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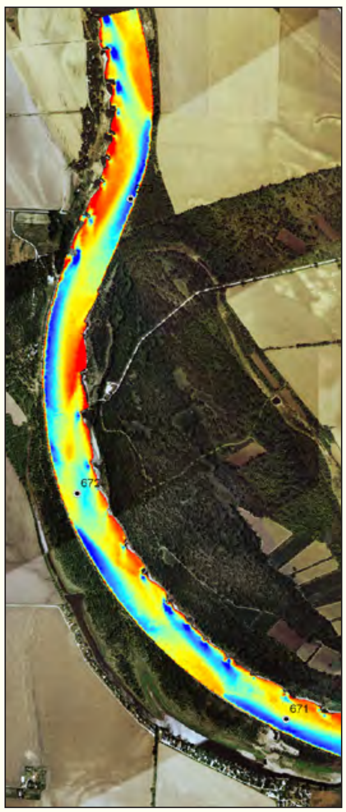
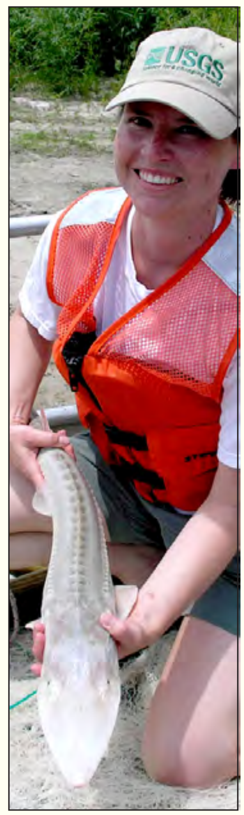
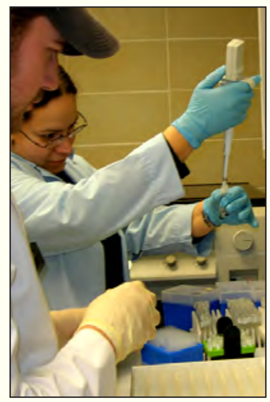
Factors Affecting the Reproduction, Recruitment, Habitat, and Population Dynamics of Pallid Sturgeon and Shovelnose Sturgeon in the Missouri River







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Cover

USGS habitat vessel

Biologists retrieve sturgeon eggs

Habitat map showing the depth in a river bend

Biological technician with an immature pallid sturgeon

Researchers studying physiology of the sturgeon

Taking sturgeon measurements

Factors Affecting the Reproduction, Recruitment, Habitat, and Population Dynamics of Pallid Sturgeon and Shovelnose Sturgeon in the Missouri River

Edited by Carl E. Korschgen

Contributions by Aaron J. DeLonay, Diana M. Papoulias, Robert B. Jacobson, Mark L. Wildhaber, Darin G. Simpkins, Carl E. Korschgen, Gerald E. Mestl[1], Dustin W. Everitt[1], Kimberly A. Chojnacki, Mandy L. Annis, Donald E. Tillitt, Steven R. LaBay[2], Dale W. Blevins, Roy Bartholomay, Kathleen Neitzert, David Rus, Richard Wilson, Michael Andersen, Rich Kopish, and Roger Haschemeyer

[1] Nebraska Game and Parks Commission.
[2] South Dakota Game, Fish, and Parks, Yankton Field Office.

Volume comprises Chapters A, B, C, D, E, and F

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
mile, nautical (nmi)	1.852	kilometer (km)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
square centimeter (cm^2)	0.1550	square inch (ft^2)
	Volume	
cubic meter (m^3)	6.290	barrel (petroleum, 1 barrel = 42 gal)
cubic kilometer (km^3)	0.2399	cubic mile (mi^3)
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
meter per second (m/s)	3.281	foot per second (ft/s)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32$$

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

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Project Overview

By Aaron J. DeLonay, Diana M. Papoulias, Robert B. Jacobson,
Mark L. Wildhaber, Darin G. Simpkins, and Carl E. Korschgen

Chapter A of

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U.S. Geological Survey

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Abstract

For more than a hundred years, human activities have modified the natural forces that control the Missouri River and its native fish fauna. While the ecological effects of regulation and channel engineering are understood in general, the current understanding is not sufficient to guide river restoration and management. The U.S. Geological Survey (USGS) is in the third year of a multiagency research effort to determine the ecological requirements for reproduction and survival of the endangered pallid sturgeon (*Scaphirhynchus albu*s) and shovelnose sturgeon (*Scaphirhynchus platorhynchus*) in the Missouri River. The multidisciplinary research strategy includes components of behavior, physiology, habitat use, habitat availability, and population modeling of all life stages. Shovelnose sturgeon are used to design the strategy because they are closely related to the pallid sturgeon and are often used as a surrogate species to develop new research tools or to examine the effects of management actions or environmental variables on sturgeon biology and habitat use.

During fiscal years 2005 and 2006, the U.S. Army Corps of Engineers (USACE) provided funds to USGS for tasks associated with the Comprehensive Sturgeon Research Program (CSRP) and for tasks associated with evaluation of the Sturgeon Response to Flow Modifications (SRFM). Because work activities of CSRP and SRFM are so integrated, we are providing information on activities that have been consolidated at the task level. These task activities represent chapters in this report.

Introduction

The U.S. Army Corps of Engineers (USACE) has been charged with altering operations of the Missouri River Main Stem Reservoir System, operation and maintenance of the Missouri River Bank Stabilization and Navigation Project, and operation of the Kansas River Reservoir System to remove a jeopardy opinion for the endangered pallid sturgeon (U.S. Fish and Wildlife Service, 2003). The emphasis on restoring flow regime and channel morphology in the 2003 biological opinion reflects the understanding that these two factors have been highly altered by river management and that physical habitat is likely a bottleneck in reproduction and survival of Missouri River sturgeon.

Background

Intensive management of the Missouri River for purposes of navigation, flood control, and power generation has resulted in dramatic physical changes to the river corridor (Ferrell, 1993,1996; Galat and Lipkin, 2000). As in other rivers with large flood plains, agricultural pesticides, nutrient runoff, and increasing discharge of domestic and industrial effluents may also have affected the aquatic biota and the ecological health of the Missouri River basin (Tockner and Stanford, 2002). Recent proliferation of introduced and non-indigenous species has further threatened to diminish the ecological integrity of the river ecosystem (Pflieger, 1997; Galat and others, 2005). In combination, these changes in flow regime, physical habitat, water quality, and biota have been implicated in the decline of important components of the Missouri River native fish assemblage (Funk and Robinson, 1974; Hesse and others, 1989; Hesse and Sheets, 1993).

The most notable and conspicuous evidence of these declines has been the loss of sturgeon species native to the Missouri River basin. Conservation and restoration of native species, such as sturgeon, require knowledge both of the biology of the specie, and of the factors limiting recovery. The goal of this research is to improve understanding of the factors affecting reproduction and survival of sturgeon in the Missouri River. Most immediately, our intent is to determine where, when and under what conditions sturgeon spawn; to evaluate how successfully sturgeon are spawning; to identify factors affecting the recruitment of age-0 sturgeon; and to develop sturgeon forecasting models.

Status of Missouri River Sturgeon

The pallid sturgeon (*Scaphirhynchus albus)* is endemic to the turbid waters of the Missouri River and the Middle and Lower Mississippi River (from the mouth of the Missouri River downstream to New Orleans, La.) (Mayden and Kuhajda, 1997). It was listed as a federally endangered species in 1990 (Dryer and Sandvol, 1993). The pallid sturgeon is rare in the Lower Missouri River, and no reliable population estimate exists. Based upon recent capture rates and the incidence of occurrence, managers estimate that as few as several thousand individuals remain in the Lower Missouri River (Duffy and others, 1996; U.S. Fish and Wildlife Service, 2000). Natural recruitment of juvenile pallid sturgeon to the adult population is insufficient to sustain the species and has not been documented in recent years (U.S. Fish and Wildlife Service, 2000). Hybridization of pallid sturgeon with the sympatric and closely related shovelnose sturgeon (*Scaphirhynchus platorynchus*) has been documented and has been identified as a potentially serious threat to the persistence of the pallid sturgeon (Carlson and others, 1985; Keenlyne and others, 1994; Wills and others, 2002). Since 1989, Missouri River basin management agencies have been involved in revising the operating plan for the Missouri River mainstem reservoirs and consulting on the implementation of the USACE navigation and bank stabilization projects (U.S. Fish and Wildlife Service, 2000, 2003). As a result, several significant management activities have been initiated to benefit the pallid sturgeon in the Lower Missouri River, including propagation efforts to supplement wild populations, physical habitat rehabilitation projects to improve riverine habitat conditions, and planned experimental reservoir releases to promote reproduction and increased survival of juvenile pallid sturgeon.

The shovelnose sturgeon is more common and widespread than the pallid sturgeon (Becker, 1983). The historical distribution of the species included the Mississippi, Missouri, Ohio, and Rio Grande Rivers and their tributaries. Similar to the pallid sturgeon, the shovelnose sturgeon is declining and has been extirpated or is at risk of extirpation from considerable portions of its native range (June, 1977; Moos, 1978; Keenlyne, 1997; Quist and others, 2002). Of the 24 States that compose the historical range of the shovelnose sturgeon, 5 list the species as extirpated, and 8 list the species as either imperiled or vulnerable (Hesse and Carreirov, 1997; NatureServe, 2005). The World Conservation Union recently listed the species as "vulnerable" (Surprenaut, 2004). The "vulnerable" assessment reflects a past reduction in species range of 30 perceny, and anticipates a further 30 percent reduction in population within the next 10 years, or three generations of fish. The closely related but allopatric shovelnose species from the Mobile River basin, the Alabama sturgeon (*S. suttkusi),* is extremely rare and close to extinction (Mayden and Kuhajda, 1996). The causes of decline and extirpation of shovelnose sturgeon are similar to those that resulted in the listing of the pallid sturgeon. Dam construction, impoundment, sedimentation, impacts related to navigation, pollution, and past and current exploitation have all been implicated as causative factors (Williams and others, 1989; Keenlyne and Jenkins, 1993; Hesse and Carreirov, 1997; Mayden and Kuhajda, 1997; U.S. Fish and Wildlife Service, 2000).

