Omaha, Nebr. Duration of the flood above the 1-percent flow exceedance threshold decreased in the downstream direction, reflecting the lack of additional runoff from tributaries.

The hydroclimatic conditions of 2011 added unexpected variability to the CSRP experimental framework for addressing how environmental conditions relate to reproductive ecology of pallid sturgeon (figs. 5, 6). The rarity of the 2011 high-flow event diminishes its value to serve as an analog for possible management actions, but the rarity also expands the dynamic range of the experiments, allowing us to see how sturgeon react to extremes. In the Upper Missouri River system, three major rivers interact to determine discharge events and water temperature. The Milk River enters the Missouri about 14 kilometers (km) downstream from Fort Peck Dam (about 3 km downstream from the spillway). Depending on conditions, the Milk River provides the potential to deliver water at different times and with higher temperature and turbidity compared to water from Fort Peck Dam. In 2011, the Milk River had an April pulse of 20,000 cubic feet per second (ft^3/s) whereas water temperatures were still below 10 degrees Celsius (°C), and a later June pulse, also of 20,000 ft^3/s, when water temperatures were 15–20 °C. Water temperature in the Milk River peaked in late July in excess of 25 °C.

Discharge from Fort Peck Dam (indicated by discharge at Wolf Point and Culbertson, Mont.) was characterized by a 25,000-ft^3/s pulse in April and a second pulse of 95,000 ft^3/s in June. Daily average water temperature at Wolf Point never exceeded 19.3 °C and warmed only to 21.6 °C at Culbertson (fig. 5). The inverse relation between water temperature and discharge in early June suggests that flows out of Fort Peck Dam diminished the seasonal warming trend in the Upper

Table 1. Peak reservoir releases, 2011.

Dam	Release,[1] in cubic feet per second (ft^3/s)
Fort Peck	65,000
Garrison	150,000
Oahe	160,000
Big Bend	166,000
Fort Randall	160,000
Gavins Point	160,000

[1] Data from Missouri River Flood Independent Review Panel (2011).

Table 2. Peak daily mean discharges for selected streamflow-gaging stations for 2011 flood.

[n/a=no data]

River	U.S. Geological Survey streamflow-gaging station location	2011 Peak discharge, in cubic feet per second (ft^3/s)	Date of 2011 peak	Days during 2011 greater than 1 percent daily exceedance	Note
Yellowstone	Near Sidney, Montana	121,000	5/25/2011	52	2011 was sixth highest flood of record.
Upper Missouri	Near Culbertson, Montana	97,200	6/21/2011	77	Previous highest daily mean discharge was 69,200 cubic feet per second in 1943.
Lower Missouri	At Gavins Point Dam, South Dakota [1]	160,000	6/24/2011–7/29/2011	n/a	Previous highest release was 70,000 cubic feet per second in 1997.
Lower Missouri	At Sioux City, Iowa	189,000	7/20/2011–7/21/2011	122	2011 flood was highest since dam closure. 2010 peak daily mean discharge estimated to be in excess of 500-year return interval (U.S. Army Corps of Engineers, 2004). Next highest post-dam daily mean discharge was 103,000 cfs in 1984. Highest on record was 438,000 cubic feet per second in 1952.
Lower Missouri	At Omaha, Nebraska	212,000	7/2/2011	118	2011 peak was highest on record since dam closure. 2011 peak daily mean discharge estimated to be between 200- and 500-year return interval (U.S. Army Corps of Engineers, 2004).
Lower Missouri	At Nebraska City, Nebraska	218,000	7/25/2011–7/26/2011	100	2011 peak daily mean discharge estimated to be between 50- and 100- year return interval (U.S. Army Corps of Engineers, 2004).
Lower Missouri	At St. Joseph, Missouri	227,000	7/27/2011	76	2011 peak daily mean discharge estimated to be between 20- and 50- year return interval (U.S. Army Corps of Engineers, 2004).
Lower Missouri	At Kansas City, Missouri	243,000	7/3/2011	58	2011 peak daily mean discharge estimated to be between 5- and 10- year return interval (U.S. Army Corps of Engineers, 2004).
Lower Missouri	At Boonville, Missouri	260,000	6/29/2011	1	2011 peak daily mean discharge estimated to be between 2- and 5-year return interval (U.S. Army Corps of Engineers, 2004).

[1]Data from U.S. Army Corps of Engineers (USACE), Reservoir Control Center (written commun., 2011)

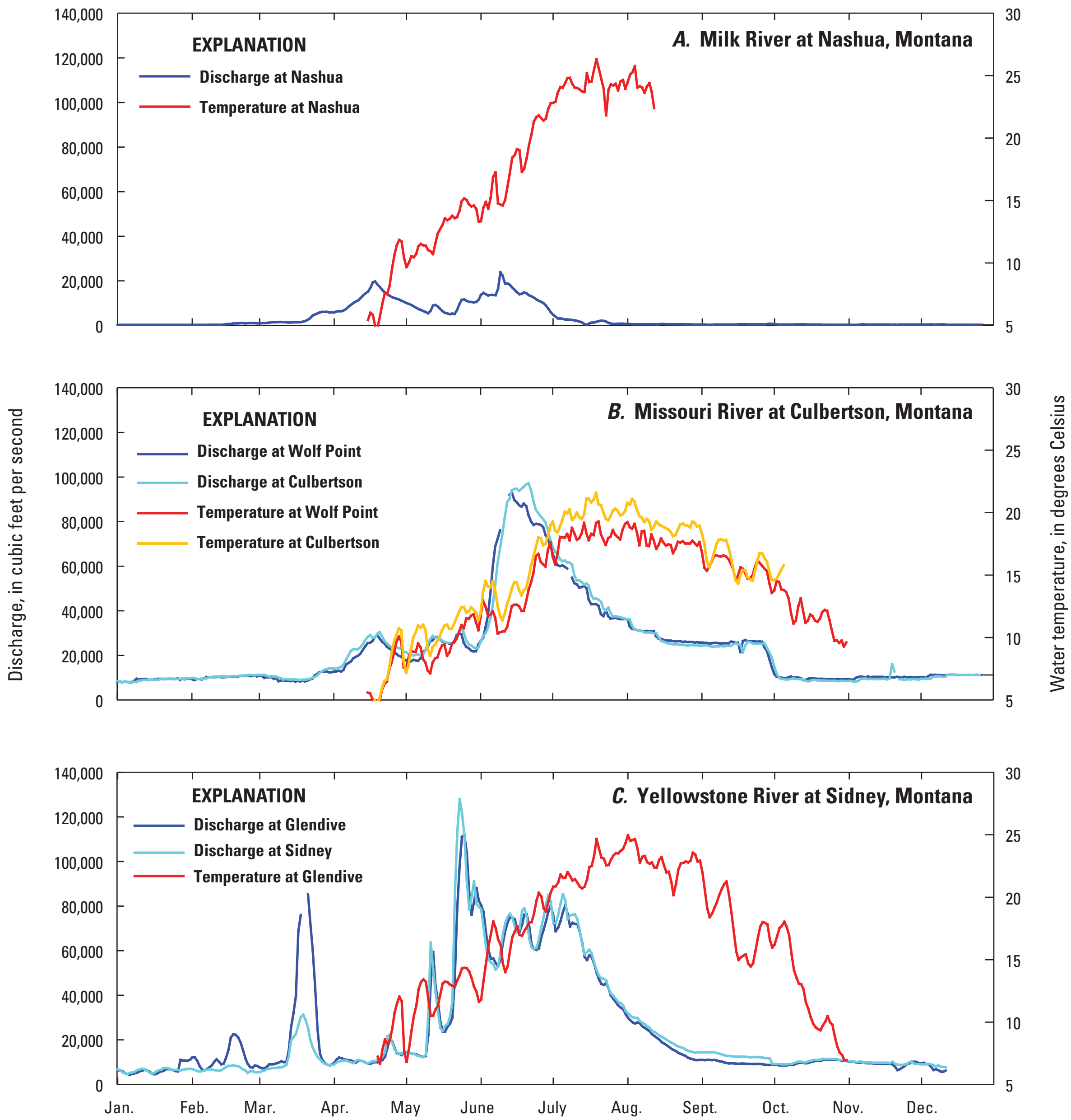


Figure 5. Hydrographs and temperature plots for 2011, for *A*, Milk River at Nashua, Montana; *B*, Missouri River at Wolf Point and Culbertson, Montana; and *C*, Yellowstone River at Glendive and Sidney, Montana.

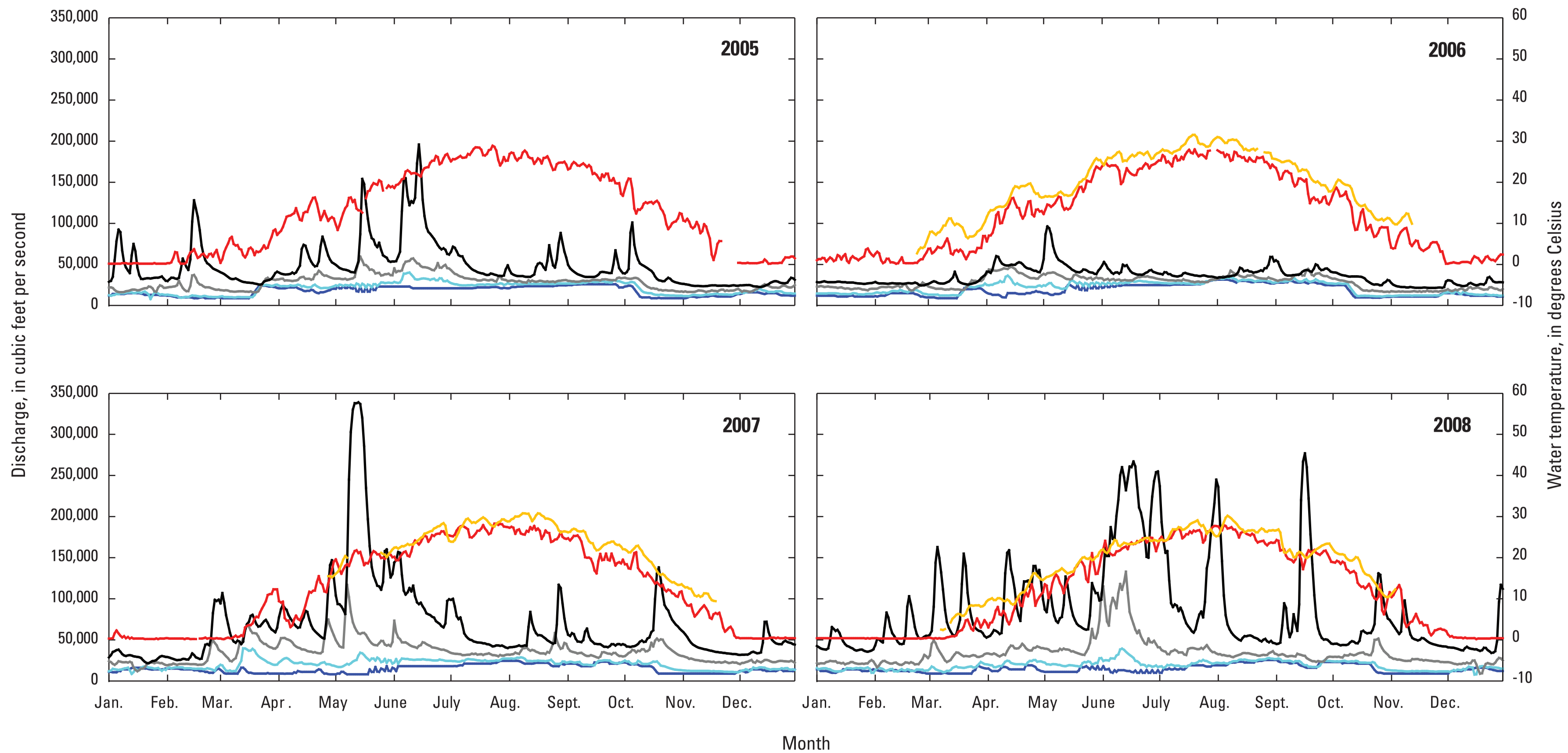
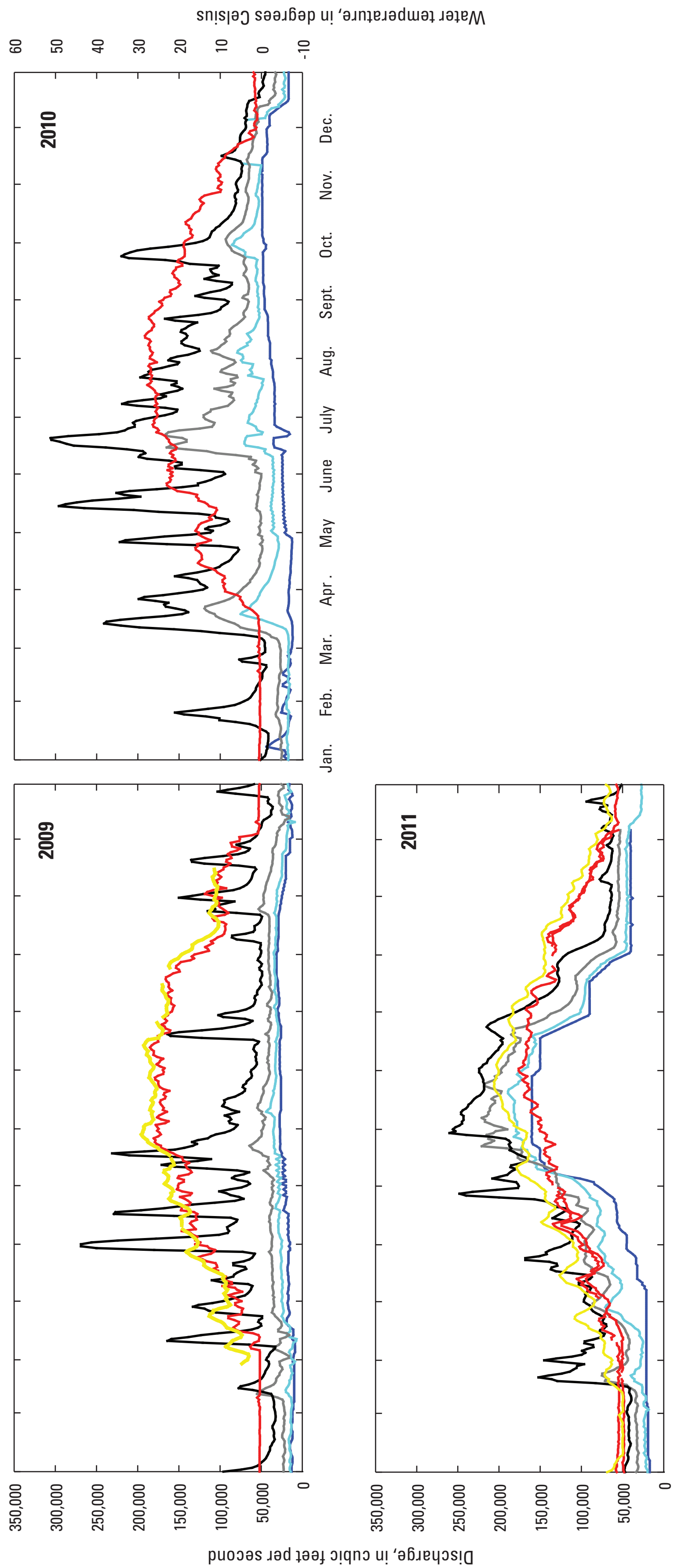


Figure 6. Hydrographs for 2005–11 for discharges from Gavins Point Dam (dark blue); at Sioux City, Iowa (light blue); at Nebraska City, Nebraska (light gray); and at Boonville, Missouri (black). Water temperatures for Sioux City, Iowa, or Decatur, Nebraska (red) and Boonville, Missouri, or Jefferson City, Missouri (yellow). Sites of available water temperature data vary by year.



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Missouri River water temperature. National Weather Service (NWS) flood stage at Culbertson is 19 feet (ft), a stage that is reached by discharges beyond 100,000 ft^3/s at that location. The NWS flood stage at Wolf Point is 13 ft and is attained by discharges of about 70,000 ft^3/s (U.S. Geological Survey, 2011). Hence, using flood stage as an approximate indicator of hydrologic connection, it seems that there was variable opportunity for overbank flooding and associated exchange of nutrients, organisms, and energy on the Upper Missouri River during the June pulse. Flood stage is an approximate predictor of hydrologic connection because it is defined specifically to address flood damages in the areas adjacent to streamflow gages and usually is calibrated to urban and infrastructure damage. More detailed hydraulic information would be needed to assess the spatial extent of overbank flooding along the river.

The Yellowstone River experienced an 80,000-ft^3/s pulse in mid-March (fig. 5). Although this was before temperature loggers were deployed, it is likely that water temperatures were 5 °C or less during this time based on data collection from previous years (Fuller and others, 2008). A pulse of as much as 130,000 ft^3/s occurred in mid- to late May associated with as much as 20 inches of rainfall in southeastern Montana during May (Missouri River Flood Independent Review Panel, 2011). At Sidney, NWS flood stage is 19 ft, which occurs at about 100,000 ft^3/s discharge. At Glendive, the NWS flood stage is 53.5 ft, which equates to about 90,000 ft^3/s. Using flood stage as an approximate indicator of flood-plain connection, it seems the May flood pulse may have provided opportunities for exchange of organisms, nutrients, and energy on the Yellowstone River. Discharges remained elevated on the Yellowstone River through mid-July and water temperatures peaked at about 25 °C.

Releases from Gavins Point Dam on the Lower Missouri River increased steadily from a low discharge of 21,000 ft^3/s during winter to nearly 60,000 ft^3/s by late May of 2011 (fig. 6). Through the month of June, releases increased steeply to a peak of about 160,000 ft^3/s on or about June 24, which was steady until July 28. Releases decreased by a step to about 150,000 ft^3/s which was held until August 18. Releases were subsequently reduced again to a plateau at 90,000 ft^3/s that was held August 31 to September 16. This pulse from Gavins Point Dam was the highest peak and longest duration of any pulse since completion of the reservoir system in 1957 (U.S. Geological Survey, 2011).

Main-stem water temperatures near the dam were diminished in 2011 compared to previous years. The peak daily mean water temperature at Sioux City, Iowa, reached only 23.1 °C, compared to usual peak main-stem temperatures of 26–28 °C (fig. 6). The difference between water temperatures at Sioux City and Jefferson City, Missouri, also was notably larger compared to upstream-downstream differences in previous years.

The pulse propagated downstream and formed the core of the flood event along the entire Lower Missouri River. Pulses of 150,000 ft^3/s (mid-February); 160,000 ft^3/s (mid-April); and 240,000 ft^3/s (late June) were recorded at the Boonville, Mo., streamgage in 2011(fig. 6).

Mapping of maximum flood extent by the USACE (U.S. Army Corps of Engineers, 2011) was available to evaluate the spatial extent of flood-plain connection along the Lower Missouri River (table 3). Flood extent was controlled in part by the regional distribution of channel incision and aggradation (Jacobson and others, 2009a; Jacobson and others, 2011), by the lack of floodwaters contributed by tributaries relative to that released at Gavins Point Dam, and, locally, by locations of levee breaks. Across the entire Lower Missouri River valley, 33 percent was inundated at some time during 2011. The greatest inundation occurred in the Platte River segment (downstream from the Platte River to the Kansas River), where nearly two-thirds of the valley bottom experienced flooding. Maximum flooding extent occurred in that part of the river that also has experienced persistent aggradation during the last several decades (Jacobson and others, 2009a).

Long and extensive hydrologic connection of the main stem with flood-plain habitats on the Lower Missouri River during 2011 allowed for an unprecedented opportunity to see if sturgeon or other native fishes would take advantage of flood-plain access for feeding, spawning, or rearing. Although the CSRP study design was not intended to evaluate sturgeon use of flood-plain habitats, opportunistic telemetry tracking succeeded in documenting pallid sturgeon locations on flood plains of the Platte River segment (see “Task 1” section). Age and growth studies of native fishes in subsequent years may be useful to assess if the extraordinary flood-plain inundation of 2011 had an effect on reproduction, survival, and growth.

Table 3. Maximum flooded area by 2011 flood, by hydrologic segment, Lower Missouri River.

Hydrologic segment[1]	Area, in square kilometers
Fort Peck	65,000
Garrison	150,000
Oahe	160,000
Big Bend	166,000
Fort Randall	160,000
Gavins Point	160,000

[1]Hydrologic segments from Jacobson and others (2010).

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

Background

After more than two decades of Federal protection, and despite artificial propagation and stocking, pallid sturgeon remain rare in the Lower Missouri River. The general lack of evidence of successful reproduction and survival of juvenile pallid sturgeon suggests that any reproduction occurring in the Missouri River is insufficient to increase or sustain viable populations (U.S. Fish and Wildlife Service, 2007). Although recent commercial harvest and habitat fragmentation by reservoirs may limit pallid sturgeon populations in parts of the species' range, limited numbers of adults and poor reproduction have been recognized among the greatest threats to pallid sturgeon in the Lower Missouri River. In species recovery plans, and in several workshops, management agencies and scientists have consistently 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 (YOY), 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). Tagging studies have been used throughout the range of the pallid sturgeon to examine 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 others, 2002; Hurley and others, 2004, Garvey and others, 2009). Because pallid sturgeon have a complex life history strategy, inhabit large and dynamic rivers, and are capable of moving long distances to complete critical life functions, the ability of individual studies to address hypotheses relevant to management concerns is challenging. This study attempts to characterize reproductive migrations, describe spawning behavior and habitat, assess spawning success, and examine patterns of habitat use by pallid sturgeon over multiple reproductive cycles. This study is designed to document precisely where pallid sturgeon spawn and to provide information necessary to link pallid sturgeon migration, spawning, or reproductive success to large-river management.

The CSRP studies have developed effective telemetry tagging and tracking methodology 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; DeLonay and others, 2012). Telemetry provides the opportunity to recollect, reassess, and re-implant individual sturgeon to monitor changes in growth, condition, and reproductive status through multiple years. Information gained through telemetry enhances the interpretation of data from sturgeon population and habitat monitoring programs on the Lower Missouri River that use traditional fisheries sampling techniques by sampling individual fish repeatedly, in all habitats, throughout all time periods. Through time, telemetry data provide a means for defining characteristic migration patterns of reproductive fish, identifying spawning locations, and detecting the patterns of habitat selection and spatial fidelity (DeLonay and others, 2009, DeLonay and others, 2012). In addition to telemetry transmitters, CSRP makes wide use of environmental data collection tags in telemetered fish to continuously characterize and quantify sturgeon behavior and the environmental conditions of habitats used (DeLonay and others, 2007a; Holan and others, 2009). Telemetry, as a fisheries sampling technology, is central to CSRP's unique multidisciplinary approach in which documentation of sturgeon location and movement is coordinated with physiological assessments of reproductive behavior and hydroacoustic habitat assessments (DeLonay and others, 2007a; 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, 2009b; Reuter and others, 2009; Bonnot and others, 2011). Incorporation of the volumes of complex, multidisciplinary data into a single database system provides investigators the ability to explore the relations among individuals and groups of tagged sturgeon over time across the landscape.

Between 2006 and 2010, CSRP 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 4 years has emphasized pallid sturgeon (DeLonay and others, 2009). Generally, fish are captured in the late fall through 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 (DSTs) and re-implant with long-lived telemetry tags. For the last 5 years, the approach has resulted in an at-large population of about 70 adult male and female pallid sturgeon at various reproductive stages. This at-large population provides opportunities to study multiyear pallid sturgeon reproductive cycles.

Studies under this task in 2011 increased the number of observations of spawning pallid sturgeon in the Lower Missouri River to refine understanding of where, when, and under what conditions pallid sturgeon spawn. Intensive tracking of upstream migrations identifies migration corridors, whether sturgeon use shallow water or constructed habitats during migration, and if there are impediments to upstream movement. Assessments of environmental conditions at the spawning site refine our understanding of habitat characteristics selected by spawning pallid sturgeon and address the hypothesis that spawning or egg-maturation habitats are limiting. Validation and verification of critical components of the spawning sequence will fill gaps in our understanding of conditions selected for spawning, reproductive behavior, and spawning success. An expansion of hydroacoustic habitat assessments to areas where late-larval and juvenile sturgeon are captured provides important parameters for models characterizing habitats where drifting larval sturgeon may settle, start feeding, and survive this potentially limiting early transition.

Scope and Objectives

The studies in task 1 are designed to examine reproduction and habitat use of adult pallid sturgeon in the context of the contemporary Missouri River at spatial scales that are relevant to the ecological needs of the species and the management actions that can be applied to meet those needs. While the studies are highly interrelated the activities and emphases among various studies in task 1 require that they be described separately in annual reports of progress. The scope and objectives change slightly from year to year within each of the studies in task 1 as activities are modified with new knowledge or to exploit emerging hypotheses. Various components of each of the studies within task 1 are combined as sufficient data are accumulated for analyses and publication.

Movement and Reproductive Behaviors

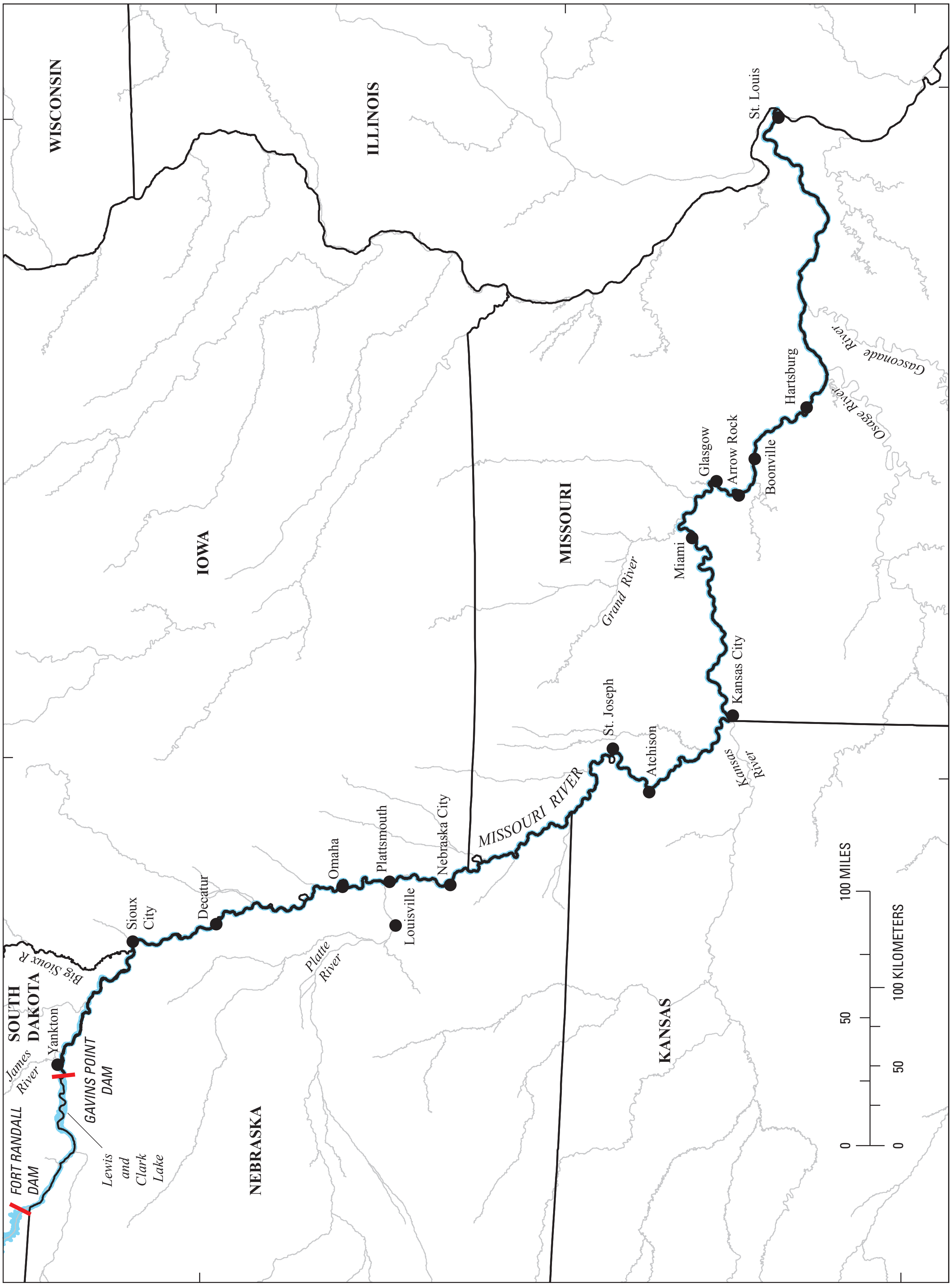
Under CSRP, the USGS began collaboration with the NGPC on studies of the movement, habitat use, and behavior of sturgeon in 2005 (DeLonay and others, 2007b), and this work continued in 2011. The objectives of this work were to (1) identify pre-spawning habitat, (2) determine the direction and magnitude 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 success of spawning relative to status and environmental conditions including natural and augmented spring flows, and (7) determine and characterize post-spawn and nonreproductive habitat. Movement and behavioral studies focused exclusively on pallid sturgeon in 2011. The work was carried out 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 (fig. 7). The overall approach used in the study is to capture and evaluate the reproductive status of pallid sturgeon, instrument each with transmitters and DST, track reproductive sturgeon through spawning, and attempt to recover as many as possible to evaluate their reproductive success (DeLonay and others, 2009). Previous work completed in this study had determined that pallid sturgeon are spawning and releasing eggs in the Lower Missouri River (DeLonay and others, 2009; DeLonay and others, 2012). Work in 2011 increased the emphasis on verification of spawning and validation of spawning success. Verification and validation of spawning included observing aggregation and spawning behavior using Dual-Frequency Identification Sonar (DIDSON) imagery, the capture of ripe males or gravid females at probable spawning locations, and sampling for eggs and free-embryos downstream from spawning locations. Pallid sturgeon not in reproductive condition were tracked to determine movement, habitat use, and the location of important habitats.

Reproductive Physiology

Physiological and morphological measurements allow scientists to evaluate the direct biological responses of sturgeon to environmental conditions. Responses may be general, such as stress, or may be specific, such as indicating how close a sturgeon is to ovulation. During 2005–07 we have demonstrated that we can assess the reproductive condition of shovelnose sturgeon (*Scaphirhynchus platorynchus*) 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). Since 2006, we also have applied this approach to understanding pallid sturgeon reproductive condition. A primary objective of the reproductive physiology studies is to provide the supporting data to evaluate the biological (for example, behavioral) responses of pallid sturgeon to environmental conditions in the Missouri River. In addition to this yearly activity, our second objective is long-term acquisition of multiyear geographic and condition-specific data from the field and the laboratory to answer questions about when, where, and what environmental cues are necessary for pallid sturgeon to spawn. The third objective is to continue to develop tools and methodologies that ultimately will provide measures of reproductive condition and biological response.

Quantify Migration and Spawning Habitat

In 2011, habitat assessments quantified Missouri River habitats used by pallid sturgeon as well as habitats that were available but not used in order to understand habitat selection. Paired with studies of reproductive movements and physiology, patterns of habitat selection can indicate whether specific habitats are limiting the reproduction and survival of pallid sturgeon. Definition and quantification of spawning habitat was emphasized in 2011 as in previous years and was complemented with assessments of habitats used by upstream migrating reproductive sturgeon, continuing the effort begun in 2010.



Base from U.S. Geological Survey digital data, 2012, 1:100,000
Albers Equal Area projection

Figure 7. Lower Missouri River main stem and major tributary rivers within the Comprehensive Sturgeon Research Project study areas.

In 2011, we also began a series of exploratory habitat surveys to assess larval and YOY sturgeon habitat in the main-stem Missouri River and natural and constructed side channels.

The first objective was to survey spawning habitats to replicate assessments from prior years and to increase understanding of the role of habitat building on prior habitat assessments and analysis (Reuter and others, 2008; DeLonay and others, 2009; Elliott and others, 2009; Reuter and others, 2009). The goal of this objective was 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. In 2011, as a pilot project, the high-resolution habitat-mapping protocol at spawning sites was enhanced with deployment of an underwater microscope to image the bed of the river, evaluate the potential for viewing eggs near spawning sites, and quantitatively measure sediment grain size on the bed.

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 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 continued in 2011 and will help provide an understanding of the effects of spawning migrations on reproductive success.

In 2011, two new efforts were begun to understand the dynamics of Missouri River habitats for larval and young sturgeon. Hydroacoustic surveys were completed in and around chutes and confluences during the high flows of the summer of 2011 to assess the environments and potential flow refugia that larval sturgeon may encounter as they drift in the Missouri River. These surveys also were intended to examine the potential for exchanges of drifting larvae through the main-stem Missouri River and off-channel natural and constructed chutes. In a joint effort with the USFWS Columbia Fisheries Resource Office, we also surveyed sites believed to provide habitat for YOY sturgeon in the Missouri River. These surveys were done at a variety of discharges in coordination with USFWS trawling efforts and will be analyzed in the context of their fishing results.

Database Integration and Spatial Analysis

The CSRP for the Lower Missouri River involves simultaneous data collection from multiple field crews tracking more than 800 miles of river requiring a robust and scalable relational database and standardized data collection parameters. The research activities of CSRP generate large volumes of data about the physiology, ecology, and habitat requirements of pallid and shovelnose sturgeons; the usefulness of the data depends on the ability to effectively archive, retrieve, display, and analyze these data. The Sturgeon Information Management System (SIMS) framework was developed by the USGS for data collection, maintenance, and exploration of the large volume of data using a range of software and hardware products (fig. 8). There are several components of the SIMS platform funded under this activity. The general objectives 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

Movement and Reproductive Behaviors

The methods used in 2011 follow closely those developed for the CSRP in previous years (DeLonay and others, 2007b; DeLonay and others, 2009). In 2011, female and male pallid sturgeon meeting established criteria [greater than or equal to 2 kilograms (kg) and reproductively mature adults] were implanted with 2-year acoustic transmitters and data storage tags recording depth and temperature at 30-minute intervals (DeLonay and others, 2009). Within each study section in the Lower Missouri River, the goal was to have at least two, but no more than five gravid females with telemetry transmitters before the onset of spring migration and spawning. Actual numbers of tagged sturgeon used in any specific year were determined in consultation with the USFWS and the Middle Basin Pallid Sturgeon Workgroup. In 2011, concerted efforts were applied to recollect, reevaluate, and re-implant pallid sturgeon telemetered in previous years. The designated river segments studied represent two hydrologically distinct units based on river hydrology and morphology (fig. 7). The first segment is located on the Lower Missouri River between the Osage River and Grand River (RM 130–250). The second segment is located between the Platte River in Nebraska and the Big Sioux River (RM 595–734). Crews located and tracked individual telemetered fish to record habitat use and seasonal movements. Fish were tracked extensively during pre- and post-spawn periods. Fish in reproductive condition were tracked intensively from April through July. Gravid female pallid sturgeon were targeted for daily contact in early spring until water temperatures reached 14 °C, at which time they were contacted more frequently. Crews attempted to collect high-frequency observations of fish locations and habitat use during upstream migration and spawning. Fish not in reproductive condition were contacted at a targeted frequency of one to three times monthly. Measurements of water conditions (temperature, conductivity, dissolved oxygen, and turbidity) and habitat characteristics (depth and substrate) were recorded at each location to qualitatively and quantitatively describe habitat used by sturgeon during pre-spawn and spawning periods. Suspected spawning sites were sampled for eggs, larvae, and the presence of adult pallid sturgeon in reproductive condition. Spawning locations were imaged with DIDSON

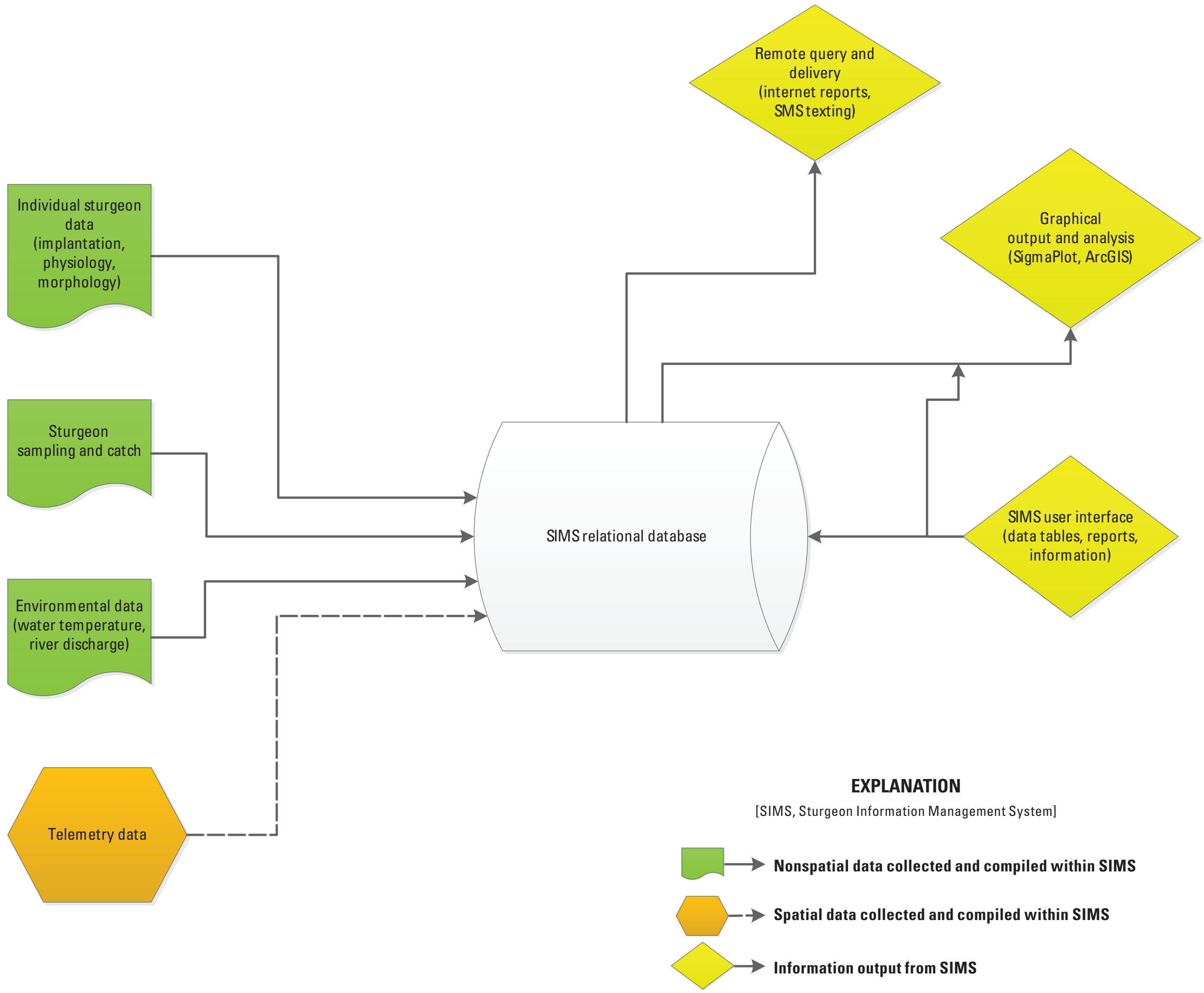


Figure 8. Functional elements of the Sturgeon Information Management System (SIMS) developed by the U.S. Geological Survey.

and side-scan sonar to identify sturgeon aggregations and document spawning behavior.

The CSRP recapture, reassessment, and re-implantation of telemetry-tagged sturgeon begin each year with falling water temperatures in late August or early September. Pallid sturgeon recapture activities continue through November until water temperatures fall below 8 °C. Targeted recaptures resume in mid-February and may continue through June or until water temperatures approach 25–28 °C. 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) (DeLonay and others, 2009). Standardized reports from the SIMS database track the implantation history, past reproductive status, and the life-expectancy of implanted transmitters for all pallid sturgeon at large. The inventory of tagged sturgeon in the database is assessed monthly and individual sturgeon are identified and prioritized for targeted recapture.

Reproductive Physiology

For the first and second physiology objectives, field, laboratory, and hatchery personnel were supplied with tissue collection materials (for example, centrifuge, syringes, solutions, and vials). The first objective of the reproductive physiology studies was to provide the supporting data to evaluate the biological (for example, behavioral) responses of pallid sturgeon to environmental conditions in the Missouri River. We determined readiness of females to spawn from blood plasma (for measurement of sex hormones) and from oocytes collected at implantation of transmitters or from pre-spawning captive or hatchery, adult pallid sturgeon (see detailed methods in Wildhaber and others, 2007). Oocytes were collected and placed into 10-percent formalin for measurement of polarization index (PI) or into Ringers solution for progesterone assay to determine germinal vesicle breakdown (GVBD) (Dettlaff and others, 1993). As the oocytes mature in preparation for ovulation, the nucleus, or germinal vesicle (GV), begins to move from its position in the center of the egg towards the animal pole on the outside of the egg. The PI value is calculated as the distance from the GV to the animal pole, divided by the egg diameter. When conditions are suitable, the final stages of maturation commence such that specific hormones (luteinizing hormone and maturation-inducing hormone) are released and GVBD occurs, followed by ovulation. During the tracking study, blood plasma was collected each time a fish was recaptured, and if the fish had not spawned, another egg sample was collected. Most hatchery and captive research fish were sampled only once during the season. All tissues were returned to the CERC laboratory for analyses. Spawning success was evaluated based on visual inspection of gonads and blood reproductive hormones.

The second research objective was to 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 objective was to assess the reproductive condition of sturgeon before the spawning migration, during the migration, and 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 studies and on pallid sturgeon used in the propagation program, and included measures of reproductive stage, blood hormones, and PI values when available. Temperature and flow data were obtained from streamgages, deployed data loggers, and data collected by field crews.

The third objective extends ongoing work to develop tools and assays to measure gonadotropin II (GtH II) and maturation-inducing hormone (MIH) in order to develop a precise indicator of reproductive condition. Changes in gonadotropic and maturation-inducing hormones occur close to the final oocyte maturation, ovulation, and spawning, and therefore are more intimately tied to environmental conditions that trigger the spawning event. For the last few years, several approaches (biochemical and molecular) were attempted to isolate or sequence the *Scaphirhynchus* GtH II protein in order to develop a 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 developed successfully. Difficulties encountered during synthesis of the antibody resulted in insufficient antibody production for blood measurements; therefore, antibody production continues in order to increase volume of reagent available.