Despite evidence of substantial decline, the shovelnose sturgeon remains relatively common in the Lower Missouri River and the Mississippi Rivers (Becker, 1983). The persistence and resiliency of the shovelnose sturgeon in comparison to the pallid sturgeon may be due in part to its earlier maturity, lower trophic status, and adaptability to a broader range of environmental conditions. The shovelnose sturgeon matures earlier and attains a smaller maximum size than the pallid sturgeon (Keenlyne and Jenkins, 1993). The smaller shovelnose sturgeon subsists primarily on invertebrates, while the larger pallid sturgeon becomes piscivorous relatively early in life (Modde and Schmulbach, 1977; Carlson and others, 1985; Keenlyne, 1997). Both pallid and shovelnose sturgeon are highly adapted to large, turbid, riverine environments, but pallid sturgeon apparently do not use tributaries or clear-water riverine habitats that are frequented by shovelnose sturgeon (Mayden and Kuhajda, 1997). Despite these differences, the morphological, physiological, and genetic similarity between the taxa clearly indicates that these two sympatric species are very closely related (Bailey and Cross, 1954; Campton and others, 2000; Simons and others, 2001; Snyder, 2002). Consequently, the shovelnose sturgeon is a suitable model for the development of physiological indicators and reproductive assessment tools that are applicable to pallid sturgeon. The commonalities and dissimilarities in lifehistory specifics and patterns of decline between the two sturgeon species provide opportunities to investigate factors limiting species recovery and to evaluate the response to experimental system alterations and management actions.

Reproductive Ecology of Missouri River Sturgeon

The decline of sturgeon populations is a global phenomenon (Birstein, 1993). Habitat alteration, river regulation, pollution, and overharvest have been implicated in the now predictable patterns of decline and localized extirpation of sturgeon across species and geographic areas. Symptomatic of this generalized pattern of decline are poor reproductive success and low or no recruitment of juveniles to the adult population. Evidence from various monitoring efforts suggests that recruitment of pallid sturgeon to the adult population is limited or nonexistent throughout most of the Missouri River (U.S. Fish and Wildlife Service, 2000). Some reproduction of the endangered pallid sturgeon has been documented in the Lower Missouri River (L. Mauldin, U.S. Fish and Wildlife Service, oral commun., 2000) and in the Middle Mississippi River (R. Hrabik, Missouri Department of Conservation, oral commun., 2002). Evidence also suggests that pallid sturgeon may be spawning in the Yellowstone River or Upper Missouri River below Fort Peck Dam, though juvenile survival apparently has not occurred there for decades (Pat Braaten, U.S. Geological Survey, oral commun., 2006). In contrast, shovelnose sturgeon are reproducing, and recruitment is occurring in the Missouri River (Moos, 1978; Keenlyne 1997).

Unfortunately, the location of spawning and the relative suitability of spawning conditions for these sturgeon species in the Lower Missouri River are poorly understood. In addition, the specifics of the reproductive physiology and spawning behavior of both species are not well documented. Increased knowledge of the reproductive physiology of both species is necessary to develop methods that can accurately assess reproductive readiness and success in these species. These methods can be employed in comparative studies to evaluate reproductive success among species over a range of environmental conditions. Successfully conducted, these comparative studies will help to characterize the natural progression from gamete maturation through spawning in *Scaphirhynchus* sturgeons. In addition, comparative studies will aid in the determination of important environmental variables that may serve as reproductive cues or will identify factors that may impair or preclude successful reproduction.

Most North American sturgeon spawn between the spring equinox and summer solstice, with a peak in spawning runs often coinciding with the annual peak flow (Cech and Doroshov, 2004). The effect of hydrology on spawning has not been documented specifically for shovelnose sturgeon or pallid sturgeon, but fishery biologists speculate that those spawning runs are similarly dependent on river flow (Becker, 1983; Keenlyne and Jenkins, 1993; U.S. Fish and Wildlife Service, 2000). Migrations of shovelnose sturgeon into smaller streams, presumably for spawning, have been reported when sufficient water is available (Becker, 1983), but similar use of small tributaries by pallid sturgeon has not been documented. The sequence of spawning behavior from migration and aggregation at the spawning site through egg deposition has not been documented for the shovelnose or pallid sturgeon. The timing, periodicity, and location of spawning events in relation to the substrate and overlying water conditions (that is, temperature, turbidity, flow, and velocity) also are not known. This information is critical to designing adequate habitat alterations and flow manipulations intended to promote reproduction and survival of young sturgeon.

Spawning areas of other North American sturgeon species are most often characterized by coarse or hard substrates. White sturgeon, *Acipenser transmontanus* (Scott and Crossman, 1973; Parsley and others, 2002); green sturgeon, *A. medirostris* (Houston, 1988); shortnose sturgeon, *A. brevirostrum* (Taubert, 1980; Buckley and Kynard, 1985); Atlantic sturgeon, *A. oxyrinchus oxyrinchus* (Scott and Crossman, 1973); gulf sturgeon, *A. oxyrinchus desotoi* (Fox and others, 2002); and lake sturgeon, *A. fulvescens* (Scott and Crossman, 1973; LaHaye and others, 1992; Bruch and Binkowski, 2002) all spawn primarily over gravel, cobble, boulder, bedrock, or other hard surfaces. Little is known about the substrate preferences of spawning pallid and shovelnose sturgeon. Pallid sturgeon and shovelnose sturgeon are assumed to spawn in current over coarse substrate in, or adjacent to, the main river channel (Becker, 1983; Mayden and Kuhajda, 1997). Eggs of most sturgeon species are broadcast over spawning areas, become adhesive soon after release, and attach to the substrate until hatch (Breder and Rosen, 1966). Knowing the location and type of substrate preferred by spawning pallid and shovelnose sturgeon would allow biologists to locate adult fish during the spawning season, estimate the population of reproductive adults, monitor spawning activity and relative success, and assess habitat suitability during the spawning period.

Research Goal

The goal of this research is to determine the ecological requirements for successful pallid and shovelnose sturgeon reproduction and recruitment in the Missouri River. Past research on these species has focused on geographic distribution, morphological and genetic characteristics, and ecology of adults that are not reproductively active (Duffy and others, 1996; U.S. Fish and Wildlife Service, 2000). Consequently, substantial gaps exist with respect to biotic and abiotic factors affecting the development, growth, and reproduction of pallid sturgeon and shovelnose sturgeon. Lack of knowledge about habitat conditions necessary for successful reproduction of these species limits the ability of biologists to evaluate or define conservation or engineering criteria needed for habitat rehabilitation efforts. Factors that affect the survival of early-life stages of sturgeon are poorly understood, even though this is the period of life history when most mortality occurs and year-class strength is established for each generation (Gross and others, 2002; Kynard and others, 2002, 2004; Parsley and others, 2002; Kynard and others, unpub. data). The ability to predict or assess relative reproductive success, coupled with knowledge about factors affecting recruitment of sturgeon, and an ability to accurately forecast future populations will enable managers to tailor prescribed management actions to promote species recovery.

Product Development and Delivery

The USGS sturgeon research team has developed and delivered a large number and diversity of products (table A1) in relation to Missouri River recovery issues that have been funded by the USACE. Some of the activities and products have been funded in part by other sources, including USGS appropriated funds, but they support the CSRP and the SRFM efforts to understand reproduction and survival of Missouri River sturgeon. Printed or electronic copies of these USGS products can be provided as long as they comply with USGS Fundamental Science Practices peer review and Bureau approval policies.

Other activities such as database management, outreach, and report generation activities related to CSRP Task 10: Information Infrastructure and Decision Support System and SRFM Task 5 have been incorporated into table A1 and other chapters of this report.

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Table A1

Table A–1. List of publications, reports, presentations, meeting attendance, training, technical assistance, and outreach contacts provided by U.S. Geological Survey (USGS) staff.

Author/Person	Title	Venue
Publications		
Gaeuman, D., Jacobson, R.B., and Johnson H.E II	Quantification of Fluid and Bed Dynamics for Characterizing Benthic Physical Habitat in Large Rivers	Submitted: Journal of Applied Ichthyology
Bajer, P.B. and Wildhaber, M.L.	Population viability analysis of Lower Missouri River shovelnose sturgeon with initial application to the pallid sturgeon	Submitted: Journal of Applied Ichthyology
Wildhaber, M.L.	The Role of Reproductive Behavior in the Conservation of Fishes: Examples from the Great Plains Riverine Fishes	The Conservation Behaviorist, 2006, v. 4, no. 1, p. 1.
Wildhaber, M.L., Papoulias, D.M., DeLonay, A.J., Tillitt, D.E., Bryan, J.L., and Annis, M.L.	Reference guide for physical and hormonal examination of Missouri River shovelnose sturgeon reproductive stage using non- and minimally invasive methods	Submitted: Journal of Applied Ichthyology
Bryan, J.L., Wildhaber, M.L., Papoulias, D.M, Delonay, A.J., Tillitt, D.E., and Annis, M.L	Effectiveness of non- and minimally invasive methods for estimating reproductive stage and fecundity of shovelnose and pallid sturgeons	Submitted: Journal of Applied Ichthyology
DeLonay, A.J., Papoulias, D.M., Wildhaber, M.W., Griffith, S.A., and Allert, J.A	Application of telemetry and biologically-delivered remote-sensor technology to evaluate reproductive behavior of shovelnose sturgeon	Submitted: Journal of Applied Ichthyology
Wildhaber, M.L., Papoulias, D.M., Delonay, A.J., Tillitt, D.E., Bryan, J.L., Annis, M.L., and Allert, J.A.	Gender identification of shovelnose sturgeon using ultrasonic and endoscopic imagery and the application of the method to the pallid sturgeon.	Journal of Fish Biology, 2005, v. 67, p. 114–132.
Gaeuman, D., and Jacobson, R.B.	Acoustic bed velocity and bed load dynamics in a large sand bed river	Journal Geophysical Research, v. 111, F02005, doi:10.1029/2005JF000411, 14 p.
Johnson, H.E., Jacobson, R.B., and Delonay, A.J.	Hydroecological modeling of the Lower Missouri River	Proceedings of the Third Federal Interagency Hydrologic Modeling Conference, Reno, Nev, April 2–6, 2006: Subcommittee on Hydrology of the Interagency Advisory Committee on Water Information, ISBN 0–9779007–0–3.
Jacobson, R.B., and Galat, D. L.	Flow and form in rehabilitation of large river ecosystems—an example from the Lower Missouri River	Geomorphology, 2006, v. 77, p.249–269, doi:10.1016/j.geomorph.2006.01.014, 21 p.
Reports		
Korschgen, C.	Missouri River Sturgeon	Fisheries and Aquatics Bulletin, 2006, v. 5, no. 2, p. 4–5.
Chojnacki, K., Tracy-Smith, E., Clark, S., DeLonay, A., and Henke, C.	Integrating Data Collection and Management for Fisheries Research	Fisheries and Aquatics Bulletin, 2006, v. 5, no. 3, p. 5.
DeLonay, A., Jacobson, R., Papoulias, D., Wildhaber, M., Simpkins, D., and Korschgen, C.	Sturgeon Research activities	The GROOVE, June, 28, 2006. Email to Craig Fleming
Wildhaber, M.L., Papoulias, D.M., DeLonay, A.J., Tillitt, D.E., Bryan, J.L., and Annis, M.L.	Development of Methods to Determine the Reproductive Status of Pallid Sturgeon in the Missouri River	USGS, Columbia Environmental Research Center. Final Science Support Program Report, 81 p. (2006)
DeLonay, A., Jacobson, R., Papoulias, D., Wildhaber, M., Simpkins, D., and Korschgen, C.	MIPR Quarterly Reports	March, June, and September, 2006. Emails to Craig Fleming

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	Author/Person	Title	Venue
		Presentations	
Platform	DeLonay, A.J., Papoulias, D.M., Wildhaber M.L., and Griffith, S.A.	Application of Telemetry and Biologically-Delivered Remote-Sensor Technology to Evaluate Reproductive Behavior of Shovelnose Sturgeon	Evolution, Ecology, and Management of Scaphirhynchus, St. Louis, Mo, Jan. 11–13, 2005
	Gaeuman, D., Jacobson, R.B., and Johnson, H.E. II	Quantification of Fluid and Bed Dynamics for Characterizing Benthic Physical Habitat in Large Rivers,	Evolution, Ecology, and Management of Scaphirhynchus, St. Louis, Mo, Jan. 11–13, 2005
	Papoulias, D.M., DeLonay, A.J., Annis, M.L., and Tillitt, D.E.	Evaluating Scaphirhynchus Spawning Success: The Use of Physiological Indicators	Evolution, Ecology, and Management of Scaphirhynchus, St. Louis, Mo, Jan. 11–13, 2005
	Wildhaber, M.L., Papoulias, D.M., DeLonay, A.J., Tillitt, D.E., Bryan, J.L., and Annis, M.L.	Physical and Hormonal Examination of Missouri River Shovelnose Sturgeon Reproductive State	Evolution, Ecology, and Management of Scaphirhynchus, St. Louis, Mo, Jan. 11–13, 2005
	Bryan, J.L., Wildhaber, M.L., Papoulias, D.M., DeLonay, A.J., Tillitt, D.E., and Annis, M.L.	Effectiveness of non- and minimally invasive methods for estimating reproductive stage and fecundity of shovelnose and pallid sturgeons	Evolution, Ecology, and Management of Scaphirhynchus, St. Louis, Mo, Jan. 11–13, 2005
	Johnson, H.E. III, Jacobson, R.B, and DeLonay, A.J.	Hydroecological Modeling of the Lower Missouri River	Third Federal Interagency Hydrologic Modeling Conference, Reno, Nevada, April 2–6, 2006
	Simpkins, D., Papoulias, D., Lebay, S., Stukel, S., and Kral, J.	Assessment of Sturgeon Aggregation and Spawning Occurrence in the Missouri River below Gavins Point Dam	Missouri Natural Resources Committee, Annual Meeting, Oct 3–5, 2006, Pierre, S. Dak,
	Papoulias, D. M.	Physiological Measures of Reproductive Readiness to Spawn: Use of the Polarization Index	Missouri Natural Resources Committee, Annual Meeting, Oct 3–5, 2006, Pierre, S. Dak,
	DeLonay, A. J.	Sturgeon Behavior and Reproductive Ecology—Update October 2006	Missouri Natural Resources Committee, Annual Meeting, Oct 3–5, 2006, Pierre, S. Dak,
	Simpkins, D., Papoulias, D., Lebay, S., Stukel, S. and Kral, J.	Assessment of Sturgeon Aggregation and Spawning Occurrence in the Missouri River below Gavins Point Dam	SRFM meeting, 13 July, 2006, Omaha, Nebr.
	Lebay, S., Stukel, S., Kral, J., Simpkins, D., Papoulias, D., and Laustrup, M.	Assessment of Sturgeon Aggregation and Spawning Occurrence in the Missouri River below Gavins Point Dam	Fisheries Division Meeting, July 16–17, 2006, Pierre, S. Dak.
	Mac, M.	Missouri River: Science and Management—Briefing for Deputy Secretary of the Interior Lynn Scarlett	Department of the Interior, 25 January 2006. Washington, D.C.
	Mac, M.	Missouri River: Science and Management—Briefing for Assistant Secretary for Water and Science, Department of Interior	Department of the Interior, 5 January, 2006, Washington, D.C.
	Bartholomay, R.	U.S. Geological Survey Water-Quality Monitoring Activities on the Missouri River	Sixth Annual Missouri River Institute Research Symposium, March 28, 2006, Vermillion, S. Dak.
	Wilson, R. and Bartholomay, R.	U.S. Geological Survey Real-Time Water-Quality Monitoring Activities on the Missouri River	Missouri Natural Resources Committee, Annual Meeting, Oct. 3–5, 2006, Pierre, S. Dak.
	Neitzert, L. and Bartholomay, R.	Real-time continuous water-quality monitoring in Eastern South Dakota	2006 Eastern South Dakota Water Conference, Nov. 1–2, 2006, Brookings, S. Dak.
	Bartholomay, R.	U.S. Geological Survey Nebraska and South Dakota Research activities on the Missouri River	Missouri River Futures meeting, Nov. 8, 2006, Ponca, Nebr.

Table A–1. List of publications, reports, presentations, meeting attendance, training, technical assistance, and outreach contacts provided by U.S. Geological Survey (USGS) staff.—Continued

	Author/Person	Title	Venue
	Jacobson, R.B., and Galat, D.G.	Hydrograph Design, Lower Missouri River: Endangered Species and Floods	American Association for the Advancement of Science, Annual Meeting, February 20, 2006, St. Louis, Mo.
	Jacobson, R.B. and Reuter, J.M.	Topographically based habitat assessment tools for riverine ecosystem management	American Geophysical Union Fall Meeting, December 14, 2006, San Francisco, Calif.
		Poster	
	DeLonay, A., Jacobson, R., Papoulias, D. Wildhaber, M., Simpkins, D. Laustrup, M., and Korschgen, C.	Factors Affecting the Reproductive Status, Movements, and Habitat Use of Pallid Sturgeon and Shovelnose Sturgeon in the Missouri River	Missouri Natural Resources Conference, May 9–12, South Sioux City, Nebr.
	Fleming, C., DeLonay, A., Jacobson, R., Papoulias, D., Wildhaber, M., Simpkins, D., Laustrup, M., Korschgen, C. Wilson, R., Blevins, D., Gorman, J., Bartholomay, R., Mestl, G., Steffensen, K., Hesse, L., Hill, T., Doyle, W., Stukel, S., LaBay, S., and Nelson-Stastney, W.	Sturgeon Response to Gavins Point Dam Flow Modification	Missouri River Natural Resources Conference, May 9–12, South Sioux City, Nebr.
	DeLonay, A., Jacobson, R., Papoulias, D., Wildhaber, M., Simpkins, D., and Korschgen, C.	The Missouri River, USA: Science for Management and Restoration of Sturgeon in a Large, Multi-Purpose River Corridor	Second International Symposium on Ecology and Fishery Biodiversity in Large Rivers of Northeast Asia and Western North America, Sept. 25–29, 2006. Harbin, People's Republic of China
	Chojnacki, K., Tracy-Smith, E., Clark-Kolaks, S., and DeLonay, A.	Integrating Data Collection and Management Tools To Support Multidisciplinary Research of Sturgeon on the Lower Missouri River	The 67th Midwest Fish and Wildlife Conference, December 3–6, 2006, Omaha, Nebr.
	DeLonay, A., Neely, B., Gonsior, J., Haas, J., Hamel, M., Everitt, D., Mestl, G.. Chojnacki, K., Clark-Kolaks, S., and Tracy-Smith, E.	Characterizing Spawning Migration Movements of Pallid Sturgeon and Shovelnose Sturgeon in the Lower Missouri River	The 67th Midwest Fish and Wildlife Conference, December 3–6, 2006, Omaha, Nebr.
	Gaeuman, D. G. and Jacobson, R.B.	Cross-validation of dune-tracking and acoustic bed velocity measurements for assessing bedload transport in a large river	American Geophysical Union Fall Meeting, December 14, 2006, San Francisco, Calif.
	Papoulias, D.M., Wildhaber, M.L. Delonay, A.J., Annis, M.L., Krentz, S., and Tillitt, D.E.	Abnormal hermaphroditism in shovelnose sturgeon (Scaphirhynchus platorynchus) from the Missouri River	International Workshop, Modern Problems of Aquatic Toxicology, September 20–24, 2005, Borok, Yaroslavl, Russia,
	Candrl.,J.S., Papoulias, D.M., Buckler, J.A., Tillitt, D.E.	Temperature and Diet as Factors in the Early Life stage development of shovelnose sturgeon	Missouri Natural Resources Committee, Annual Meeting, Oct 3–5, 2006, Pierre, S. Dak.
Informal	DeLonay, A., Jacobson, R., Papoulias, D., Wildhaber, M., Simpkins, D., Korschgen, C., Mac, M., and Galat, D.	Development of a Pallid Sturgeon Life History Model as a Conceptual Framework for Species Recovery Science in the Lower Missouri River	Pallid Sturgeon Recovery Team, September 13, 2006, Columbia, Mo.
		Meeting Attendance	
	Korschgen, C. and Blevins, D.	Agency Coordination Team (ACT), Missouri River Recovery Program	September 14 , 2006, St. Joseph, Mo.
	Korschgen, C.	Agency Coordination Team (ACT), Missouri River Recovery Program	June 20, 2006, St. Joseph, Mo.
	Blevins, D. and Wilson, R.	Agency Coordination Team (ACT), Missouri River Recovery Program	December 15, 2005
	Korschgen, C. and Blevins, D.	Agency Coordination Team (ACT), Missouri River Recovery Program	June 20, 2006, St. Joseph, Mo.