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.

Successful reproduction is dependent on the proper functioning of a number of metabolic pathways. Similar to other large-bodied, long-lived fish that migrate long distances to reproduce, pallid and shovelnose sturgeon possess intrinsic physiological mechanisms to allocate energy resources. Leptin is a peptide that recently has been identified as key to metabolic coordination among competing demands for energy (Copeland and others, 2011). Leptin is produced by the adipose tissues and interacts through feedback loops with reproductive hormones, growth hormones, fat metabolism, and the immune system among other processes. We have observed that some pallid sturgeon held in the hatchery, as well as some wild fish, have seemingly high percentages of visceral fat at times of the year when stores should be low (Aaron DeLonay, USGS, Columbia Environmental Research Center, oral commun.) (for example, just before spring spawning). Monitoring of leptin levels together with reproductive hormones will increase our understanding of how excess fat affects reproduction. We have developed a preliminary assay to measure leptin in sturgeon blood and are working to test its efficacy in laboratory pilot studies.

Apart from reproductive readiness, evaluation of the blood for general hematological parameters can provide insight on the overall health and metabolic activity of a fish. Limited information exists for some sturgeon species, but to date, no information is available for *Scaphirhynchus* sturgeons. Therefore, we have begun to evaluate triglycerides, lactate, cholesterol, lipase, bilirubin, glucose, creatinine, and protein in blood samples. Measurements have been made on an Ortho Clinical Diagnostics Vitros Chemistry System DT60 II (Johnson & Johnson, New Brunswick, New Jersey). Blood preparation and analysis is according to manufacturer's instructions.

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 was used to analyze ovary and barbel tissue samples collected during the 2010 field season. Two experiments were carried out in December 2010 to (1) evaluate a time course of gene expression in an ovary for a reproductive season, and (2) test for sex and reproductive stage differences in gene expression in a barbel tissue. Ovarian tissues did not yield any useable DNA, possibly because the DNA had degraded because of improper collection or because of high lipid content. Barbel tissues were successfully analyzed and catalogued. Additional samples will be collected in 2012 from immature pallid sturgeon to complete the comparisons before data analysis.

Quantify Migration and Spawning Habitat

Habitat survey methods used in 2011 replicated those used in 2008–10; detailed documentation of methods are on file at USGS CERC. For the 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 (ADCP) surveys within 10 percent of the discharge that existed when the fish was located. An additional criterion 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 at 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. As with the spawning habitat surveys, 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 ADCP for mapping current-velocity fields. The GPS base-stations were used to obtain real-time kinematic (RTK) positioning with nominal positioning errors of plus or minus 0.02 meter (m) horizontal and plus or minus 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.

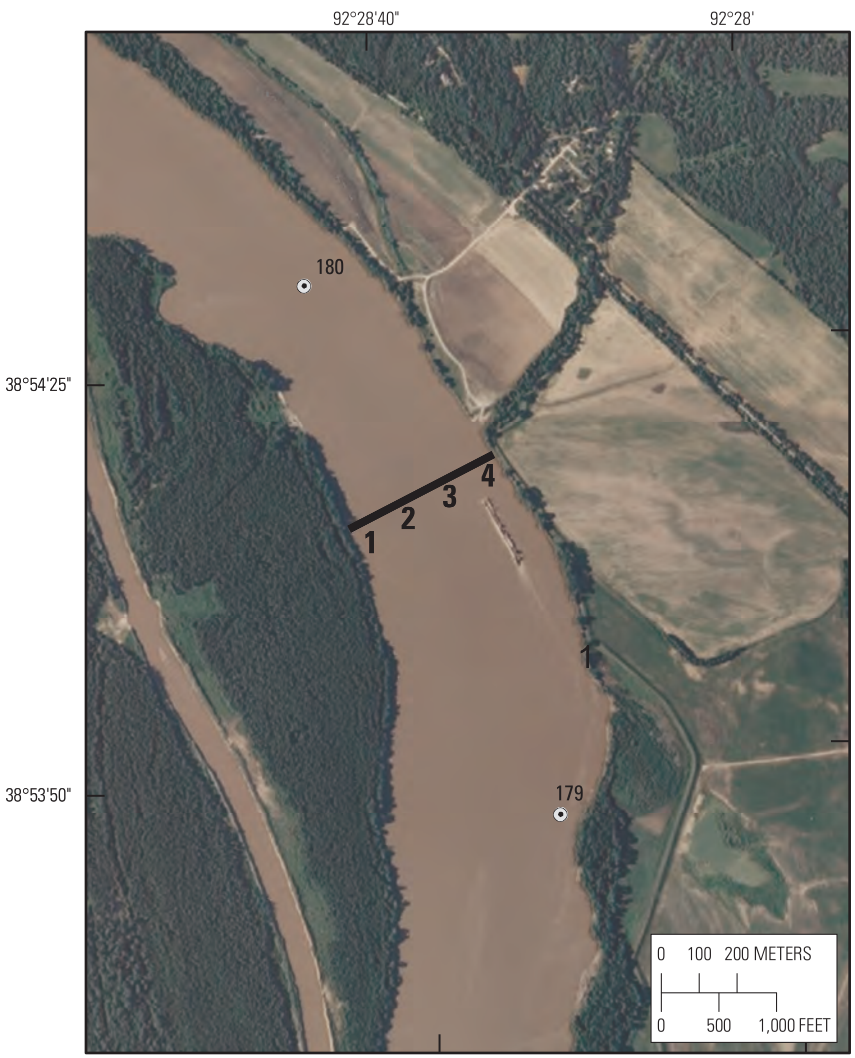
The multibeam system and boat mount were calibrated with a "patch" test that corrects for internal geometry of the boat, transducer/receiver, and GPS receiver. Patch test results were used to update geometry files used by the data acquisition software. In addition, sound-velocity profiles were collected to assess stratification of sound-velocity with depth. HYPACK/HYSWEEP® software (Hypack, Inc., Middletown, Connecticut) 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 navigation errors and anomalous acoustic returns inconsistent with the river bed. These data subsequently were exported from the Hypack environment and imported into Fledermaus (Quality Positioning Services, Portsmouth, New Hampshire), where the data were gridded at the 1-m scale using the Combined Uncertainty and Bathymetry Estimator (CUBE) algorithm (Calder and Mayer, 2003; Calder and Wells, 2007) for analysis and display. The final grids were imported into ArcMap (ESRI, Redlands, California) for map production and analysis with sturgeon telemetry data and other data.

Current-velocity fields were mapped using either a 600-kHz or a 1200-kHz ADCP (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. The 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, Colorado). Mapping crews applied 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.

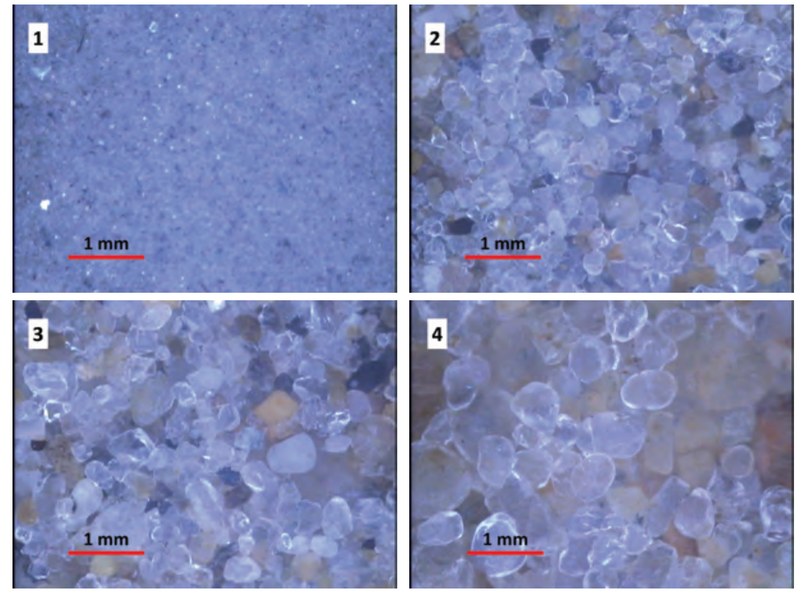
For spawning habitat surveys (objective one), channel cross-section lines for the ADCP survey were laid out in a grid with 20-m spacing in the direction of water flow over an area that equally covered the multibeam survey, approximately twice the width of the river. For migration habitat surveys (objective 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.

In 2011, we developed and deployed an underwater microscope, or "sand cam." This sand cam is designed to take optical-light pictures of the river substrate, and it can distinguish mud, silt, sand, gravel, bedrock, revetment, or other objects. The camera is encased in a large steel weight to sink it through the turbulent water as it is reeled out from a bow-mounted crane. It is attached to a shipboard digital high definition video cassette recorder (HDVCR). The HDVCR returns continuous images so that we can see the camera sinking through the water and finally coming to rest on the river bottom. It also takes high-resolution still photos, which are used for grain size estimation (fig. 9).



Imagery from U.S. Department of Agriculture
National Agriculture Imagery Program, 2012
Universal Transverse Mercator projection
Zone 15

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



Underwater microscope images of sand grains on the bottom of the Missouri River. Photographs by Brandon McElroy.

EXPLANATION

[mm, millimeter]

1 — **Location of sampling transect**—Numbers on the map correspond to the location along the transect where the images to right were collected

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

Figure 9. Example of a dataset collected with the underwater microscope.

In areas where spawning was thought to have occurred, the sand cam was deployed in a grid-like fashion sampling points across the channel, bracketing the spawning area upstream and downstream, with a semiregular set of substrate image collection points. Multiple photographs were taken at each location to allow substrate type and grain-size information to be extracted digitally from each photograph. The data can then be used to address questions of spawning substrate use and availability.

Sites to assess larval sturgeon drift were mapped in longitudinal swaths with the multibeam echosounder at high resolution and with transects perpendicular to flow spaced at 50-m with an ADCP. Surveys to assess YOY sturgeon habitat in collaboration with the USFWS trawling efforts generally were mapped over region of the trawl transects with a single-beam echosounder and an ADCP with perpendicular transects and 5-m spacing.

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

Database Integration and Spatial Analysis

The SIMS was developed by the USGS as a central platform for data collection, integration, maintenance, exploration, and distribution of the large volumes of data generated by CSRP. The 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). Structured Query Language (SQL) Server 2008® (Microsoft Inc., Seattle, Washington) was selected to manage tabular data. 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).

Continuing practices since 2005, the customized SIMS mobile mapping and data collection application was deployed to collect geospatial data on sturgeon movements and habitat use in near-real time. The SIMS mobile mapping application was developed using ESRI's ArcPad and deployed on ruggedized laptop computers. The SIMS application contained all the customized tools, data layers, and data entry forms to streamline the collection of two types of data, search effort and sturgeon telemetry datasets. At the beginning and end of each telemetry search effort, a custom data entry form was used to record relevant search effort information (such as crew member names, types of receivers used, and the telemetry frequencies scanned during the search effort). Once an individual fish was pin-pointed, another custom data entry form was used to record the telemetry location; this form prompted an observer to record data identifying the particular fish, as well as data describing the habitat, substrate, and water quality at the location. The SIMS application automatically recorded date, time, and spatial coordinates for each point captured from the GPS unit connected to the laptop computer. Additional tools were created within the SIMS application that allow crew members to review or edit sturgeon telemetry and search effort data collected that day while they are still out on the river.

The cruise log and telemetry location data were transmitted back to a secure server located at CERC on a daily basis, to facilitate near real-time data delivery. The data from each search effort were then archived. Newly recorded data were compiled and incorporated into a larger spatial database using a custom ArcMap application, providing a complete record of the movement of the tracked pallid sturgeon within the study.

A relational database was developed using Microsoft SQL Server to manage and maintain large volumes of tabular data (for example, millions of DST records from dozens of individual fish and temperature data from a network of stations). Each table in the database is designed to store a specific set of data. Currently (2013), the SIMS relational database contains data in more than 30 searchable tables, including individual fish metrics, physiology, habitat use, and environmental variables. These data often originate in disparate physical locations and often in different file formats (for example, ESRI shape files, text files, comma delimited files, and spreadsheets). Each record (or row) in the table represents a particular collection of data and is identified by a mutually exclusive primary key (PK) value. In general, the PK values in one table are used to identify the records in another table containing related information. For example, a unique fish identification number (Fish_ID) identifies each individual sturgeon in the database. This key is used to identify all information in the database that is associated with any specific fish. Relationships (or linkages between tables) were created by using keys in two or more tables. The PK from the parent table is linked with a foreign key (FK) in the child, or receiving table. The relationships between tables provided a mechanism for data from multiple tables to be combined into a single view, or virtual table. The virtual table looks and functions like a table but is maintained dynamically by the database. For example, the PIT tag number is the PK in the implantation table and the FK in the hatchery history table, and this relationship identifies the hatchery history of each fish implanted with a telemetry device. Similar relationships have been developed and maintained between tabular data in the database and geospatial sturgeon telemetry location data collected in the field using mutually exclusive identifiers. Relationships between tables were modeled, developed and maintained in the database. By creating well defined relationships between many tables in various combinations, the relational data model provides a way to extract and integrate data from several sources.

A functionally driven user interface was developed to allow users to quickly edit and view data, and to access near real-time reports that integrate information from spatial and tabular data. Navigation within the SIMS user interface is accomplished through a series of user actions involving clicking on-screen buttons or tabs, selection from drop-down menu options, and entering appropriate search queries in predefined fields, essentially the same navigation features present in most basic software packages or websites. The SIMS user interface also provides quick access to a wide variety of information in preformatted reports. These reports were developed to present researchers with access to frequently requested information in an easy to read format. For example, one preformatted report details the number of pallid sturgeon with active transmitters and highlights those that are at risk of transmitter expiration, and, therefore, need to be targeted for immediate recapture. Another report displays the history of the individual fish during the multiple years of the CSRP, including gender, origin (wild or hatchery), reproductive history, and migration pathway (fig. 10).

This interface also allows users to quickly filter and display data graphically; within the SIMS or by linking to other commonly used software packages, such as SigmaPlot and ArcMap, to rapidly generate charts and maps. For example, a selection on the Individual Fish Summary Report triggers an algorithm that uses telemetry data to calculate the mean river mile and identifies the closest stream-gaging station for the particular pallid sturgeon of interest. The database then relays the selected streamgage discharge data, telemetry location data, and DST data to SigmaPlot to automatically update a chart preformatted to USGS standards. These presentation-ready graphics are generated automatically, streamlining the process needed for researchers to combine and analyze these complex data (fig. 11). Similar connections have been established between the SIMS platform and ArcMap to automatically generate standard maps depicting near real-time movements of individual pallid sturgeon.

Additionally, the SIMS platform has enabled remote data delivery and query capabilities. The SIMS makes it possible to export pertinent information about particular fish directly to the cell phone of a biologist in the field by the way of Short Message Service (SMS) text message. Other reports are served by the way of an internet webpage, making it possible for remotely located biologists and co-operators at the Nebraska Game and Parks Commission to view relevant and timely information on individual pallid sturgeon.

Results

Movement and Reproductive Behaviors

Spring sampling efforts for reproductive adult pallid sturgeon are dependent on discharge, temperature, and ice conditions. The USGS coordinates with the USFWS-Columbia Fisheries Office, Missouri Department of Conservation Missouri River and Open River Field Stations and Management Offices, Nebraska Game and Parks Monitoring Programs, and State and Federal Hatcheries during spring sampling to collect pallid sturgeon for telemetry studies and propagation broodstock. In spring of 2011, we sampled using gill nets and trot lines beginning the first week in March 2011 and continuing through April 15, 2011, using methods described by DeLonay and others (2007b). Success of spring sampling for adult pallid sturgeon in 2011 varied widely among the various programs and agencies sampling on the Lower Missouri River. The preponderance of reproductive adults for the propagation program was captured by NGPC sampling downstream from the confluence of the Platte and Missouri Rivers in Nebraska. The USGS and NGPC sampling in the upper study section upstream from the Platte River yielded no new reproductive adults, whereas sampling in the lower study section resulted in only one new reproductive female and one ripe male. Most of the reproductive individuals tracked by the CSRP in 2011 were collected by the broodstock collection effort and only released for research after genetic analyses deemed them to be excess to the propagation program or after artificial induction failed. Only one female in each study section was not transported to the hatchery during the spring of 2011. These two females were prioritized for intensive tracking. Unexplained interannual variability in sturgeon distribution and sampling success is problematic for all sturgeon programs on the Lower Missouri River, including the CSRP. The inability to reliably collect reproductive adults is among the principle reasons for the CSRP's emphasis on recapture and retention of telemetry-tagged individuals in the study.

In 2011, a total of 41 pallid sturgeon adults were captured, assessed for reproductive condition, and implanted or re-implanted with telemetry transmitters in the CSRP. Of the adults assessed in 2011, 51 percent or 21, were recaptured, previously tagged individuals from 2007 (3), 2008 (11), 2009 (2), and 2010 (5). Of these, eight were evaluated after being captured by broodstock collection crews from other agencies and sent to the hatchery as possible broodstock. Recaptured adults included one female and five males in reproductive condition during the spring of 2011. Of the adult pallid sturgeon tagged for the first time in 2011 (20), 13 were captured and implanted on the same day by field crews sampling the Missouri River, including 2 reproductive females and 3 ripe males. The remaining seven, all reproductive females, were implanted and released in late spring (April 28–May 4, 2011) after being held in hatcheries for various lengths of time for use as possible broodstock in the conservation augmentation program. As a result of the CSRP's emphasis on spawning habitat and measures of spawning success, the male to female sex ratio of assessed and implanted pallid sturgeon in 2011 was strongly biased toward females (1:1.9). The mean size of fish evaluated and implanted during spring efforts was 939 millimeters (mm) and 3,530 grams (g).

In the lower study section, two reproductive females and one ripe male were available for intensive tracking to document migration pathways, determine spawning locations, and document spawning success. One reproductive female migrated upstream, was tracked to a probable spawning location, subsequently recaptured, and determined to have spawned. The second reproductive female did not migrate upstream and was later recaptured after going atretic and failing to successfully spawn in 2011. The male migrated upstream and stopped at an outside bend location consistent

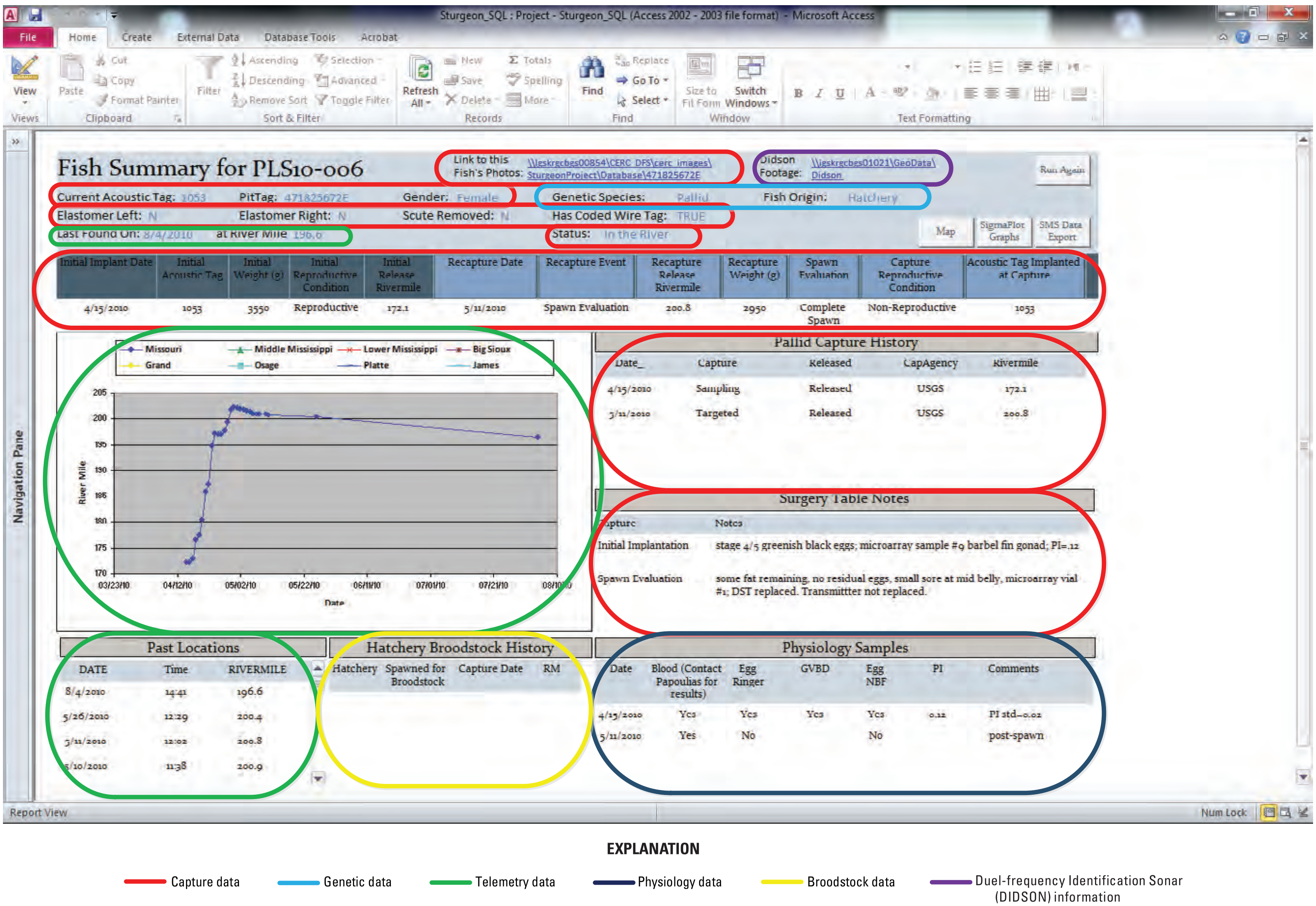


Figure 10. Sturgeon Information Management System (SIMS) data elements and relationships leveraged to create the Individual Fish Summary report. Objects represent SIMS data elements and lines represent relationships.

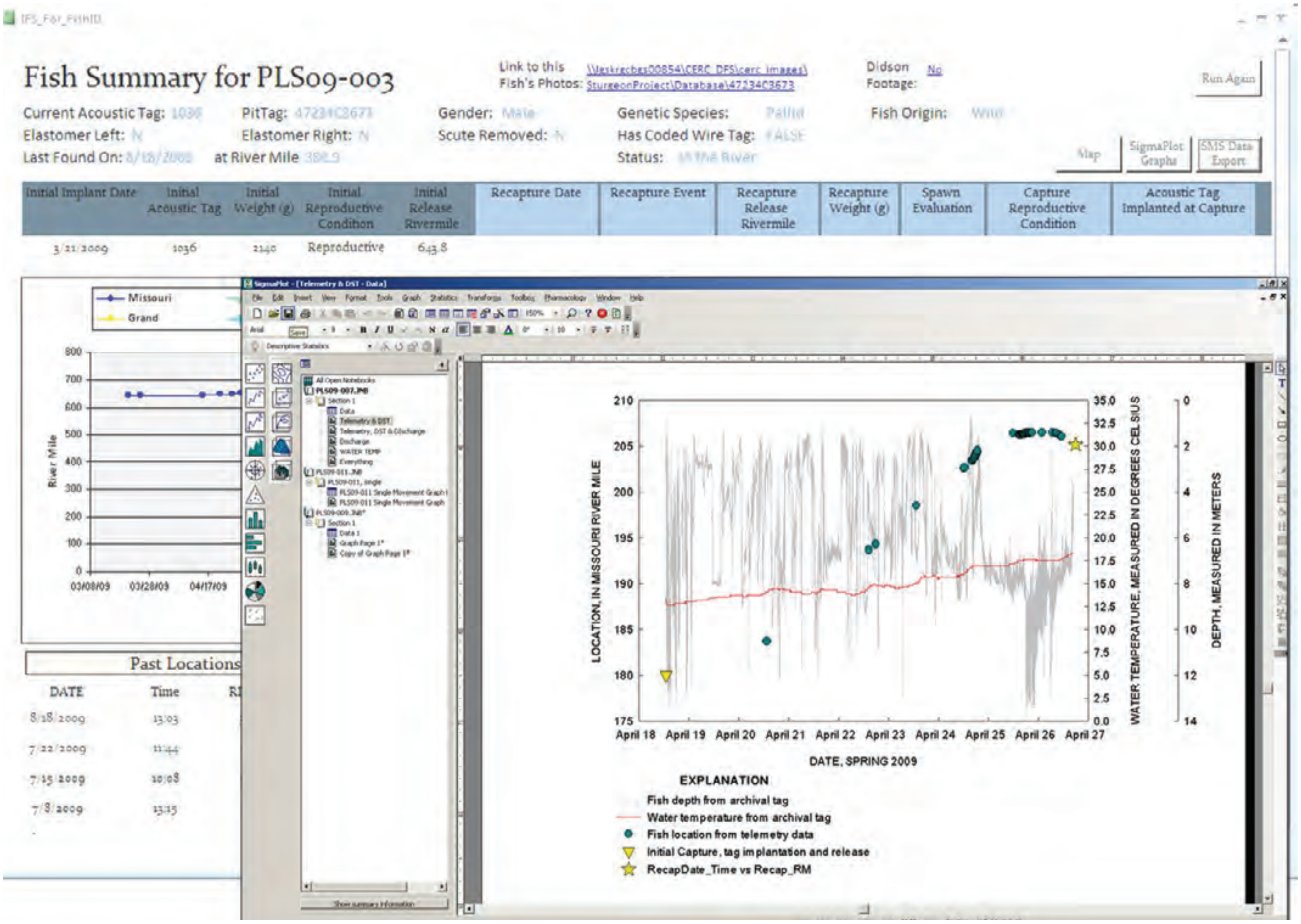


Figure 11. Sturgeon Information Management System (SIMS) Individual Fish Summary Report (background) and the automatically updated SigmaPlot chart (foreground) generated and populated by a user request from the SIMS interface.

with spawning sites used by female sturgeon in previous years. In the upper study section, intensive tracking efforts focused on a single female that migrated upstream into the Missouri National Recreational River, above Ponca, Nebr. This female was selected as a high priority female because it was suspected to have previously spawned in the Recreation River, and intensive tracking efforts in 2011 were a rare opportunity to examine spawning in the unchannelized river near Gavins Point Dam, South Dakota. It was recaptured after the spawning season and it was determined to have spawned successfully. A complex migration pattern and a delay in the recapture and reproductive reassessment of this female prevented the determination of a precise spawning location. Six additional reproductive females excess to the propagation program's broodstock collection efforts were implanted with telemetry transmitters and released in the upper study section. These females were not intensively tracked because of logistic challenges of deploying limited tracking resources and the timing of their release during the peak of the spawning period. Although not intensively tracked, efforts were made to locate and recapture all reproductive individuals to assess spawning and retrieve DST data after the spawning season.

Female pallid sturgeon PLS11-008 (PIT no. 472E437424) was captured in reproductive condition in the lower study section on April 15, 2011, at Missouri River RM 185.7 (fig. 12). PLS11-008 resumed migrating to the spawning location from May 6 to 10, 2011, and was intensively tracked as it moved upstream. Spawning is believed to have occurred on an outside bend near Arrow Rock, Mo. (RM 215.9–216.8) during May 17–19, 2011. Water temperature was 16.1–17.3 ºC. Surveys of the spawning site using high-frequency side-scan sonar showed rock, cobble, and the presence of bedrock outcroppings (fig. 13). DIDSON imagery of the female recorded it actively moving along bedrock with several other sturgeons. PLS11-008 was recaptured on June 14 after moving downstream and determined to have spawned completely. Crews sampled for larvae during the time when eggs were likely to hatch based on calculated developmental times at ambient river temperatures. The suspected spawning locations were sampled for larvae May 20–24, 2011. A single day-old *Scaphirhynchus* free drifting embryo was captured on May 20, 2011. Genetic analyses identified it as a shovelnose sturgeon. Eight drifting, free-embryo paddlefish (*Polyodon spathula*) larvae [greater than (>) 5 days old] also were captured. Paddlefish are

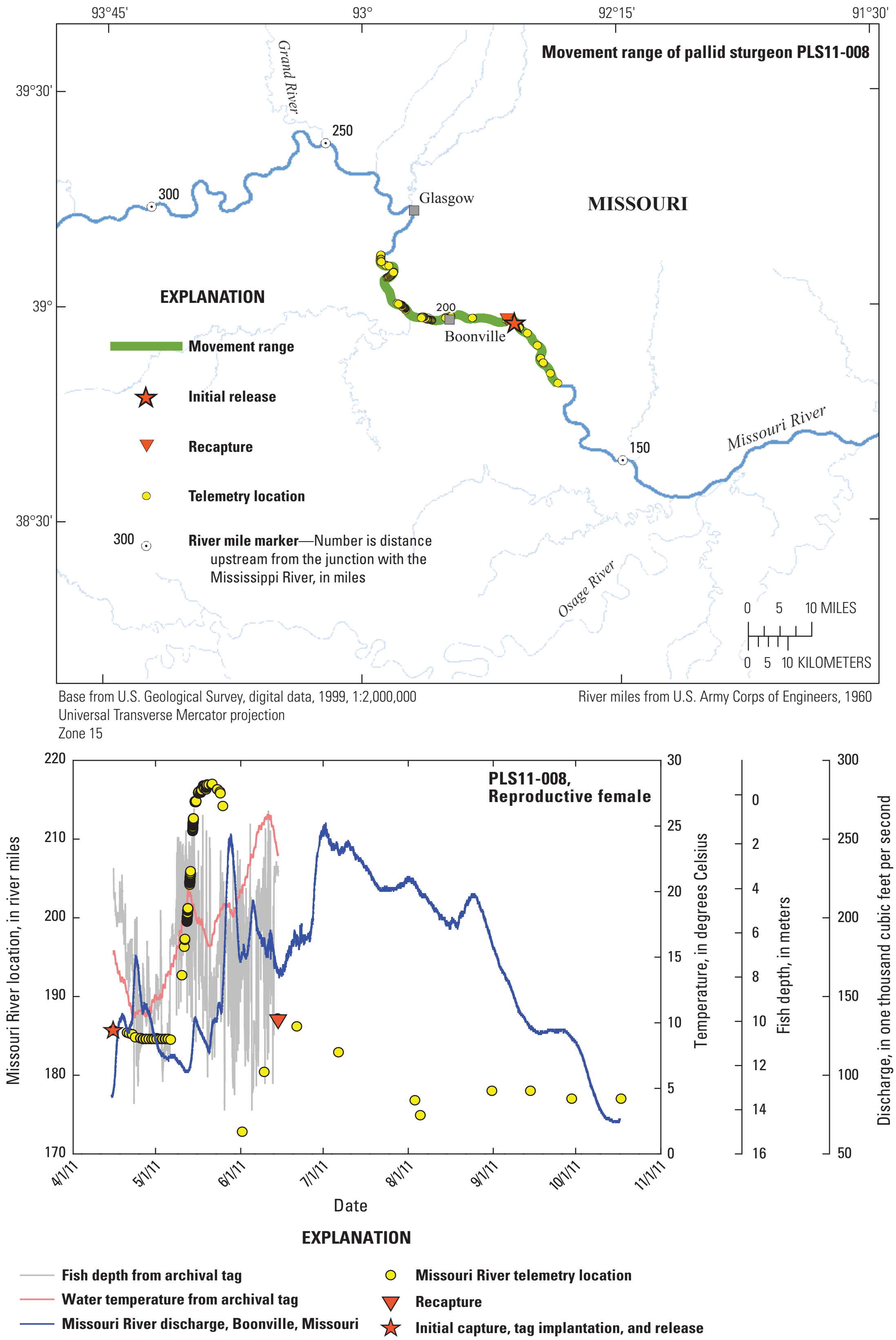


Figure 12. Movement range of female pallid sturgeon PLS11-008. Depth and temperature recorded from data storage tag (DST), discharge from the nearest streamgage at Boonville, Missouri, and telemetry locations for implanted gravid pallid sturgeon PLS11-008. Fish was implanted in reproductive condition, later recaptured, and determined to have spawned.

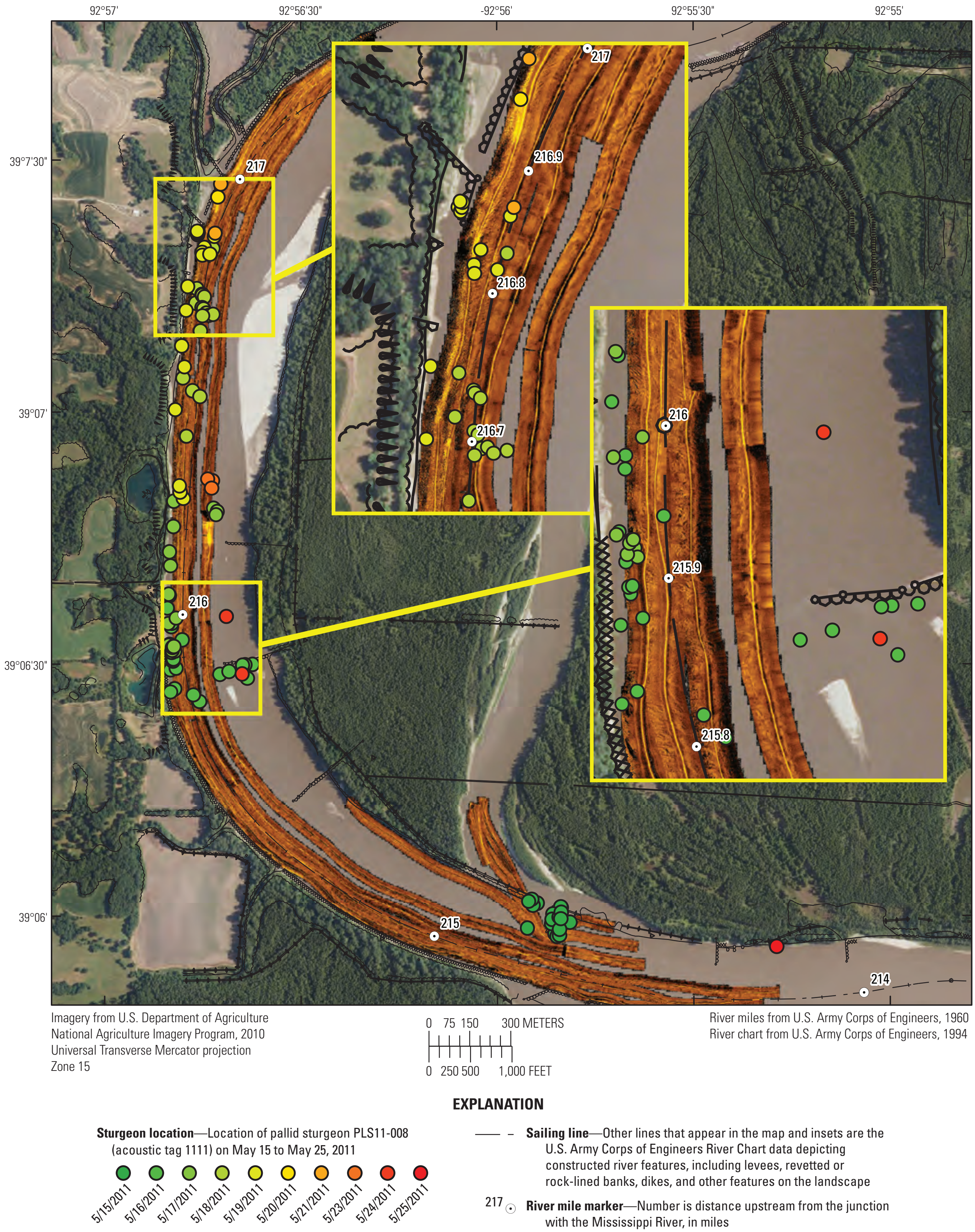


Figure 13. Side-scan sonar imagery of spawning locations of telemetry tracked reproductive female pallid sturgeon PLS11-008.

presumed to use similar habitats for spawning as *Scaphirhynchus* sturgeons and share similar early life history attributes, including a prolonged, free-embryo drifting period after hatch (Becker, 1983).

Female pallid sturgeon PLS11-018 (PIT no. 47156C1037) was received from Neosho National Fish Hatchery on May 4, 2011, in reproductive condition after attempts to artificially induce ovulation failed. PLS11-018 was captured in the Missouri River and transported to the hatchery on April 23, 2010. This female spent more than 1 year in the propagation program before being released to the CSRP. PLS11-018 was implanted with a transmitter and DST and released back into the Missouri River at RM 185.1 in the lower study section (fig. 14). It did not begin upstream migration before or during the spawning period. It was recaptured on June 10, 2010, at RM 188.1, and reproductive assessments determined that it had gone atretic and failed to spawn.

Male pallid sturgeon PLS11-003 (PIT no. 4723307D1A) was captured in the lower study section on the Missouri River at RM 178.7 on March 23, 2011 (fig. 15). Reproductive assessment verified that it was a ripe, reproductive male in spawning condition. PLS11-003 moved upstream 83.6 miles before reaching the apparent apex of its migratory movement at RM 262.3 on May 4, 2011. From May 4 to 8, 2011, the male remained on an outside bend in habitat consistent with spawning. Side-scan sonar survey data showed cobble and rock along the base of outside bend revetment (fig. 16). DIDSON imagery of the probable spawning location also showed sturgeon at the base of the revetment. PLS11-003 has not yet been recaptured to retrieve the DST data.

In the upper segment, the intensively tracked female PLS07-001 (PIT no. 460D390133) originally was implanted as a nonreproductive female in March 2007. It was recaptured as a spent female on July 24, 2008, at Missouri River RM 698.4. Based on tracking locations recorded in 2008, it likely spawned in the Missouri National Recreational River between RM 790.7–811.0 before June 3, 2008. PLS07-001 was recaptured and re-evaluated on September 21, 2010, at RM 749.5 and was recaptured again near that location on March 22, 2011 in gravid, reproductive condition (fig. 17). PLS07-001 began migrating steadily upstream in mid-April 2011, eventually reaching the confluence with the James River on May 3, 2011 (figs. 17, 18). It hesitated for several days in the gradient between the main-stem Missouri River and the warmer, turbid water of the James River, S. Dak., before moving up the tributary on May 7, 2011 (fig. 18). Movement up the James River was limited. The migratory apex was 3.3 miles up the tributary on May 8, 2011. Water temperatures in the main-stem Missouri River at this time were less than (<) 10 ºC, whereas the James River ranged from 14.1 to 19 ºC. PLS07-011 descended the James River on May 9, 2011, suggesting that it may have spawned. The location in the James River was sampled for larvae May 12–13, 2012. Two days of sampling did not result in the collection of any larval sturgeon, although 84 recently hatched day-old larval paddlefish were sampled. The presence of recently hatched paddlefish suggests that suitable sites for sturgeon spawning may exist in the James River. After moving downstream from its apex, the tagged female's behavior became erratic and it made repeated upstream and downstream movements of several miles. Tracking crews lost contact with PLS07-001 as it began to move downstream and flows from Gavins Point Dam increased in late May.

Based on movement data alone, the spawning location of PLS07-001 was in the James River near RM 3.3 or in the Missouri River between RM 799.6–787.1 from May 8 to 23, 2011. PLS07-001 is the first instance of a gravid, reproductive female ascending a tributary during the spawning period in the Lower Missouri River, upstream of the Platte River. Whether or not PLS07-001 spawned in the James River is uncertain. In 2007, several telemetry-tagged, reproductive shovelnose sturgeon were documented ascending the Big Sioux River, S. Dak., for a short time, only to descend the tributary and continue moving up the main-stem Missouri River to spawn. Increased flow, turbidity, and warmer water may have attracted PLS07-001 given the alternate choice of colder, clearer water discharge from Gavins Point Dam only 11 miles upstream. The subsequent complex movement pattern commonly is observed in pallid sturgeon females from the upper study section closer to the dam (DeLonay and others, 2009; DeLonay and others, 2010). Regardless of the uncertainty and lack of precision associated with the spawning location of PLS07-001, the general section of river used for spawning is consistent with the probable spawning location in 2008.

In late May, water levels on the Missouri River began to rise precipitously as discharge from Gavins Point Dam rose to historic levels (U.S. Geological Survey, 2011). Tracking telemetry-tagged pallid sturgeon on the main-stem Missouri River became increasingly difficult as boat ramps and roads near the Missouri River became inundated. Portions of the river were closed to boat traffic and tracking activities in the main-stem Missouri River above Atchison, Kansas, were suspended for most of the summer months. Research crews from NGPC switched focus from the main-stem Missouri River to the selected habitat mitigation sites and associated portions of the flood plain in the upper study area. The NGPC crews repeatedly searched three inundated habitat mitigation sites [Boyer Chute National Wildlife Refuge (NWR), Schilling State Wildlife Management Area (WMA), and the William Gilmour State WMA] along the Missouri River to determine if newly available flood-plain habitats were being used by telemetry-tagged pallid sturgeon. An acoustic Doppler current profiler was used to collect depth and velocity data for flood-plain habitats being used by implanted pallid sturgeon. Five implanted pallid sturgeon were relocated at two of the three locations (Boyer Chute NWR and Schilling State WMA). A single fish was located in the constructed chute at Boyer Chute NWR on one sampling date in July 2011. Four telemetry-tagged sturgeon were located on the flood plain at the Schilling State WMA for a total of 12 relocations across 5 sampling dates from July 6 through August 8, 2011 (fig. 19). Tagged pallid sturgeon tracked on the flood plain were located in areas with 1.54–2.6-m depth and 0.55–0.94 meter per second (m/s)

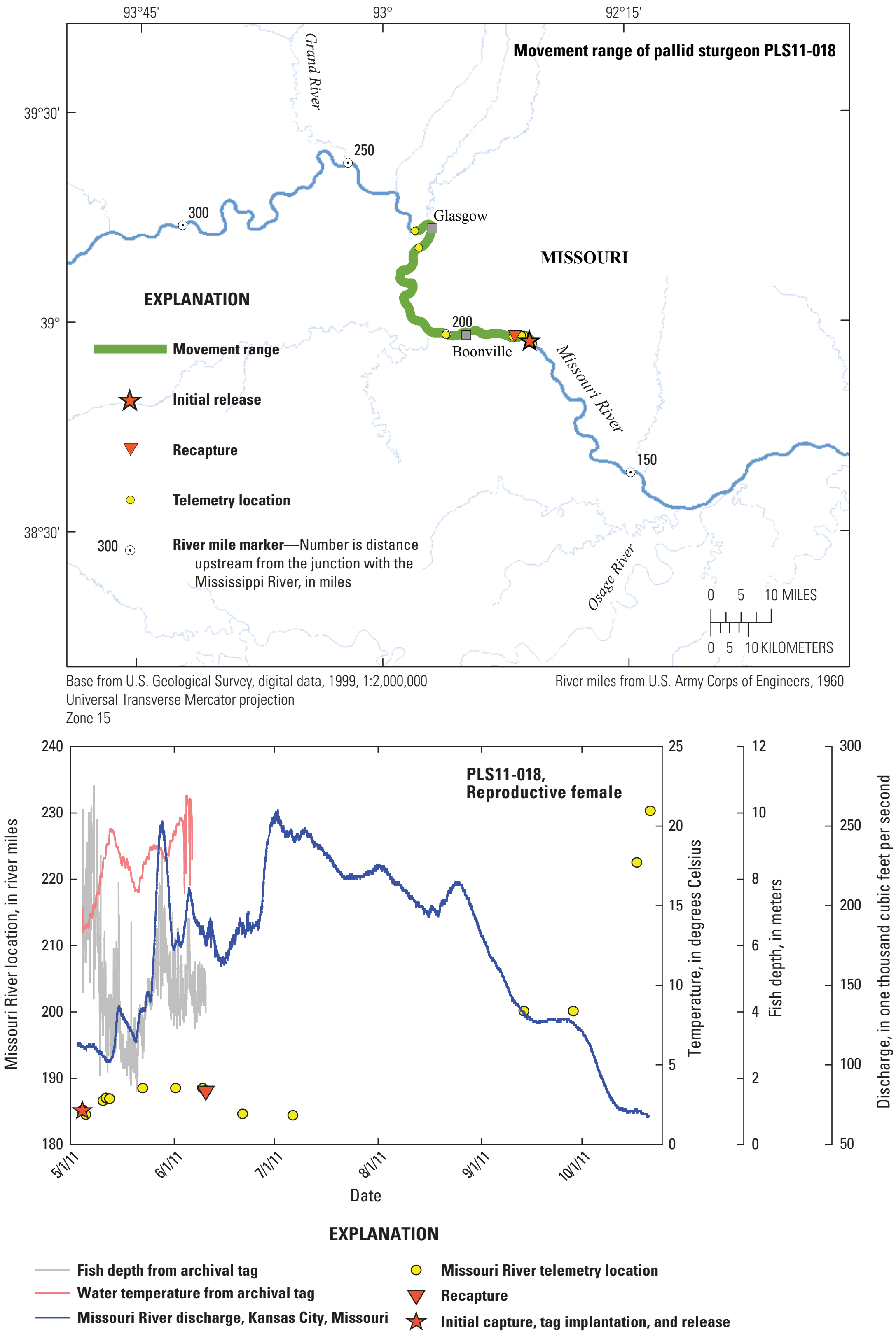


Figure 14. Movement range of female pallid sturgeon PLS11-018. Depth and temperature recorded from data storage tag (DST), discharge from the nearest streamgage at Kansas City, Missouri, and telemetry locations for implanted gravid pallid sturgeon PLS11-018. Fish was implanted in reproductive condition and later went atretic.

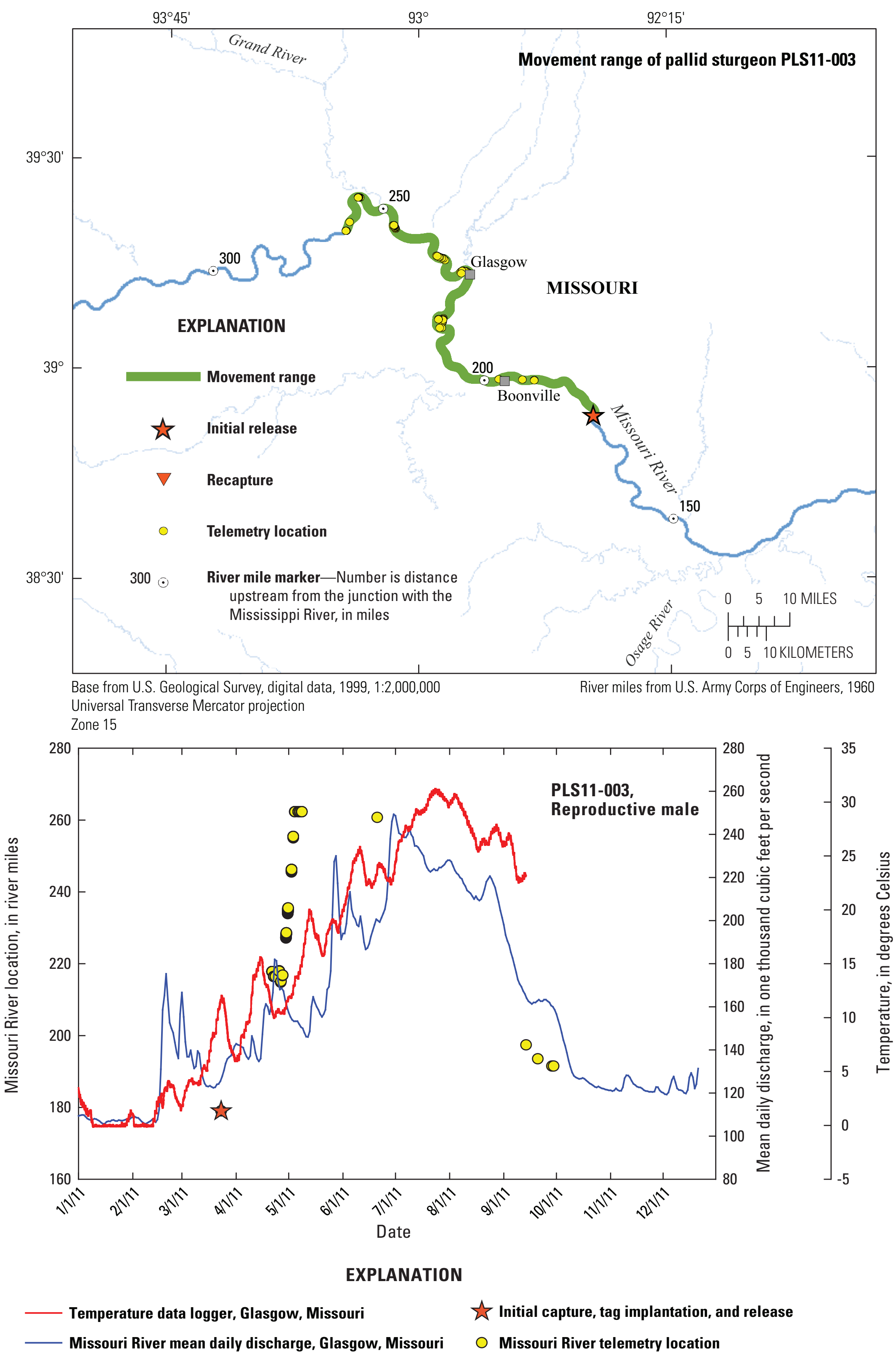


Figure 15. Movement range of male pallid sturgeon PLS11-003. Discharge from the nearest streamgage and at Glasgow, Missouri; temperature from temperature data logger at Glasgow, Missouri; and telemetry locations for implanted gravid pallid sturgeon PLS11-003. Fish was implanted in reproductive condition.

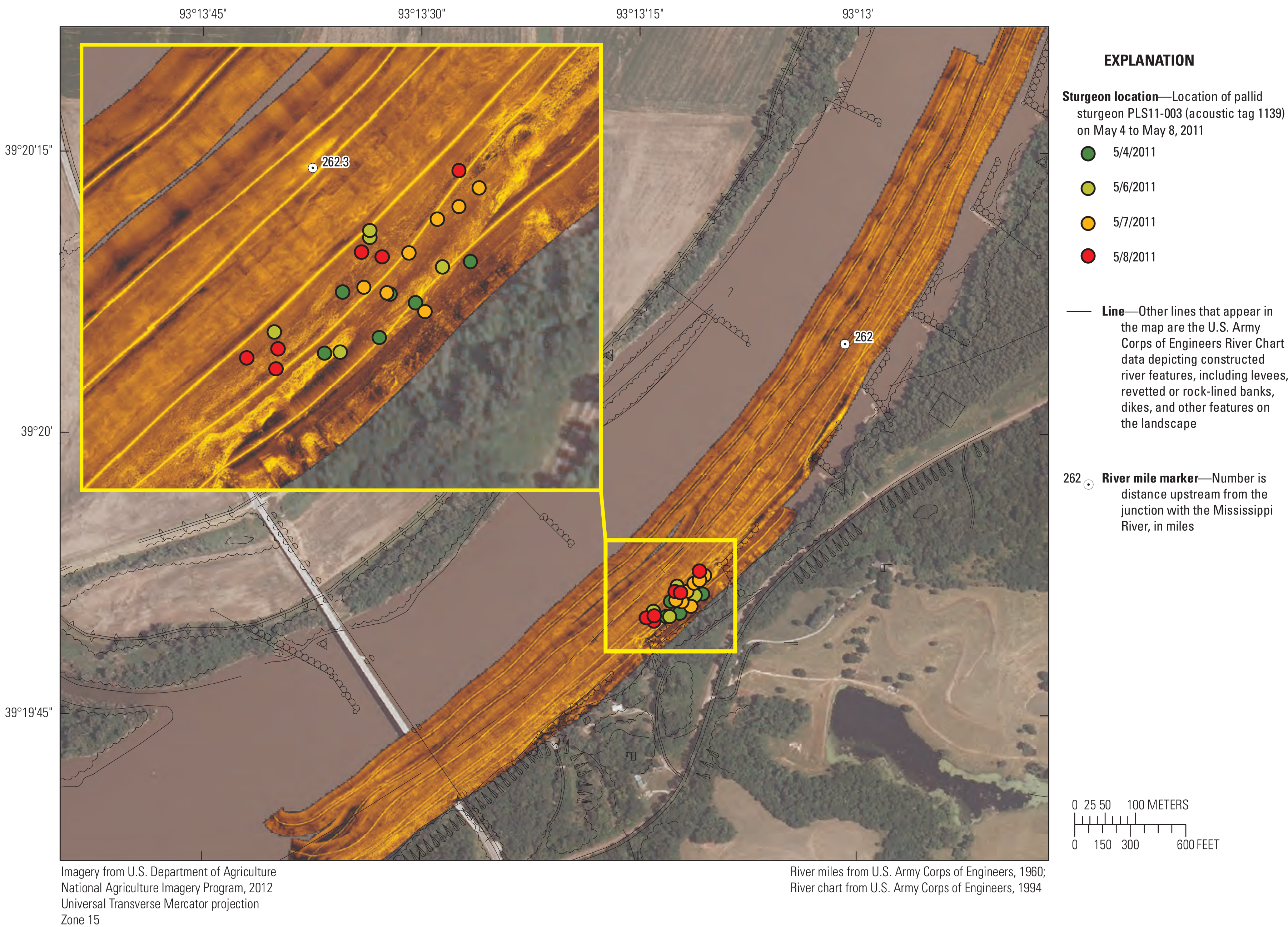


Figure 16. Side-scan sonar imagery of spawning locations of telemetry tracked reproductive male pallid sturgeon PLS11-003.

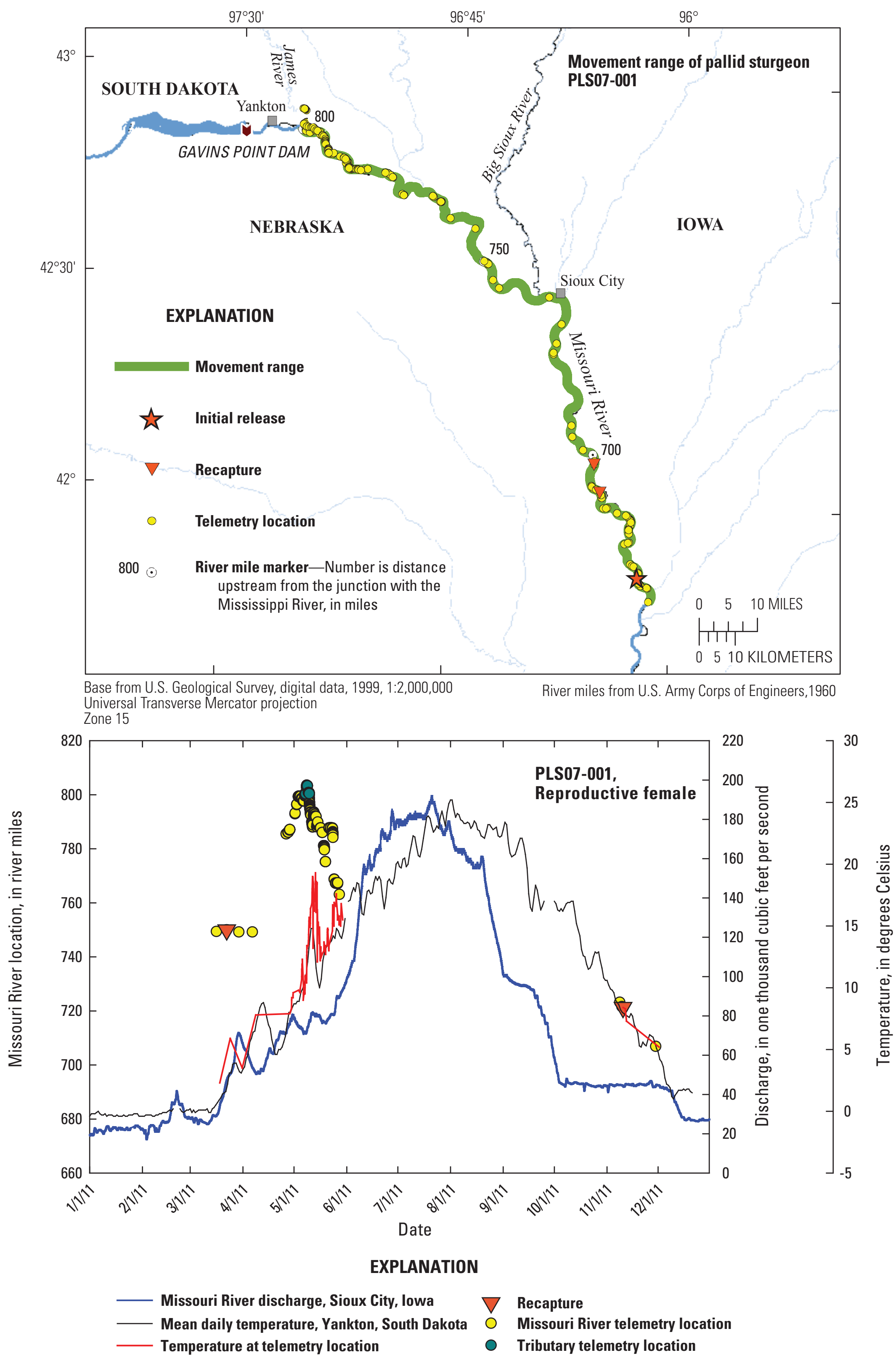


Figure 17. Movement range of female pallid sturgeon PLS07-001. Discharge from nearest streamgage at Sioux City, Iowa; mean daily temperature from nearest streamgage at Yankton, South Dakota; temperature at telemetry locations; and telemetry locations for implanted gravid pallid sturgeon PLS07-001. Fish was recaptured in reproductive condition and later determined to have spawned.

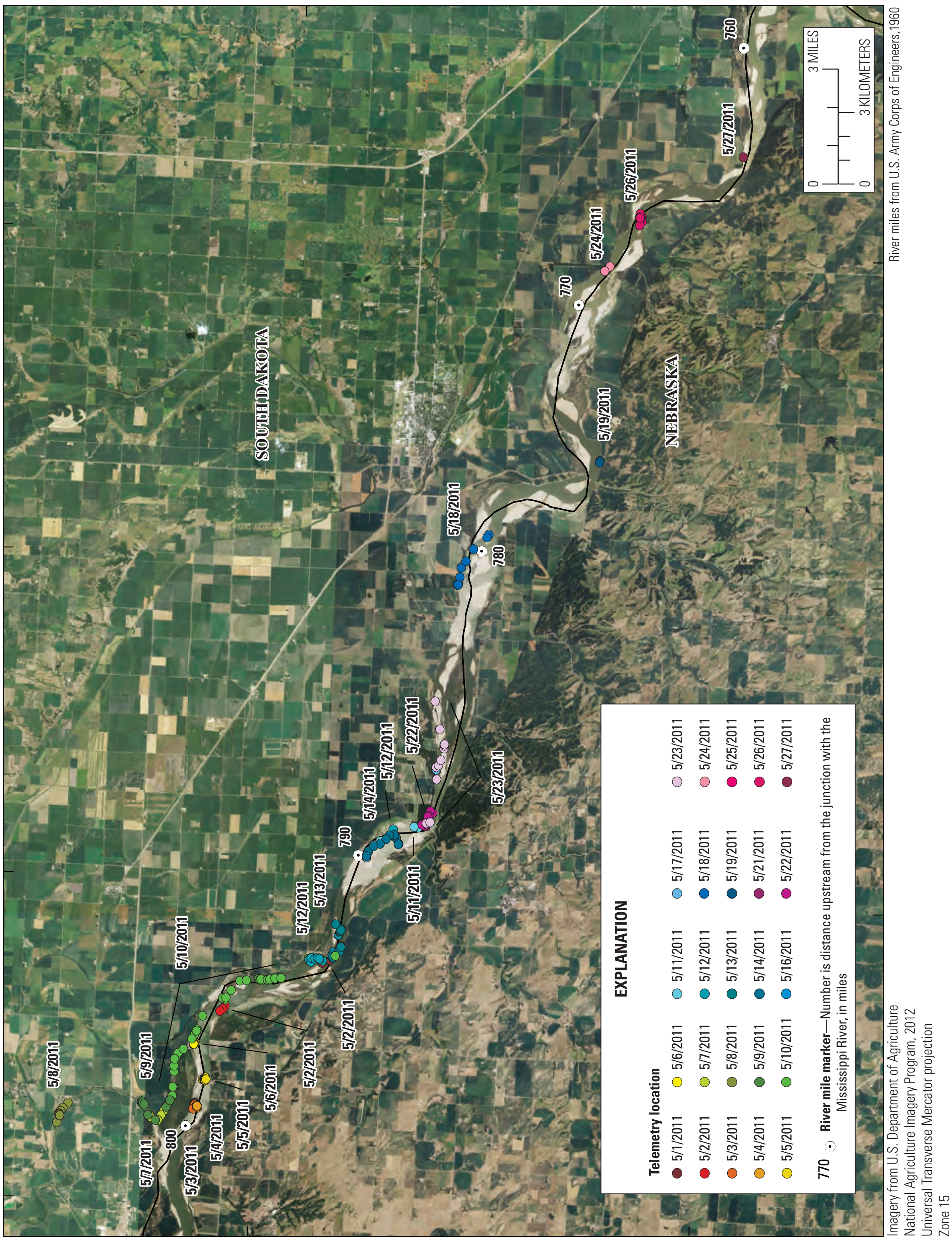


Figure 18. Telemetry locations of female pallid sturgeon PLS07-001 during upstream spawning migration.

current velocity, often near constructed side channels. These results indicate that under extreme flooding events sturgeon will use portions of inundated flood plains.

From June through September 2011, research crews in the lower study area searched accessible portions of the main-stem Missouri River and major tributaries in tandem. During high water events, one tracking boat cannot effectively search many parts of the Missouri River for tagged fish. When possible, field crews resorted to tandem tracking (two boats simultaneously tracking, one on each side of the river) to locate tagged sturgeon with acceptable efficiency. During high water events, the efficacy of the receivers decreases substantially. Fish also are more often located behind obstacles or structures that block the signals and prevent them from being detected from a distance. Whether single or tandem, boats track at about 6 miles per hour and cover 30–40 river miles a day. Tandem tracking improves tracking effectiveness, but drastically reduces the amount of area that can be monitored with limited resources. Tributaries searched included the accessible portions of the Platte, Kansas, Grand, Osage, and Gasconade Rivers. Pallid sturgeon continued to be documented with regularity near the confluence of the Osage River, and upstream to the old lock and dam structure, 12 miles upstream from the confluence with the Missouri River. No pallid sturgeon were present in the Kansas, Grand, or Gasconade Rivers in 2011. Tracking efforts in the Lower Missouri River recorded telemetry locations on 78 individual tagged pallid sturgeon. Located sturgeon included fish first captured and tagged in 2006 (3), 2007 (8), 2008 (18), 2009 (8), 2010 (22), and 2011 (19).

As releases of water from Gavins Point Dam declined and flood water receded in September 2011, research crews inspected boat ramps and access points weekly. When access was restored to sections of the river, research crews began searching for pallid sturgeon for recapture and re-implantation. Emphasis was placed on recapturing five gravid, reproductively ready pallid sturgeon females that were released from the propagation program on April 28 because of results from genetic tests suggesting that all may be the progeny of artificially spawned adults. The uncertainty surrounding their status resulted in their being declared unsuitable for propagation broodstock. All five were transported from Blind Pony State Fish Hatchery, Sweet Springs, Mo.; reproductively evaluated; implanted with transmitters and DST; and released into the Missouri River at RM 591.5, downstream from the Platte River, near Plattsmouth, Nebr. None of the five were tracked intensively or relocated during the spawning season; however, reproductive assessments at recapture can determine if females spawned the previous spring, even many months later. Also, the DST depth data can be used to infer activity patterns suggestive of migration during the spawning season (Wildhaber and others, 2011b), and temperature data collected by the DST can be compared to temperature profiles collected at numerous locations along the river to infer general spawning location.

Two of the five nonintensively tracked females were recaptured in 2011. Female pallid sturgeon PLS11-014 (PIT no. 470C211568) was first relocated on October 20, 2011, at Missouri River RM 542.2. The female was recaptured successfully on October 31, 2011, at RM 544.0. Minimally invasive and surgical reproductive assessments showed that PLS11-014 had spawned in 2011. Temperature data downloaded from the implanted DST closely matched water temperatures of the main-stem Missouri River from the closest downstream stream-gaging station at Nebraska City, Nebr. (fig. 20). Female pallid sturgeon PLS11-015 (PIT no. 470B00564A) also was first located on October 20, 2011, at Missouri River RM 544.0, and successfully recaptured on October 31, 2011, at RM 553.1. Minimally invasive and surgical reproductive assessments showed that PLS11-015 also had spawned in 2011. In contrast to PLS11-014, temperature data downloaded from the implanted DST did not match with water temperatures of the main-stem Missouri River throughout most of the spawning period (fig. 20). The DST temperature data closely matched the temperature profile of the Platte River, recorded at the Louisville, Nebr., streamgage, for nearly the entire month of May, 2011. Based on the reproductive readiness of PLS11-015 at implantation, and the length of time that it was inferred to be in the Platte River, the temperature data indicate that it spawned somewhere in the Platte River. Although not a direct observation of spawning behavior, these data strongly support the inference that pallid sturgeon are capable of spawning in the Platte River.

Intensive and extensive tracking of pallid sturgeon between 2007 and 2011 has resulted in the documentation of spawning by 16 individual females in the Lower Missouri River and tributaries (table 4). The precision of spawning locations varies for individual sturgeon. 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 (DeLonay and others, 2009) after a characteristic upstream migration. 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 (DeLonay and others, 2012).

Observations of spawning in 2011 are consistent with trends observed in previous years (DeLonay and others, 2012), with some important new trends emerging (table 4). Although it is clear that pallid sturgeon are capable of spawning in most reaches of the main-stem Missouri River under a wide variety of conditions (fig. 21), it remains unclear whether this is the natural, adaptive condition or spawning distributions have been altered by modified hydrology and channel engineering. The relative success of sturgeon spawning at different locations along the Missouri River remains unknown.

The timing of pallid sturgeon spawning in 2011 also is consistent with observations in previous years. Pallid sturgeon females in the Lower Missouri River seem to have a narrower spawning window than the closely related shovelnose

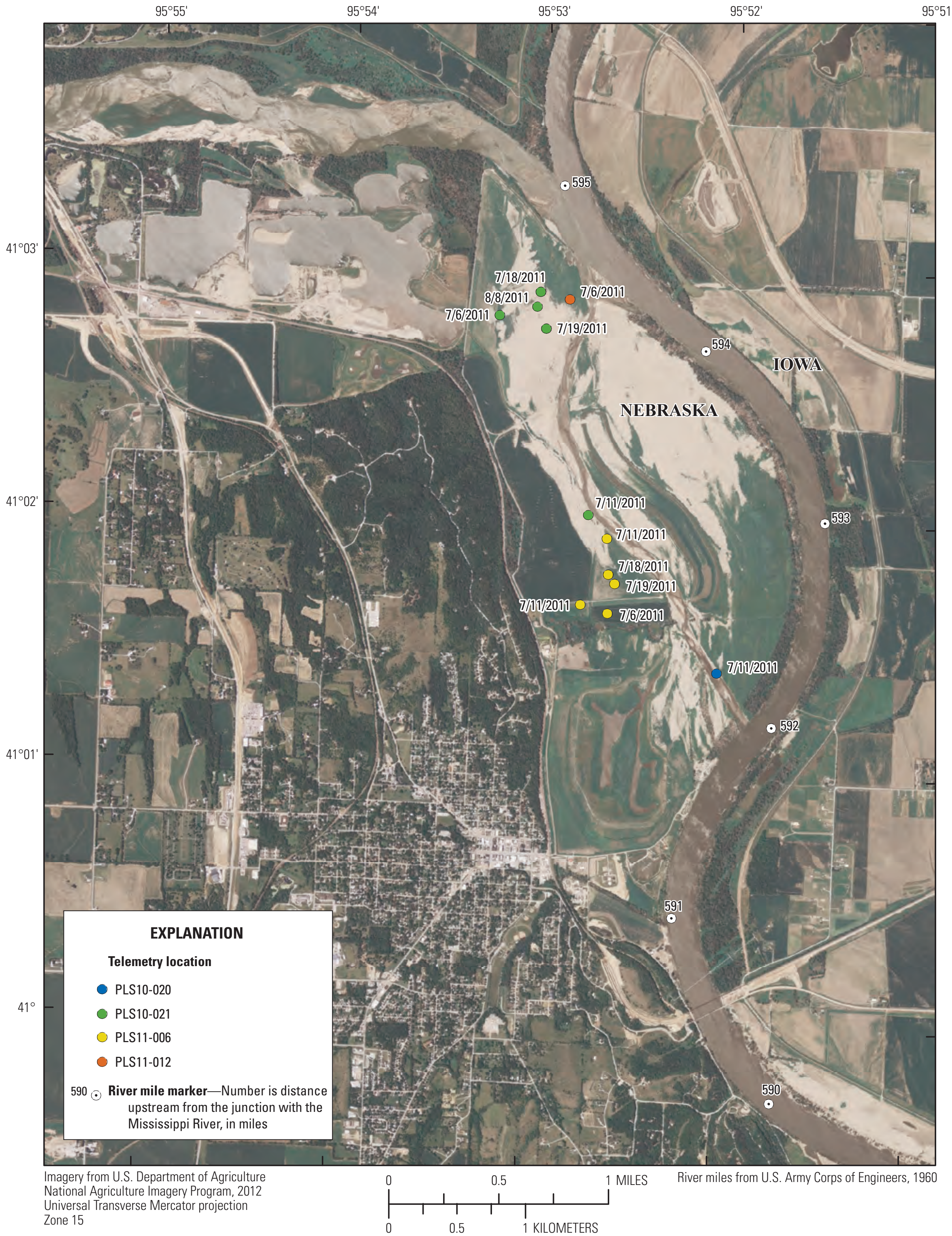


Figure 19. Flood-plain use and telemetry locations of four implanted pallid sturgeon.

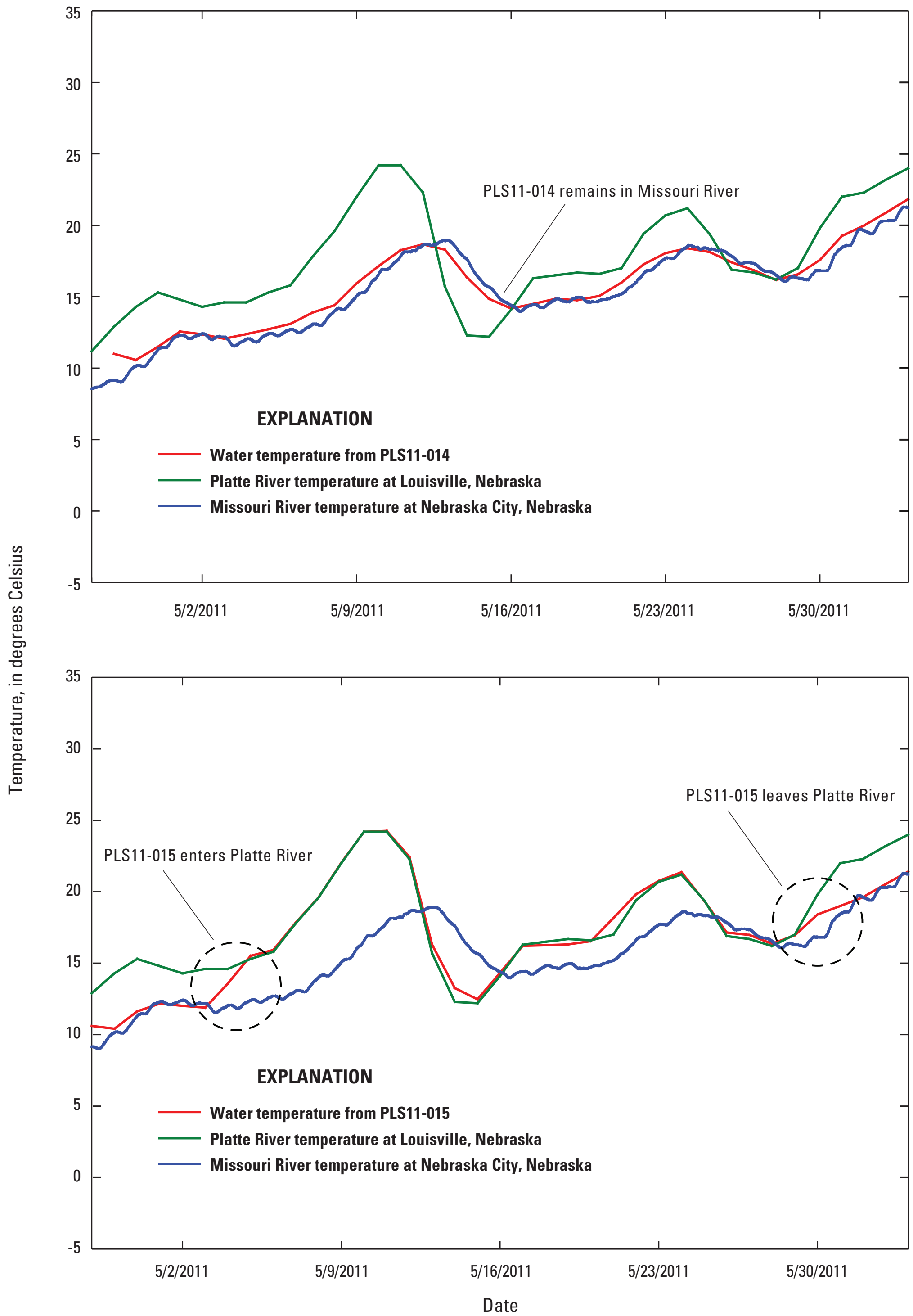


Figure 20. Comparison of temperatures recorded by data storage tags (DSTs) implanted inside two female pallid sturgeon show the two fish spawned at different locations within the Missouri River Basin.

Table 4. Probable spawning locations of telemetry tracked reproductive female pallid sturgeon, 2007–11.

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

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	Spawning end date	Upstream extent	Down-stream extent	Center of spawning site	Pre-spawn 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 interrupted 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	Intensively tracked female showed complex disrupted 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 before 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 4. Probable spawning locations of telemetry tracked reproductive female pallid sturgeon, 2007–11.—Continued

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

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	Spawning end date	Upstream extent	Down-stream extent	Center of spawning site	Pre-spawn 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. Initially 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 initial downstream movement and it had not yet spawned. It was recovered again June 9 more than nearly 150 miles downstream and it had spawned.
3	PLS07-001	2011	5/8/2011	5/23/2011	799.6 (3.3)	787.1	NA	Yes	Intensive	Yes	Intensively tracked. Complete migration documented. Complex, disrupted migration. May have spawned in the James River. Most likely spawning location is in the Missouri River. Spawning behavior not documented.
1	PLS11-008	2011	5/17/2011	5/19/2011	216.8	215.9	216.4	Yes	Intensive	Yes	Intensive tracking to spanwning location. Complete migration documented. Spawning behavior not documented.

Table 4. Probable spawning locations of telemetry tracked reproductive female pallid sturgeon, 2007–11.—Continued

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

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	Spawning end date	Upstream extent	Down-stream extent	Center of spawning site	Pre-spawn evaluation	Tracking	Spawning confirmed	
4	PLS11-014	2011	NA	NA	Missouri River, Nebraska	NA	NA	Yes	NA	Yes	The fish was not located during the spawning period. Spawning location is inferred from data storage tag records of temperature matching the temperature profile of the main-stem Missouri River, Nebraska.
4	PLS11-015	2011	NA	NA	Platte River, Nebraska	NA	NA	Yes	NA	Yes	The fish was not located during the spawning period. Spawning location is inferred from data storage tag records of temperature matching the temperature profile of the Platte River, Nebraska.

[1] 1 is the probable spawning site located within <1 river miles; 2 is the probable spawning site located within 1–10 miles; 3 is the probable spawning site located within 10–25 miles; 4 is the probable spawning site located within 25–100 miles; 5 is the 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 river miles 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. Values (in parenthesis) are river miles in a Missouri River tributary. In 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 if the female sturgeon was evaluated for reproductive condition in the months just prior to spawning, if the sturgeon was targeted 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.

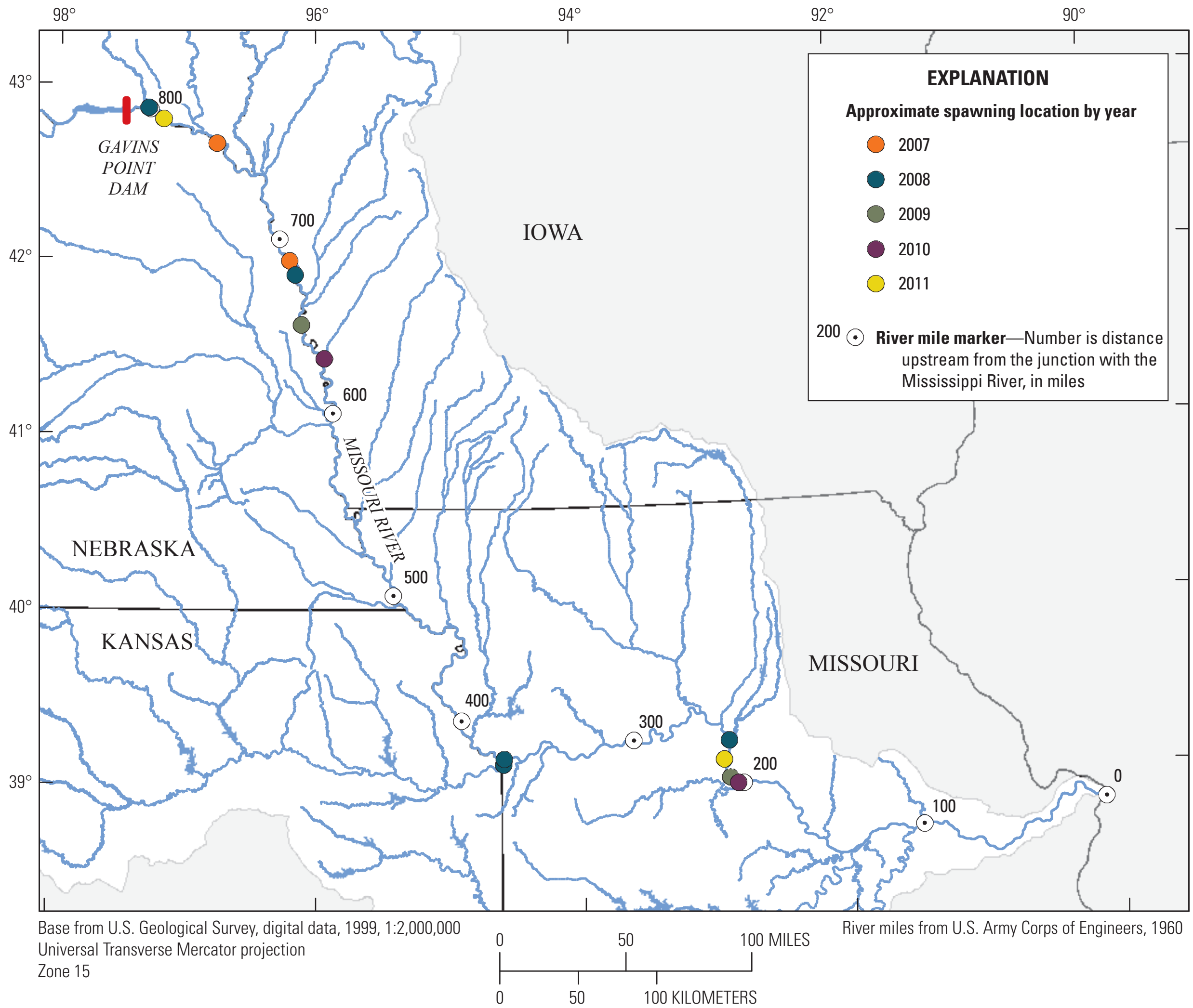


Figure 21. Spawning locations of pallid sturgeon in the Lower Missouri River.

sturgeon. Pallid sturgeon in the Lower Missouri River spawn from the end of April through May (DeLonay and others, 2009; DeLonay and others, 2010; DeLonay and others, 2012). Shovelnose sturgeon, in contrast, may spawn from mid-April to July (DeLonay and others, 2009). 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 2 weeks of May. Sturgeon with complex, disrupted patterns and sturgeon nearer Gavins Point Dam typically spawn later, from the middle to the end of May. Gravid, reproductive, female pallid sturgeon that do not migrate fail to spawn and their oocytes eventually become atretic. Data suggest that pallid sturgeon are spawning in the Platte River, and there are instances of individual pallid sturgeon of both sexes returning to the same section of river to spawn with surprising fidelity. Tracking adult sturgeon over longer periods would allow researchers to assess the level of spawning site fidelity in pallid sturgeon and the role geographic specificity may play in preserving population genetic structure.

Reproductive Physiology

Female Reproductive Condition

Nine reproductive females were tracked during part (six fish) or all (three fish) of the 2011 reproductive season. Six of the nine fish were recaptured and of these, three had spawned completely (460D390133, 470B00564A, 472E437424), two did not spawn (412C275E0A, 47156C1037), and one partially spawned (470C211568) (table 5). The fish that did not spawn or partially spawned had been received from the hatchery, where they were induced to spawn before the start of tracking, and the oocytes had become atretic. The female pallid sturgeon that was not induced at the hatchery spawned completely (470B00564A) (table 5). All females that spawned completely showed a normal reproductive hormone pattern of a decrease in all hormone levels. No distinct trends in blood chemistry parameters could be discerned distinguishing the fish that did spawn from those that did not. An additional six females from the hatchery propagation program were monitored for PI and in some cases also for blood hormones and chemistry (table 6).

Fifty-eight pallid sturgeon females from the lower and upper study sections of the Lower Missouri River were bled and tested for reproductive hormones (table 7) from March 1 to May 31. A total of 37 of those females were field collected sturgeon during the reproductive season. Estradiol in nonreproductive females from the lower section (n=6) was less than the limit of detection (LOD), testosterone averaged 1,214±467 picograms per milliliter (pg/mL) and ranged from 606±1,867 pg/mL. 11-ketotestosterone from these females averaged 72±16 pg/mL and ranged from 49 to 90 pg/mL. Reproductive hormones were elevated in the lower study section reproductive females (n=7) between March 29 and April 18 then decreased after May 4 (fig. 22). Nonreproductive females from the upper study section (n=11) had estradiol levels of 17±24 pg/mL, ranging from 3 to 83 pg/mL; testosterone levels of 1,244±1,464 pg/mL, ranging from 103±4,795 pg/mL; and 11-ketotestosterone levels of 116±202 pg/mL, ranging from 3 to 683 pg/mL. Estradiol levels were high in the upper study section reproductive females (n=13) until approximately April 28 then decreased on May 4. Concomitantly, the androgens decreased after March 29 then progressively increased to May 4, when the last female was sampled (fig. 23).

The ratio of 11-ketotestosterone to estradiol (KT:E) was used as an indicator of readiness to spawn and was compared to discharge and temperature during the reproductive season. Increasing temperature corresponded to a decrease in the KT:E ratio in fish collected in the lower section in late March to early April (fig. 24*A*). In contrast, the KT:E ratio increased in fish collected in the upper section in late April to early May (fig. 24*B*).

Table 5. Mean polarization index of gravid female pallid sturgeon collected and tracked during 2011.