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Author/Person	Title	Venue
Blevins, D.	Agency Coordination Team (ACT), Missouri River Recovery Program	March 29, 2006
Blevins, D., Wilson, R., and Gorman, J.	Agency Coordination Team (ACT), Missouri River Recovery Program	August? 2006, Kansas City, Mo.
Blevins, D., Wilson, R., and Gorman, J.	Agency Coordination Team (ACT), Missouri River Recovery Program	December. 6, 2006. Omaha, Nebr.
Simpkins, D.	Habitat Assessment and Mitigation Program	March 21, 2006, Omaha, Nebr.
Simpkins, D.	Habitat Assessment and Mitigation Program	January 16–19, 2006, Kansas City, Mo.
	Long-term pallid sturgeon and associated fish community assessment for the Missouri River	December 6–7 , 2006, Omaha/Lincoln, Nebr.
DeLonay, A., Jacobson, R., Papoulias, D., Wildhaber, M., Simpkins, D., and Korschgen, C.	Spring Rise #1, Research Planning	January 20, 2006, Columbia, Mo.
DeLonay, A., Jacobson, R., Papoulias, D., Simpkins, D., and Korschgen, C.	Spring Rise #2, Research Planning	October 5, 2006, Pierre, S. Dak.
Jacobson, R., and DeLonay, A.	Spring Rise Plenary Group	Multiple dates and locations
DeLonay, A. J., Korschgen, C., Simpkins, D., Wildhaber, M., and Mac, M.	Pallid Sturgeon Recovery Team Meeting	September 12–13, 2006, Columbia, Mo.
DeLonay, A., Jacobson, R., Papoulias, D., Wildhaber, M., Simpkins, D., and Korschgen, C.	Annual Meeting of the Missouri River Natural Resources Committee	October 3–5, 2006, Pierre, S. Dak.
Training		
DeLonay, A. J., Tracy-Smith, E., and Clark, S.	Telemetry Workshop sponsored by CERC and Lotek Wireless, Inc.	August 15–18, 2006, Columbia, Mo.
Jacobson, R.	Hydrograph Survey Techniques for Nebraska Game and Parks Commission	March 2006, Columbia, Mo.
DeLonay, A. J.	Telemetry Techniques for tracking sturgeon for Nebraska Game and Parks Commission	August 14, 2006, Columbia, Mo,
Nebraska and South Dakota Water Science Centers	Water Quality Monitoring Training	March 16–17, 2006
Iowa. Missouri, Nebraska, and South Dakota Water Science Centers	Water Quality Monitoring Training	April 11–13, 2006
Technical Assistance		
Wildhaber M., and Bryan, J.	Evaluation of pallid sturgeon broodstock at Gavins Point National Fish Hatchery	Yankton, S. Dak.
DeLonay A., and Simpkins, D.	Pallid sturgeon broodstock capture	River miles
DeLonay, A. and Braaten, P.	Yellowstone River Intake consultation	Billings, Mont.
DeLonay, A.	Catfish Telemetry —— graduate student at Univ. of Missouri	Columbia, Mo.
Outreach Contacts		
Jacobson, R.	Water level shy for rise in March	Columbia Missourian, February 28, 2006
Papoulias, D.	Sturgeon — Coddling Needed	Science News, March 4, 2006
Mac, M.	Interview about Missouri River research	“The Amy Miller Show” on The Eagle talk radio station, KSSZ/93.9 FM, June 29 2006, Columbia, Mo.

Table A–1. List of publications, reports, presentations, meeting attendance, training, technical assistance, and outreach contacts provided by U.S. Geological Survey (USGS) staff.—Continued

Author/Person	Title	Venue
DeLonay, A.	Missouri River research on the endangered pallid sturgeon	Front page article—Columbia Missourian, April 20, 2006, Columbia, Mo.
DeLonay, A.	Newspaper article—The species is so very rare that you do have to have propagation as the number one priority	Argus Leader, May 7, 2006, Sioux Falls, S. Dak.,
Jacobson, R.	Experts "Collaborate at the Current"	KTIV, May 8, 2006, Sioux City, Iowa,
DeLonay, A.	USGS research program on endangered pallid sturgeon in relation to the Missouri River spring rise	Morning Edition, National Public Radio, May 19, 2006
DeLonay, A.	Extra H2O Might Save Sturgeons	Kansas City Star, June 24, 2006, Kansas City, Mo.
USGS Water Science Centers	Missouri River Water Information Portal Web site for Realtime Information	Made available to the public in early October, 2006 at *http://ne.water.usgs.gov/*

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For more information concerning this publication, contact:
Director
U.S. Geological Survey
Columbia Environmental Research Center
4200 New Haven Road
Columbia, MO 65201
(573) 875–5399
Or visit the Columbia Environmental Research Center website at:
http://www.cerc.usgs.gov

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

By Aaron J. DeLonay[1] Diana M. Papoulias[1], Mark L. Wildhaber[1], Gerald E. Mestl[2], Dustin W. Everitt[2], and Kimberly A. Chojnacki[1]

Chapter B of

Factors Affecting the Reproduction, Recruitment, Habitat, and Population Dynamics of Pallid Sturgeon and Shovelnose Sturgeon in the Missouri River

Edited by Carl E. Korschgen

[1] U.S. Geological Survey, Columbia Environmental Research Center.
[2] Nebraska Game and Parks Commission.

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U.S. Geological Survey

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By Aaron J. DeLonay[1] Diana M. Papoulias[1], Mark L. Wildhaber[1], Gerald E. Mestl[2], Dustin W. Everitt[2], and Kimberly A. Chojnacki[1]

Abstract

This chapter is a summary of activities conducted by the U.S. Geological Survey (USGS) in collaboration with Nebraska Game and Parks Commission (NGPC). The intent of these activities was to extensively and intensively study the movement, habitat use, and reproductive behavior of pallid sturgeon (*Scaphirhynchus albus*) and shovelnose sturgeon (*S. platorynchus*) in the Lower Missouri River. This work consisted of five components: telemetry system development, an extensive sturgeon reproduction study, development of a stationary receiver network, an aggregation and spawning site location study, and an intensive pallid sturgeon reproduction study.

A telemetry system was sourced in 2004 and deployment was initiated in 2005. A combination of analog radio and ultrasonic technology, with the addition of digital ultrasonic technology, was used to provide effective transmitter detection and tracking capabilities for sturgeon and other riverine species in the mainstem Missouri River and tributaries. Research vessels were outfitted as mobile-data collection platforms complete with an array of telemetry receivers, water and habitat sampling equipment, and computers for data collection. A computer-based data collection framework was developed to support simultaneous data collection from multiple field crews working on large stretches of the river. A customized ArcPad™ (ESRI, Inc., Redlands, Califorina) application was developed for mobile geographical information system field mapping of telemetry relocation events and habitat data collection on each research vessel. Data from field computers are uploaded to a secure server and linked to a larger spatial database. A graphical user interface was developed to allow users to easily update, enter, or view data and summary reports in near real-time.

In 2005 and 2006, 100 female shovelnose sturgeon were implanted with a telemetry transmitter and a Data Storage Tag (DST). Fifty shovelnose sturgeon were captured, implanted, and released in each of two study segments; the lower study segment (Kansas City, Missouri to St. Louis, Missouri) and the upper study segment (Gavins Point Dam, South Dakota to Plattsmouth, Nebraska). All implanted shovelnose sturgeon were in reproductive condition. Pallid sturgeon of any sex and condition were implanted and incorporated into the study when available (5 in 2005 and 16 in 2006). Only two pallid sturgeon implanted in 2006 were in reproductive condition (one male and one female). Systematic search efforts were conducted to document direction and distances moved, and to locate potential spawning habitat. Most tagged shovelnose sturgeon moved upstream after implantation for a variable distance, stopped, and then initiated a downstream movement. Shovelnose sturgeon were recollected following the spawning season to determine if spawning had occurred. Results indicate that shovelnose sturgeon that moved upstream after implantation spawned successfully, and most recollected shovelnose sturgeon spawned successfully. In contrast to the implanted shovelnose sturgeon, most pallid sturgeon were not in reproductive condition and did not exhibit predictable patterns of movement similar to that of the shovelnose sturgeon.