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

Fish ID	Date	Mean PI	GVBD? (percent)	Spawn?
412C1E3214	4/8/2011	0.13	--	Not attempted
412C1E3214	4/18/2011	0.12	No	Not attempted
412C1E3214	4/28/2011	0.12	40	Unknown
412C275E0A	4/7/2011	0.12	Yes	No, attempted
412C275E0A	4/18/2011	0.12	Yes	No, attempted
412C275E0A	[1]4/28/2011	--	--	Atretic
412C3D4274	4/7/2011	0.11	Yes	Not attempted
412C3D4274	[1]4/28/2011	0.13	No	Unknown
434C356D48	5/4/2011	0.06	Yes	Unknown
460D390133	3/22/2011	0.15	--	Yes
470B00564A	4/8/2011	0.11	Yes	Not attempted
470B00564A	4/18/2011	0.17	60	Not attempted
470B00564A	[1]4/28/2011	0.13	Yes	Yes
470C211568	4/12/2011	0.13	--	No, attempted
470C211568	4/18/2011	0.11	Yes	No, attempted
470C211568	[1]4/28/2011	0.09	50	Partial
47156C1037	3/29/2011	0.16	No	No, attempted
47156C1037	5/1/2011	0.06	--	Atretic
472E437424	4/15/2011	0.12	Yes	Yes

[1]Transferred from propagation program for tracking.

Development of Additional Markers of Reproductive Condition

Maturation-inducing hormone.—Our research during the last several years indicates the maturation-inducing hormone, important to *Scaphirhynchus* sturgeon, is one or a combination of 20β-S (4-pregnen-17, 20β-21-triol-3-one); 17,20β-P (4-pregnen-17, 20β-diol-3-one); and 17α-hydroxy progesterone (4-pregnen-17-ol-3, 20-dione). These compounds were identified as causing germinal vesicle breakdown in an in vitro assay and also are produced by the oocyte follicles at maturation.

Table 6. Mean polarization index of gravid female pallid sturgeon not tracked during 2011 reproductive season.

[Fish ID, fish identification code; PI, polarization index; GVBD, germinal vesicle breakdown; --, no data; NA, not applicable]

Fish ID	Date	Mean PI	GVBD? (percent)	Spawn?
4626553E42	4/14/2011	0.08	Yes	Yes
4627111945	4/7/2011	0.09	40	Unknown
4627111945	4/18/2011	0.12	60	Unknown
4868364835	4/14/2011	0.08	Yes	Unknown
48684B3101	4/7/2011	0.12	No	Unknown
434A00324C	11/1/2011	0.15	--	NA
4864436C13	5/4/2011	0.41	--	NA

Table 7. Plasma hormone values for female pallid sturgeon collected in 2011.

[Fish ID, fish identification code; pg/mL, picograms per milliliter; >, greater than; LOQ, limit of quantitation; <, less than; LOD, limit of detection; --, no data; estradiol LOD equals 3 pg/mL; testosterone LOQ equals 10,835 pg/mL; 11-ketotestosterone LOQ equals 9,425 pg/mL]

Fish ID	Date	Estradiol, pg/mL	Testosterone, pg/mL	11-Ketotestosterone, pg/mL
4A472A1652	3/29/2011	51	3,205	305
4A472A1652	9/6/2011	1,147	>LOQ	2,559
4A47567A35	4/5/2011	78	3,651	190
4A47567A35	4/7/2011	251	>LOQ	3,742
4A47567A35	9/16/2011	<LOD	4,208	683
412C1E3214	4/18/2011	179	5,197	663
412C1E3214	4/28/2011	126	>LOQ	906
412C275E0A	4/28/2011	533	5,169	385
412C275E0A	4/7/2011	<LOD	745	83
412C3D4274	4/28/2011	1,478	>LOQ	1,028
412C3D4274	4/28/2011	205	>LOQ	1,436
423373582F	10/6/2011	<LOD	6,484	333
424F36204E	4/16/2011	83	920	166
424F36204E	11/3/2011	32	1,679	166
4310112466	4/18/2011	<LOD	1,159	70
4311424979	9/6/2011	<LOD	1,772	162
4311540824	9/22/2011	<LOD	3,395	259
4311540824	11/23/2011	<LOD	1,937	92
4315654C74	4/7/2011	<LOD	2,918	161
4445390169	4/13/2011	<LOD	614	58
434A411537	4/7/2011	<LOD	2,787	148
434B6B0207	4/7/2011	53	5,109	381
4349472D74	4/18/2011	30	693	107
4349472D74	4/28/2011	<LOD	1,400	77
434A00324C	11/1/2011	739	>LOQ	3,697
434C356D48	3/29/2011	181	>LOQ	5,403
434C356D48	5/4/2011	<LOD	>LOQ	3,953
435E673F40	3/22/2011	<LOD	2,285	109
460D734E50	4/5/2011	205	>LOQ	1,202
460D390133	3/22/2011	3,388	>LOQ	845
460D390133	11/10/2011	1,528	708	44
460E344873	4/7/2011	<LOD	779	54
460E356D5D	4/7/2011	<LOD	848	90
460E52494D	4/7/2011	<LOD	827	72
460E52494D	9/6/2011	<LOD	932	87
460E58630C	4/7/2011	<LOD	1,600	109
461847733B	4/14/2011	<LOD	922	65
4618591F4D	4/7/2011	50	>LOQ	78
4618591F4D	9/6/2011	<LOD	362	<LOD
4623505367	4/12/2011	<LOD	606	49
462508307B	9/6/2011	<LOD	1,920	226
4626553E42	4/14/2011	71	1,867	416
462704502D	9/6/2011	<LOD	700	98
4627111945	4/7/2011	940	6,276	1,088

Table 7. Plasma hormone values for female pallid sturgeon collected in 2011.—Continued

[Fish ID, fish identification code; pg/mL, picograms per milliliter; >, greater than; LOQ, limit of quantitation; <, less than; LOD, limit of detection; --, no data; estradiol LOD equals 3 pg/mL; testosterone LOQ equals 10,835 pg/mL; 11-ketotestosterone LOQ equals 9,425 pg/mL]

Fish ID	Date	Estradiol, pg/mL	Testosterone, pg/mL	11-Ketotestosterone, pg/mL
4627683B2B	4/7/2011	<LOD	3,368	217
470C211568	4/18/2011	169	4,962	712
4703770622	4/14/2011	<LOD	1,505	113
4703770622	9/6/2011	1,326	>LOQ	2,380
47044E3232	3/29/2011	211	278	40
4704771730	2/22/2011	<LOD	1,518	87
47061F690A	4/14/2011	<LOD	--	144
47061F690A	9/6/2011	<LOD	1,071	137
470A765E19	4/7/2011	<LOD	1,880	147
470B00564A	4/18/2011	68	1,905	338
470B00564A	4/28/2011	<LOD	>LOQ	767
470B00564A	11/1/2011	<LOD	418	46
470C211568	4/18/2011	169	4,962	712
470C211568	4/28/2011	92	8,061	545
470C211568	10/31/2011	<LOD	1,440	75
471C0F3819	4/14/2011	<LOD	429	36
47156C1037	3/29/2011	127	>LOQ	3,344
47156C1037	5/4/2011	<LOD	247	<LOD
47156C1037	6/10/2011	<LOD	286	61
4716781353	3/16/2011	<LOD	1,413	61
4716781353	9/15/2011	<LOD	491	38
47235C3508	4/7/2011	175	>LOQ	>LOQ
472E437424	4/15/2011	293	6,344	804
472E437424	6/14/2011	<LOD	608	50
472E481B31	4/14/2011	<LOD	103	<LOD
486A305F5A	4/7/2011	<LOD	3,436	383
4864436C13	5/4/2011	46	4,795	521
4864436C13	3/29/2011	395	9,544	2,188
4864436C13	5/4/2011	46	4,795	521
48665E2D76	3/22/2011	<LOD	323	30
4866602808	3/23/2011	<LOD	1,021	78
4866727804	4/29/2011	44	559	92
4866727804	9/6/2011	<LOD	789	92
4868364835	4/14/2011	56	1,188	630
486842447F	4/7/2011	<LOD	3,841	259
48684B3101	4/7/2011	809	4,318	321
48684E0A35	4/7/2011	<LOD	1,992	113
48685E2C74	9/6/2011	<LOD	1,023	89
4868660124	3/29/2011	<LOD	1,867	90
4875257231	3/24/2011	<LOD	860	67
4627111945	4/7/2011	940	6,276	1,088
4866727804	3/29/2011	44	559	92
4868364835	4/14/2011	56	1,188	630
48686A0A2E	4/7/2011	<LOD	1,530	94

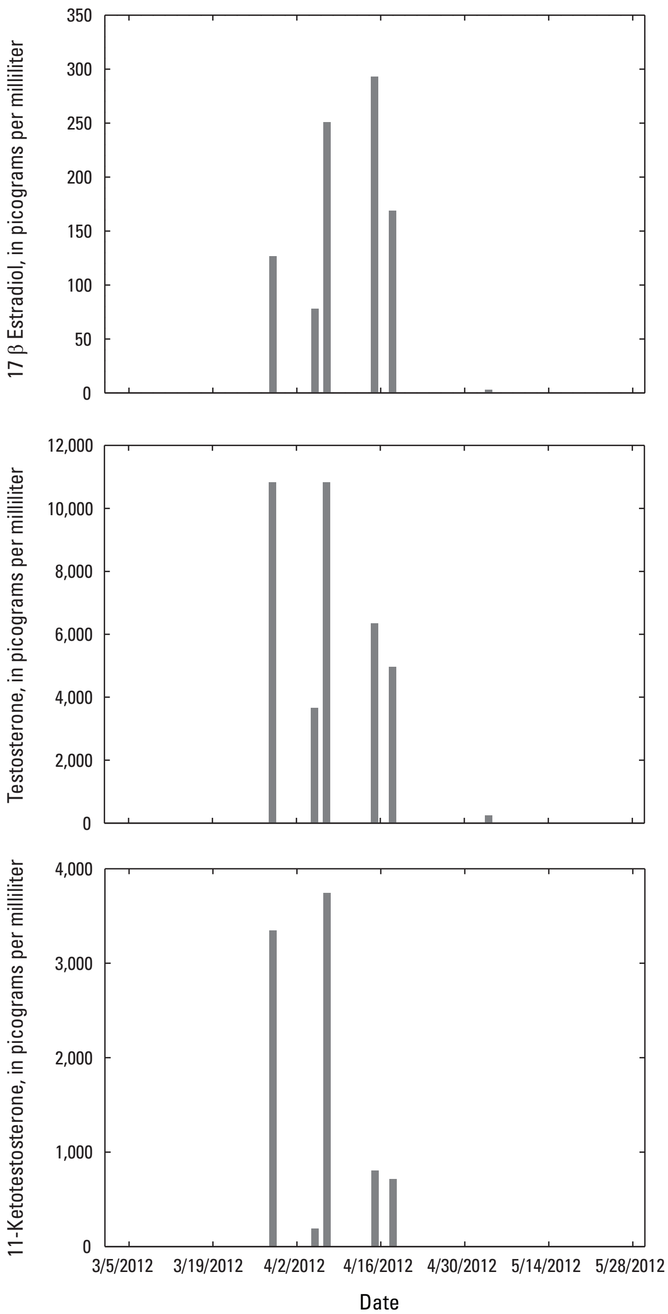


Figure 22. Reproductive hormone concentrations by date in reproductive females captured in the lower study section of the Lower Missouri River. When multiple females were captured on a date, results were averaged.

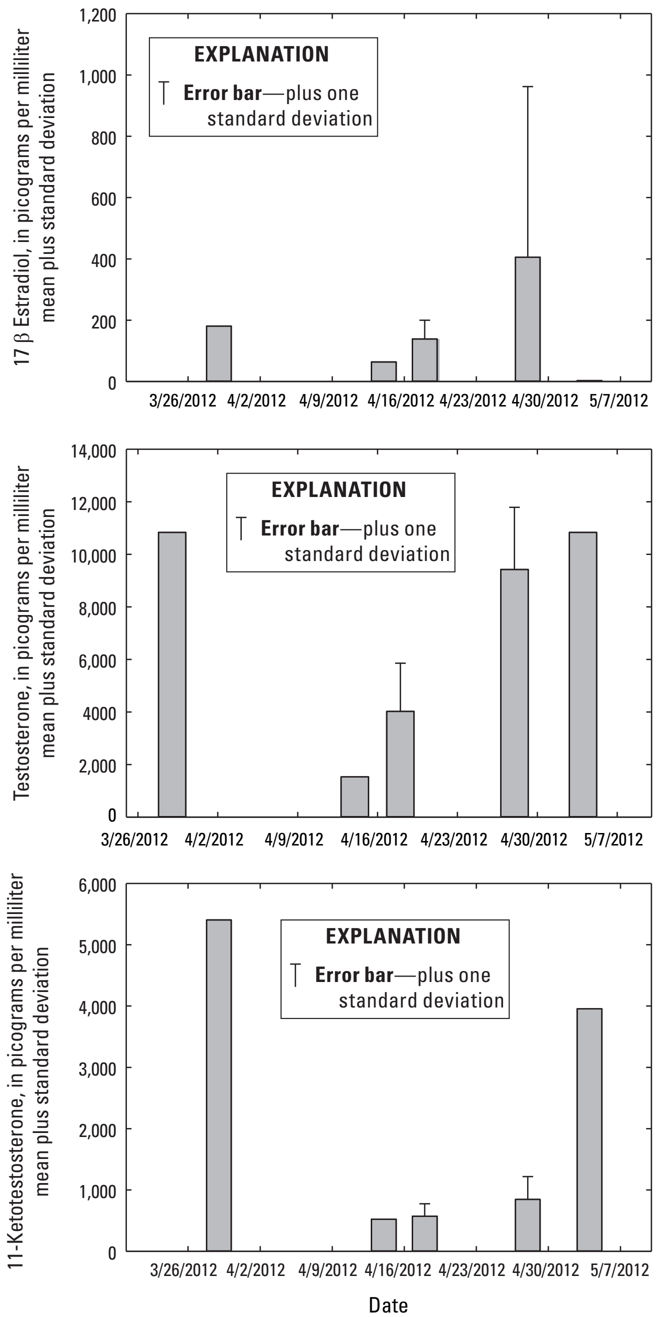


Figure 23. Reproductive hormone concentrations by date in reproductive females captured in the upper study section of the Lower Missouri River. When multiple females were captured on a date, results were averaged.

Leptin.—Leptin was measured in blood collected from a reproductive female pallid sturgeon kept in captivity for 7 months and fed to satiation [4.4 nanograms per milliliter (ng/mL)] and a wild-caught male shovelnose sturgeon (5.4 ng/mL). Initial results are promising but the assay requires further optimization. Serum concentrations of the hormone, leptin, may be used to evaluate condition of fish in the field, or to indicate obesity among captive broodstock before long-term negative effects are manifest. Future work will correlate leptin measurements with measures of body fat to evaluate the roles of migration, feeding, and metabolism on reproduction.

Blood chemistry.—A larger dataset of blood chemistry data is needed to make robust comparisons between male and female sturgeon, life stages, reproductive stage, and time held in captivity; however, a few trends are beginning to emerge from the data collected to date. Lipase generally was below the limit of detection for all fish and bilirubin was similar for males and females at all reproductive stages (tables 8 and 9).

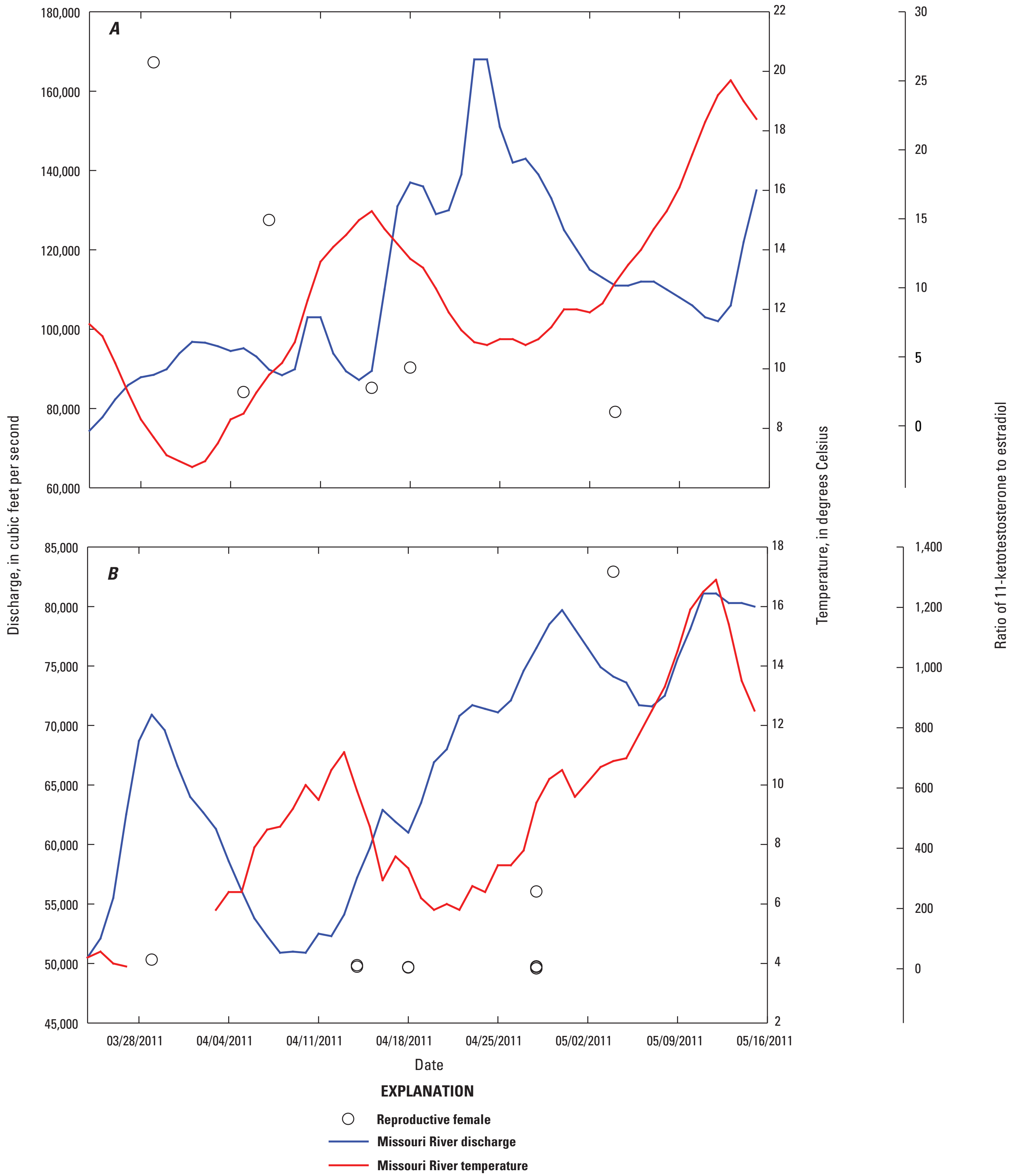


Figure 24. Ratios of reproductive hormone concentrations, 11-ketotestosterone to estradiol (KT:E), by date in reproductive females (symbol) captured in the upper and lower study sections of the Missouri River plotted against Missouri River temperature (red) and discharge (blue). Temperature and discharge recorded at the USGS streamgages at Boonville, Missouri (lower study section): *A*, and Sioux City, Iowa (upper study section): *B*. When multiple females were captured on a date, results were averaged.

Values for triglycerides, glucose, and creatinine tended to be greater for male than female sturgeon and reproductive fish tended to have higher triglycerides than non-reproductive fish (tables 8 and 9). Lactate and cholesterol values tended to be greater for reproductive males than reproductive females (tables 8 and 9). Protein and cholesterol values of nonreproductive females tended to be greater than nonreproductive males (tables 8 and 9). Lactate was similar among the non-reproductive sturgeon (tables 8 and 9). Reproductive females held in captivity all their life tended to have lower triglycerides, but this may also be attributable to the post-spawn season when blood samples were collected (table 8). Similarly, captive reproductive males post-spawn had lower average cholesterol (table 9). Sturgeon held their entire life in captivity tended to have higher creatinine and protein levels than the other sturgeon examined (tables 8 and 9).

Quantify Migration and Spawning Habitat

In 2011, 22 habitat assessments totaled about 21.4 river miles: 15.3 miles in the main-stem Lower Missouri River, 1 mile in the Osage River, and 5.1 miles in off-channel chutes or side channels (table 10). These pallid sturgeon habitat assessments included 2 suspected spawning locations, 1 general habitat-use site, 4 pallid sturgeon migration movements of interest, and 15 Lower Missouri River sites mapped to investigate habitat for larval and YOY sturgeon.

Two suspected spawning locations were mapped in 2011. Documented spawning sites in the main stem were similar to those identified in previous years, outside revetted banks. These spawning locations, near RM 262.5 and RM 216, were mapped (table 10) using the high-resolution multibeam habitat protocol, which includes a reach-long swath map and ADCP mapping at 20-m transects perpendicular to flow. The site at RM 262.5 near Miami, Mo., was believed to be a spawning site for male pallid sturgeon PLS11-003 in May. An incomplete attempt was made to complete multibeam and ADCP mapping at this site on May 5, 2011, and high discharges over the course of the summer prevented mapping of this reach within the discharge range of the suspected spawning event until the site was mapped on October 4–5, 2011 (figs. 25, 26). The site at RM 216 was the site of a female, PLS11-008, believed to have spawned on May 17–19, 2011 and was mapped on May 19 and 21, 2011 (figs. 27, 28). One habitat use assessment was located at a possible spawning location, approximately 3 miles up the James River in South Dakota, which enters the Missouri River from the north 10 river miles downstream from Gavins Point Dam. This site was mapped with the lower-resolution single-beam echosounder and ADCP habitat protocol. Pilot investigations involved deployment of the underwater microscope at the spawning sites near RM 262.5 and 216 on the main-stem Missouri River and the habitat-use site on the James River. Analyses of images from the underwater microscope in 2011 did not detect the presences of eggs or larvae. Estimates of spawning location through telemetry do not precisely determine the location of egg deposition. The efficacy of the underwater microscope is likely to increase with more refined spawning locations. The number of spawning sites mapped was limited by the number of sites documented by tracking crews.

Four migration pathways were surveyed in 2011 (table 10). Three of these pathways, for pallid sturgeon, PLS11-003 and PLS10-28, were mapped April 22 through April 29, 2011, in the Lisbon Chute, RM 213–218. A pathway resulting in 11 ADCP transects documents the pathway of the male pallid sturgeon (PLS11-003) on April 30, 2011, from RM 233.9–235.5; this pathway was mapped on May 2, 2011 (fig. 29).

Eight sites totaling 9 river miles were mapped to assess the dynamics of larval drift and exchange between the main channel and off-channel habitats (table 10). All eight of these sites were mapped with the high-resolution protocol using a combination of multibeam bathymetry and ADCP transects. An example of this mapping effort is the vicinity of the Overton Bottoms North Chute inlet near RM 187 (figs. 30, 31). Nine total surveys at three sites were coordinated with USFWS sampling to assess larval and YOY habitat on the Missouri River over a range of flows. Each of the areas mapped contains broad shallow areas of habitat adjacent to the main channel where hypotheses regarding the conditions that affect larval and juvenile retention may be examined. These sites were near RM 162, just upstream of Hartsburg, Mo.; at Jameson Island near RM 213; and at California Island near RM 177. Surveys were repeated at the site at RM 162 near Hartsburg, Mo., where the entire bend was surveyed using a single-beam RTK protocol on June 23–24, 2011; a high-resolution multibeam protocol over the entire bend on August, 18, 2011; and detailed single-beam and ADCP transects with 5-m spacing over the trawl sample area on July 7, July 24, and September 14, 2011 (figs. 32, 33). The Jameson and California Island bend sites were mapped using a single-beam echosounder and an ADCP with transects coincident with trawling sample areas and spaced 5 to 10 m apart.

Database Integration and Spatial Analysis

The SIMS mobile mapping application was used to record geospatial data detailing all sturgeon telemetry locations and search-effort location data from the CSRP tracking efforts in the Lower Missouri River during 2011. Since 2005, more than 13,800 pallid and shovelnose sturgeon locations have been recorded and archived using the SIMS data collection and maintenance platform. During 2011, USGS and NGPC field crews recorded approximately 1,250 pallid sturgeon locations during more than 335 search efforts. Additionally, SIMS recorded and archived 20 initial telemetry device implantations and 29 evaluations and re-implantations of pallid sturgeon during 2011. Since 2005, 549 telemetry devices have been implanted in pallid and shovelnose sturgeon and the details recorded and archived in the SIMS platform. Additionally, 264 recaptures and reproductive evaluations of telemetered pallid and shovelnose sturgeon have been recorded.

Table 8. Plasma chemistry values for female pallid sturgeon collected in 2011.

[Fish ID, fish identification code; d, days; mg/dL, milligrams per deciliter; mmol/L, millimoles per liter; g/dL, grams per deciliter; <, less than; LOD, limit of detection; NA, not applicable; ?, unknown; triglycerides LOD equals 15; lactate LOD equals 0.5; lipase LOD equals 10; creatinine LOD equals 0.05]

Fish ID	Time in captivity (d)	Date	Triglycerides (mg/dL)	Lactate (mmol/L)	Cholesterol (mg/dL)	Lipase (mg/dL)	Total bilirubin (mg/dL)	Glucose (mg/dL)	Creatinine (mg/dL)	Total protein (g/dL)
Nonreproductive										
460D734E50	1	3/29/2011	286	1.3	330	<LOD	0.3	42	<LOD	3.9
434B6B0207	2	4/7/2011	245	0.8	246	<LOD	0.4	46	<LOD	2.1
4A472A1652	150	3/29/2011	<LOD	1.1	191	<LOD	0.3	32	<LOD	3.1
4866727804	330	3/29/2011	258	1.2	336	<LOD	0.3	45	<LOD	4
47044E3232	510	3/29/2011	116	<LOD	304	<LOD	0.3	31	<LOD	2.1
Reproductive										
4626553E48	1	4/14/2011	361	<LOD	129	<LOD	0.4	39	<LOD	2.5
4868364835	5	4/18/2011	464	<LOD	129	<LOD	0.4	41	<LOD	2.4
470B00564A	21	4/28/2011	140	<LOD	179	<LOD	<LOD	51	<LOD	2.5
412C1E3214	?	4/28/2011	264	2.1	135	<LOD	0.4	50	<LOD	2.7
412C275E0A	1	4/7/2011	596	<LOD	113	<LOD	0.3	44	<LOD	2.3
412C275E0A	22	4/28/2011	256	<LOD	135	<LOD	0.3	40	<LOD	2.3
412C3D4274	23	4/28/2011	384	1.4	274	<LOD	0.2	59	<LOD	2.4
434C356D48	25	5/4/2011	174	<LOD	322	<LOD	0.2	41	<LOD	4.9
47156C1037	330	3/29/2011	490	0.6	273	<LOD	0.3	51	<LOD	3.6
47156C1037	360	5/4/2011	148	0.8	166	<LOD	0.2	34	<LOD	2.4
47156C1037	NA	6/10/2011	106	<LOD	56	<LOD	0.4	50	<LOD	2.8
472E437424	?	6/14/2011	184	2.5	55	<LOD	0.2	28	<LOD	<LOD
471B4F4241	Life	3/29/2011	287	1.3	110	<LOD	0.3	47	<LOD	4.2
4716072D74	Life	5/26/2011	185	1.3	55	13	0.4	32	0.2	4.6
4717727767	Life	5/26/2011	166	1.1	61	<LOD	0.3	42	0.2	3.8
4723595053	Life	5/26/2011	195	2.3	55	<LOD	0.3	37	0.2	4

Table 9. Plasma chemistry values for male pallid sturgeon collected in 2011.

[Fish ID, fish identification code; d, days; mg/dL, milligrams per deciliter; mmol/L, millimoles per liter; g/dL, grams per deciliter; <, less than; LOD, limit of detection; >, greater than; ~, approximately; triglycerides LOD equals 400; lactate LOD equals 0.5; cholesterol LOD equals 50–325; lipase LOD equals 10; creatinin LOD equals 0.05; total protein LOD equals 2.0]

Fish ID	Time in captivity (d)	Date	Triglycerides (mg/dL)	Lactate (mmol/L)	Cholesterol (mg/dL)	Lipase (mg/dL)	Total bilirubin (mg/dL)	Glucose (mg/dL)	Creatinine (mg/dL)	Total protein (g/dL)
Nonreproductive										
412C323E04	0	4/7/2011	255	0.6	155	<LOD	0.3	40	<LOD	<LOD
434B655531	0	4/7/2011	392	0.6	134	<LOD	0.4	48	<LOD	2.4
44235B7576	0	4/7/2011	400	0.6	64	<LOD	0.3	37	<LOD	<LOD
486452493A	0	4/8/2011	>LOD	2.9	108	<LOD	0.5	59	<LOD	2.1
4628120F23	0	4/7/2011	186	<LOD	166	<LOD	0.2	51	<LOD	<LOD
412C311632	4	4/14/2011	214	<LOD	222	<LOD	0.3	50	0.2	2.7
4614482D2A	13	4/28/2011	183	0.7	55	<LOD	0.2	40	<LOD	<LOD
4723336646	29	4/14/2011	183	0.9	138	<LOD	0.3	45	<LOD	2.8
Reproductive										
472E177B6E	0	4/15/2011	300	8.6	286	<LOD	0.5	125	<LOD	2.9
46262F791C	~7	4/14/2011	172	1	332	<LOD	0.5	43	<LOD	2.8
470C547B78	~7	4/14/2011	70	0.7	71	<LOD	0.4	40	<LOD	<LOD
4821002F65	~7	4/14/2011	302	1	302	<LOD	0.4	41	<LOD	3.1
48643A7120	~7	4/7/2011	370	2.3	336	<LOD	0.4	48	<LOD	2.4
46183F0D1A	~150	3/29/2011	254	0.7	>LOD	< LOD	0.4	41	<LOD	3.6
412C3F5754	163	4/28/2011	389	1.3	185	<LOD	0.5	93	<LOD	2.6
471B6A6774	Life	6/15/2011	550	1.4	187	<LOD	0.4	81	0.5	3.6
471818214D	Life	6/15/2011	>LOD	1.6	125	10	0.4	35	0.4	4.9
47193F0827	Life	6/15/2011	490	1.5	212	<LOD	0.4	87	0.5	4.2
472E2E1918	Life	6/15/2011	242	1.1	145	<LOD	0.3	122	5.8	4

Table 10. Summary data for habitat assessment efforts on the Lower Missouri River in 2011.

[Sturgeon ID, identification code; ADCP, acoustic Doppler current profiler; YOY, young-of-year; --, no data]

Habitat surveyed	Sturgeon ID	Date	River mile[1]	Nearest streamflow gage and identification number	Discharge,[2] in cubic feet per second (ft^3/s)	Survey type
Spawning	PLS11-003	5/10/2011, 10/04/2011	262.1–262.6	Missouri River at Waverly, Missouri, 06895500	96,400	Multibeam and ADCP
Spawning	PLS11-008	5/19/2011, 5/21/2011	215.9–216.8	Missouri River at Boonville, Missouri, 06969000	130,000	Multibeam and ADCP
Habitat use	PLS07-001	5/12/2011	James River	James River near Yankton, South Dakota, 06478513	14,000	ADCP
Migration	PLS11-003, PLS10-28	4/22/2011	Lisbon Chute	Missouri River at Boonville, Missouri, 06969000	139,000	ADCP
Migration	PLS11-003, PLS10-28	4/26/2011	Lisbon Chute	Missouri River at Boonville, Missouri, 06969000	142,000	ADCP
Migration	PLS11-003, PLS10-28	4/29/2011	Lisbon Chute	Missouri River at Boonville, Missouri, 06969000	133,000	ADCP
Migration	PLS11-003	5/2/2011	233.9–235.5	Missouri River at Boonville, Missouri, 06969000	155,000	ADCP
Larval/ YOY sturgeon	--	5/31/2011	214.1–214.5 and chute inlet	Missouri River at Boonville, Missouri, 06969000	177,000	Multibeam and ADCP
Larval/ YOY sturgeon	--	6/1/2011–6/2/2011	214.2–215.1 and chute outlet	Missouri River at Boonville, Missouri, 06969000	177,000	Multibeam and ADCP
Larval/ YOY sturgeon	--	6/6/2011	214.1–215 and chute inlet	Missouri River at Boonville, Missouri, 06969000	199,000	Multibeam and ADCP
Larval/ YOY sturgeon	--	6/8/2011	211.2–211.4 and chute inlet	Missouri River at Boonville, Missouri, 06969000	187,000	Multibeam and ADCP
Larval/ YOY sturgeon	--	6/15/2011–6/16/2011	129.6–130.6 and Osage River mouth	Missouri River at Boonville, Missouri, 06969000	167,000	Multibeam and ADCP
				Osage River at Saint Thomas, Missouri, 06926510	34,100	
Larval/ YOY sturgeon	--	6/30/2011–7/1/2011	186.9–187.6 and chute inlet	Missouri River at Boonville, Missouri, 06969000	256,000	Multibeam and ADCP
Larval/ YOY sturgeon	--	7/29/2011	185.2–185.6 and chute outlet	Missouri River at Boonville, Missouri, 06969000	221,000	Multibeam and ADCP
Larval/ YOY sturgeon	--	8/10/2011	211.5–211.5 and chute outlet	Missouri River at Boonville, Missouri, 06969000	206,000	Multibeam and ADCP
Larval/ YOY sturgeon	--	8/18/2011	161.2–162.5	Missouri River at Boonville, Missouri, 06969000	195,000	Multibeam and ADCP
Larval/ YOY sturgeon	--	6/23-2011–6/24/2011	161–162.7	Missouri River at Boonville, Missouri, 06969000	187,000–189,000	Singlebeam and ADCP

Table 10. Summary data for habitat assessment efforts on the Lower Missouri River in 2011.—Continued

[Sturgeon ID, identification code; ADCP, acoustic Doppler current profiler; YOY, young-of-year; --, no data]

Habitat surveyed	Sturgeon ID	Date	River mile[1]	Nearest streamflow gage and identification number	Discharge,[2] in cubic feet per second (ft^3/s)	Survey type
Larval/ YOY sturgeon	--	7/7/2011	161.3–161.6	Missouri River at Boonville, Missouri, 06969000	246,000	Singlebeam and ADCP
Larval/ YOY sturgeon	--	7/24/2011	161.2–161.6	Missouri River at Boonville, Missouri, 06969000	218,000	Singlebeam and ADCP
Larval/ YOY sturgeon	--	9/14/2011	161.3–161.6	Missouri River at Boonville, Missouri, 06969000	131,000	Singlebeam and ADCP
Larval/ YOY sturgeon	--	7/14/2011-7/15/2011	212.7–214.1	Missouri River at Boonville, Missouri, 06969000	234,000–237,000	Singlebeam and ADCP
Larval/ YOY sturgeon	--	8/23/2011	176.8–177.8	Missouri River at Boonville, Missouri, 06969000	211,000	Singlebeam and ADCP

[1] River mile, distance upstream from the junction with the Mississippi River, in miles.

[2] Discharge is reported as the mean discharge over the course of the survey.

During 2011, more than 150,000 records from data storage tags implanted in 8 individual fish were recovered and archived in the database. Since 2006, more than 1.8 million data storage tag records from 53 individual pallid sturgeon have been archived. Nine individual pallid sturgeon have had more than one data storage tag implanted, retrieved, and the data maintained in the SIMS. In 2011, over 460,000 records were added to the SIMS from a network of temperature loggers in the Lower Missouri River and its tributaries.

In total, SIMS houses 45 tables essential to reporting the results of task 1 of the CSRP. The SIMS platform allows for rapid compilation and dissemination of information, internally and externally, because information frequently is requested by other programs and agencies to aid in decision making. Data often are requested by the Missouri Department of Transportation, Environmental Design Section before any bridge construction, demolition, or alteration. Information also is shared with USFWS and several State agencies regarding the history for many fish captured during broodstock collection efforts. SIMS also allows for coordination with the Population Assessment Project database manager to obtain and integrate capture data for any telemetered pallid sturgeon obtained from propagation efforts.

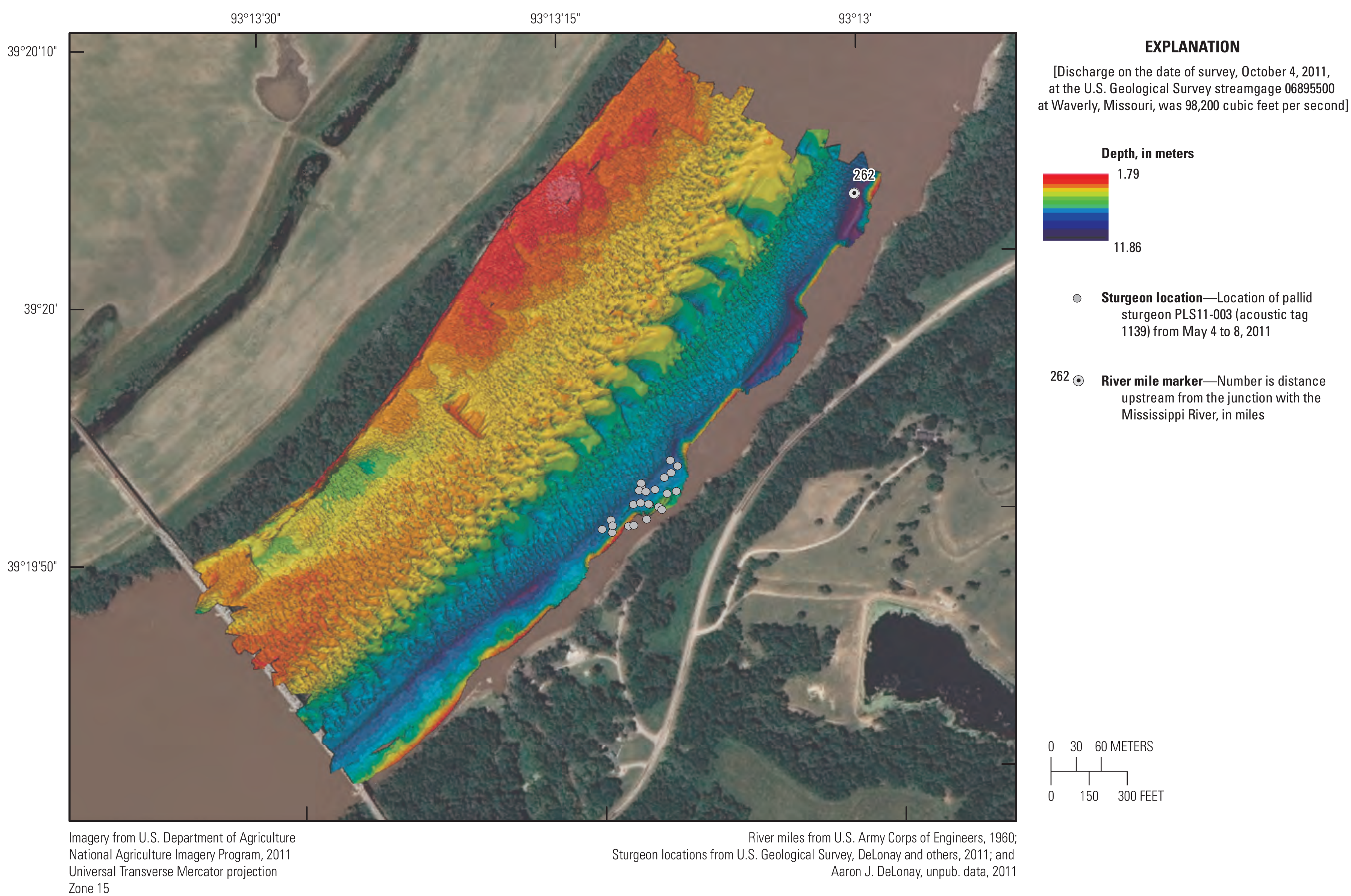


Figure 25. Multibeam bathymetry of reproductive male pallid sturgeon PLS11-003 spawning site mapped on May 10 and October 4, 2011.

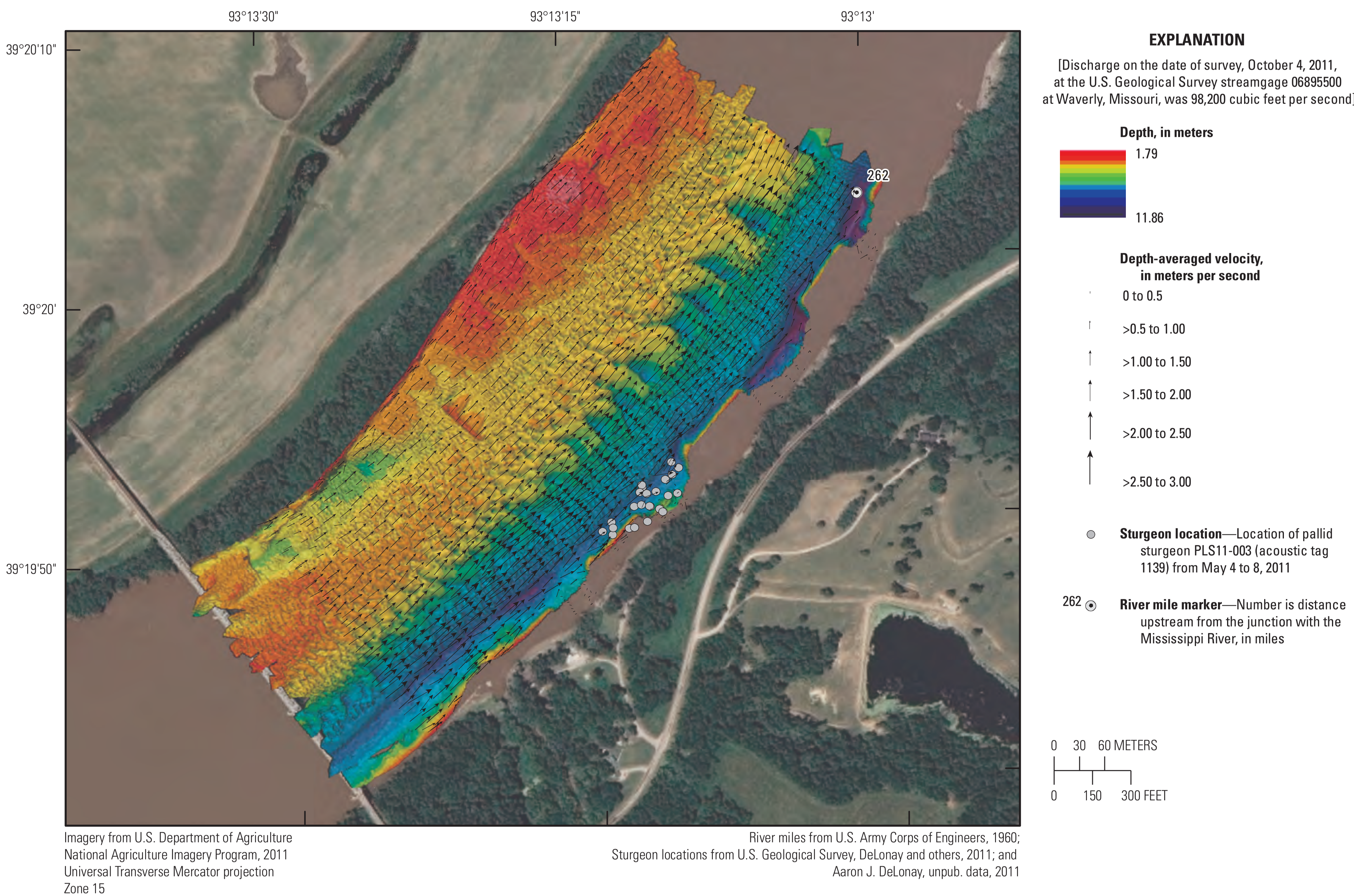


Figure 26. Acoustic Doppler current profiler velocity vectors and multibeam bathymetric map of reproductive male pallid sturgeon PLS10-013 spawning site mapped on October 5, 2011.