Three planned components of the study, the aggregation study, the intensive pallid sturgeon tracking study, and the remote telemetry receivers were not fully implemented. The transmitters for the aggregation component did not arrive in time for implantation in 2006, and these activities were not completed; this work may begin during 2007. The equipment for the intensive pallid sturgeon component did not arrive in time for implantation in 2006, and all pallid sturgeon in reproductive condition were transferred into the hatchery system for the propagation efforts. This component is scheduled to begin in 2007 if pallid sturgeon can be captured. Remote telemetry receivers have been developed and await deployment for the entire lower Missouri River in the fall of 2007.

Introduction

In 2004 the U.S. Army Corps of Engineers (USACE) completed an extensive process to revise the master manual for the operation of the Missouri River main stem reservoir

[1] U.S. Geological Survey, Columbia Environmental Research Center.

[2] Nebraska Game and Parks Commission.

system, operation and maintenance of the Missouri River Bank Stabilization and Navigation Project, and operation of the Kansas River reservoir system. Coincident with the Master Manual revision, the USACE was in consultation with the U.S. Fish and Wildlife Service (USFWS) about the impacts of these projects on several endangered species. A jeopardy opinion for the pallid sturgeon (*Scaphirhynchus albus*) was issued by the USFWS in 2000. The biological opinion was outlined in a comprehensive document replete with reasonable and prudent alternatives provided to the USACE to remove jeopardy (U.S. Fish and Wildlife Service, 2000). The biological opinion was reviewed in 2003, and an amended biological opinion was issued. The amended biological opinion (U.S. Fish and Wildlife Service, 2003) reaffirmed the jeopardy opinion for the pallid sturgeon and restated many of the reasonable and prudent alternatives listed in the original 2000 biological opinion. The USACE in collaboration with numerous partners and stakeholders convened a multi agency workshop in 2004. The workshop drew upon sturgeon experts from within the Missouri River basin, including sturgeon researchers with national and international expertise. The workshop developed a list of research needs for pallid sturgeon recovery (Quist and others, 2004). These research needs were subsequently prioritized by the Pallid Sturgeon Subbasin Working Groups, including the Middle Basin Pallid Sturgeon Recovery Work Group (2005). The top-ranked research needs from the Middle Basin Pallid Sturgeon Recovery Work Group were related to spawning and early-life-stage habitats. Priority needs included locating, quantifying, and characterizing pallid sturgeon spawning sites and quantifying spawning frequency and behavior.

This chapter is a summary of progress that describes activities conducted by the U.S. Geological Survey (USGS) in collaboration with Nebraska Game and Parks Commission (NGPC). The intent of these activities is to extensively and intensively study the movement, habitat use, and reproductive behavior of pallid sturgeon and shovelnose sturgeon (*S. platorynchus*) in the Lower Missouri River. This work was funded under two research and monitoring programs with complementary objectives and approaches. Portions of this work were conducted under the Comprehensive Sturgeon Research Program (CSRP). The CSRP is a multi year research framework developed by USGS and its partners to support pallid sturgeon recovery through increased understanding of the life history requirements of the species. Other parts of this work were conducted under the Sturgeon Response to Flow Modification project (SRFM), an initiative designed to evaluate the response of sturgeon to flow management actions undertaken at Gavins Point Dam.

Background

Conservation and restoration of native species, such as sturgeon, require knowledge of both the biology of the species and the factors limiting recovery. Thus, the goal of this research is to improve understanding of the factors affecting reproduction and survival of sturgeon in the Missouri River. Most immediately, there was a need to determine where, when, and under what conditions sturgeon spawn in the Lower Missouri River. Numerous studies have examined habitat use and movement of *Scaphirhynchus* sturgeon (Hurley and others, 1987; Latka and others, 1995; Quist and others, 1999; DeLonay and others, 2000; Bramblett and White, 2001; Snook and Peters, 2002; Hurley and others, 2004), but few of these studies have addressed the reproductive status of the sturgeon or followed individual fish to assess whether those that are gravid actually spawn successfully. None of the previous studies have specifically focused on reproductively mature fish prior to and during the spawning season. As a result, little information is available to indicate precisely where, when, and under what conditions shovelnose sturgeon and pallid sturgeon spawn. Under the CSRP program, the USGS has developed and tested methodology and technology to track sturgeon during the spring spawning migration and to document changes in reproductive status and reproductive success. A pilot study examining telemetry and remote-sensing technology, in combination with sturgeon reproductive assessment methodology, was conducted in 2004 (DeLonay and others, 2007). In March 2004, thirty gravid adult female shovelnose sturgeon were collected from the lower Missouri River and implanted with ultrasonic transmitters and archival data storage tags (DST). The implanted sturgeon were then tracked through the spawning period. Results indicate that upstream migration of shovelnose sturgeon may be rapid (>8 km/day) and cover long distances (>300 km). Fish implanted with transmitters and DSTs and recaptured following the spawning period showed that they spawned successfully. Analysis of depth data recorded by the DSTs also indicates a characteristic pattern of behavior that may indicate spawning. This work was expanded in 2005 and 2006 in anticipation of potential flow management actions and consisted of five components: (1) telemetry system development, (2) an extensive sturgeon reproduction study, (3) the development of a stationary receiver network, (4) an aggregation and spawning site location study, and (5) an intensive pallid sturgeon reproduction study. This chapter summarizes the approach and activities conducted in 2005 and 2006.

Objectives: 2005–06 Activities

Telemetry System Development

The objective of this component was to develop a telemetry tracking and data management system for sturgeon on the Lower Missouri River and its tributaries.

Extensive Sturgeon Reproduction Study

The objectives of this component are to (1) determine the direction and magnitude of spawning movements, (2) characterize patterns of habitat use during spawning migrations, (3) determine where and under what conditions sturgeon spawn, and (4) assess the relative success of spawning in relation to physiological status and environmental condition. The work was conducted within two geographically and hydrologically distinct reaches of the Lower Missouri River to evaluate results in relation to the longitudinal variability in the system.

Development of Stationary Receiver Network

The objective of this component is to increase the spatial and temporal resolution of sturgeon-tracking activities by augmenting manual tracking efforts with the addition of stationary receivers along the length of the Missouri River.

Aggregation and Spawning Site Location

The objectives of this work were to (1) provide a larger number of sturgeon of known sex and reproductive status (that is, individuals likely to spawn) that would provide information on the rate and extent of fish movement in relation to flow, (2) increase the likelihood of observing aggregations and identifying spawning locations, (3) provide location and movement data that could be used to modify or direct fisheries sampling activities or remote-sensing technologies to increase the probability of verifying spawning behavior, and (4) allow repeated sampling of individual fish to document progression of reproductive maturation and validate observed spawning behaviors. The work was to be conducted only within the uppermost experimental reach in conjunction with other CSRP activities.

Intensive Pallid Sturgeon Reproduction Study

The objective of this component is to (1) implant and track a small number of gravid adult pallid sturgeon through the spawning season, (2) use direct sampling and underwater remote-sensing technology, (3) include real-time imaging with the DIDSON™ (Dual Frequency Identification Sonar, Sound Metrics Corp., Chesapeake, Va.) acoustic camera to locate pallid sturgeon reproductive aggregations, and (4) describe pallid sturgeon spawning behavior and habitat.

Methods and Approach

Telemetry System Development

The Missouri River is a varied and difficult system in which to use telemetry. The large size, diverse habitat, dynamic flows, and extreme conductivity, turbidity, sediment load, and background noise of the system pose unique challenges to biologists tracking the movement of fish and other aquatic organisms in the Lower Missouri River. In 2004 the USGS developed specification and criteria for ultrasonic telemetry systems for use with sturgeon and other large river species on the Lower Missouri River and solicited all major telemetry system manufacturers for competitive bids. The specified system was intended to be used by a single operator in a small vessel. The selected system was required to meet the following criteria for consideration:

1. System may be either single or multiple frequency (40–85 kHz).
2. Each system must support two or more hydrophones for increased coverage and directionality.
3. System must support large numbers (>10,000) of individually coded transmitters on a single frequency.
4. System must have the capacity to simultaneously track and identify multiple coded transmitters (>10) within limited areas (400 m^2) with low lag times.
5. System must support transmitters equipped with environmental sensors including depth and temperature.
6. System must support real-time manual tracking of individual transmitters from a mobile platform or vessel.
7. System must effectively detect and decode transmitters in high noise environments. Ambient noise levels in the Lower Missouri River may be expected to exceed 78 dbuPa/Hertz (Hz).
8. Operator display in manual tracking mode must include transmitter code, relative direction to transmitter, and signal strength.
9. System must supply audio feedback to operator in manual tracking mode.
10. System must provide for fixed site data logging, in either attended or unattended mode, with internal data storage capability.
11. System must be portable for operation in small vessels. External power requirements limited to 9–30 volts direct current (DC).
12. System must operate under ambient temperature conditions expected during all seasons (-40°C to +85°C).
13. A variety of transmitters of different sizes and battery life expectancies must be available for this system for application to a broad range of species and research questions.
14. In consideration of future expansion and system flexibility, manufacturer must also indicate the availability of remotely deployable automated receivers

that are compatible with this system and the coding scheme used by transmitters. Specifications of remotely deployed receivers (size, configuration options, detection range, power requirements, and price) may influence selection of the telemetry tracking system.

In addition to meeting the selection criteria, the system was also required to demonstrate performance to desired specifications in field trials conducted in the Lower Missouri River prior to purchase. Acceptable demonstration of performance included the following:

1. Demonstration of receiver and hydrophone combination on the Lower Missouri River near Columbia, Mo.

2. Determination of detection and discrimination range for receiver, hydrophone, and transmitter combination likely to be used with target species in the Lower Missouri River. Transmitters likely to be used in initial studies would measure approximately 16 mm in diameter and from 50 to 90 mm in length.

3. A detection and discrimination range exceeding 300 m with high efficiency was desired. A detection and discrimination range exceeding 500 m with high efficiency would be preferable.

4. Successful demonstration of manual tracking capability of system in the Lower Missouri River. Operator must be able to detect, locate, and track the transmitter in a noisy environment with a high degree of accuracy (<8 m).

Lotek Wireless Inc. of Newmarket, Ontario, Canada, was the only company to respond to the request for bids issued by USGS for an acoustic telemetry system for use in the Lower Missouri River. The specifications of the equipment as listed by Lotek Wireless Inc. satisfied the specifications stated in the original solicitation. A field trial was conducted to demonstrate that the selected equipment could perform effectively to meet anticipated study objectives in the Lower Missouri River. The USGS has shown through previous experience and engineering feasibility studies that the Lower Missouri River contains environmental conditions in which it is extremely difficult to work. Telemetry equipment should not be expected to perform near manufacturer-stated optimum levels in this environment.

Field trials were conducted in the Lower Missouri River near Huntsdale, Mo. (approximately river mile (RM) 182) with the assistance of USGS, Columbia Environmental Research Center (CERC), Rivers Studies Branch's research vessels and staff. The evaluated system included the following components configured for potential field use in the Missouri River (fig. B1):

1. One Lotek MAP 600 RT acoustic telemetry receiver with two hydrophone ports operating at 76.8 kHz. The system was powered on 12 volts DC by using standard marine deep cycle batteries. The receiver was interfaced with a Lenovo Thinkpad® notebook computer (Lenovo, Morrisville, N.C.) running Microsoft Windows® 2000 (Microsoft Corporation, Redmond, Wash.). The receiver's operation and detection of deployed transmitters was monitored by using Lotek's MapHost software (Version 3.09).

2. One Lotek SRX 600 radio receiver and UUC 164 acoustic upconverter.

3. Two Lotek LHP_1 omnidirectional amplified hydrophones centered at 76 kHz were fitted with 90-degree directional baffles. A 10-m cable connected each hydrophone to the receiver. The hydrophones were attached to 3 m polyvinyl chloride (PVC) struts temporarily mounted on either side of the bow of a 7-m shallow-draft research vessel. Hydrophones were mounted approximately 2.4-m apart.

4. Eight Lotek MAP16_1 MAP series coded acoustic series transmitters (16 x 54 mm standard power). Transmitters were attached to a weighted cable and drifted or held stationary in the main channel of the Missouri River. Transmitters were deployed in several experiments, either singly or in multiples.

Under the test conditions the Lotek MAP_600 RT receiver reliably detected and decoded MAP standard power transmitters (16 x 54 mm) at measured ranges of 200–225 m. The Lotek MAP_600 RT receiver was a significant improvement over systems currently in use at CERC. Current systems often require the operator to close within 10 m before transmitters can be reliably decoded.

The Lotek MAP16_1 transmitter has the lowest signal output power of the MAP series tags. Earlier engineering and feasibility studies on the Missouri River indicate that the higher power transmitters (>6 db increase) in this series should have detection ranges of nearly double the tested transmitters (400–450 m). The range limitations for detection and decoding of transmitters for this system are therefore within an acceptable range of 200–400 m. These transmitters are similar in size and output power to acoustic components currently used by USGS for shovelnose sturgeon on the Lower Missouri River (fig. B2).

The Lotek MapHost software allows the operator to monitor the detection of partial codes by the receiver (fig. B3). Partial codes are incomplete subsets of the entire digital code of a transmitter. While partial codes do not allow the discrimination of the individual identity of a transmitter, they do allow the operator to detect transmitter signals at extended distances and move the vessel in the direction of the signal (fig. B4). The detection range of the system may therefore be significantly greater than the 200 m measured in the field trial. Tags tested in this field trial may be detectable at distances exceeding 300 m.

In multiple tag deployments, all codes were received and decoded, with no evidence of missed detections caused by code collision (figs. B3 and B4). The ability to discriminate between multiple tags within a very small area was demonstrated with 100 percent efficiency. No problems were experienced with echoes or signal multipath. A number of configurations of the system are available and include options for combined acoustic/radio tags (CART), stationary receivers (both underwater and bank solutions), and three-dimensional acoustic positioning. Based upon the satisfaction of solicitation criteria and successful completion of required performance trials, Lotek Wireless of Canada was awarded the bid for the telemetry system.

In addition to the telemetry tracking system, it is necessary to develop a data collection framework to support simultaneous data collection from several field crews working over 800 river miles. The construction of a robust and scalable relational database as well as standardized data collection parameters was required. Accurate and rapid reporting of results in a geographic information system (GIS) environment is required since it is necessary to integrate information from this study with results from other ongoing studies to direct sampling efforts and other activities (for example, mapping crews).

The development of the data collection and handling framework was completed within USGS with a range of products. A customized ArcPad™ (ESRI, Inc., Redlands, Calif.) application was developed for mobile GIS field mapping and validation of relocation events for implanted sturgeon, eliminating the need for paper field sheets. Custom data entry forms prompt a user to collect data for each relocation event, including water quality, hydrologic conditions, habitat, and substrate (figs. B5 and B6). In addition, the program automatically records date, time, and spatial coordinates from the Global Positioning System (GPS) unit. The customized ArcPad application is also used to document the search efforts of all relocation crews. Data collected for each search effort include the date, time, spatial coordinates, boat used, crew members, search type (drift, intensive monitor, or search for a specific fish), types of transmitter receivers used, and the radio and acoustic frequencies scanned during the search effort. A paper data form logging all critical data is also used by field crews for quality control and as a backup in case of system failure.

All data for sturgeon relocations and search efforts are then uploaded to a secure server located at CERC on a daily basis. As many as 10 crews can be collecting data on any given day, including 2 to 3 crews from the Nebraska Game and Parks Commission. Crews that have access to the CERC network servers upload their daily data across the local network, and remote field crews upload their daily data to a secure File Transfer Protocol (FTP) site. The data from each crew are then archived. The new relocation events and all associated data are incorporated into the larger spatial database.

Sturgeon relocation data are linked (via linked server technology Microsoft in SQL Server™) to the other essential data in the database framework. Relationships have been established between spatial data and data tables in the database by using mutually exclusive individual identifiers, allowing summary reports to be generated by using information from several sources. This linkage allows the spatial data to be maintained in its native shapefile (ESRI, Inc.) format while still being accessed by the database, making it possible to maintain data in a near real-time environment.

A Microsoft Access™ user interface was developed to allow users to easily update or enter data (that is, initial capture data) and to view data and summary reports. The data and reports accessed through the Microsoft Access™ user interface are near real-time. The linkage between the database and spatial data facilitates the creation of several useful textual reports. The detailed movements report also is organized by river segment and individual sturgeon and details the release and each relocation event. This report includes the date, time, and location (river mile), as well as the number of days since the last relocation and the distance traveled during that time. The movements summary report is organized by river segment and individual sturgeon. This report is a summary of the release and relocation events, including release date, release location (RM), number of relocations, apex location (farthest upstream relocation), last location (RM), and date of the last location. The data in these reports are maintained in the database in near real-time because of the linkages with the spatial data collected daily by the field crews (figs. B7 and B8).

The database and spatial data relationships are also used to create spatial products. Maps are created for movements of each individual fish, showing the release location, all relocation events, the last known relocation and lines connecting the relocations to show the upstream and downstream movements. These maps provide information on the movements of each individual fish through space and time. Aggregation maps are created showing the number of relocations per river mile. Because of the linkages between the database and the spatial data collected by the field crews, the data driving these maps are created and maintained in the database in near real-time.

Deployment of the telemetry system and tracking on the Missouri River require specialized and customized tracking vessels (figs. B9 and B10). Tracking vessels are designed to serve as instrumented platforms, capable of searching long distances or monitoring individual fish or locations for long periods of time. Boats are purchased and built in pairs to allow crews to track long distances and exchange trailers if necessary. Boats are either equipped with cabins to allow operation during inclement weather or are open to allow for either tracking or fish capture as required. Boats range in length from 6.5 to 8.0 m. Boats operating in the unchannelized reach are shallow draft and equipped with outboard jets. Each tracking boat is outfitted with ultrasonic and radio telemetry equipment, a ruggedized field computer running ESRI ArcPad™ software (ESRI, Inc.), a submeter GPS, water-quality equipment, and a depth sounder. Boats are required to operate under adverse weather conditions (within agency safety guidelines) and must make accommodations for the operation of sensitive electronic equipment under all conditions.

Extensive Sturgeon Reproduction Study

This work primarily focuses on shovelnose sturgeon, but pallid sturgeon were incorporated when available, albeit in limited numbers. This work attempted to intensively evaluate the reproductive status of gravid female shovelnose sturgeon, instrument each with transmitters and DSTs, track their movements through spawning, and attempt to recover as many as possible to evaluate their reproductive success after the spawning season.

Gravid shovelnose sturgeon were implanted with telemetry devices prior to spawning in early spring. Fish were captured in two hydrologically distinct segments of the Missouri River in 2005 (fig. B11) and 2006 (fig. B12). The lower segment was located on the Lower Missouri River between the Osage River and Grand River (RM 130–250). The upper segment was located between the Platte River in Nebraska and the Big Sioux River in Iowa (RM 595–734). Each river segment was expected to exhibit distinctive differences in availability of habitat and environmental variables prior to and throughout the sturgeon spawning season. The upper segment was considered most likely to be influenced by planned flow releases out of Gavins Point Dam in 2006 (fig. B13). Discharge and temperature relationships among several segments of the Lower Missouri River indicate that a wide range of conditions may exist along the length of the river and within its tributaries at any given time (figs. B14 to B23).