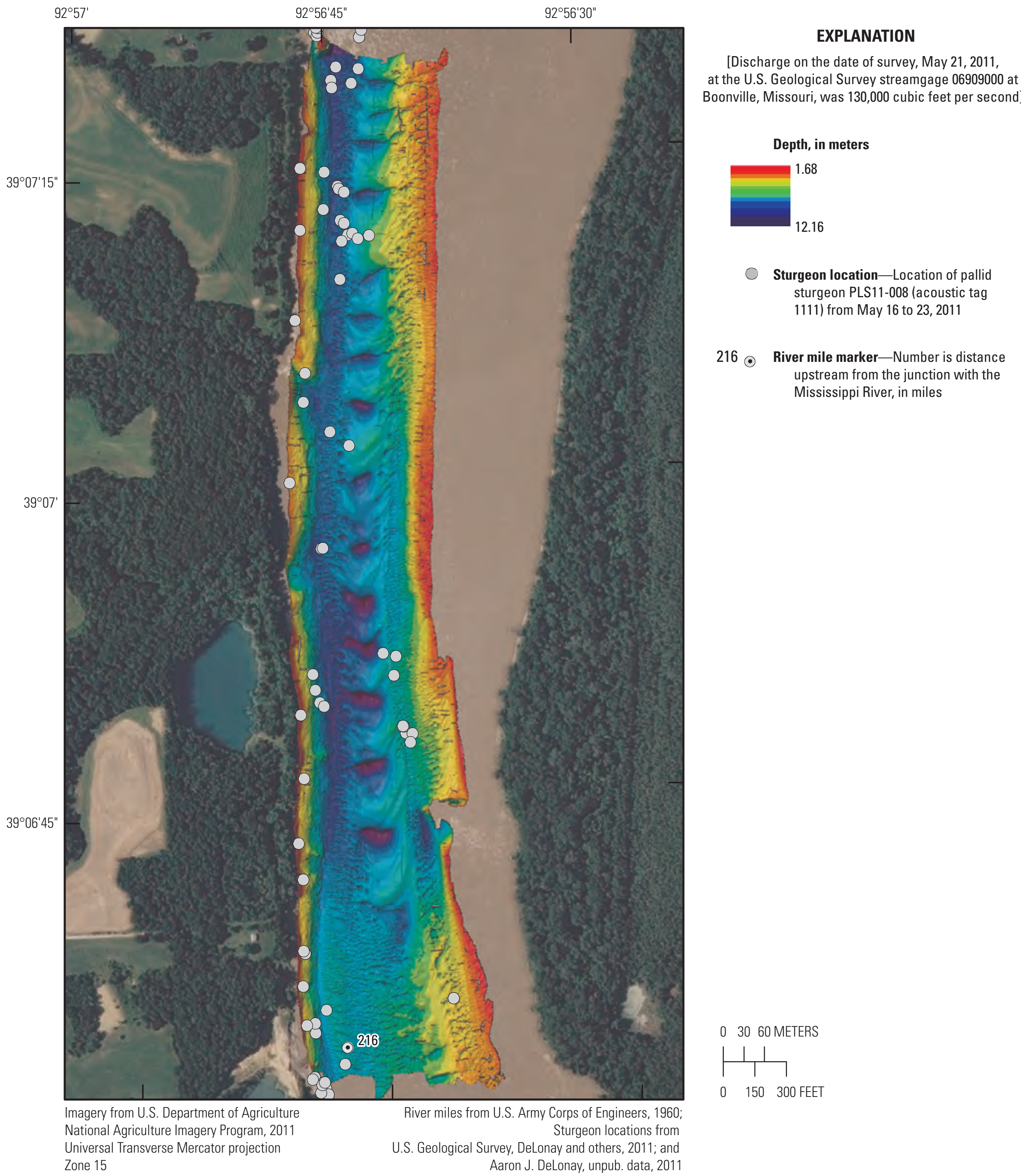


Figure 27. Multibeam bathymetry of reproductive female pallid sturgeon PLS11-008 spawning site near river mile 216 mapped on May 21, 2011.

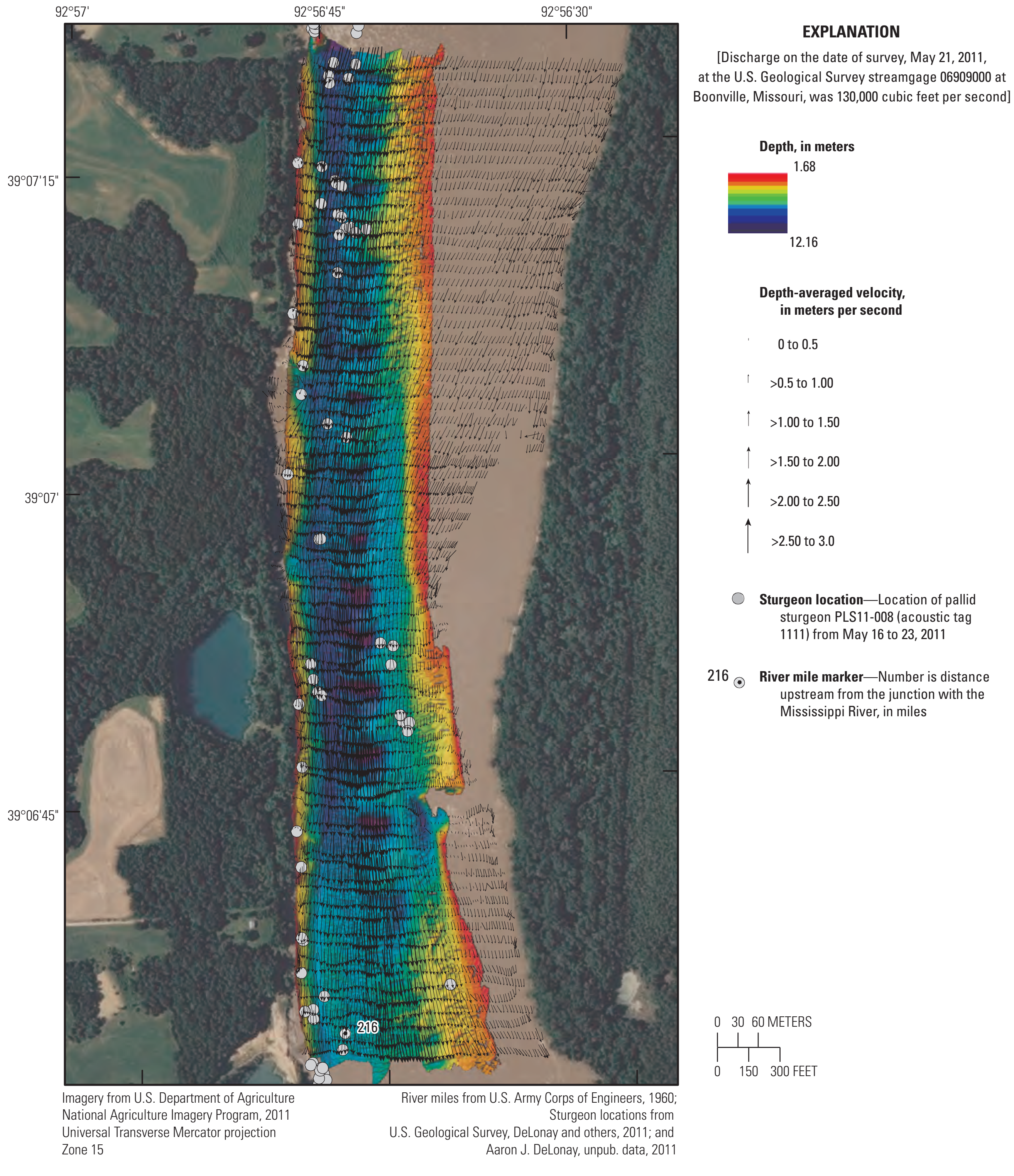
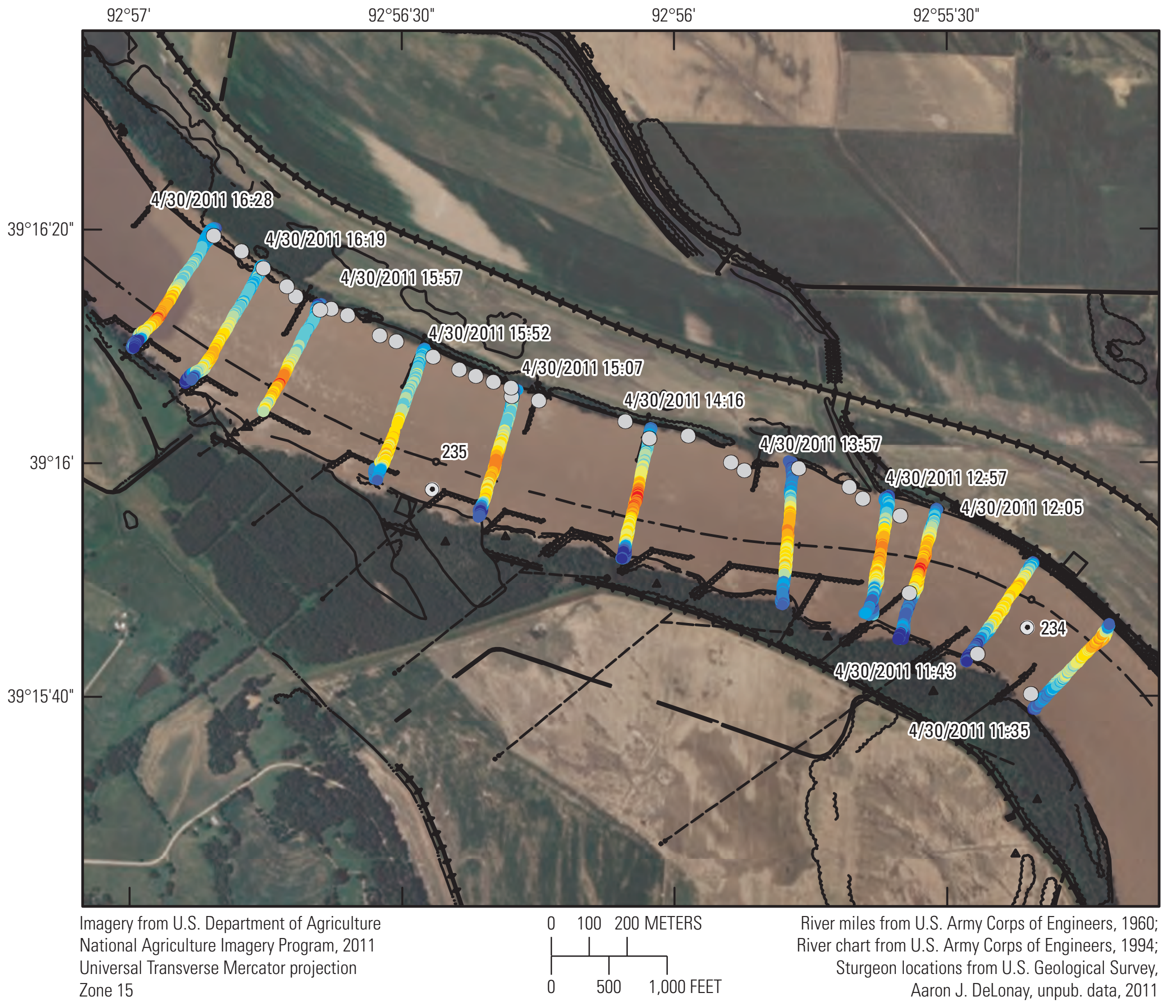


Figure 28. Acoustic Doppler current profiler velocity vectors and multibeam bathymetric map of reproductive female pallid sturgeon PLS11-008 spawning site mapped on May 19, 2011.



EXPLANATION

[Discharge on the date of survey, May 2, 2011, at the U.S. Geological Survey streamgage 06909000 at Boonville, Missouri, was 155,000 cubic feet per second]

Depth-averaged velocity, in meters per second

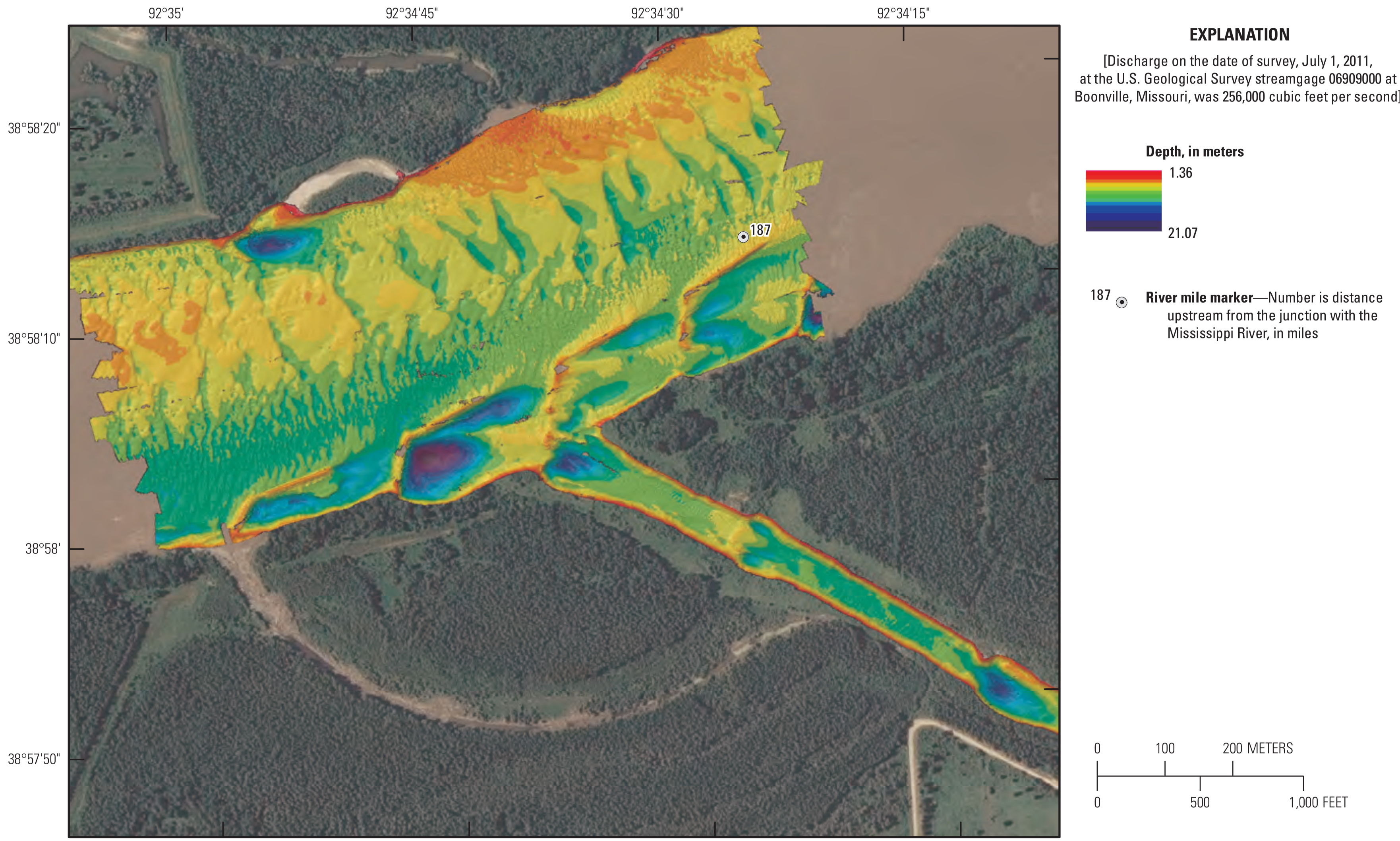
- >0 to 0.25
- >0.25 to 0.50
- >0.50 to 0.75
- >0.75 to 1.00
- >1.00 to 1.25
- >1.25 to 1.50
- >1.50 to 1.75
- >1.75 to 2.00
- >2.00 to 2.25
- >2.25 to 2.50
- >2.50 to 2.75

Sailing line—Other lines that appear in the map are the U.S. Army Corps of Engineers River Chart data depicting constructed river features, including levees, revetted or rock-lined banks, dikes, and other features on the landscape

Sturgeon location—Location of pallid sturgeon PLS11-003 on April 30, 2011

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

Figure 29. Acoustic Doppler current profiler transects and male pallid sturgeon, PLS11-003 migration pathway from April 30, 2011 from RM 233.9-235.5, mapped on May 2, 2011.



Imagery from U.S. Department of Agriculture
National Agriculture Imagery Program, 2011
Universal Transverse Mercator projection
Zone 15

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

Figure 30. Multibeam bathymetry at the inlet of the Overton Bottoms North Chute near river mile 187.

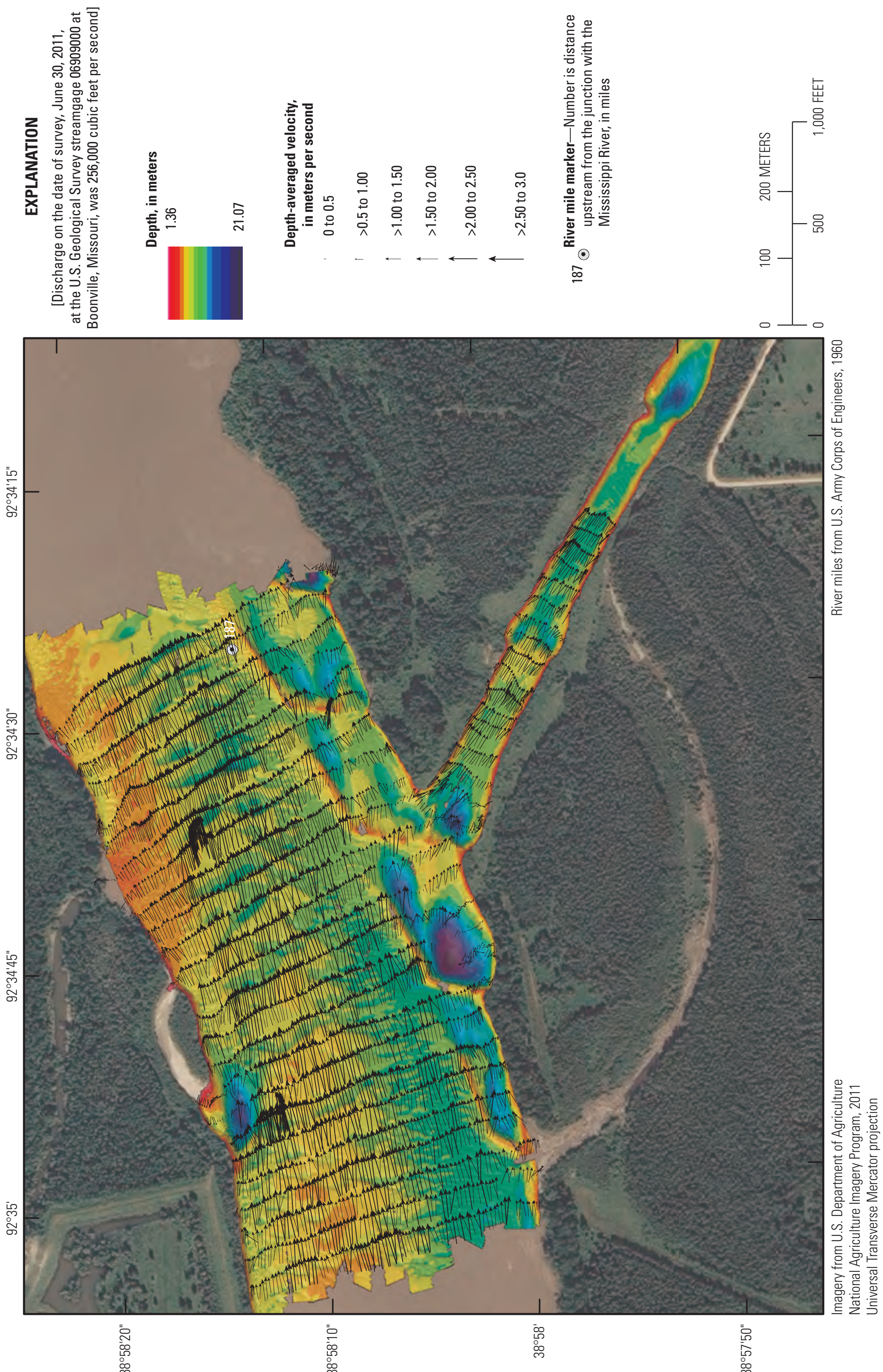


Figure 31. Acoustic Doppler current profiler velocity vectors and multibeam bathymetric map at the inlet of the Overton Bottoms North Chute near river mile 187.

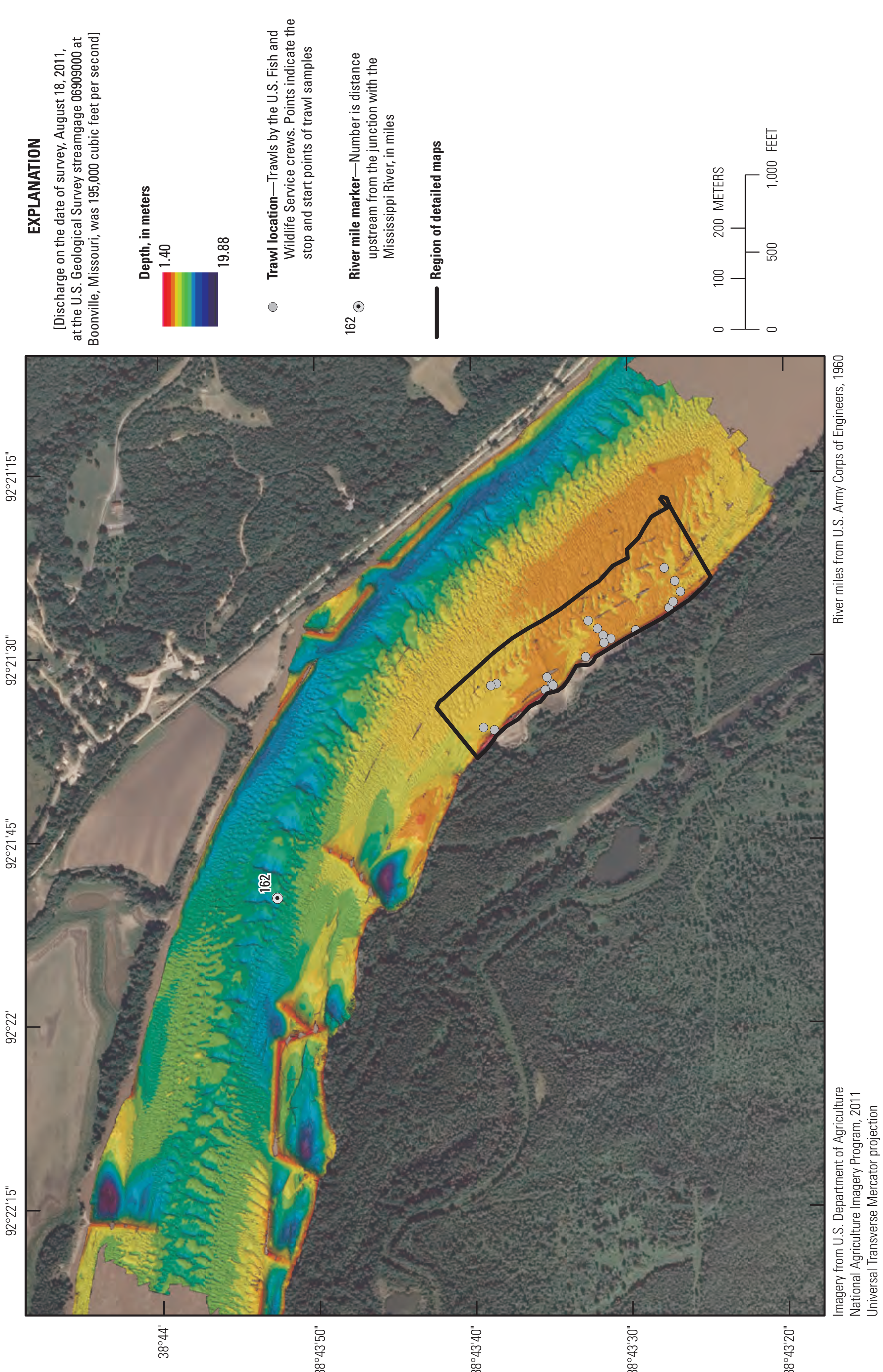


Figure 32. Multibeam bathymetry near river mile 162 and U.S. Fish and Wildlife Service young-of-year sturgeon sampling trawl endpoints. Mapped on August 18, 2011.

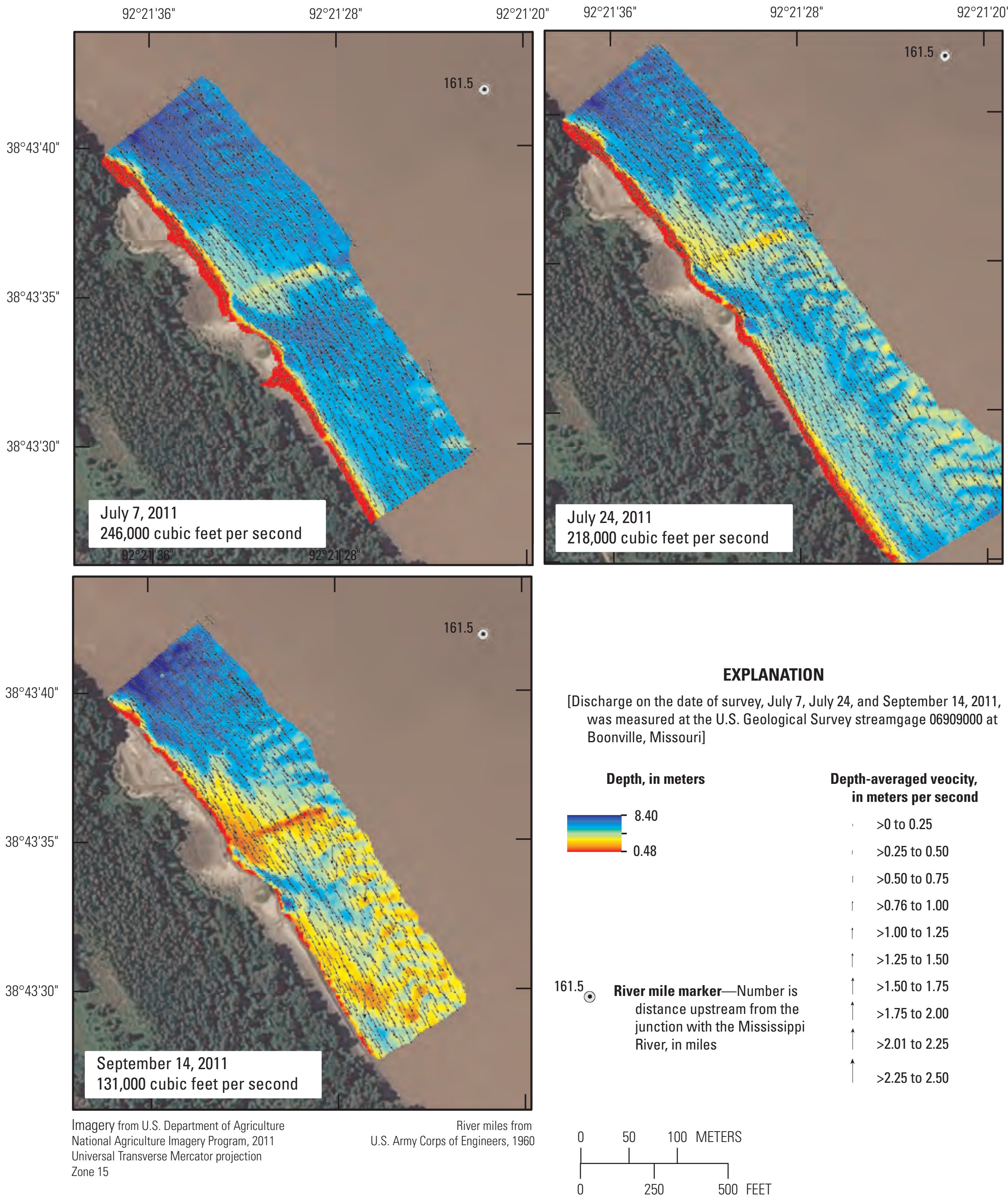


Figure 33. Detailed acoustic Doppler current profiler velocity vectors and single-beam bathymetry near river mile 162 and U.S. Fish and Wildlife Service young of the year sturgeon sampling sites from July 7, July 24, and September 14, 2011.

Task 2—Reproductive Ecology and Migrations of Pallid Sturgeon in the Yellowstone River

Background

The Upper Missouri River and lower Yellowstone River in North Dakota and Montana (fig. 1) contain one of the last remaining concentrations of wild adult pallid sturgeon in the Missouri River Basin. This extant group of wild pallid sturgeon has access to the hydrologically and thermally affected Missouri River downstream from Fort Peck Dam and the Yellowstone River, which is characterized by relatively natural hydrologic and thermal regimes. Over the last decade, research studies have demonstrated that adult pallid sturgeon migrate primarily into the Yellowstone River during early spring and use this river system during the spawning season (Bramblett and White, 2001; Fuller and others, 2008). Conversely, little use of the Missouri River downstream from Fort Peck Dam occurs during the spawning season, presumably caused by the altered thermal and hydrologic regimes (U.S. Fish and Wildlife Service, 2000, 2003).

The intact hydrologic and thermal regimes of the Yellowstone River (fig. 2), relatively pristine channel morphology (fig. 3*A*), and annually consistent use of the river by migrating and presumed spawning wild pallid sturgeon provide the template for understanding natural migration and spawning processes of wild stocks under near-natural habitat conditions. This template is not available throughout the remaining range of the species because other river reaches supporting pallid sturgeon are channelized, have highly altered habitat conditions, and are subjected to altered flow and temperature regimes, or exhibit other anthropogenic alterations. The template for natural migration patterns and reproduction of pallid sturgeon in the Yellowstone River is applicable to ongoing pallid sturgeon research, management, and restoration activities throughout the Missouri River Basin and important information can be gained about their behaviors and habitats by comparisons with observations of other pallid sturgeon populations.

Before 2011, the only spawning by pallid sturgeon in the Upper Missouri River Basin had been documented in the Yellowstone River as indicated by studies in 2007 and 2008 (Fuller and others, 2008). The 2007 and 2008 studies established the suitability of the Yellowstone River for pallid sturgeon spawning under two contrasting hydrologic regimes, and provided initial inferences on the timing and general location of spawning events; however, specific information on habitat attributes (for example, depth, velocity, and substrate) at spawn locations was not ascertained. Continued efforts to document the reproductive population of pallid sturgeon in the Yellowstone River are warranted to not only examine the temporal periodicity of spawning events in relation to environmental conditions, but also quantify specific habitat elements on the spawning grounds in a natural system. In the lower channelized Missouri River, spawning by pallid sturgeon has been documented along revetment of outside bends of the river (DeLonay and others, 2009). It is not known whether revetment and associated hydraulic conditions at presumed spawning sites in the channelized Missouri River are optimal or similar to spawning habitats in natural river reaches such as the lower Yellowstone River.

Second, the Yellowstone River is the focus of a substantial pallid sturgeon restoration effort; however, information is needed to direct engineering design specifications for this restoration effort. Specifically, Intake Diversion Dam, located at RM 71.0 of the Yellowstone River, is an impediment to pallid sturgeon passage (U.S. Army Corps of Engineers, 2011). Through a cooperative effort between the USACE, Bureau of Reclamation, and other agencies, alternative geometries of Intake Diversion Dam are proposed under the objective of improving the likelihood of pallid sturgeon passage in the reach of river affected by the dam (U.S. Army Corps of Engineers, 2011). Primary passage alternatives include (1) removing the existing dam structure and replacing it with a rock ramp more suitable for passage or (2) constructing a bypass channel around the existing ramp to enhance the likelihood of passage. For either alternative, limited information exists relative to swimming abilities of large (for example, >1,000 mm) pallid sturgeon and migration pathways (for example, depth, velocity, and channel location) used and avoided by pallid sturgeon during upstream migrations. With regard to the proposed bypass channel, little information is available on use of side channels by migrating adult pallid sturgeon in the Yellowstone River and there is uncertainty regarding side channel size (or discharge conveyed relative to the main stem) as an attractant for increasing the likelihood of use and passage around Intake Diversion Dam. Information on migration pathways of pallid sturgeon in the Yellowstone River also is complementary to research in the Lower Missouri River where migration pathways of pallid sturgeon have been examined in a highly altered system (DeLonay and others, 2009). Comparisons and contrasts of pallid sturgeon migration pathways between reaches may elicit knowledge regarding energy allocation and reproductive output in natural and altered systems.

Scope and Objectives

As a pilot project for 2011, task 2 builds on previous studies in the Yellowstone River (Fuller and others, 2008) and habitat quantification work in the Lower Missouri River (DeLonay and others, 2009). The objectives were (1) to examine migration pathways and habitat use of wild adult pallid sturgeon in the Yellowstone River, and (2) to assess reproduction of wild pallid sturgeon in the Yellowstone River.

Methods

A research population of wild adult male and female pallid sturgeon surgically implanted with radio transmitters [MCFT-3L, 149.760 megahertz (MHz); 16 x 73 mm; air weight 26.0 g; 1,624 d expected battery life; 1994 and 2000 code sets; Lotek Wireless, Inc., New Market, Ontario] as part of previous studies was available for research efforts at the outset of the 2011 research season. Three females (radio codes 38, 66, 117) were potential spawning candidates for 2011 based on known or suspected spawning cycles. Manual tracking by boat of the Yellowstone River and Missouri River downstream from the Yellowstone River confluence began in mid-April of 2011. Boats were equipped with two 4-element Yagi antennas (or in some cases one antenna with a coaxial splitter) and two observers listened for radio signals. Several physicochemical attributes (depth, temperature, conductivity, and dissolved oxygen concentration) were recorded at fish locations. The SIMS customized ArcPad mobile mapping and electronic data collection application was operated on ruggedized laptop computers and adapted to record telemetry data in the Upper Missouri and Yellowstone Rivers. Numerous data layers (for example, aerial photography, and river mile datasets) were obtained or created to facilitate on-board computer visualization and reference during data collection. Telemetry data were transmitted to and archived at CERC. Incoming data from multiple crews were compiled and incorporated into the master geospatial dataset. These data were validated for accuracy and completeness at the end of the spawning season. To complement manual tracking and obtain additional information on migrations and movements among river reaches, automated ground-based logging stations were deployed in the Yellowstone River (RM 0.75, 7.0, 16.5, 39.3, 71.4), and in the Missouri River 2 miles upstream and 8 miles downstream from the Yellowstone River confluence.

Quantification of migration pathways and spawning habitat was pursued by applying protocols that have been developed in the Lower Missouri River for mapping physical habitat; however, extreme high discharge conditions during 2011 confounded efforts, and prevented the observation of likely spawning sites (see the “Results” section). For this reason, no spawning site protocol was used. Rather, a migration pathways survey protocol and a general hydroacoustic survey protocol were used. Both protocols were executed with the R/V Schmudde equipped with a differential global GPS and an ADCP for mapping current-velocity fields. The migration pathway protocol is described in the methods of task 1. The general hydroacoustic survey protocol was used to survey around a single, station-holding, nonreproductive female pallid sturgeon (code 79). The location of code 79 and the immediate surrounding area were mapped in detail with side-scan sonar and a 1,200-kHz ADCP (Teledyne RD Instruments, Poway, Calif.). The 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 applied the “Method 3” compass calibration procedure at each site by rotating the boat in a tight circle (RD Instruments, 2003). Velocity and depth data were edited in the office and exported from WinRiver® into generic text files. These data subsequently were imported into ArcMap or MATLAB (The Mathworks, Natick, Mass.) for processing and gridding, including the creation of physical habitat maps.

Results

The elevated flow regime in the Yellowstone River during 2011 in concert with high conductivities (600–900 microsiemens) through early June and deep water through early July contributed to difficulties in detecting radio signals from implanted pallid sturgeon. Manual relocations were obtained for 30 individual pallid sturgeon in the Yellowstone River from April through July. Several pallid sturgeon (n=7) were contacted on only a single date, whereas others (n=6) were contacted on 10 or more dates. Detections from ground-based logging stations augmented the manual tracking datasets and provided additional information on movements and locations of pallid sturgeon. Detections and relocations of spawn-candidate female pallid sturgeon varied among individuals. Female code 38 was not relocated during 2011 in either the Missouri River or Yellowstone River. Female code 66 was detected in the lower 7.5 miles of Yellowstone River on April 18 and April 20; thereafter, this individual primarily used the Missouri River and Milk River (see task 5). Female code 117 was relocated multiple times in the Yellowstone River between late April and late June, and was relocated in the Missouri River later in the season.

Migration of pallid sturgeon into the Yellowstone River was underway by mid-April (fig. 34). Nearly 60 percent of the implanted pallid sturgeon were present in the Yellowstone River by late April, and the number of pallid sturgeon using the Yellowstone River remained relatively constant through late June. Emigration from the Yellowstone River began in late June, and use of the Yellowstone River declined through July. In comparison to other years, a slightly lower percentage of the implanted population of pallid sturgeon used the Yellowstone River during 2011.

Substantial variation in the magnitude and extent of pallid sturgeon migrations in the Yellowstone River was observed among individuals as some individuals exhibited large-scale movements and others exhibited limited movements (fig. 35). For example, male (codes 11, 19, 70) and female (code 117) pallid sturgeon exhibited rapid long-distance upstream movements over short time periods and similarly exhibited rapid downstream movements. Comparatively, other pallid sturgeon exhibited little movement during spring and summer (male code 106) or movements were of short extent for portions of the season (for example, male code 142, female code 56; fig. 35).

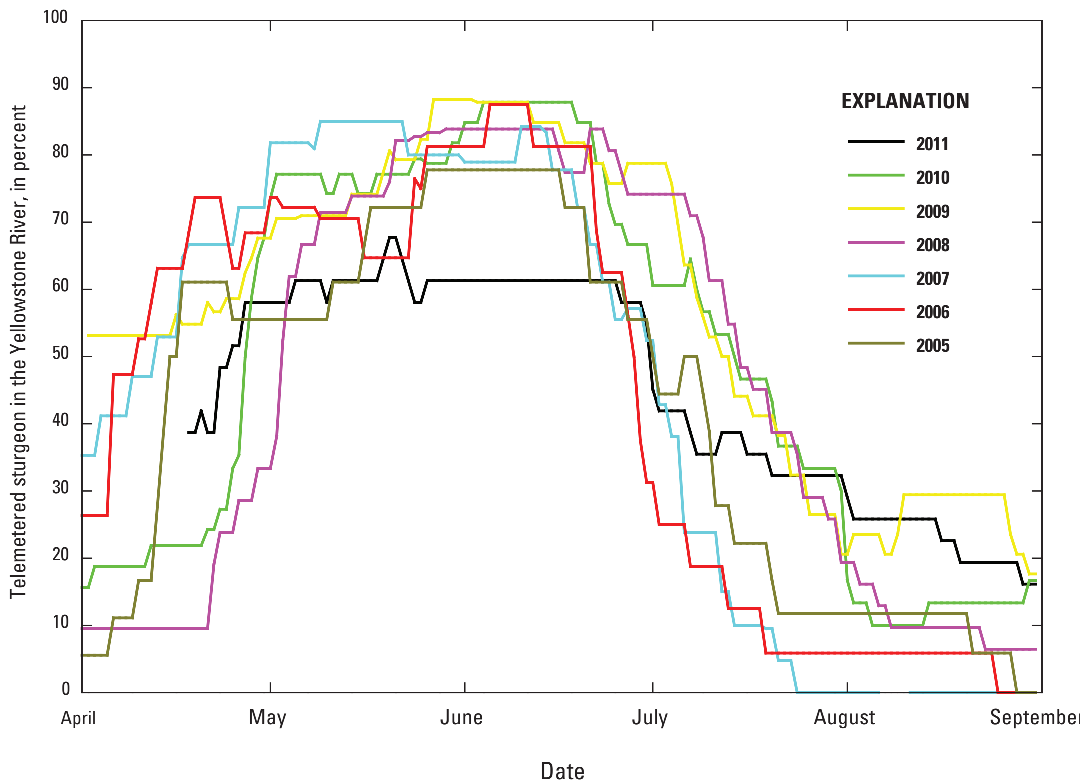


Figure 34. Percent of telemetered pallid sturgeon located in the Yellowstone River by date, 2005–11.