Shovelnose sturgeon were captured by using overnight monofilament gill net sets (6.35-cm mesh, 208 twine, 36.58x1.83 m, 1.27-cm foam core float line and a 22.68-kg lead line) (fig. B24). Past experience with this mesh size resulted in about 50 percent of captured sturgeon larger than the target size of 1 kg (figs. B25 and B26). This mesh size is also effective at sampling adult pallid sturgeon in the Lower Missouri River (figs. B27 to B29). Fish greater than or equal to 1 kg and determined to be female at reproductive stage IV or V based on examination made by using ultrasonic and endoscopic methods (Wildhaber and others, 2005) were selected as candidates for implantation with ultrasonic telemetry transmitters and archival DSTs (Lotek Wireless, Inc., Newmarket, Ontario, Canada). Transmitter and DST weight did not exceed 3 percent of fish body weight to minimize instrumentation-related mortality postrelease (Winter, 1996; Zale and others, 2005). Transmitters in 2005 were ultrasonic only (16 x 65 mm). They had a battery life expectancy of 9–14 months, individual ID recognition, minimum pulse intervals of 3,500 millisecond (ms), and frequency of 77 kHz. In 2006, CARTs (16 x 65 mm) were used. These transmitters had a battery life expectancy of 9–14 months, individual identification number (ID) recognition, minimum pulse intervals of 5,000 ms for any signal (10,000 ms for a given frequency), and frequency of 77 kHz. Archival DSTs (11 x 32 mm) continuously recorded time, temperature, and pressure every 15 minutes. Shovelnose sturgeon were marked with a uniquely numbered external Floytag in the pectoral fin.

Sturgeon were transported to a suitable site along the river for processing and surgery. During the device implantation procedure, all shovelnose sturgeon were photographed and weighed (g), and standard length was recorded (mm) (fig. B30). Gonads were visually inspected through a 3–4 cm abdominal incision to verify reproductive stage. Blood and ovarian tissue was collected to determine readiness to spawn (fig. B31). The transmitter and DST were inserted, and the abdominal incision was closed with a series of simple, interrupted sutures (fig. B32). Tagged shovelnose sturgeon were allowed to recover from the procedure for 30–90 minutes and were released as near as practicable to the initial site of capture.

Individual fish were tracked to estimate the general direction and scale of movement or migratory behavior associated with shovelnose sturgeon spawning. Boat crews following fish recorded daily movements from time of implantation until the end of the summer (figs. B33 and B34). Relocations of fish were precisely documented by using submeter GPS. At each location, we measured depth, temperature, conductivity, dissolved oxygen, pH, turbidity, percent gravel, percent sand, and percent silt. Depth was measured to the nearest 0.1 m by using a Lowrance LCX–15™ electronic depth sounder (Lowrance Electronics, Inc., Tulsa, O.K.). Temperature, conductivity, dissolved oxygen, and pH were measured with an YSI 556 MPS multiparameter water quality instrument (YSI Hydrodata, Ltd., Hertfordshire, UK). Turbidity was measured with a Hach 2100P Portable Turbidimeter (Hach Company, Loveland, Colo.). Substrate was visually estimated from bottom samples collected by using a custom built Hesse Substrate sampler. All data were recorded directly to a GIS by using the customized ESRI ArcPad™ application developed by USGS.

After the summer tracking period, attempts were made to recapture the fish and recover the DSTs. Upon recapture, the reproductive condition of the fish was reassessed to evaluate spawning success, and the DST data were collected.

During the course of this study, physiological measurements were initially made to assess the readiness of the tracked shovelnose sturgeon to spawn and later their degree of spawning success. At time of implantation, oocytes were sampled to calculate polarization index (PI, distance between germinal vesicle and animal pole relative to distance between animal and vegetal poles) and to determine whether germinal vesicle breakdown (GVBD) could be hormonally induced in vitro. Ten oocytes were preserved in 10 percent neutral buffered formalin (NBF) for the PI measurement and another 25 oocytes were placed in ringers solution in a petri dish to which was added progesterone (Sigma-Aldrich Co., St. Louis, Mo.). After 24 hours of incubation at 19°C, oocytes were preserved in 10 percent NBF followed by PI measurement to determine if GVBD had taken place.

Hormone measurements could indicate readiness to spawn and may be useful in interpreting why spawning did not occur. Consequently, a blood sample was collected from the caudal vein by using a heparinized syringe at both implantation and again when the fish were recaptured. Estradiol (E2), 11-ketotestosterone (11-KT), ketotestosterone (KT), and cortisol were measured in plasma by using radioimmunoassay.

Upon recapture, shovelnose sturgeon were humanely euthanized and necropsied. The incision for the transmitter was evaluated externally and internally for healing. The condition of the gonad was grossly observed for indications of spawning, and a gonad sample was preserved in 10 percent NBF for histology.

Pallid sturgeon were included in this study as available. Ten pallid sturgeon were implanted with transmitters and tracked in 2005. None were in reproductive condition. Sixteen additional pallid sturgeon were implanted with transmitters and tracked in 2006. Only two implanted pallid sturgeon, one male and one female of hatchery origin from the lower study segment, were in reproductive condition in 2006 when captured.

Development of Stationary Receiver Network

Stationary monitoring receivers have been shown in other studies to be invaluable for monitoring the rapid, long-range movement of large riverine species and increasing the efficiency of manual tracking activities in large systems. A network of stationary receivers deployed at intervals of 25–50 RM along the length of the Lower Missouri River from Gavins Point Dam to the mouth was determined to be a priority not only for the study of sturgeon but also for the study of all large river species.

Previous studies demonstrated that shovelnose and pallid sturgeon are capable of extensive movements within the Missouri River and associated tributaries. Reproductive and postreproductive movements of shovelnose sturgeon in the Missouri River have exceeded 1,100 km (DeLonay and others, 2007). Effective tracking of long-range seasonal movements in a dynamic river system requires technology that can monitor stretches of river continually to detect fish passage and to increase the efficacy of manual fish-tracking crews. Combining data-logging receivers with cellular modems that provide near real-time data communication capability allows researchers to more efficiently allocate valuable tracking resources among river segments. Rapid data reporting also facilitates collaboration with field crews tasked with mapping habitat or sampling for reproductive products (for example, eggs or larvae). The infrastructure of CSRP provides for a total of 16 stationary data-logging telemetry receiver sites at increments of roughly 50 river miles along the length of the Missouri River from the mouth at St. Louis to Gavins Point Dam. Under SFRM we propose to increase the density of remote datalogging receivers to one every 25 river miles from Gavin's Point Dam to the mouth of the Platte River. Spacing may be modified to monitor the confluence of major tributaries to the Missouri River. Five more stations will be required in addition to those stations proposed under CSRP. Configuration of each stationary receiver will vary depending on the unique conditions within the segment of river monitored. Lotek MAP 600 RT acoustic receivers and Lotek SRX 600 radio receivers have been selected to instrument these sites. Equipment from other telemetry manufacturers may also be added later. Each remotely sited receiver will have communication capabilities to relay data files to a central location daily. The need to process telemetry data and relay results in near real time is critical for the scheduling of coordinated habitat and fisheries sampling activities. The potential exists for investigators to modify their location and monitoring strategies on the basis of relocations of sturgeon or of identified aggregations within their study reach. This equipment was purchased in 2006 and will be installed in 2007.

The first stationary receivers should be sited, installed, calibrated, and tested by March 1, 2007. Deployment of receivers may be adjusted or delayed on the basis of water and winter ice conditions.

Aggregation and Spawning Site Location

This component allows for the implantation of a large number of female and male shovelnose sturgeon with telemetry transmitters and takes advantage of the increased monitoring capability provided by stationary receivers. Previous data indicate that female sturgeon appear to have a characteristic migration pattern (DeLonay and others, 2007). It is unknown how the male pattern compares, and it is unknown for *Scaphirhynchus* species whether spawning occurs in large aggregations at a few discrete locations or in many smaller groups along the length of the river.

In 2006, we were scheduled to implant and track 100–200 additional male and female shovelnose sturgeon in reproductive condition with short-duration telemetry transmitters. All fish were to be captured from the Missouri River above the Platte River in Nebraska (RM 595). Crews were to intensively relocate these as time allowed, but they would rely heavily on the stationary receiver network to document relative location and movement. Fish were to be tracked from March through July. During the spawning period, tracking crews would record locations of fish in an effort to locate aggregations of sturgeon and to identify spawning locations. Increased numbers of sturgeon implanted with transmitters would have provided a means to validate the selection criteria and locations preselected for monitoring activities conducted as part of the site-specific evaluations detailed later in this report (chap. E). The potential exists for investigators working under either this project or SRFM to modify their sampling strategies on the basis of relocations of sturgeon or identified aggregations within their study reach. Selected fish were to be targeted for recapture prior to, during, and immediately after suspected spawning events to validate the association between observed movement patterns and spawning. The current assumption is that sturgeon are spawning at the farthest upstream apex of their spawning migration. This observed pattern needs to be minimally verified by the recapture of tagged adults.

Capture and implantation of the shovelnose sturgeon for this component should begin by February 15 and conclude prior to March 15 to take advantage of the start of navigation season. Shovelnose sturgeon may be implanted as late as May 1 of the study year depending on the river reach and funds availability. Unfortunately the transmitters for this component did not arrive in time for implantation in 2006, and these activities were not completed. We anticipate initiating this work in 2007.