The upstream extent of pallid sturgeon migrations was restricted for several pallid sturgeon during 2011 (fig. 36). Specifically, based on manual relocations and radio detections from the logging station at Intake Diversion Dam, seven pallid sturgeon (codes 11, 16, 19, 70, 105, 117, 142) were detected immediately downstream from the dam between May 6 and June 16 (fig. 36). In addition, male code 80 was caught and released by an angler on June 7 immediately downstream from the dam. The radio tag had expired in code 80, and this accounts for nondetection of the fish by the Intake Diversion Dam logging station. Positive identification of code 80 was made by the PIT tag. Furthermore, another angler presented pictures and reported catching a telemetered pallid sturgeon (identified by the antenna) immediately downstream from Intake Diversion Dam. Collectively, these results indicate that at least eight telemetered pallid sturgeon were present immediately below Intake Diversion Dam during 2011, and that the dam likely served as a barrier to further upstream migrations. The antenna array at Intake Diversion Dam did not indicate passage over the dam by any pallid sturgeon.

Four fish were tracked over six distinct pathway segments between June 3, 2011, and June 9, 2011 (table 11). Extreme high-discharge conditions in the Yellowstone River before, during, and after this period directly and indirectly inhibited the tracking efforts. The six pathways were individually composed of 4–12 telemetric relocations that included 3–12 surveyed ADCP cross sections. Collectively, the pathways span 17 miles of the Yellowstone River downstream from the Intake Diversion Dam (fig. 37). In contrast to the Lower Missouri River, this part of the Yellowstone River is characterized by a highly complex, multithread channel system.

During upstream migration, pallid sturgeon were observed to follow migration pathways including main-channel trajectories primarily along the inside banks of bends and through side channels (fig. 38). The range of channels traversed by pallid sturgeon varied from a single channel that carried nearly all of the discharge to small side channels where a shallow-draft jet-propelled boat could not pass through at the upstream inlet of the channel. Depth and velocity attributes of migration pathways in the Yellowstone River will be compared in detail to those observed in the Lower Missouri River in a subsequent report. Initial analyses of ADCP measurements corresponding to migration pathways indicate that pallid sturgeon use depths ranging between 1.0–5.0 m with most of the migration locations between 1.0 m and 3.0 m (fig. 39). Most of the velocities used during upstream migrations were less than or equal to 2.0 m/s.

One proposed alternative for the reach affected by Intake Diversion Dam includes construction of a bypass channel on the south bank of the river to facilitate pallid sturgeon passage around the diversion structure. Migration pathways documented during 2011 are a rare source of information on how pallid sturgeon use side channels. During 2011, 11 different pallid sturgeon were observed in 12 different channels that could be classified as side channels because they obviously or presumably carried less discharge than the main-stem river.

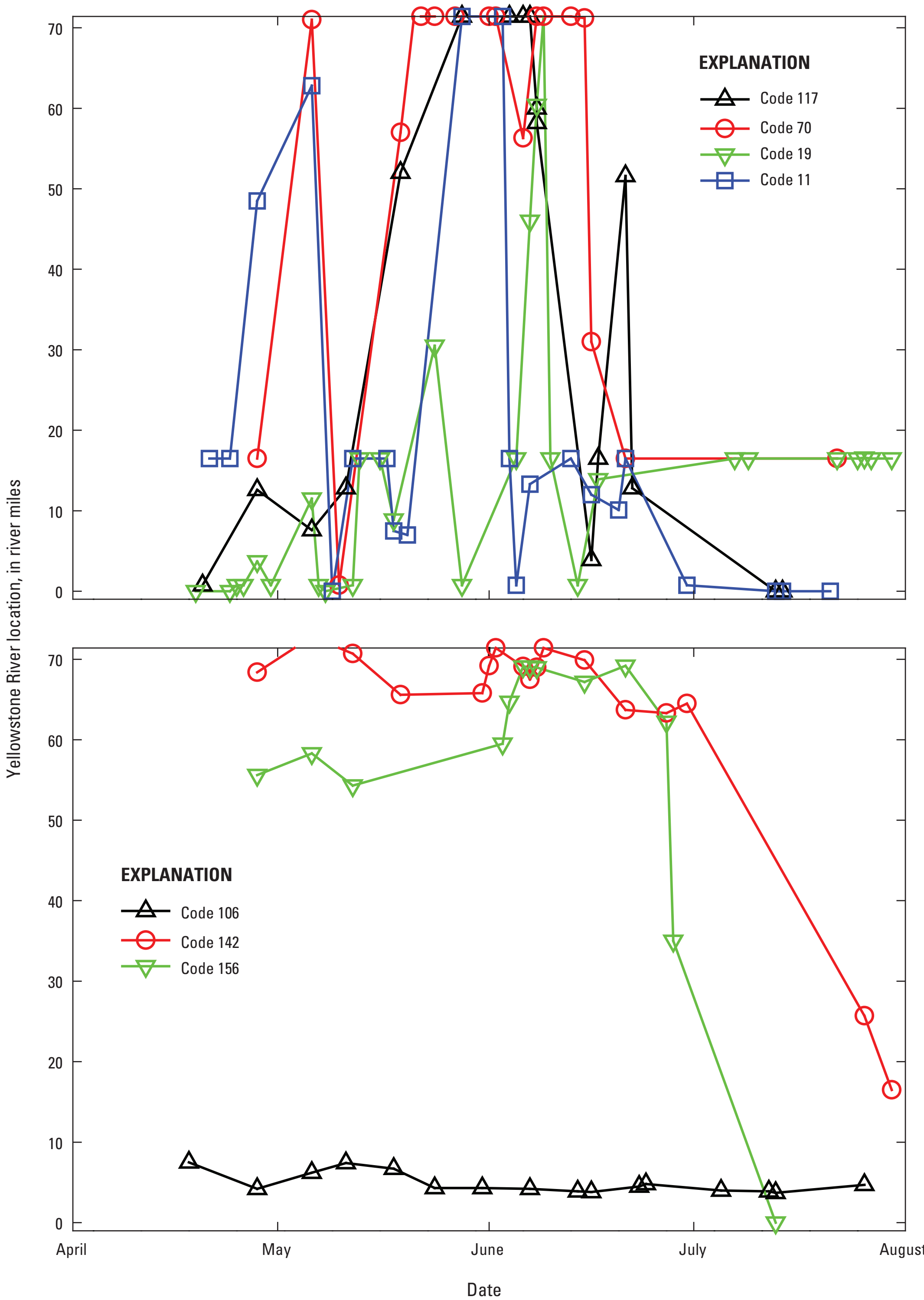


Figure 35. Various movement patterns by adult pallid sturgeon in the Yellowstone River during 2011. Locations of telemetered pallid sturgeon in the Yellowstone River by river mile and date. Locations at river mile zero indicate that the individual exited the Yellowstone River.

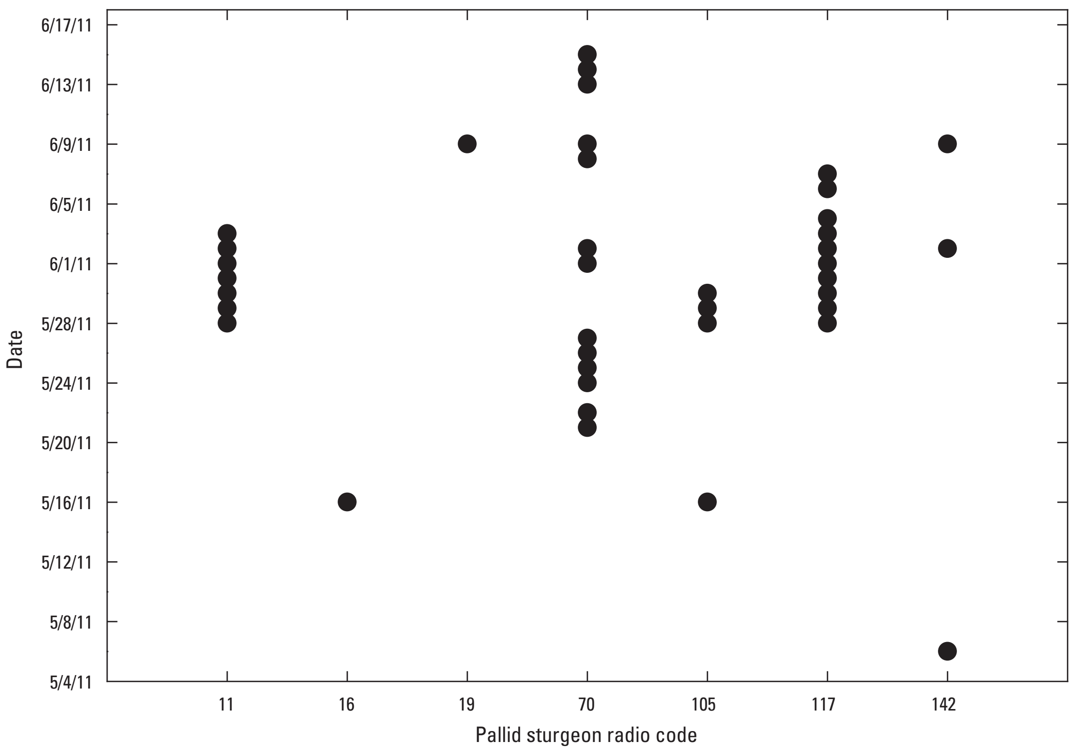


Figure 36. Dates that pallid sturgeon were located immediately downstream from Intake Diversion Dam during 2011 based on records from a ground-based telemetry logging station at Intake Diversion Dam and manual relocations.

Table 11. Summary data for habitat assessment efforts on the Yellowstone River in 2011.

[ADCP, acoustic Doppler current profiler; --, no data]

Habitat surveyed	Sturgeon identification code	Tracking date	Map date	Number of relocations	Number of ADCP transects	River mile[1]	Discharge,[2] in cubic feet per second (ft^3/s)
Migration	56	6/3/2011	6/4/2011	4	4	63.7–65.4	60,400
Migration	56	6/4/2011	6/4/2011	4	3	59.5–60.1	60,400
Migration	70	6/6/2011	6/6/2011	4	4	55.6–56.9	56,400
Migration	142	6/7/2011	6/7/2011	8	7	66.7–68.1	54,500
Migration	19	6/8/2011	6/8/2011	12	12	59.0–61.8	53,300
Migration	19	6/9/2011	6/9/2011	10	3	70.4–70.8	56,300
Habitat use	79	6/27/2011–6/30/2011	6/30/2011–7/1/2011	3	--	67.5–68	78,000

[1]River mile, distance upstream from the junction with the Missouri River.

[2]Discharge is reported as the mean discharge over the course of the survey recorded at U.S. Geological Survey steamflow-gaging station at Yellowstone River at Sidney, Montana, 06329500.

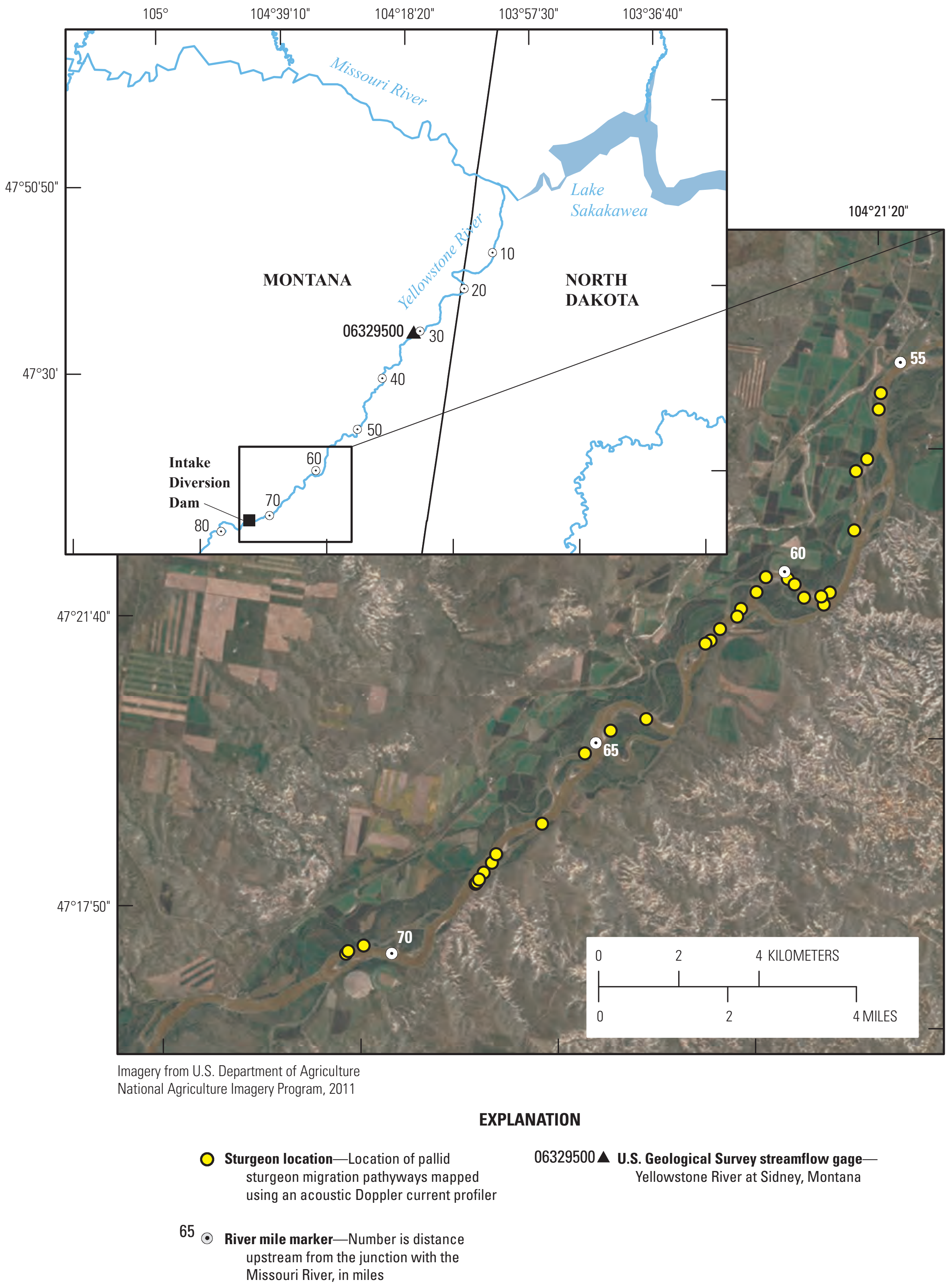


Figure 37. Positions pathway surveying efforts on Yellowstone River, 2011.

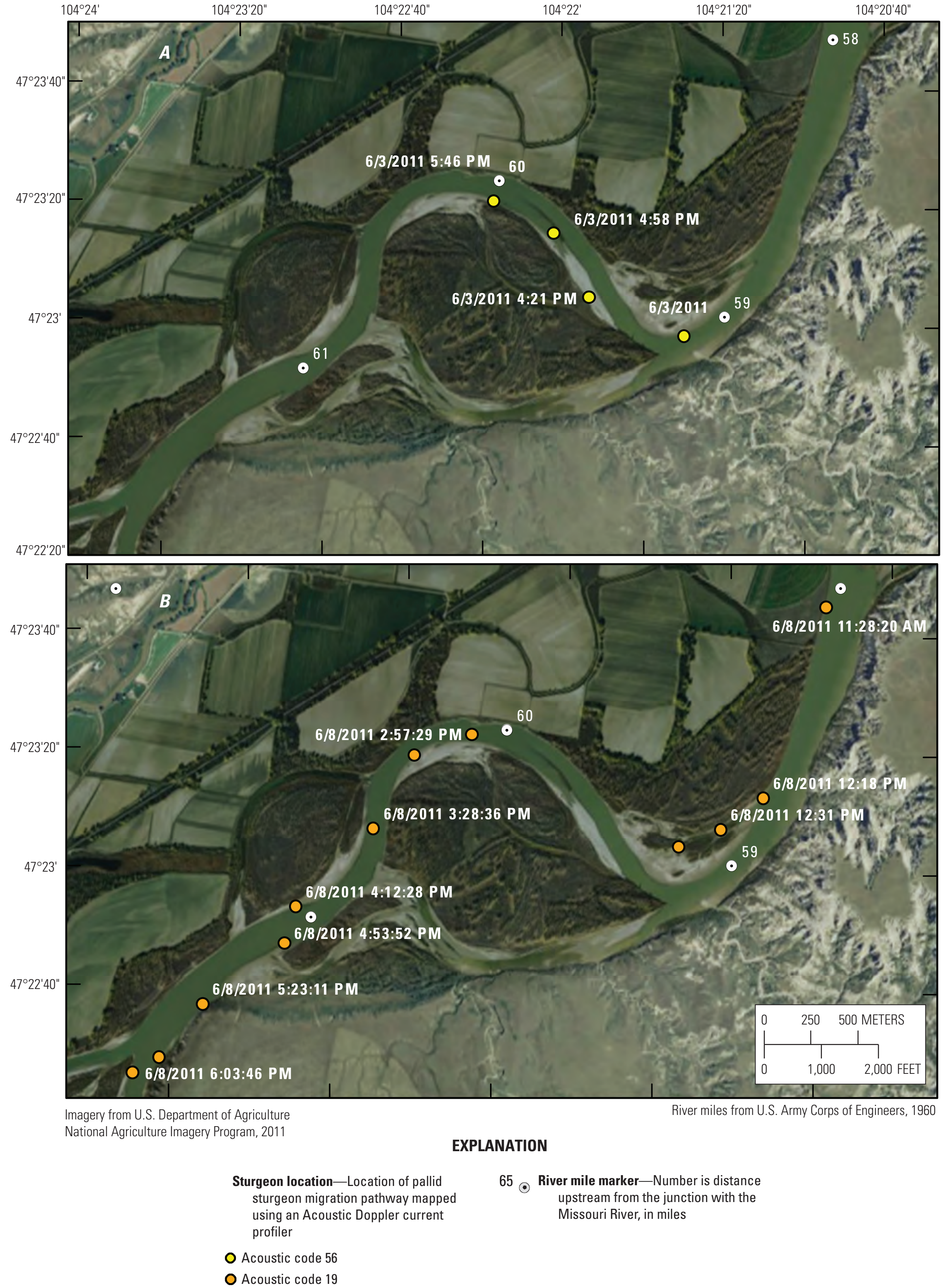


Figure 38. Pathway of fish (code 19) in main channel around *A*, Mary's Island and pathway of fish (code 56) through *B*, multiple side channels.

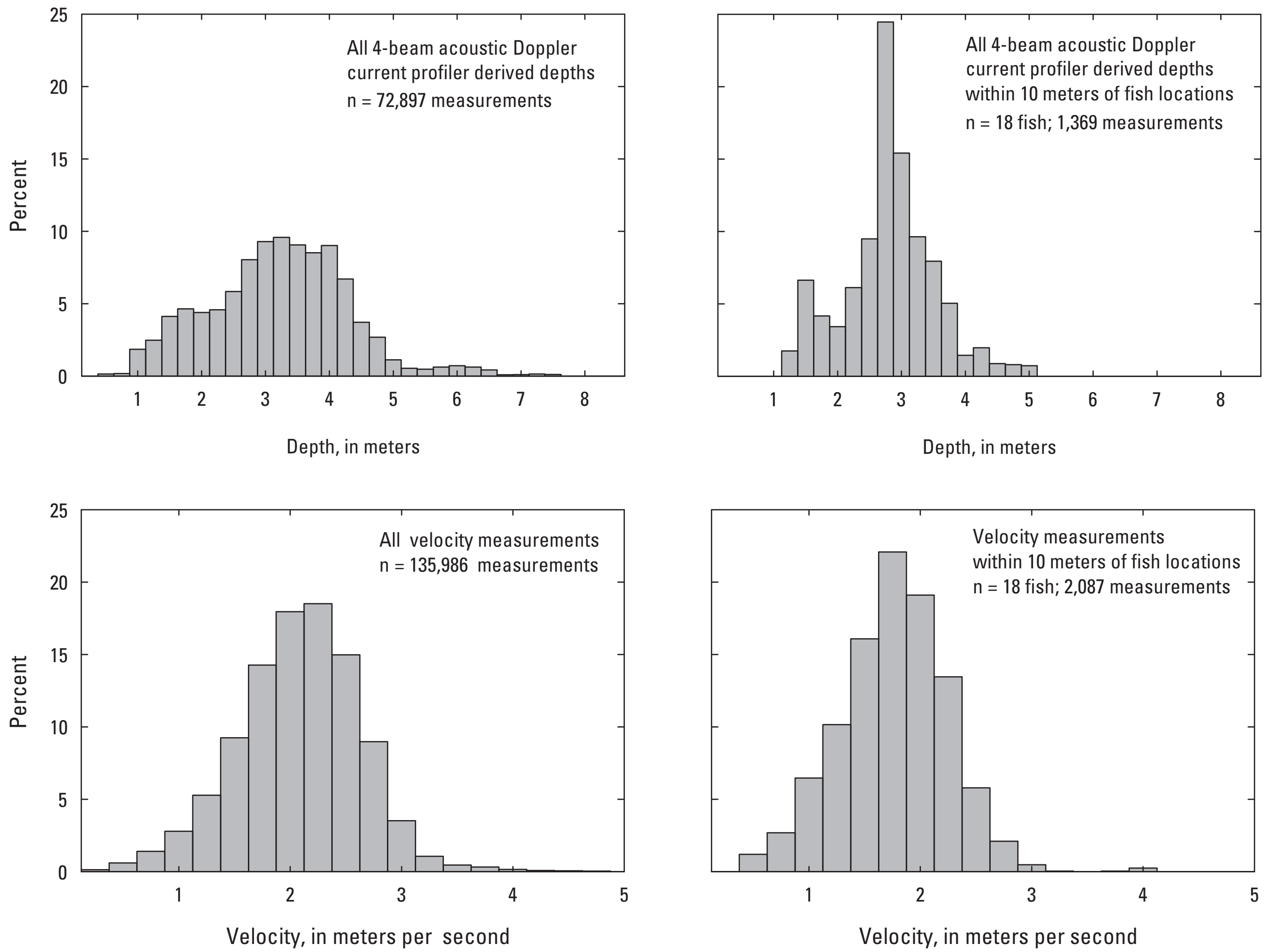


Figure 39. Distributions of depths and velocities available to and used by pallid sturgeon along migration pathways in the Yellowstone River during 2011.

Although many side channels were used, it is unknown for several observations as to whether the fish entered the side channel from the downstream end (that is, attracted to the side channel for upstream passage as applicable to the proposed bypass channel at Intake Diversion Dam) or upstream end; these observations only document use of the side channel by pallid sturgeon. For three cases (code 19 at RM 59.0, code 56 at RM 64.8, and code 56 at RM 65.8), it was known that upstream-migrating pallid sturgeon entered the side channel from the downstream end. In all three cases, the used side channel was located on the inside bend of the river channel.

In addition to limited information on side channel use, no information has been previously available to help understand how pallid sturgeon approach Intake Diversion Dam relative to accessing a potential bypass channel on the south bank of the river. On June 9, at a discharge of 56,300 ft^3/s, one pallid sturgeon (code 19) exhibiting upstream migration behavior was tracked intensively through a 2-mile migration pathway immediately downstream from Intake Diversion Dam (fig. 40). This individual was first located on the north side of the river downstream from a split channel and maintained an upstream migration pathway along the north bank of the river to just below the diversion dam. Although code 19 initially moved along an outside bend-migration pathway in a split-channel situation, later locations were along the inside bend, which was typical of other migration pathways observed during 2011. In addition to code 19, relocations of other pallid sturgeon were primarily on the northern part of the river channel.

A nonreproductive female pallid sturgeon (code 79) consistently held position at the downstream tip of an island approximately 5 miles below Intake, Mont., near RM 68. Because of the inability to track other gravid fish, the opportunity to survey habitat surrounding this particular fish was exploited. The habitat was mapped on June 30 and July 1, 2011, at a discharge of approximately 75,800 ft^3/s at the USGS stream-gaging station on the Yellowstone River at Sidney, Mont. Depths at this discharge ranged to as many as 5.50 m and velocities ranged to as many as 4.6 m/s (fig. 41). With a total of three telemetric relocations, on June 27 and June 30, this female seemed to explore a large subset of the available

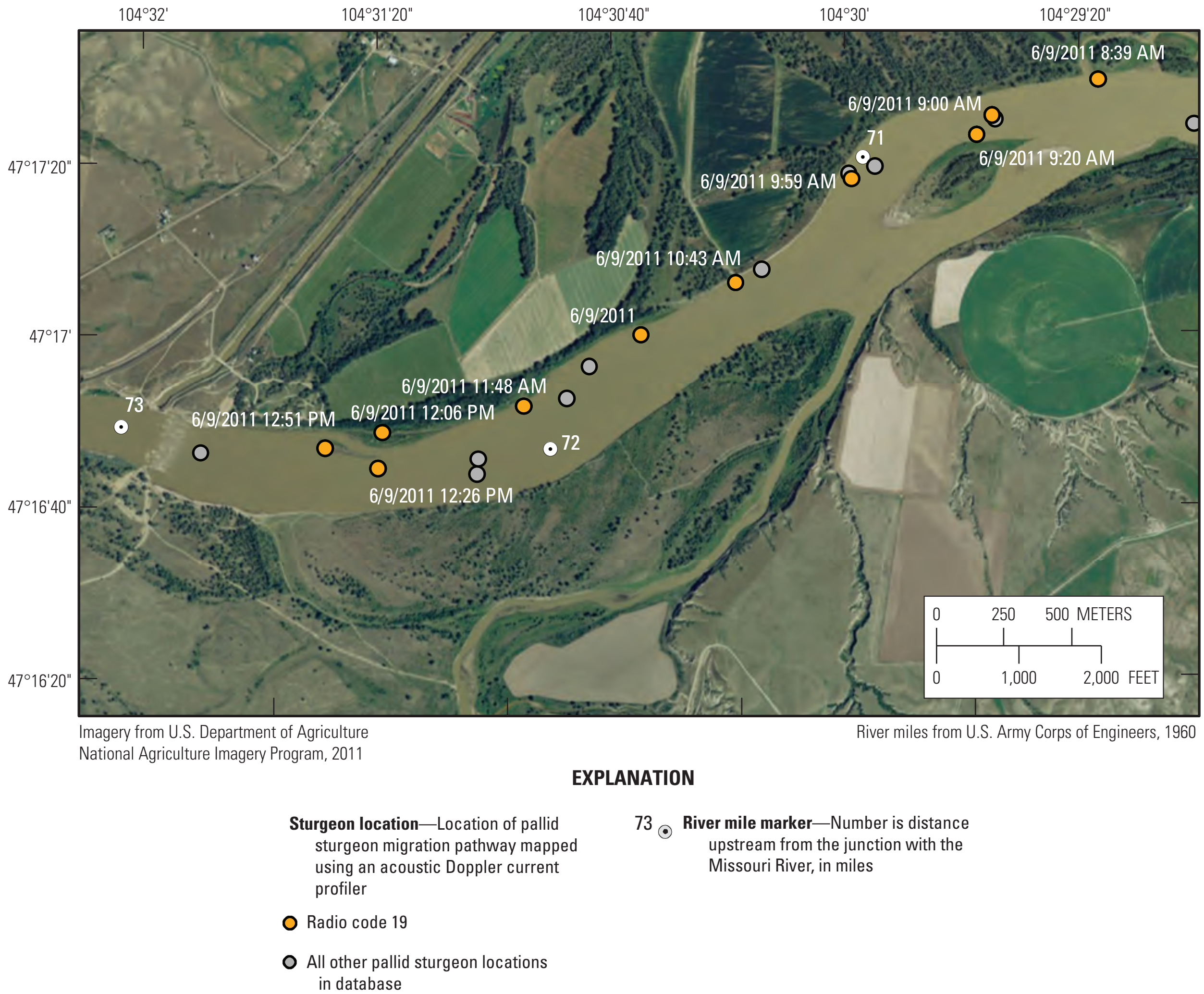


Figure 40. Code 19 pallid sturgeon approaching Intake Diversion Dam and other sturgeon located immediately downstream from diversion.

velocity and depth range. The position near the downstream end of the island remained consistent.

Female pallid sturgeon code 117 was the only spawn-ready female consistently detected in the Yellowstone River, and this individual exhibited substantial movements during residence in the Yellowstone River (fig. 42). Between April 20 and May 11, code 117 was located in the lower 13 miles of the river. On May 19, code 117 was relocated at RM 52.0 following an initial increase and subsequent decrease in discharge. This individual was detected at the base of Intake Diversion Dam between May 28 and June 7 following a major increase in discharge as water temperatures varied between 11.8–18.1 ^{o}C. After initiating a rapid downstream migration from Intake Diversion Dam, code 117 was captured on June 8 at RM 58.2 for reproductive assessment. This fish weighed 18.0 kg at capture. Hormone analysis indicated it had a testosterone (T) concentration of 41.03 ng/mL and an estradiol-17β (E2) concentration of 0.39 ng/mL, suggesting that this female was in spawning condition. After a second upstream migration in late June followed by a rapid downstream migration, code 117 was relocated several times on June 21 (RM 48.9–55.0) and captured for reproductive assessment. On this date, it remained at 18.0 kg, but the concentration of T had nearly doubled (79.07 ng/mL), and the concentration of E2 was 0.19 ng/mL. These attributes provided indications that code 117 had not spawned during the 2-week interval, but was progressing towards spawn-readiness. On June 22, code 117 maintained a consistent downstream migration, being initially located at river mile 20 at 12:31 p.m. (approximately 30 miles downstream from the location of code 117 on the evening of June 21) and last located at RM 6.7 at 4:59 p.m. Following the last location on June 22, code 117 was not documented for several weeks. On July 13 and July 14, code 117 was relocated in the Missouri River downstream from the Yellowstone River confluence (RM 1577); however, capture of code 117 was not attempted because this fish was residing adjacent to a pipeline crossing. Given the recent (July 1, 2011) rupture of an oil pipeline in the Yellowstone River near Billings, Mont.,

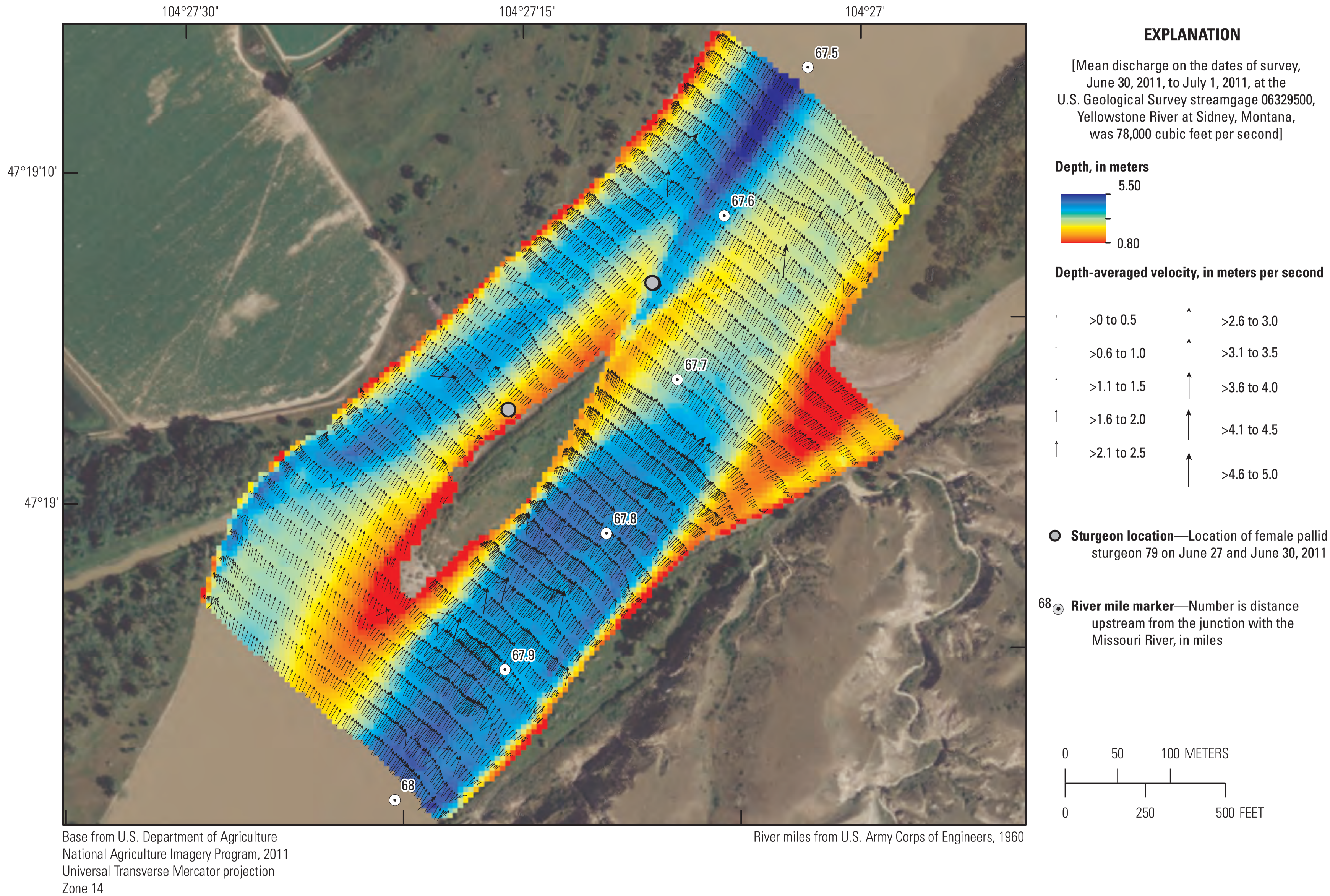


Figure 41. High-resolution locations of code 79 sturgeon, with depth and velocity.

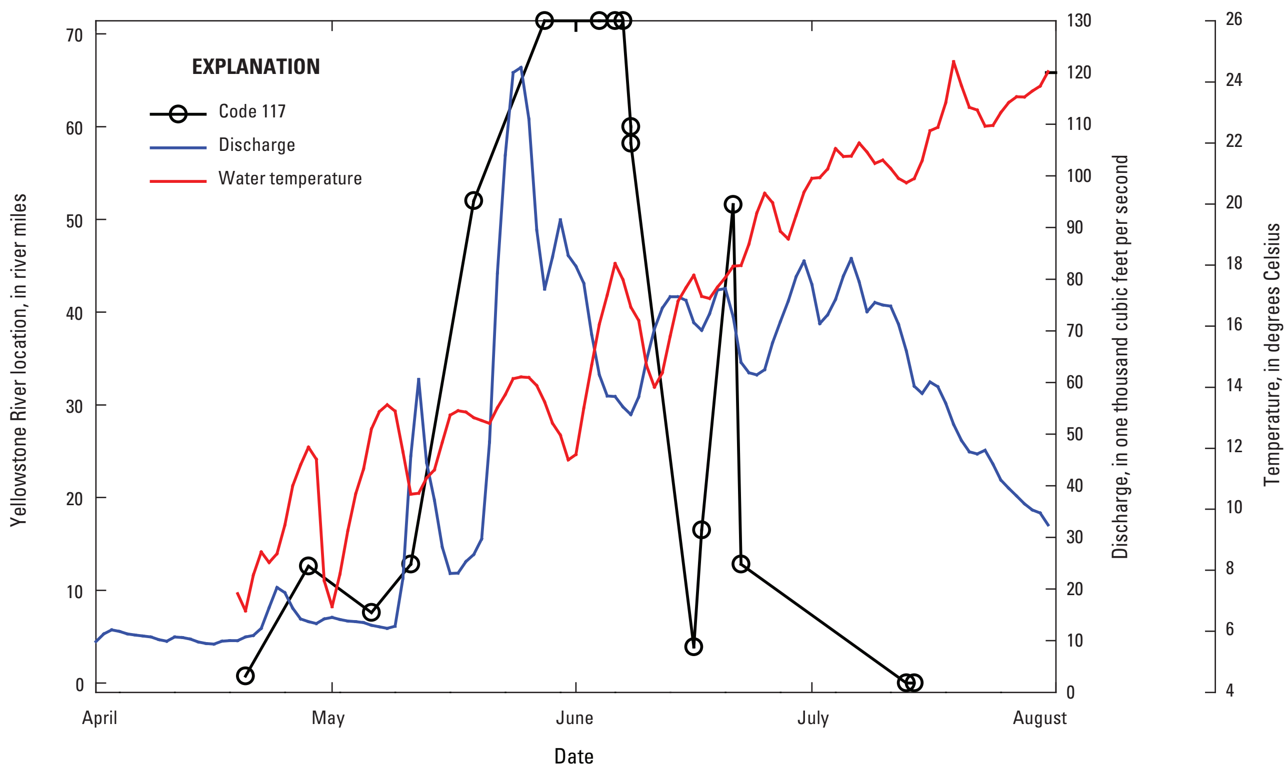


Figure 42. Movements and locations of female code 117 by date, and corresponding discharge and temperature conditions in the Yellowstone River during 2011.

and the potential risk associated with netting at a pipeline, an executive decision was made to forego netting attempts. In mid-October, code 117 was relocated and captured. A gonadal biopsy indicated this female had spawned.

Pallid sturgeon moved into the Yellowstone River during April, maintained residency in the system from late April to late June, and then emigrated from the river by late June. A relatively similar pattern has been observed for this stock during the last several years (for example, Braaten and others, 2010b); however, in contrast to earlier study years, a lower proportion of the total population of telemetered pallid sturgeon used the Yellowstone River during 2011 as several individuals primarily used the Missouri River rather than the Yellowstone River. While maintaining residency in the Yellowstone River, a variety of movement and migration behaviors were observed. Several individuals (for example, codes 11, 19, 70, 117) exhibited rapid long-distance upstream and downstream movements whereas other pallid sturgeon (codes 56, 106, 142) exhibited limited movements during residency in the Yellowstone River. Fuller and others (2008) documented similar movement behaviors for pallid sturgeon in the Yellowstone River during 2007.

The terminus of upstream movements for at least eight pallid sturgeon during 2011 occurred at the Intake Diversion Dam, and these observations represent the greatest number of telemetered pallid sturgeon ever recorded at the diversion structure. Typically, 1–2 individuals are reported at or close to Intake Diversion Dam (for example, Fuller and others, 2008). Factors contributing to the large number of migrants upstream to Intake Diversion Dam are not known; proposed work in 2012 emphasizes examining pallid sturgeon occurrences at Intake Diversion Dam. Pallid sturgeon initially were observed at Intake Diversion Dam on May 6 during low flow conditions (13,200 ft^3/s), but were present below the structure during a wide range of flows (as much as 112,000 ft^3/s through mid-June. Observations on the timing and residency of migrating pallid sturgeon at Intake have implications for design and construction of proposed fish-passage options. Specifically, given that telemetered pallid sturgeon arrived at Intake Diversion Dam through a broad time frame and under a range of flows, fish passage options might be designed to facilitate passage under a broad range of flows including low pre-runoff events (to accommodate early migrants) and larger flows during peak runoff (to accommodate late migrants).

As a pilot project in 2011, research on migration pathways provided initial information on migration routes used by pallid sturgeon in the Yellowstone River. Migration pathways of large adult pallid sturgeon under exceptionally high flow conditions occurred primarily along the inside bends, similar to migratory routes observed for smaller adult pallid sturgeon in the Lower Missouri River (DeLonay and others, 2010). Migration pathways were not restricted exclusively to the main channel, as pallid sturgeon also used side channels on the inside bend of the river. Although the sample population of pallid sturgeon for the migration pathways was small for 2011, differences in swimming behavior were observed between small-channel and large-channel migration pathways. For example, upstream migrations in the main channel or large split channels were nearly continuous as pallid sturgeon gradually moved upstream, likely using a combination of sustained swimming (that is, long-term endurance without fatigue) and prolonged swimming (that is, endurance of 20 seconds to 30 minutes) (Peake and others, 1997; Katopodis and Gervais, 2011). Swimming faster than velocities encountered, migrating pallid sturgeon exhibited ground speeds of about 0.20–0.25 m/s. For two separate cases when pallid sturgeon (codes 19, 56) entered small side channels (RM 59.0, 64.8), a different pattern was observed. In both cases, the fish entered the side channel and swam upstream to a location just downstream from the side channel inlet. At that point, the individual remained relatively stationary for several minutes before to exhibiting a burst swimming behavior (high output speed for <20 seconds; Peake and others, 1997; Katopodis and Gervais 2011) or a combination of burst and prolonged swimming that enabled the fish to pass through the side channel inlet. Inlets of the side channels were similar, characterized by high velocities, shallow depths, and gravel substrate. Although quantification of hydraulic conditions at the inlets was attempted to index conditions under which burst swimming was successful, the boat-mounted ADCP could not be successfully deployed because of maneuverability problems associated with high velocities, shallow depths, and gravel substrates. In anticipation of side channel use during 2012 and the need to quantify hydraulic conditions at the side channel inlets, tag lines or cabling may be required to obtain depth and velocity data in these habitats. Detailed information on habitat conditions passable through burst swimming behavior is applicable to proposed construction alternatives at Intake Diversion Dam because pallid sturgeon will need to negotiate a rock ramp and crest or some type of water control structure at the upstream inlet of the bypass channel.

The migration pathway of code 19 in conjunction with relocations of other pallid sturgeon (codes 70, 79, 105, 142) in close proximity to Intake Diversion Dam provides initial considerations relevant to a bypass channel around Intake Diversion Dam. For example, under elevated flow conditions of 2011, documented movements and relocations for all pallid sturgeon in the 2.0 mile reach downstream from Intake Diversion Dam were restricted to the mid-channel or north bank of the river along the inside bend. Despite several tracking runs in this reach, no pallid sturgeon were relocated on the south bank of the river. The bypass channel around Intake Diversion Dam is proposed for construction on the south bank of the river, whereby a new channel would be excavated to open and join the main channel immediately downstream from the diversion structure. Use of a south-bank bypass channel by pallid sturgeon may require some aspect of attraction, such as routing a specified volume of water through the bypass channel (for example, main channel as compared to side channel flow split) that attracts pallid sturgeon to the south bank of the river and stimulates upstream movements. A range of flow splits for the bypass channel have been discussed, but definitive targets have not been established. In addition to flows, juxtaposition of the side channel relative to the main channel configuration may play an important role in side channel (bypass channel) use by pallid sturgeon. For example, if pallid sturgeon primarily use side channels on the inside bend of the river (as observed during 2011), the bypass channel on the outside bend may require some attractive properties for pallid sturgeon to find and use the channel. Although detections from the Intake Diversion Dam logging station and manual relocations indicated that pallid sturgeon were in close proximity to the dam, swimming behaviors were not observed in this area to discern whether individuals moved laterally between the north and south banks seeking passage options or maintained relatively fixed positions below the dam.

Code 117 was the only spawn-ready telemetered female pallid sturgeon that maintained residency in the Yellowstone River for much of the spring and early summer. This female exhibited two long-distance upstream and downstream migrations, with the initial migration during late May terminating at Intake Diversion Dam and the second in mid-June terminating upstream from river mile 50. Neither migration was associated directly with spawning as indicated by hormone levels on June 8 and June 21; however, given the high and increased concentrations of testosterone between collection dates, code 117 was likely close to spawning on the latter date of capture. Extensive upstream and downstream pre-spawn movements exhibited by code 117 also have been observed in other spawn-ready female pallid sturgeon in the Yellowstone River. For example, Fuller and others (2008) observed that code 155 female exhibited a migration to Intake during mid-May 2007 followed by a rapid downstream movement pattern. Similar to code 117, spawning in code 155 did not occur in association with the upstream-downstream migration sequence; however, in contrast to code 117 who exhibited a second long-distance upstream migration, code 155 did not exhibit a second upstream migration. Rather, code 155 remained localized in the lower 12 miles of the Yellowstone River and spawned by mid-June. The upstream-downstream movements of spawn-ready females in the Yellowstone River differ from spawning migrations in the lower channelized Missouri River. For example, female pallid sturgeon in the channelized Lower Missouri River typically maintain a consistent upstream movement progression and spawn at the upstream apex of the migration (DeLonay and others, 2009; DeLonay and others, 2010). Factors contributing to the different migration patterns between river reaches are not known.

Task 3—Pilot Study to Assess Male Sturgeon Reproductive Biology and Indicators of Successful Spawning, Lower Missouri River

Background

Pallid sturgeon, similar to most sturgeons, presumably are litho-pelagophiles (Frimpong and Angermeier, 2010) and ecologically intermediate r-K strategists (Klimley and others, 2006). In part, we know the pallid reproductive strategy is to live and spawn over many years and mature late at large body size to produce a large number of gametes on an annual or longer cycle; therefore, we can infer that spawning is coincident with environmental conditions suitable for offspring development. The CERC telemetry studies on female pallid sturgeon in the Lower Missouri River have determined that the behavioral and physiological tactics to complete reproduction include solitary deliberate upstream migrations in springtime when temperatures begin to rise (DeLonay and others, 2009). Movements are along inside bends with spawning occurring primarily on revetted outside bends, at the upstream apex when water temperatures are 16–18 ^{o}C, followed by a slow downstream movement. Recaptured post-spawn females rarely have residual or atretic eggs; most fish spawn completely. Individual variation exists in timing and rate of movement, migration distance, and presumed spawning date and location. What we do not know is what motivates a female to begin and end upstream migration, if or how potential mates are identified, what cues the release of eggs, and if eggs are being fertilized and deposited in a place where the embryos will successfully hatch. Answers to these critical questions require an improved understanding of male pallid sturgeon reproductive biology and behavior under conditions in the regulated Lower Missouri River.

Contributions of the male fish in offspring recruitment often are ignored and as such an understanding of the reproductive requirements of a species can be incomplete (Potts and Wooton, 1984). A female focus has been justified given that egg number and quality often are more likely to be limiting than number or quality of sperm; however, the importance of the number of high-quality males relative to females will vary depending on the naturally selected reproductive strategy of the species. Mating systems that involve multiple males mating with a single female may be less resilient to reduced numbers of males than mating systems where a single male guards a territory and attracts multiple females. In other species, elaborate male courtship behavior or secondary sexual character development are a necessary prerequisite to spawning and consequently dependent on male fitness. Reproductive events that are synchronized closely with environmental conditions or specific habitats often involve large aggregations of males to attract females. In such cases, a decrease in male reproductive functionality may be an important factor in recruitment success, particularly if mortality is greater in males than females, when a species is very rare, or for species existing in chemically or physically disturbed environments.

Little is known about the pallid sturgeon reproductive strategy and their specific tactics to achieve reproductive success. Nevertheless, what is known, and what can be inferred from other sturgeon and fish species as well as from Missouri River environmental conditions, suggest that male pallid sturgeon may have difficulty encountering female mates within the spawning period and they may have reduced fitness if they do. It is plausible, for instance, that male tactics to attract females (for example, male aggregations) in the large, turbid Missouri River could fail when males are very scarce. Moreover, female pallid sturgeon have a smaller temporal window than the males within which they can spawn, and because of the comparably larger physiological cost associated with egg development and resorption, females arguably have a stronger biological need to shed rather than resorb gametes. With so few conspecific males among numerous shovelnose sturgeon males, the chances are high that female pallids are mating with shovelnose males. This supposition is supported by estimates, based on scant available data, that hybrid pallid x shovelnose sturgeon constitute from 0 to 100 percent of the pallid population depending on management unit and new information on introgression in pallid sturgeon (Schrey and others, 2011).

It is not enough that the sexes simply find each other. Available males must also be reproductively fit. Degraded environmental conditions in the Missouri River and coincident observations of male sturgeon (pallid and shovelnose) reproductive abnormalities provide evidence of reduced individual fitness. Hormonally active chemicals (HACs) are present in a diverse group of products used as pesticides, by industry, and present in pharmaceuticals and personal care products. These chemicals, detected nationwide in our surface waters (Kolpin and others, 2002), have been demonstrated to adversely affect the fish reproductive system in many ways (Arwukwe, 2001). Wastewaters and agricultural land runoff are two major sources for HACs. In the Lower Missouri River, within a 5-mile buffer of the main stem between Kansas City and St. Louis, there are 77 confined animal feeding operations and 102 wastewater treatment plants (Gust Annis, Missouri Resource Assessment Partnership, written commun.). Research at CERC has demonstrated a high (as much as 12 percent) incidence of intersex in pallid and shovelnose sturgeon males from the Lower Missouri River (Wildhaber and others, 2005). Additional reproductive anomalies reported for Missouri River shovelnose and pallid sturgeon include testicular malformations, shortened testis lobes, and teratomas (DeLonay and others, 2009). Intersex and the reproductive abnormalities can be caused by exposure to HACs present in wastewaters and these chemicals have been measured in the Missouri River and its tributaries (Petty and others, 2004; Soto and others, 2004; Wilkison and others, 2005; Kolok and others, 2007; Vogel and others, 2009; U.S. Geological Survey, 2011).

Scope and Objectives

This scope of work began a new effort to describe the reproductive biology of male pallid sturgeon and evaluate the male contribution to spawning and offspring production. Under this objective, we attempted to collect male pallid sturgeon at the locations where tracked females were suspected of spawning. Data were collected in two river sections of the Lower Missouri River main stem (fig. 1). Our objective was to collect a blood sample for hormone analysis, a milt sample to evaluate sperm quantity and quality, and a testicular biopsy to evaluate reproductive stage histologically from each male.

Methods

Analysis of blood for reproductive hormones and vitellogenin followed Wildhaber and others (2007). Urine-free milt was collected into a large collection vessel from which 0.5 milliliters (mL) of milt was collected by syringe then dispensed to a cryovial with an equal volume of Hank's Buffered Saline Solution (HBSS). Milt was maintained at 4 ^{o}C until overnight shipment to Dr. Jill Jenkins, National Wetland Research Center (NWRC). All samples were measured at 48 hours from collection. Upon arrival at NWRC, observations were made on sample condition, milt volume was estimated, and osmolality was measured with a vapor pressure osmometer (Wescor Corp., Logan, Utah). Spermatozoa morphology was measured on glass slides smeared with an eosin-nigrosin stained milt sample (Lane Manufacturing Inc., Denver, Colo.). Preparations were examined with an Olympus BX51 light microscope (Olympus America, Center Valley, Pennsylvania) with oil at 1000x total magnification. Between 200 and 500 spermatozoa were evaluated per slide (World Health Organization, 1987). Spermatozoa motility was measured as percentage with forward motion and duration of motility. Movement in an aliquot of 0.25 microliters milt mixed with 25 microliters water was visualized under darkfield microscopy at 100x on a Leitz Diaplan microscope (Wetzlar, Germany) by one or two readers and estimated to the nearest 5 percent. Total and progressive motility also was measured with computer-assisted sperm motion analysis (CASA). At least three view fields per sample were electronically captured and analyzed (Sperm Vision, Version 3.0, Minitube of America, Verona, Wisconsin). Mitochondrial function, apoptosis and viability, DNA integrity, and sperm cell counts were measured using flow cytometry (FACScalibur, Becton Dicknison Immunocytometry System, San Jose, Calif.) with an excitation laser at 488 nanometers (nm) and data acquisition speeds of no more than 300 cells per second for assays using propidium iodide (PI; Sigma Aldrich, St. Louis, Mo.) or <1,000 cells/s for other assays. The instrument was calibrated using FACSCmp software with Calibrite beads® (Becton Dickinson Immunocytometry Systems, San Jose, Calif.) and with at least 10,000 events per sample in triplicate. Samples were assayed in triplicate. The ViaLight Plus Kit® (Lonza Rockland Inc., Rockland, Maine) was used to determine adenosine triphosphate (ATP) concentrations on a TECAN GENios Microplate reader (San Jose, Calif.).

Results

Reproductive Condition

Thirty-nine male pallid sturgeon were bled and tested for reproductive hormones (table 12) in the two study sections on the Lower Missouri River. Five males were sampled on more than one occasion. Sturgeon were collected through the USGS and NGPC CSRP crews, and by broodstock collections efforts by USFWS, South Dakota Game Fish and Parks, NGPC, and the Missouri Department of Conservation. Pallid sturgeon from both study sections collected through the broodstock collection efforts were transferred to the Blind Pony Fish Hatchery, Sweet Springs, Mo., or to Neosho National Fish Hatchery, Neosho, Mo., where they were assessed for reproductive readiness and blood was collected. Select individuals from among those transferred to the hatchery were implanted with transmitters and had their blood sampled yet again before release back into the Missouri River.

For some unknown reason, reproductive males were rare among previously telemetered pallid sturgeon in the CSRP, and males proved to be rare in the catch among all agencies sampling in the lower study section of the Missouri River in 2011. There were only two nonreproductive males collected from the lower study section, both with low hormone values; estradiol was <3 pg/mL in both, 11-ketotestosterone was 110 in one and <3 pg/mL in the other, and testosterone was 249 and 651 pg/mL (data not shown). Androgens were elevated and estradiol was low in the reproductive males (n=4) from the lower section between March 23 and April 15. Androgens decreased whereas estradiol increased after April 18 (fig. 43). Nonreproductive males from the upper study section (n=19) had mean estradiol levels of 24±25 pg/mL ranging from 1.5 to 65 pg/mL. Testosterone levels were 2,212±1,364 pg/mL ranging from 316 to 5,020 pg/mL and 11-ketotestosterone measured 128±58 pg/mL ranging from 28 to 283 pg/mL (data not shown). All hormones in reproductive males (n=14) from the upper section were increasing from late March through April 7, plateaued until April 18, then decreased (fig. 44).

The androgen levels in male sturgeon were compared to discharge, temperature, and day length during the reproductive season to explore this relation. A sudden decrease in temperature after spawning temperatures were reached for the first time corresponded to a decrease in androgens in male fish collected in the lower section in mid-April (fig. 45*A*). Androgen levels in males in the upper section followed the first rise and fall of temperature in early April after which additional fish could not be captured because of high water levels (fig. 45*B*).

Table 12. Plasma hormone values for male pallid sturgeon collected in 2011.

[Fish ID, fish identification code; pg/mL, picograms per milliliter; <, less than; LOD, limit of detection; >, greater than; LOQ, limit of quantitation; testosterone; LOQ equals10,835 pg/mL; 11-ketotestosterone LOQ equals 9,425 pg/mL; estradiol LOD equals 3 pg/mL]

Fish ID	Date	Estradiol (pg/mL)	Testosterone (pg/mL)	11-Ketotestosterone (pg/mL)
4704237D39	3/24/2011	47	2,501	105
4866371E29	3/24/2011	<LOD	4,531	186
4723336646	4/14/2011	<LOD	2,550	148
431E15567B	3/30/2011	37	5,020	195
44235B7567	4/7/2011	45	971	93
44232F1957	3/30/2011	52	2,357	102
4723307D1A	3/23/2011	<LOD	>LOQ	>LOQ
46262C5627	3/24/2011	<LOD	8,156	1,188
486452493A	4/8/2011	<LOD	>LOQ	>LOQ
412C311632	4/14/2011	<LOD	>LOQ	>LOQ
472E177B6E	4/15/2011	<LOD	>LOQ	>LOQ
472E177B6E	6/10/2011	<LOD	249	<LOD
4614482D2A	4/18/2011	28	557	114
4614482D2A	4/28/2011	<LOD	1,904	103
471C094113	3/29/2011	43	>LOQ	851
412C311632	4/22/2011	17	4,911	288
4723336646	4/14/2011	124	>LOQ	1,129
412C323E04	4/7/2011	62	2,643	147
434B655531	4/7/2011	65	2,969	137
46183F0D1A	3/29/2011	50	>LOQ	>LOQ
46262F791C	4/18/2011	49	9,844	>LOQ
4628120F23	4/7/2011	48	2,988	186
470C547B78	4/18/2011	49	3,121	8,457
4821002F65	4/18/2011	46	5,518	3,896
48643A7120	4/7/2011	51	>LOQ	>LOQ
460E647803	4/28/2011	<LOD	2,263	1,606
44232F1957	3/30/2011	53	2,309	100
412C3F5754	4/28/2011	<LOD	1,834	1,460
462600695D	4/18/2011	<LOD	>LOQ	>LOQ
412C50027B	4/14/2011	<LOD	1,708	121
460D59401F	4/18/2011	<LOD	651	110
4325765632	4/18/2011	<LOD	1,070	131
412C37665D	4/14/2011	<LOD	1,622	122
431D0D6539	4/14/2011	<LOD	915	92
431004231F	4/14/2011	<LOD	1,754	146
4618430729	4/14/2011	<LOD	316	33
4704012031	4/14/2011	<LOD	1,230	28
47154C4C7B	4/18/2011	<LOD	>LOQ	>LOQ
462600695D	4/18/2011	<LOD	>LOQ	>LOQ
48685D1608	4/14/2011	<LOD	9,776	>LOQ
48690C5864	4/7/2011	<LOD	4,665	283
48691C3872	4/7/2011	<LOD	>LOQ	>LOQ
43152D6A6F	4/7/2011	58	>LOQ	>LOQ
4715590C76	4/7/2011	<LOD	8,174	642

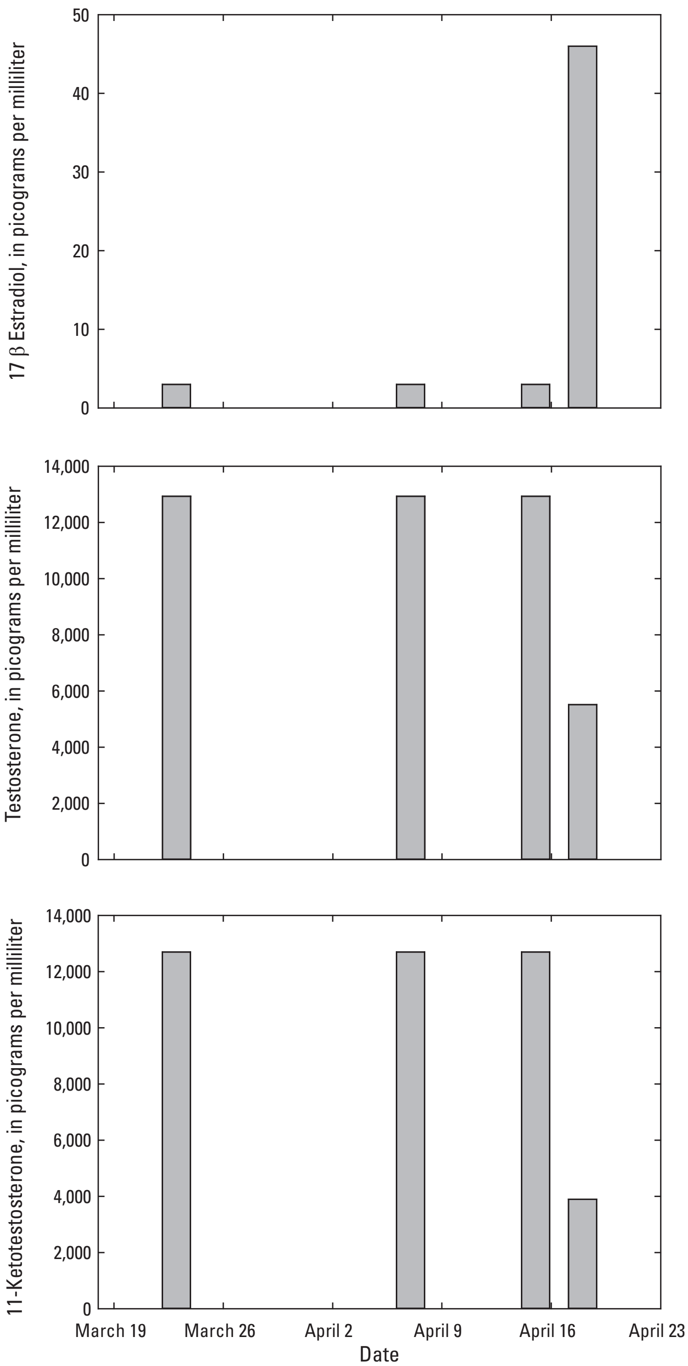


Figure 43. Reproductive hormone concentrations by date in reproductive males captured in the lower study section of the Lower Missouri River.

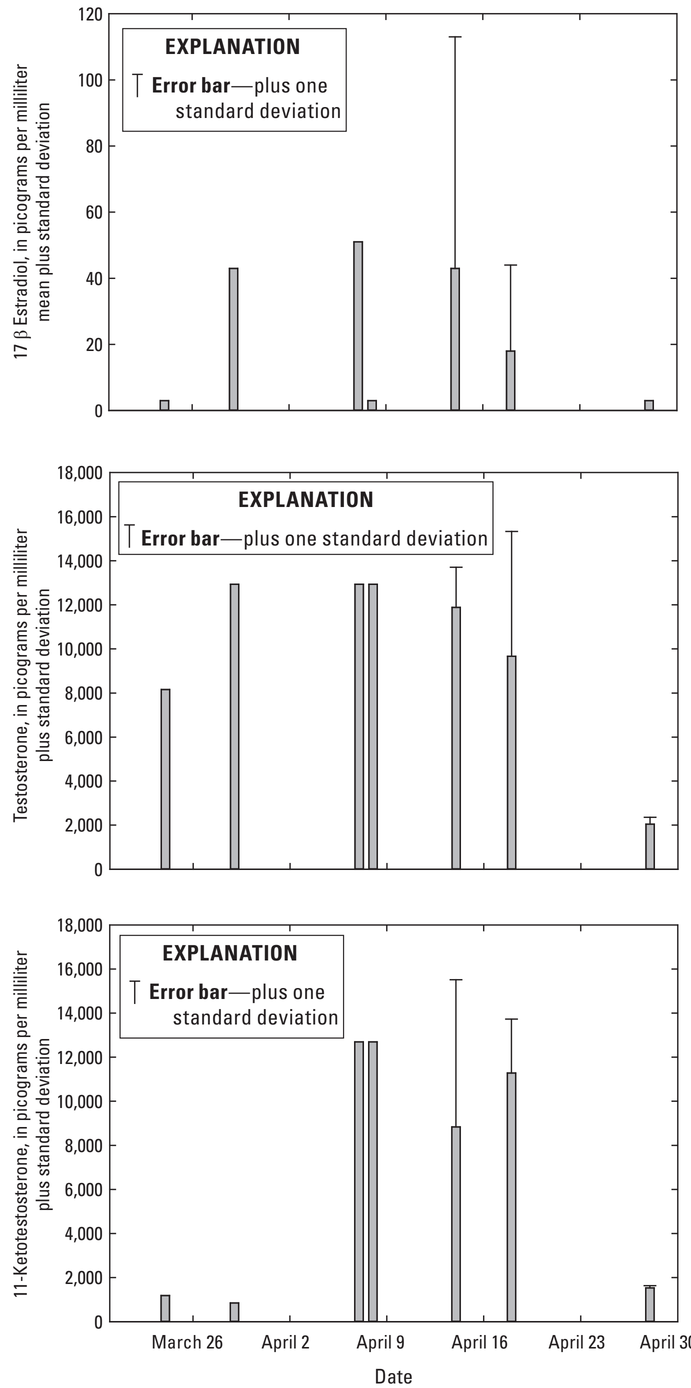


Figure 44. Reproductive hormone concentrations by date in reproductive males captured in the upper study section of the Lower Missouri River. When multiple males were captured on a date results were averaged.

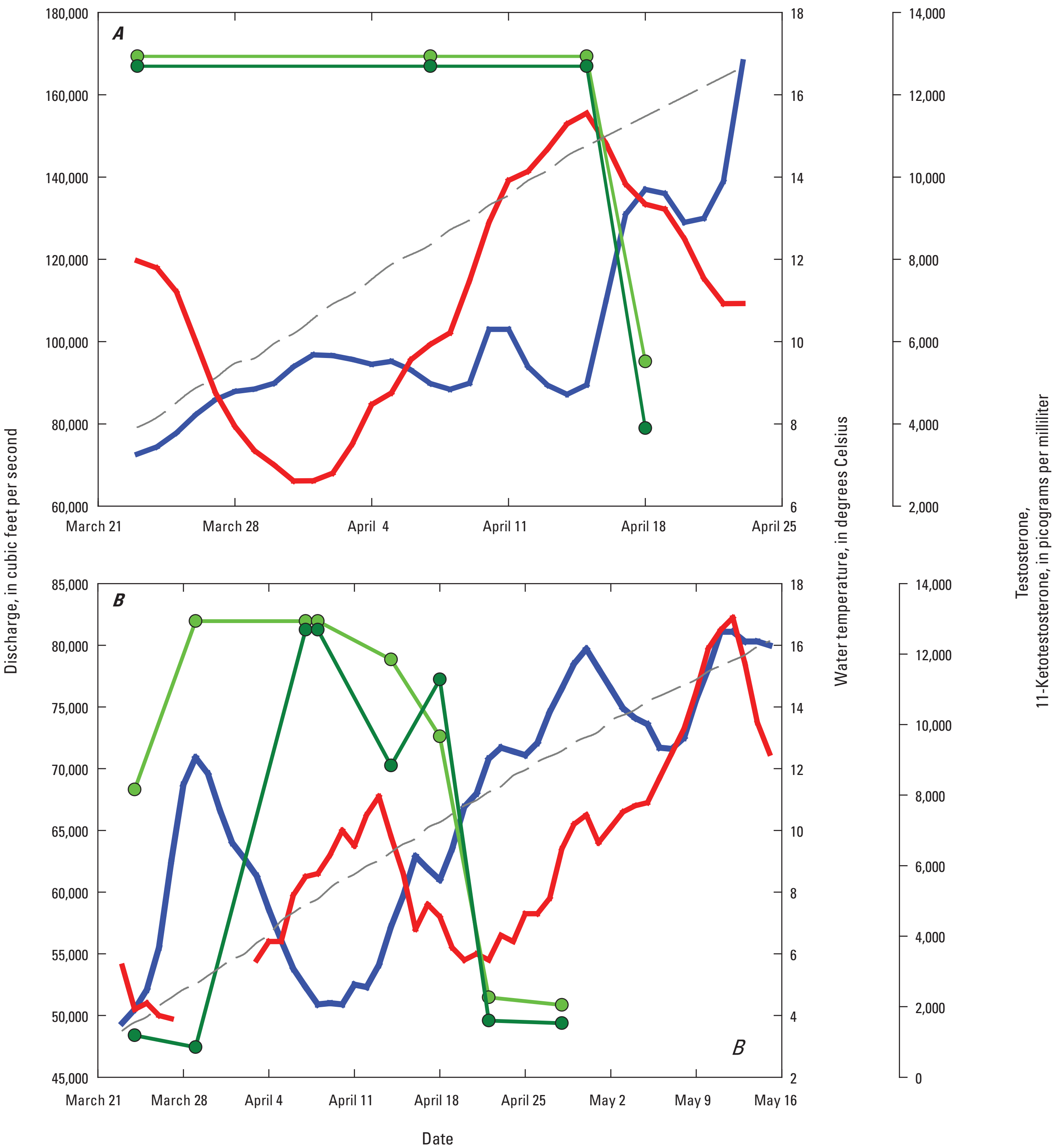


Figure 45. Discharge (blue), temperature (red), and day length (grey) relative to androgen concentrations (11-ketotestosterone and testosterone) of reproductive male pallid sturgeon captured in the *A*, lower study section and *B*, upper study section during the spawning season.

Male Gamete Quality and Quantity

Because of the rarity of reproductive males among telemetered sturgeon, milt samples for study were available only from wild-caught broodstock sturgeon transported to hatcheries and induced for artificial propagation, and from captive broodstock populations held at CERC and Gavins Point National Fish Hatchery, Yankton, S. Dak. Milt from 20 male pallid sturgeon was evaluated for various metrics of quality and the number of spermatozoa (table 13) and results from captive males were compared to results from wild-caught males (table 14). Two of the males were sampled 3 days after induction and spawning in the hatchery, before implantation with transmitters and release back into the river. One of these was sampled twice with similar results. A single sample was collected and analyzed from a reproductive male captured in the Yellowstone River, Mont., and held at Miles City Fish Hatchery, Miles City, Mont., for comparison.

In freshwater fish, activation of sperm occurs when milt osmolality is lowered. Spermatozoa are immotile within the fish but become active once released to the outside environment. Number of sperm that are motile, the direction of movement, and the length of time they continue to move have all been used as indicators of spermatozoa quality. Poor quality sperm can result from damage to DNA as measured by apoptosis and DNA integrity. Evaluation of the amount of energy available for sperm activity is made through measurement of ATP levels. The mitochondria produce and store the ATP; therefore, evaluation of mitochondrial function serves as an additional indicator of sperm health. In general, sperm were healthy and abundant. Pallid sturgeon osmolality ranged from 74 to 101 milliosmole per kilogram (mOSm/kg) and was lower for wild-caught pallid compared to captive pallid sturgeon males. Generally, motility measured as percent motility was high for all samples measured; ranging from 78 to 100 percent. Only one fish showed poor motility, with only 5 percent motile spermatozoa (table 13). Total motility measured with CASA ranged from 28 to 98 percent. Progressive or forward motility, as measured by CASA, was similar, ranging from 6 to 98 percent. All measures of motility were lower for captive compared to wild-caught pallid but only mean progressive motility was significantly different (table 14). Spermatozoa remained active for a range of 95 to 676 seconds with captive male sperm having a longer mean motile period. The percent of live sperm was high and ranged from 90 to 98 percent. Conversely, measures of DNA damage were low either by apoptosis (2 to 9 percent) or DNA integrity (3 to 7 percent). Additional measures of spermatozoa quality as either ATP content or mitochondrial function also were high, although both measures tended to be lower for captives.

Vitellogenin is an egg yolk protein normally produced in females. Estrogen produced by the female's ovary goes to the liver to produce vitellogenin, which returns to the ovary to be deposited in the oocytes. Males, because they lack estrogen, do not normally produce vitellogenin even though their livers are capable; however, males exposed to estrogen in the water or diet, will produce vitellogenin. The concentrations of vitellogenin measured in pallid sturgeon males were from 76 ng/mL to above the upper LOD of 315 ng/mL (table 15). Although the samples with the >LOD levels must be further diluted and remeasured, the remaining samples are 100–1,000 times lower than females, suggesting no exposure to estrogenic compounds.

Task 4—Missouri River Pallid Sturgeon Population Assessment Program Synthesis towards Understanding Population Trends of Pallid Sturgeon and Other Targeted Species

Background

In 2000, the USFWS issued a Biological Opinion (BiOp) to the USACE for the Missouri River pallid sturgeon. To address USACE compliance activities, the Pallid Sturgeon Population Assessment Program (PSPAP) was developed to provide the information needed to detect changes in pallid sturgeon and native target species populations in the Missouri River Basin (Drobish, 2008). The PSPAP sampling approach is based on the Missouri River Benthic Fish Study (Berry and others, 2004; Drobish, 2005; Wildhaber and others, 2011a). Through a series of concerted, multi-agency team efforts, USACE, with guidance from USGS, developed a study design for the PSPAP and has been collecting data since 2003. Now that PSPAP has been on-going for 8 years, it has been determined that it is a good time to analyze the full complement of data to assess what has been learned so far about pallid sturgeon and the populations of other species targeted through PSPAP. As such, the USACE has requested that CERC scientists and their university collaborators provide analysis and interpretation of 2003–10 PSPAP data designed to help guide Missouri River management efforts.

The primary goal of PSPAP is to detect changes in populations and habitat preferences over time for pallid sturgeon and other native fish species in the Missouri River Basin, part of which is to assess recent trends in relative abundance of target species collected by PSPAP and determine population size and survival rates for pallid sturgeon (wild and hatchery). The ultimate goal will be to provide, as much as allowed by the data, an assessment of what we now know that can provide guidance to the Missouri River Recovery and Pallid Sturgeon Recovery programs.

Analyses are being done separately for the three PSPAP sampling universes:

Table 13. Milt and sperm characteristics for male pallid sturgeon collected in 2011.

[Fish ID, fish identification code; mOsm/kg, milliosmoles per killogram; s, seconds; DNA, deoxyribonucleic acid; mL, milliliters; ATP, adenosine triphosphate; BPFH, Blind Pony Fish Hatchery; CERC, Columbia Environmental Research Center; GAVINS, Gavins Point National Fish Hatchery; MILES, Miles City Fish Hatchery; --, no data]

Collection site	Date	Fish ID	Osmolality (mOsm/kg)	Motility (percent)	Duration (s)	Live (percent)	Apoptotic (percent)	Live apoptotic (percent)	Mitochondrial function (percent)	DNA integrity (percent)	Total motility (percent)	Progressive motility (percent)	Sperm counts (mL)	ATP (per 10^6 cells)
BPFH	4/26/2011	412C2A094F	76	88	128	97	4	1	99	5	94	92	4.1×10^7	--
BPFH	4/26/2011	412C5D2741	96	93	115	95	6	2	96	4	48	29	3.8×10^7	--
BPFH	4/26/2011	412C727B25	89	78	105	93	3	1	93	6	28	26	1.7×10^8	--
BPFH	4/26/2011	460E275D2B	82	95	119	95	5	1	99	4	87	85	2.63×10^8	--
BPFH	4/26/2011	460E647803	78	93	110	97	3	0	98	5	83	79	8.63×10^6	--
BPFH	4/26/2011	462600695D	98	99	156	96	5	1	99	5	87	84	1.72×10^8	--
BPFH	4/26/2011	470C547B78	82	99	157	96	4	1	97	5	98	98	7.1×10^7	--
BPFH	4/26/2011	47154C4C7B	89	93	95	97	4	1	99	4	68	65	7.91×10^7	--
BPFH	4/26/2011	48643A7120	74	95	127	97	4	1	98	5	79	77	2.1×10^8	--
BPFH	4/26/2011	48685D1608	75	97	159	98	3	1	98	5	92	92	3.7×10^6	--
CERC	6/16/2011	47193f0827	90	91	676	95	6	1	96	4	81	77	5.46×10^7	1
CERC	6/16/2011	471b6A6774	84	98	400	98	2	1	99	3	67	43	3.38×10^7	1
CERC	6/16/2011	472E2E1918	88	89	369	95	6	1	94	3	--	--	1.17×10^8	1
GAVINS	6/17/2011	406E677B1F	98	98	331	97	3	1	98	4	51	39	5.58×10^7	1
GAVINS	6/17/2011	424E680B49	105	89	343	90	9	2	89	4	49	47	6.29×10^7	1
GAVINS	6/17/2011	4254324A29	86	5	141	91	9	1	89	4	48	6	5.21×10^7	0
GAVINS	6/17/2011	7F7D41431D	101	98	651	95	8	4	95	4	55	55	4.33×10^7	6
MILES	6/17/2011	4310624556	84	88	393	98	5	3	97	4	--	--	3.71×10^7	3
BPFH[1]	4/29/2011	412C3F5754	98	97	174	97	4	1	99	7	78	72	2.67×10^7	2
BPFH[1]	4/29/2011	460E647803	79	100	318	98	3	1	98	3	--	--	1.24×10^8	2

[1]Sampled after artificial propagation and prior to telemetry implantation and release.

- Lower monitoring area—Gavins Point Dam to Missouri River mouth
- Middle monitoring area—Fort Randall Dam to Lewis and Clark Lake headwaters
- Upper monitoring area—Fort Peck Dam to Lake Sakakawea headwaters

Scope and Objectives

The two main objectives of this task are an assessment of pallid sturgeon and other native species at the system level and an assessment of pallid sturgeon population augmentation efforts.

- System-level assessment of fishes
  1. Using a similar approach as developed using the USACE Missouri River Benthic Study (Arab and others, 2008; Wildhaber and others, 2011a), using Zero-Inflated Poisson (ZIP) or Zero-Inflated Negative Binomial (ZINB) models in a Bayesian framework, relative abundance of pallid sturgeon and other species targeted by PSPAP are being analyzed to help identify factors related to changes in relative abundance.
  2. Attempts will be made to apply the Bivariate ZIP (BivZIP) modeling approach developed using USACE Missouri River Benthic Fish data from Arab and others (2012) to key pairings of species targeted by PSPAP to try to assess their similarity in relative abundance pattern and how that might relate to environmental change.
  3. Investigative correlative-type analyses where adequate, georeferenced data exist will be done to try to relate population structure of pallid sturgeon and species targeted by PSPAP to environmental factors such as flow.
- Pallid sturgeon population augmentation (middle and lower monitoring areas)
  1. Estimate the survival of hatchery (and wild if possible) pallid sturgeon and within the limits of available data, quantify age-specific survival. If the data permit, assess factors important to survival of hatchery pallid sturgeon size at stocking, stocking location, and time of stocking.
  2. Estimate the population size of hatchery (and wild if possible) pallid sturgeon and within the limits of the available data, quantify age-specific population.

Table 14. Comparison of milt and sperm quality characteristics for wild-caught and captive male pallid sturgeon collected in 2011.

[mOsm/kg, milliosmoles per killogram; s, second; DNA, deoxyribonucleic acid; ATP, adenosine triphosphate]

Source	Number of sturgeon	Osmolality[1] (mOsm/kg)	Motility (percent)	Duration[2] (s)	Live (percent)	Apoptotic (percent)	Live apoptotic (percent)	Mitochondrial function[1] (percent)	DNA integrity[2] (percent)	Total motility (percent)	Progressive motility[1] (percent)	Sperm counts (mL)	ATP (per 10^6 cells)
Wild	13	85	93	166	96	4	1	98	5	77	73	9.571×10^7	2.3
Captive	7	93	81	416	94	6	2	94	4	59	45	5.992×10^7	1.6

[1]Significantly different at $p<0.05$.

[2]Significantly different at $p<0.005$.

Table 15. Vitellogenin and histological characterization for male pallid sturgeon collected in 2011.

[Fish ID, fish identification code; ng/mL, nanograms per milliliter; BPFH, Blind Pony Fish Hatchery; NA, not applicable; --, no data; >, greater than; LOD, limit of detection; CERC, Columbia Environmental Research Center; TAGGED, recaptured telemetry tagged; NNFH, Neosho National Fish Hatchery; vitellogenin LOD equals 315]

Collection Site	Date	Fish ID	Vitellogenin (ng/mL)	Histology
BPFH	4/18/2011	4325765632	254	NA
BPFH	4/14/2011	4618430729	103	NA
BPFH	4/14/2011	4704012031	256	NA
BPFH	4/7/2011	412C323E04	232	NA
BPFH	4/14/2011	412C37665D	118	NA
BPFH	4/28/2011	412C3F5754	--	Lumen packed with spermatids.
BPFH	4/14/2011	412C5D027B	312	NA
BPFH	4/14/2011	431004231F	315	NA
BPFH	4/14/2011	431D0D6539	169	NA
BPFH	4/18/2011	460D59401F	136	NA
BPFH	4/18/2011	4614482D2A	182	NA
BPFH	4/18/2011	462600695D	157	NA
BPFH	4/18/2011	46262F791C	176	NA
BPFH	4/7/2011	4628120F23	169	NA
BPFH	4/14/2011	47061F690A	223	NA
BPFH	4/18/2011	470C547B78	301	NA
BPFH	4/18/2011	47154C4C7B	153	NA
BPFH	4/18/2011	4821002F65	88	NA
BPFH	4/7/2011	48643A7120	>LOD	NA
BPFH	4/14/2011	48685D1608	>LOD	NA
BPFH	4/7/2011	48690C5864	101	NA
CERC	6/15/2011	47193F0827	--	Lumen with moderate numbers of spermatids, loose.
CERC	6/15/2011	471B6A6774	--	Lumen with moderate numbers of spermatids, loose.
CERC	6/15/2011	472E2E1918	--	immature.
TAGGED	4/8/2011	486452493A	--	Lumen packed with spermatids.
TAGGED	3/24/2011	4866371E29	155	NA
TAGGED	4/14/2011	412C311632	109	NA
TAGGED	3/30/2011	431E15567B	>LOD	NA
TAGGED	3/30/2011	44232F1957	239	NA
TAGGED	4/28/2011	460E647803	86	immature.
TAGGED	3/24/2011	46262C5627	129	NA
TAGGED	3/24/2011	4704237D39	235	NA
TAGGED	3/23/2011	4723307D1A	154	NA
TAGGED	4/15/2011	472E177B6E	91	immature.
NNFH	3/29/2011	46183F0D1A	103	NA
NNFH	4/7/2011	4868484D2A	76	NA

Methods

System-Level Assessment of Fishes

For the study of relative abundance, we are analyzing the observed pattern from the eight species targeted by PSPAP from 2003 to 2010: blue sucker (*Cycleptus elongatus*), pallid sturgeon, sand shiner (*Notropis stramineus*), sauger (*Sander canadensis*), shovelnose sturgeon, sicklefin chub (*Macrhybopsis meeki*), speckled chub (*Macrhybopsis aestivalis*), and sturgeon chub (*Macrhybopsis gelida*). In addition, we are analyzing juveniles and adults separately for blue sucker, pallid sturgeon, sauger, and shovelnose sturgeon. Further, we are grouping sampling gears into three groups: active [that is trammel net (TN) and otter trawl (OT)], passive [that is, gill net (GN) and minifyke net (MF)], and trotline (TL). We are analyzing each universe separately. Consequently, each fish species has at most nine combinations from three universes and three gear groups. For each combination, we use ZIP or ZINB models in a Bayesian framework to investigate possible factors affecting relative abundance. These types of models have been implemented for the USACE Missouri River Benthic Study from Arab and others (2008) and Wildhaber and others (2011a). It is important to note that the ability to complete any one of these analyses is completely dependent on the data. If the amount of zero observations is too extreme or the overlap in species occurrence is too limited, a given model may not be possible.

Pallid Sturgeon Population Augmentation

This study encompasses the Missouri River between Fort Randall Dam to Lewis and Clark Lake headwaters and Gavins Point Dam, S. Dak., to the confluence of the Missouri and Mississippi Rivers near St. Louis, Mo. The stocking, tagging, and collection data used are from 1992 to 2010 and were generated through various State and Federal agency stocking and tagging efforts. The primary sources of data are the pallid sturgeon stocking program and PSPAP. Hatchery related information (including originating hatchery and stocking size) was used to identify hatchery pallid sturgeon. Pallid sturgeon with no hatchery related information were assumed to be wild. When available, genetic information was used to determine if assumed wild fish actually were hatchery fish.

Survival of hatchery and wild pallid sturgeon is being analyzed through development of different types of Cormack-Jolly-Seber (CJS) models (that is, classical CJS model and age-structured CJS model) within a Bayesian context. Previous population abundance and modeling efforts in the Lower Missouri River were limited in geographic scope and used conventional mark-recapture analyses on a limited dataset (Steffensen and others, 2010; Steffensen and others, 2012). These models will give us annual survival rates as well as age-specific survival estimation. To assess factors important to survival of hatchery pallid, we will attempt to include covariates such as stocking location and size into the aforementioned models.

Population size of hatchery and wild pallid sturgeon is being estimated through development of classical Jolly Seber (JS) models using state-space modeling within a Bayesian context. In addition, we will attempt to build age-structured JS models using state-space modeling to achieve survival and dispersal estimates for each age group by genetic origin.

Results

System-Level Assessment of Fishes

Before any analyses, we had to exclude unusable data based on PSPAP standard protocols. First, we excluded 96 out of 47,852 subsamples collected using nonstandard macrohabitats. Second, we eliminated 4,154 subsamples from nonstandard gears (including bag seine, beam trawl, hoop net, and 63.5-mm inner mesh trammel net). Additionally, we only used data from 2010 for TL since it was not a standard gear before 2010. Third, we eliminated 963 subsamples because of sampling that did not meet the minimum requirements or when necessary information was missing: 104 subsamples missing active gear sampling distance, 112 subsamples missing set time for passive gears, 71 subsamples with GN set too shallow, 2 subsamples with MF set times less than required minimum, and 79 subsamples with active gear deployment distance less than required minimum.

Although ZIP and ZINB using Markov chain Monte Carlo (MCMC) methods are effective at dealing with data that contain large proportions of zero values, convergence problems may arise because of lack of variability in the data with a very high percentage of zero observations (Arab and others, 2008). Thus, we applied similar criteria suggested by Berry and others (2004) to avoid problems associated with zero values to the data prior to analyses. Data was selected for analyses using the following criteria: (1) data for a year, season, or gear was included if at least one fish was caught; (2) a gear was not analyzed if catch was less than 5 percent of the total catch for a species; (3) a gear for a species was not analyzed if presence of the species did not exceed 5 percent of the total number of bends samples; (4) a year for a species in a gear was excluded if the catch in a year by gear was less than 10 percent of the total fish collected for the species; and (5) a season for a species in a gear was excluded if the catch in a season by the gear was less than 5 percent of the total collected by that gear for that species. However, to keep as much information as possible, we only applied as many of these criteria (in the order given) as necessary to allow us to model the data.

Examination of the existing datasets indicates that an effective model should include information on year, season, bend, and macrohabitat; along with environmental covariates and macrohabitats nested within bend. Initial results from analysis of data from active gears for bends in which all three main-channel continuous macrohabitats were sampled in the Lower Missouri River suggest models developed from this data will be informative.

Pallid Sturgeon Population Augmentation

Before our analysis, we had to determine sampling period to get capture-recapture history for pallid sturgeon. Because of the sparseness of our data as well as overwintering stocking, we had to use sampling year to determine our sampling period. With this definition, we then obtained capture-recapture history using our data. To define age for hatchery pallid sturgeon, overwintering stocking requires us to use days post spawn to define age-0, age-1, and age-2 and older classes. For these age classes, we had to obtain capture-recapture history for each age class from the data. Because these require spawn information, we had to exclude fish with missing spawn dates from our analysis.

Following examination and classification of the existing datasets we were able to determine the appropriateness of possible modeling approaches to achieve the study objectives. Our analyses indicate that we are able to use classical CJS models to estimate annual survival for both wild and hatchery pallid sturgeon. Applying age-structured CJS models, our examination of the data indicates we can estimate age-specific survival for hatchery pallid sturgeon. From pilot runs of these models, classical CJS and age-structured CJS models all showed satisfactory convergence.

From the same pre-analyses treatment of the data we have determined that state-space JS models can be used to estimate annual survival and population size for wild and hatchery pallid sturgeon. For classical JS models using state-space modeling, it is possible to determine the model structure based on the best fit model from classical CJS model. The results from age-structured JS models with these datasets were expected to provide not only age-specific population size for pallid sturgeon but also trends in population size for each age group across time. Similar to classical JS model using Bayesian state-space modeling, the final model structure will be determined using the best fit model from age-structured CJS model. Preliminary pilot model runs with state-space based JS models using our approach showed good convergence.

Task 5—Examination of Pallid Sturgeon Use, Migrations, and Spawning in the Milk River and Missouri River below Fort Peck Dam

Background

The lower Yellowstone River and Missouri River between Fort Peck Dam and Lake Sakakawea (fig. 1) is inhabited by a wild adult population of pallid sturgeon. Over the last two decades, pallid sturgeon in this section of the Upper Missouri River Basin have been the focus of several studies examining movements, migrations, and habitat use (Bramblett and White, 2001; Fuller and others, 2008). Pallid sturgeon primarily use the Yellowstone River during the spawning season, and successful spawning has been documented in lower reaches of the Yellowstone River (Fuller and others, 2008). Conversely, to the date of this report, pallid sturgeon spawning has not been documented in the Missouri River downstream from Fort Peck Dam. Suppression of the thermal regime in association with regulated flows through Fort Peck Dam has been implicated as a major factor impeding spawning and recruitment of pallid sturgeon in the Missouri River downstream from the dam (U.S. Fish and Wildlife Service, 2000). Subsequently, the USACE proposed to modify operations of Fort Peck Dam following specifications outlined in the Missouri River Biological Opinion (U.S. Fish and Wildlife Service, 2000). Modified dam operations were proposed to increase discharge and water temperature during late May through June to provide spawning cues and enhance environmental conditions for pallid sturgeon and other native fishes. In contrast to “normal” cold water releases through Fort Peck Dam, surface water from Fort Peck Reservoir would be released over the spillway during flow modifications to increase water temperature conditions. The U.S. Fish and Wildlife Service (2000) recommended that a minimum water temperature of 18 ^{o}C be established and maintained at Frazer Rapids (RM 1746) through the spillway releases. The USACE proposed a minitest to evaluate the structural integrity of the spillway before a full test. A full test of the flow modifications would occur when a maximum of 19,000 ft^3/s would be routed through the spillway. Spillway releases would be accompanied by an additional 4,000 ft^3/s released through the powerhouse. Pending results from the full test, modified flow releases from Fort Peck Dam in subsequent years would be implemented in an adaptive-management framework. All proposed flows were dependent on adequate inflows to Fort Peck Reservoir and adequate water levels in the reservoir. The original schedule of events for the flow modifications called for the minitest to occur during 2001 and the full test in 2002; however, insufficient water levels in Fort Peck Reservoir during 2001 through 2010 precluded the mini- and full tests.

In 2011, high snowfall coupled with record spring rains resulted in rapid filling of Fort Peck Reservoir above full pool and releasing water over the Fort Peck Spillway. The hydrologic regime in the Missouri River downstream from Fort Peck Dam during 2011 was unique among the last several years because of these spillway releases, increased discharge from the powerhouses, and elevated discharge conditions during spring and early summer from the Milk River (figs. 2, 5). Given the unique hydrologic conditions of 2011 and the potential for improved pallid sturgeon spawning conditions, this study focused on evaluating use, migrations, and spawning of pallid sturgeon in the Missouri River downstream from Fort Peck Dam and the Milk River.

Scope and Objectives

The objectives of this work were to (1) assess pallid sturgeon migrations and use of the Milk River and Missouri River between Fort Peck Dam and the Yellowstone River confluence, (2) quantify reproductive products (eggs, free embryos, larvae) and potential spawning reaches in the Milk River and Missouri River below Fort Peck Dam, and (3) assess and quantify settlement of pallid sturgeon larvae from the drift based on collections of YOY pallid sturgeon in lower reaches of the Missouri River.

Methods

The Missouri River study area extended from Fort Peck Dam located at RM 1770 downstream to RM 1553.5 near Williston, N. Dak. (fig. 46). The study area also included the lower 115 miles of the Milk River from Vandalia Dam to its confluence with the Missouri River.

Pallid sturgeon were sampled using drifted trammel nets and were implanted with radio tags (MCFT-3L tags, 16 mm x 73 mm, air weight=26 g, 1,624-day longevity, 5-second pulse interval, 149.760 MHz, Lotek Wireless Incorporated, New Market, Ontario). The coded signal emitted by each tag is unique to facilitate identification of individual fish. Surgical procedures followed standard methods (Braaten and Fuller, 2005). Most fish were collected in prior years during broodstock collection near the confluence of the Missouri and Yellowstone Rivers.

Manual tracking of fish by boat during 2011 began in April. The Missouri River between Fort Peck Dam and Wolf Point (70 m), and the Milk River from its confluence with the Missouri River to various upstream areas were tracked from April through October. Two radio frequencies (149.760 MHz, 149.620 MHz) were simultaneously monitored during the boat-tracking run using two 4-element Yagi antennae. Several variables (radio frequency, fish code, latitude, longitude, time-of-day) were recorded at fish locations.

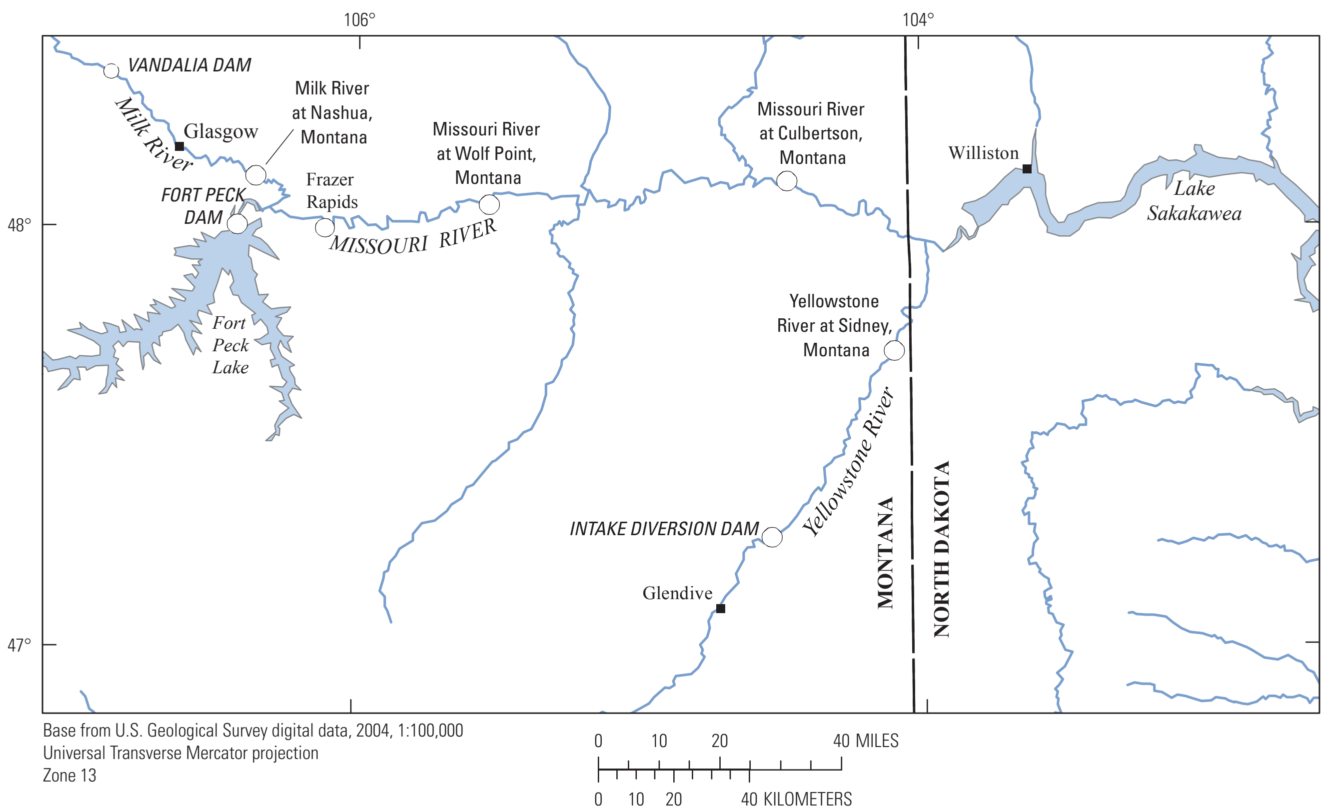


Figure 46. Study area of the Missouri River, Milk River, and Lower Yellowstone River.

Stationary telemetry logging stations were deployed in April 2011 at four sites on the Missouri River (Nickels, RM 1760; near Wolf Point, RM 1720; near Culbertson, RM 1620; at RM 1584 just upstream from the Yellowstone River confluence) and one site on the Milk River (RM 2.5). The logging stations were placed on shore with two 4-element Yagi antennae. Each logging station was equipped with a battery powered receiver (Lotek SRX- 400), solar panel, an environmental enclosure kit containing dual 12-volt batteries, and an antenna switchbox. Data recorded by the logging stations were downloaded to a laptop computer two times per month between April and October. Coupled with manual tracking efforts, the array of telemetry logging stations facilitated detection of dates and times of movement events between and within rivers and river reaches.

The lower Milk River and Missouri River near Wolf Point was sampled for free embryos and larvae following methods outlined in Braaten and others (2010b); however, high flows made it difficult to sample on the bottom in the thalweg. Therefore, to maintain contact with the bottom, sampling location generally was closer to the inside of each bend rather than the thalweg. Multiple replicate locations were sampled two times per week when flows allowed. After sampling was completed, net contents were transferred to black rubber trays where Acipenseriformes larvae (sturgeon and paddlefish) were extracted from the detritus. Extracted Acipenseriformes larvae were placed immediately in 95-percent nondenatured ethanol for genetic analysis. After extracting these larvae, the remaining sample was placed in a 10-percent formalin solution containing phloxine-B dye and contents were separated and identified in the lab (Braaten and others, 2010b)

Targeted sampling for YOY pallid sturgeon followed trawling methods outlined in Braaten and Fuller (2007) every week from mid-July through August. The Missouri River above the Yellowstone River confluence (known as, ATC) and Missouri River below the Yellowstone River confluence (known as, BTC) were sampled for YOY sturgeon (*Scaphirhynchus* spp.) with a benthic (beam) trawl. Four replicate sampling locations were established at each site where each replicate was composed of an inside bend, outside bend, and channel crossover habitat complex (IOCX) associated with a river bend. Fin clips were obtained for all *Scaphirhynchus* spp. collected, stored in 95 percent ethanol, and genetically processed by Dr. Edward Heist at Southern Illinois University to distinguish individuals as pallid sturgeon or shovelnose sturgeon. If identified as a pallid sturgeon, further analysis was done to determine parentage.

Results

The Milk River exhibited two periods of elevated flow conditions in 2011 as flood stage conditions occurred on April 18 and June 9 with peaks of 19,600 ft^3/s and 23,400 ft^3/s, respectively (fig. 47). The melting of local snow caused the first peak of elevated discharge followed by rainfall and mountain snowmelt creating the high discharge in June. Most of the year, the Milk River was at record high discharge and flooding occurred in nearby communities.

Discharge of the Missouri River at Wolf Point, which included Fort Peck Powerhouse and Spillway releases as well as contributions from the Milk River, increased from 14,000 ft^3/s to 29,000 ft^3/s from April 1 through April 15, primarily because of elevated flows from the Milk River, and declined throughout the remainder of April (fig. 47). The greatest peak occurred on June 14 when flows reached a maximum of 90,600 ft^3/s. Most of the discharge was from water being released over the spillway (52,000 ft^3/s). Discharge then declined throughout the remainder of June and July, and remained relatively stable between 25,000 and 30,000 ft^3/s through August and September. The spillway was closed on October 1 and discharges dropped to approximately 10,000 ft^3/s for the remainder of the year.

This event marked the first time the spillway had been used extensively since 1997. It initially was opened May 6–May 23, 2011, and averaged 7,000 ft^3/s, then was reopened from June 2 through September 30, and averaged 24,000 ft^3/s and reached a maximum of 52,211 ft^3/s on June 16. In 2011, the Missouri River downstream from Fort Peck Dam had the highest monthly mean discharge from May through August since records have been kept in 1942 (U.S. Geological Survey, 2011) . Discharge was higher in the Missouri River than in the Yellowstone River through May 10 and then the Yellowstone had two large pulses in mid- and late May.

Water temperature loggers (Onset Computer Corporation, HOBO® Water Temp Pro v2, operation range -20 to 70 °C, 5-minute response time, accuracy ±0.2 °C) were deployed at several locations in the Missouri River, tributaries, and in the spillway bay of Fort Peck Reservoir in mid-April through early May. Water temperature in the spillway bay averaged 6–8 °C cooler during May through mid-June than in past years (fig. 48*A*). Hypolimnetic-released water temperature below the powerhouse was very similar to spillway-released temperature during this time. Water temperature in Milk River did not vary appreciably from past years (fig. 48*B*). Despite the surface-released water from the spillway and large contribution from the Milk River, water temperatures in the Missouri River at Wolf Point (fully mixed water from powerhouse, Milk River and spillway) actually were cooler than previous years throughout May and June (fig. 48*C*). After the reservoir warmed in July, water temperature in the Missouri River was similar to previous years. As wild pallid sturgeon began their upstream migration, temperature averaged 1 °C cooler in the Missouri River ATC than in the Yellowstone River in April and May (fig. 49). This is similar to other years when mean seasonal temperatures ranged from 0.4 to 1.9 °C cooler in the Missouri River than in the Yellowstone River (Braaten and others, 2010a).

In objective 1, we assessed pallid sturgeon migrations and use of the Milk River and Missouri River between Fort Peck Dam and the Yellowstone River confluence. Telemetered wild adult pallid sturgeon (n=31) were tracked manually in the

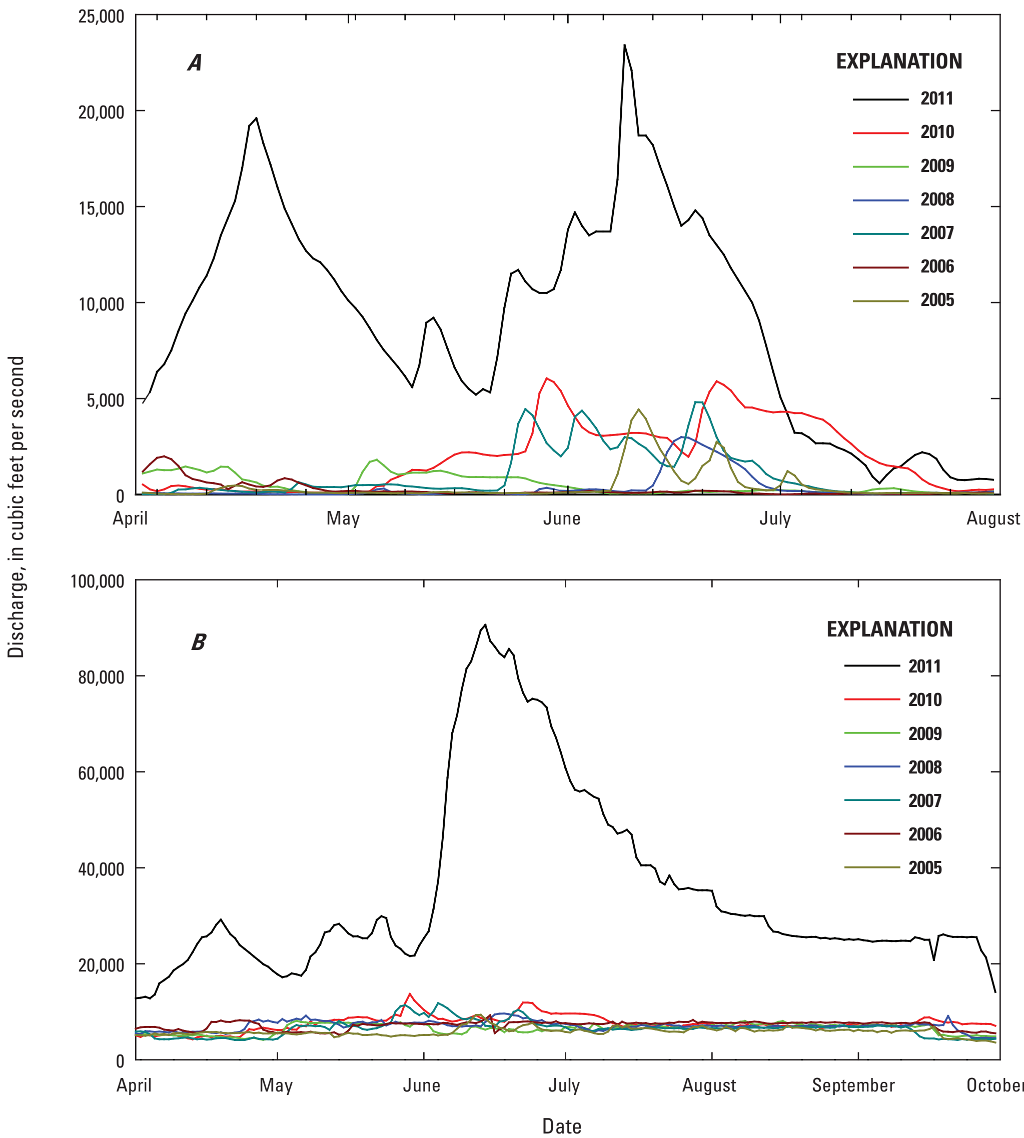


Figure 47. Mean daily discharge (cubic feet per second [ft^3/s]) in the *A*, Milk River at Nashua, Montana (streamgage 06174500) and *B*, the Missouri River at Wolf Point, Montana (streamgage 06177000).

Missouri River ATC to Fort Peck Dam and in the Milk River from its mouth to areas below Vandalia Dam. During 2011, a total of 13 different individuals used the Missouri River ATC during the spawning season. Detection of fish was very difficult because of increased depths and elevated conductivities associated with the high runoff. Of these 13 fish that used the Missouri River, manual relocations ranged from 0 to 5 (average 1.67) per fish and ground-based telemetry station detections ranged from 2 to 13 (average 5.6) per fish.

Adult pallid sturgeon began migrating into the Missouri River ATC in mid-April following a large pulse of water created by prairie runoff into the Milk River. By mid-May, nearly 40 percent (n=12) of telemetered pallid sturgeon, including a potentially gravid female (code 66) were in the Missouri River (fig. 50) upstream from the Wolf Point ground station (RM 1720). A gonadal biopsy was not done on this particular female because this fish could not be located manually. Most female pallid sturgeon in the Upper Missouri River Basin spawn every 2 years (Fuller and others, 2008). Code 66 was spawned in the hatchery in 2009 and was most likely in spawning condition in 2011. On July 6, an aggregation of four males (codes 15, 22, 43 and 92) was located at RM 1760, just downstream from the Milk River. The aggregation was observed on the descending limb of the hydrograph (52,000 ft^3/s) and when water temperature was 18 °C. This aggregation could not be relocated the following day. Approximately 35 percent (n=11) of all telemetered pallid sturgeon remained in the Upper Missouri River through early August and then began emigrating out of the Upper Missouri River to downstream areas as indicated by ground-based telemetry

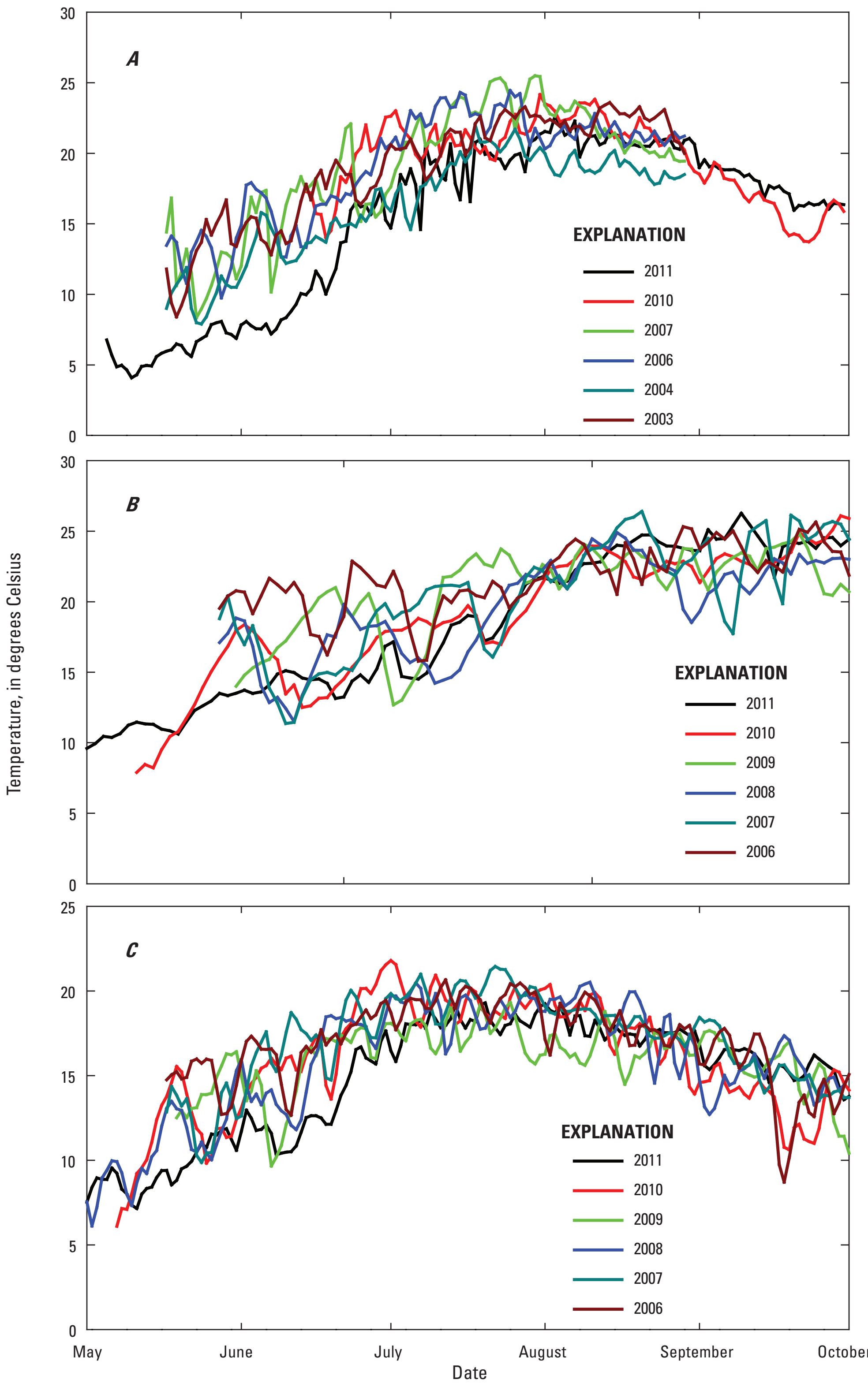


Figure 48. Mean daily water temperature (degrees Celsius) in the *A*, spillway bay of Fort Peck Reservoir; *B*, the Milk River near Nashua; and *C*, Missouri River at Wolf Point, Montana.

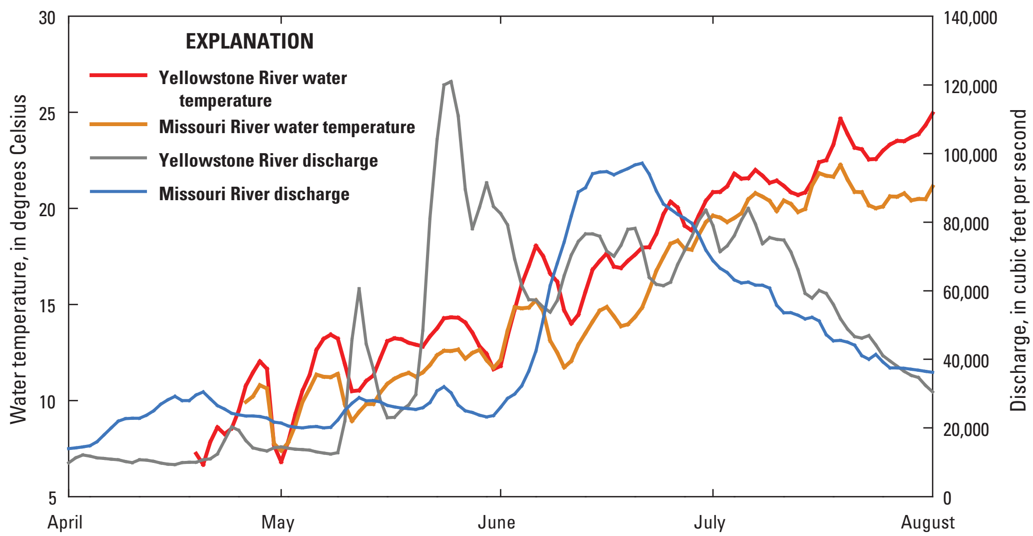


Figure 49. Water temperature and discharge of the Yellowstone River and Missouri River confluence (ATC) in 2011.

stations. These results are in stark contrast from the previous 6 years when Missouri River ATC use declined throughout the spring to approximately 0–5 percent during the June/July spawning season (fig. 50).

Most of the pallid sturgeon that used the Missouri River during 2011 entered the river when the Missouri River's discharge was higher than the discharge of the Yellowstone River (fig. 49); however, some fish did exit the Yellowstone River and migrate up the Missouri River in late May when discharge was greater in the Yellowstone River. Temperature was similar between the two rivers during this time. The remaining 60–65 percent of telemetered pallid sturgeon remained in the Yellowstone River during the spawning season.

From May 18 through May 31, four males and the potentially gravid female entered the Milk River, as evidenced by the ground-based station at the mouth of the Milk River, for an undetermined amount of time. The farthest confirmed upstream location of pallid sturgeon in the Milk River was at RM 36. Several tracking runs were terminated on the Milk River because of hazardous conditions (low power lines, log jams, or debris). During the previous 9 years, only two telemetered adult pallid sturgeon had been detected in the Milk River, one in 2004 and one in 2010 (David Fuller, Montana Fish Wildlife and Parks, Glasgow, Mont., written commun.).

In objective 2, we attempted to quantify reproductive products (eggs, free embryos, larvae) and potential spawning reaches in the Milk River and Missouri River below Fort Peck Dam. In 2011, no sturgeon larvae were collected from the Milk River. A total of 53 paddlefish larvae were collected from the Milk River with a peak occurring on June 17 (table 16). These larvae were identified by Montana Fish Wildlife and Parks personnel in the lab. No larval sampling occurred during most of the month of June and early July in the Missouri River because of high discharges. A total of 64 Acipenseriformes larvae were collected in the Missouri River near Wolf Point (table 17). All specimens were analyzed by Southern Illinois University Carbondale, Fisheries and Illinois Aquaculture Center for genetics because most were in poor condition and identification by our lab was difficult.

Results indicated that there were 39 paddlefish, 24 shovelnose sturgeon, and 1 unambiguous pallid sturgeon larva (Edward Heist, Southern Illinois University, written commun., 2011). This pallid sturgeon larva was a wild-produced fish, because there were no larval stockings in 2011. This larva was approximately 7 mm in length and collected at RM 1707 on July 12. This is the first documentation of pallid sturgeon spawning and successful reproduction in the Missouri River downstream from Fort Peck Dam and the first genetically confirmed pallid sturgeon larva in the Missouri River Basin. Parentage analysis by Jeff Kalie and Meredith Bartron (Northeast Fishery Center, Lamar, Pa.) linked the larvae to a telemetered male (code 23; PIT no. 1F4A3E1445) and a nontelemetered female (PIT no. 40636B2945). Code 23 was relocated several times in the Upper Missouri River during the study but was not detected after 24 June; therefore, exact location of this spawning event is uncertain. The female was spawned at Garrison Dam National Fish Hatchery in 2007 and several progeny were stocked in RPMA2 including 44,000 larvae for the Missouri River main-stem drift study by Braaten and others (2012).

There were an additional 19 Acipenseriformes larvae collected that were missed when samples were sorted in the field. These fish were added to the totals in table 17; distinguishing between pallid sturgeon and shovelnose sturgeon was not feasible because samples were stored in formalin.

In objective 3, we assessed and attempted to quantify settlement of pallid sturgeon larvae from the drift based on collections of YOY pallid sturgeon in lower reaches of the Missouri River. In 2011, a total of 172 trawls were completed during 7 sampling events from July 20 through August 31. Sturgeon chub and channel catfish (*Ictaluris punctatus*) made up 48 and 32 percent of the catch, respectively (table 18). Only three YOY sturgeon were collected (all BTC) and they were determined to be shovelnose sturgeon through genetic analysis.

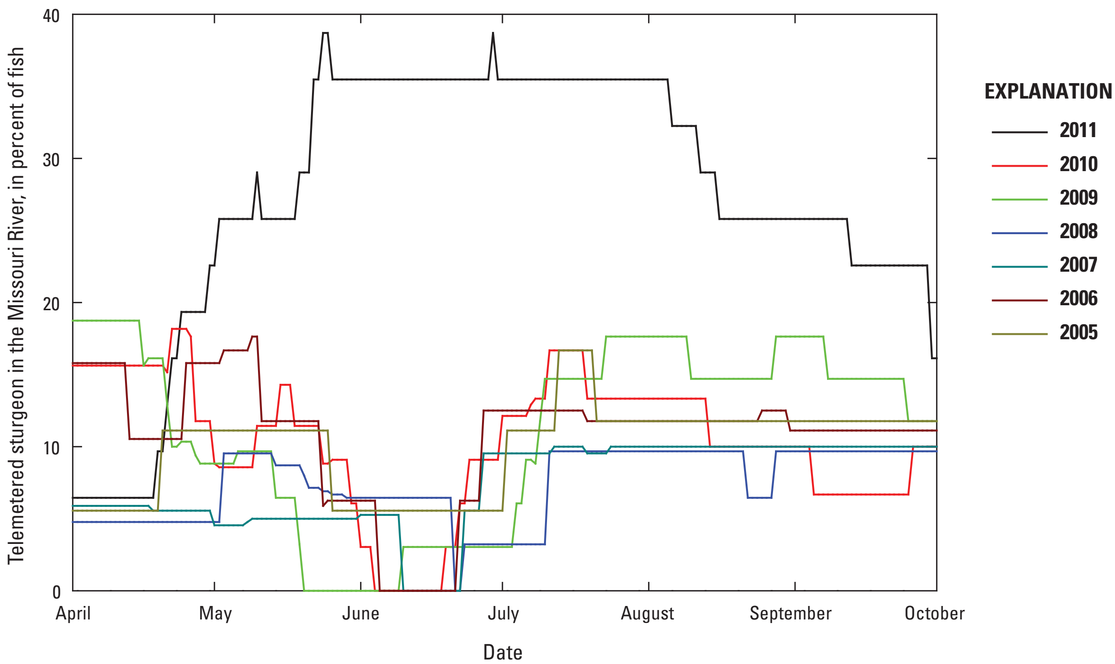


Figure 50. Percent of telemetered pallid sturgeon located in the Upper Missouri River including the Milk River by date, 2005–11.

Pallid sturgeon responses to elevated 2011 discharges provide new context for understanding the role of flow regime in reproductive ecology of the species. Discharge on the Upper Missouri River increased from 14,000 ft^3/s to 29,000 ft^3/s during April 1 through April 15, primarily because of elevated flows from the Milk River. Pallid sturgeon began migrating into the Missouri River after this pulse and continued to migrate into the Missouri River through May when discharges ranged between 20,000 and 30,000 ft^3/s. This range is similar to flows requested (total 23,000 ft^3/s) in the 2000 Biological Opinion (U.S. Fish and Wildlife Service, 2000).

The July 6 aggregation of sexually mature male pallid sturgeon observed during 2011 downstream from Fort Peck Dam is the first documented aggregation of wild pallid sturgeon in the Upper Missouri River. Tracking data from this study indicate that even though the species is extremely rare, reproductive adults can find one another. The origin of the pallid sturgeon larva that was collected on July 12 is uncertain. It may have come from the area associated with the July 6 aggregation or other nearby reaches in the Missouri River at a similar time. This fish likely was spawned in the river on July 6 for the following reasons: (1) this 7-mm larva likely was 1 day post hatch (dph) since larvae are 7–9 mm at hatch (Rob Holm, U.S. Fish and Wildlife Service, Garrison National Fish Hatchery, oral commun.), (2) the embryo would have needed approximately 5 days of incubation at 18–19 °C before hatching (Kappenman and other, 2013), and (3) the larva would have needed several hours to drift before it was collected at the downstream larval sampling site on July 12, depending on where this larva was produced (Braaten and others, 2012) .

Successful spawning of shovelnose sturgeon has been documented in the Missouri River downstream from Fort Peck Dam every year since 2001 (Braaten and Fuller, 2010). The explanation for why shovelnose sturgeon spawn successfully with higher frequency and the pallid sturgeon do not may be attributable to several factors. Spawning and recruitment of shovelnose sturgeon on the Upper Missouri River could be from a population that resides year-round in areas upstream from Wolf Point, so environmental cues are not necessary to draw these fish to upstream spawning reaches. Alternatively, the timing or magnitude of environmental cues 2005–10 may not have been sufficient to trigger migration or aggregation of pallid sturgeon even if they were sufficient for shovelnose. Fuller and others (2008) documented pallid sturgeon spawning in the Yellowstone River with a maximum flow of only 40,000 ft^3/s; therefore, other characteristic environmental cues may be necessary in addition to discharge magnitude, perhaps including timing and relation to water temperatures. Since very few sexually mature adult pallid sturgeon have been observed in the Missouri River before 2011, limited data exist that detail the flow parameters required to stimulate wild pallid sturgeon migrations and spawning.

Results of the 2011 study added substantial new information on pallid sturgeon movement, river use, and behavior in the Upper Missouri River. Verification of successful reproduction by wild pallid sturgeon has provided information that shows spawning, fertilization, egg survival, and hatch can occur in the Missouri River under some conditions. These findings lend further evidence to the leading hypothesis that the bottleneck of recruitment is the lack of distance for drifting

Table 16. Sampling dates and paddlefish larvae collected in the Milk River, 2011.

Date	Paddlefish larvae
5/18/2011	0
5/26/2011	0
6/1/2011	0
6/3/2011	0
6/6/2011	0
6/15/2011	7
6/17/2011	26
6/21/2011	6
6/23/2011	9
6/27/2011	2
6/30/2011	3
7/6/2011	0
7/11/2011	0
7/13/2011	0

Table 17. Sampling dates and paddlefish, shovelnose sturgeon, pallid sturgeon, and unknown Acipenseriformes larvae collected in the Missouri River near Wolf Point in 2011.

Date	Paddlefish	Shovelnose Sturgeon	Pallid Sturgeon	Unknown Acipenseriformes
5/18/2011	0	0	0	0
5/24/2011	0	0	0	0
6/1/2011	0	0	0	0
7/12/2011	4	3	1	2
7/14/2011	18	7	0	5
7/18/2011	1	0	0	2
7/21/2011	2	2	0	1
7/25/2011	4	3	0	4
7/28/2011	4	2	0	0
8/1/2011	3	6	0	0
8/4/2011	3	1	0	3
8/8/2011	0	0	0	1
8/11/2011	0	0	0	1

larvae in this fragmented river reach. Braaten and others (2012) estimated that 160–230 river miles are needed for the slowest 25 percent of drifting larvae to settle out when subjected to an average water velocity of 0.7 m/s and water temperature of 20 °C. There were approximately 200 river miles available from the location of the July 6 aggregation to headwater areas of Lake Sakakawea and although average water velocities may have been greater than 0.7m/s, lower velocities along channel margins and inundated lateral flood-plain habitat may have provided opportunities for slower drift or settling from the current. Consequently, there is some probability, although of unknown magnitude, that wild-produced pallid sturgeon larvae settled out before reaching lentic habitat of Lake Sakakawea. It remains uncertain at this time if this rare spawning event and the flow conditions of 2011 that produced the event will lead to successful pallid sturgeon recruitment. Current monitoring programs are in place to examine this in future years.

Summary and Conclusions

The Comprehensive Sturgeon Research Project (CSRP) is a multiagency collaboration between the U.S. Geological Survey and the Nebraska Game and Parks Commission (NGPC), U.S. Fish and Wildlife Service (USFWS), Montana Fish Wildlife and Parks (MTWFP) 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. In 2011 studies continued to emphasize movement, habitat use, and reproductive behavior of pallid sturgeon; understanding reproductive physiology of pallid sturgeon and relations to environmental conditions; and the management and synthesis of large datasets. The scope of the project was broadened to include studies on the origin, transport, and fate of drifting pallid sturgeon larvae as well as investigations of habitats needed by pallid sturgeon for all life stages.

Research for the CSRP during 2011 included detailed, interdisciplinary field studies in four contrasting river sections, new characterizations of male reproductive physiology, and the start of integrative assessments of pallid sturgeon population dynamics. Field research was challenged by the extreme discharges associated with the highest annual runoff on record, but these conditions also expanded the dynamic range of the field experiments to include sustained flooding of flood plains and riparian zones. Documented spawning sites in the main stem were similar to those identified in previous years, outside revetted banks. New this year, however, was indirect documentation of fish spawning in the Platte River and the possibility of one fish spawning in the James River. For the first time, pallid sturgeon were documented using inundated flood-plain habitats in the Lower Missouri River. On the Upper Missouri and Yellowstone Rivers, the unprecedented high discharge pulses drew pallid sturgeon into the Missouri River and away from the Yellowstone. For the first time, spawning was confirmed in the Upper Missouri River by capture of a genetically identified pallid sturgeon larva. These unique responses in 2011 expand understanding of what is possible in reproductive ecology of pallid sturgeon; however, the rare nature of hydroclimatic events in 2011 dictates that replication of these observations may take a long time, and the value of the information to management decisions must be weighed accordingly.

Table 18. Trawl catches in targeted sampling for pallid surgeon in the Upper Missouri River above the Yellowstone confluence in 2011.

[YOY, young-of-year; spp., species plural]

Species	Above the confluence (ATC)	Below the confluence (BTC)	Total
Bigmouth buffalo (*Ictiobus cyprinellus*)	7	3	10
Burbot (*Lota lota*)	30	15	45
Blue sucker (*Cycleptus elongatus*)	1	0	1
Common carp (*Cyprinus carpio*)	16	6	22
Channel catfish (*Ictalurus punctatus*)	4	428	432
Cisco (*Coregonus artedi*)	0	1	1
Emerald shiner (*Notropis atherinoides*)	1	1	2
Flathead chub (*Platygobio gracilis*)	7	15	22
Fathead minnow (*Pimephales promelas*)	1	2	3
Freshwater drum (*Aplodinotus grunniens*)	0	3	3
Goldeye (*Hiodon alosoides*)	3	2	5
Longnose dace (*Rhinichthys cataractae*)	1	6	7
Number of trawls without fish	17	8	25
Pallid sturgeon (*Scaphirhynchus albus*)[1]	3	6	9
River carpsucker (*Carpiodes carpio*)	0	3	3
Sicklefin chub (*Macrhybopsis meeki*)	38	23	61
Sturgeon chub (*Macrhybopsis gelida*)	124	539	663
Sauger (*Sander canadensis*)	3	6	9
Shovelnose sturgeon (*Scaphirhynchus platorynchus*)	5	5	10
Shovelnose sturgeon (YOY)	0	3	3
Stonecat (*Noturus flavus*)	10	36	46
Unidentified Cyprinidae	0	4	4
Unidentified chub (*Hybognathus* spp.)	0	9	9
Walleye (*Sander vitreus*)	1	0	1

[1]Nonwild, hatchery-origin.

Documentation of migration pathways on the Lower Missouri and Yellowstone Rivers presented new insights into how migrating reproductive pallid sturgeon select their pathways through fast and complex channels. On the Lower Missouri River, pathways confirmed earlier understanding that fish select the slowest water on inside bends as they move upstream, and move to fast, deep, turbulent water on the outside of bends only when spawning is imminent. Sturgeon have more pathways available to them on the Yellowstone River and those selected indicate the range of velocities and depths they are likely to find compatible in engineered passages. These data may therefore be useful in design criteria for fish passage at Intake Diversion Dam.

Research on male pallid sturgeon reproductive physiology demonstrated the applicability of blood hormone, blood chemistry, and sperm quality assays in evaluating concerns with male reproduction. Although based on few samples, these indicators seem to vary in systematic ways over the reproductive cycle and with environmental conditions. In general, wild and captive fish showed good sperm quality, although motility of captive fish was less than that of wild fish.

Substantial progress was made in 2011 on assessment of pallid sturgeon populations and on improving understanding of survival of hatchery propagated fish. Statistical analyses of data generated by the Pallid Sturgeon Population Assessment Program is underway to detect long-term trends in sturgeon populations and the extent to which population growth depends on the propagation program.

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