Intensive Pallid Sturgeon Reproduction Study

In 2006, the USGS and NGPC proposed to capture and implant up to 10 additional pallid sturgeon with telemetry transmitters and DSTs for intensive tracking efforts. Equipment did not arrive in time for implantation in 2006, and all pallid sturgeon in reproductive condition were transferred into the hatchery system for the propagation efforts. This component is scheduled to begin in 2007 if pallid sturgeon can be captured. If no pallid sturgeon are captured in 2007, intensive tracking and DIDSON™ imaging may be completed by using shovelnose sturgeon.

Intensive tracking efforts were to be limited to the reach from Gavins Point Dam to the Platte River reach. Capture crews attempted to locate and implant pallid sturgeon within the study reach, but basin priorities dictated that all adult pallid sturgeon be transported to Gavins Point National Fish Hatchery for inclusion in propagation activities.

A tiered section criterion for pallid sturgeon was developed for this study on the basis of size, gender and reproductive status. All pallid sturgeon selected for implantation should be more than 1.2 kg in weight. The first five pallid sturgeon heavier than 1.2 kg were to be implanted with transmitters. Any fish subsequently selected for implantation must be reproductively mature and heavier than 2.2 kg. Preference was to be given for individuals in reproductive stage IV or greater (Wildhaber and others, 2007) . No more than two of the individuals selected were to be females in reproductive condition. All pallid sturgeon considered for implantation were to undergo a reproductive assessment made by using minimally non-invasive methods developed at USGS to determine gender and reproductive stage (Wildhaber and others, 2005). Implanted sturgeon were to be released at the point of capture and tracked. Initially each tagged sturgeon was to be contacted two to three times per week to determine movement, aggregation, and spawning behavior. The targeted frequency of contacts was scheduled to increase with water temperature; between 15°C and 23°C, pallid sturgeon are targeted for daily contact. Resources are prioritized and allocated on the basis of species and reproductive stage. Reproductively mature pallid sturgeon are a priority, with the greatest emphasis given to females in reproductive condition. Reproductive individuals are to be targeted for continuous tracking on the basis of temperature (for example, 18–22°C) and behavior (changes in rate or pattern). Two boats were equipped by NGPC for intensive mobile tracking of pallid sturgeon within this reach. Field crews track tagged fish on an individual and area-weighted basis. Tagged fish are targeted for contact one to three times per week, with intensity increasing on the basis of reproductive status, movement, and proximity to the spawning season. Timeframe for intensive pallid sturgeon capture and tracking efforts is from "ice free" river conditions (February to March) to August 31. Measurements of water conditions (for example, temperature, conductivity, dissolved oxygen, and turbidity) and habitat characteristics (for example, depth and substrate) are recorded at each location to qualitatively and quantitatively describe habitat used by sturgeon during prespawn and spawning periods. At the end of the tracking period efforts, are made to recapture implanted pallid sturgeon to evaluate reproductive condition and spawning success by using methods developed at USGS with shovelnose sturgeon.

In addition to telemetry tracking efforts, attempts were to be made to verify and validate spawning behavior by using an acoustic camera. Through coordination and collaboration with NGPC this component is to explore the ability of the DIDSON™ acoustic camera to capture and validate spawning acts of sturgeon under Missouri River conditions. Locations for DIDSON™ acoustic camera deployment are identified through daily coordination with collaborating telemetry groups. Taking care not to influence fish behavior, crews document the behavior of pallid and/or shovelnose sturgeon that have been implanted with telemetry transmitters by using a DIDSON™ acoustic camera. A NGPC boat has been designed to deploy the DIDSON™ and operate under adverse weather conditions (safety permitting). This boat is equipped with tracking equipment to maintain contact with fish implanted with transmitters, carries a two-person crew, and is equipped to make observations for extended periods of time. Protocols for DIDSON™ are currently under development as part of the project. NPGC plans to deploy a two-person DIDSON™ crew from March 1, 2007, to July 31, 2007, to develop methods and protocols by making observations at various times (day, crepuscule, night), under various conditions, and of different fish. A more intensive observation mode is triggered during the most likely spawning period as defined by biologists, fish behavior, and water temperature. During this intensive phase the crew attempts to remain in continuous contact with a selected fish. Identified spawning locations are prioritized for characterization, mapping, and possible additional sampling for gravid adults, eggs, or larvae. Crews may selectively recapture individuals or sample identified locations to verify and validate suspected behavioral patterns.

Results and Discussion

Telemetry System Development

The telemetry system sourced and selected for this project is currently in operation on 10 research vessels (7 USGS vessels, 3 NGPC vessels) on the Lower Missouri River. In 2007 these vessels will be assisting with data collection in up to four additional telemetry projects. Other species studied include flathead catfish (*Pylodictis olivaris*), blue catfish (*Ictalurus furcatus*), blue sucker (*Cycleptus elongatus*), and paddlefish (*Polyodon spatula*). Agencies collaborating with USGS and NGPC include the University of Missouri, the Missouri Department of Conservation, and the University of Nebraska.

The data collection and data reporting database system currently provides periodic updates and reports to all partners and collaborators. The database provides for a direct near real-time link for the USACE to assess sturgeon location data.

Extensive Sturgeon Reproduction Study

During 2005, telemetry implantation of shovelnose sturgeon in the lower study area began on March 24 and was completed by April 5 (table B1). Capture and implantation of shovelnose sturgeon in the upper segment began on April 19 and was completed on April 30 (table B1). No pallid sturgeon were captured in 2005 during shovelnose sturgeon implantation. Pallid sturgeon were added to the study opportunistically through the auspices of the population assessment program and the propagation program (table B2). None of these additional pallid sturgeon were in reproductive condition when implanted.

During 2006, implantation of shovelnose sturgeon and pallid sturgeon in the lower study segment began on April 12 and was completed by April 14 (table B3). Two adult pallid sturgeon of hatchery origin (one male and one female) were captured, implanted, and released in the lower study segment. Later in the spring, three additional wild pallid sturgeon were transported from the hatchery, implanted, and released at their original point of capture after spending several months at Gavins Point National Fish Hatchery as candidates for the propagation program. Capture and implantation of shovelnose sturgeon in the upper segment began on April 19 and was completed by April 24 (table B3). All wild pallid sturgeon were transferred to the propagation program for use as potential broodstock. Five pallid sturgeon in reproductive condition were captured by USGS between the Gavins Point Dam and the Platte River, Nebr., during shovelnose collection efforts (two females and three males). These fish were transported to Gavins Point National Fish Hatchery. At the hatchery, pallid sturgeon collected and transferred to the facility by all basin programs were examined for reproductive readiness. If the fish were not ready, or if the fish later failed to spawn they were released for possible use in the telemetry study. Five wild pallid sturgeon were transported from the hatchery in May, implanted with CART and DSTs, and released in the upper segment in May. Six additional pallid sturgeon were implanted and released in the upper segment in October after having been released by the propagation program. In 2006, only the two pallid sturgeon of hatchery origin implanted in the lower segment were in reproductive condition. These fish were implanted with transmitters and were tracked in the river during the spawning period (table B4).

The number of pallid sturgeon encountered in 2006 was an unexpected result of sampling efforts (fig. B29). During the last four nights of sampling, nine large pallid sturgeon (>800 mm, >2 kg) were captured. Four pallid sturgeon were captured in one night (16 nets). A small subadult pallid sturgeon of hatchery origin was captured, but the remaining fish were believed to be wild fish. Five of these sturgeon were transported to the Gavins Point National Fish Hatchery. All pallid sturgeon transported to the hatchery were in reproductive condition. Most pallid sturgeon were captured at or near channel crossovers. Most were captured in the downstream third of the net. One pallid sturgeon was captured off a chevron structure. Pallid sturgeon captures occurred above the mouth of the Platte River to just upstream of Blair, Nebr. All captured pallid sturgeon appeared to be in good condition.

The net mesh size was selected to maximize the catch rate of shovelnose sturgeon greater than or equal to 1 kg in weight while minimizing the catch of smaller sturgeon or any other riverine species. Data from past shovelnose sturgeon sampling efforts indicated that a mesh size between 5.1 and 6.4 cm (bar) was appropriate. It was thought that fewer total numbers of fish per set would reduce the likelihood that nets would overfish (crowding and packing large numbers of fish in a small volume). Fewer but more desirable fish per set would therefore reduce stress on captured fish. Monofilament gill nets were selected because it was hypothesized that (1) monofilament nets would retain less debris and would fish cleaner and longer, resulting in a higher actualized effort per net set, with less stress to entangled fish; (2) monofilament material is slightly less effective at attaching to the surface of sharp-skinned sturgeon, would therefore be slightly more size selective, and would result in captures with a reduced degree of entanglement (that is, less gill impingement, strangulation, or fin clamping that results in net-induced stress or mortality); and (3) properly selected monofilament strand diameter would be less likely to abrade the skin of fish than a corded or twisted multifilament net and would thus result in less net trauma.

Capture and implantation crews deployed 16–18 gill net sets each night of study in 2006. Nets were set as late as possible in the evening and retrieved as early as possible the next morning. Set locations were based upon previous sampling experience and past telemetry data. One possible explanation for the success capturing pallid sturgeon may have been telemetry tracking experience of the capture crews. Crews targeted structures at channel crossovers (above and below) and selected inside-bend structures (such as wing dikes and chevrons). High-elevation structures with terminal points above the water were preferred. Capture crews selected steep velocity gradients downstream of flow-control structures with a minimum of 3.5 m depth and minimal turbulence. Nets were anchored to the structures with extension lines ranging from 15 to 30 m in length. Water temperatures ranged from 10.0°C to 15.5°C.

No sturgeon mortalities were observed, with the incidence of gill impingement, strangulation, or excessive entanglement being minimal or nonexistent. Sturgeon captured in the nets appeared to be in excellent condition. By-catch was low in our nets, and survival of by-catch was good, though sturgeon are more net tolerant than most riverine species. The primary species in the by-catch was the blue sucker. Monofilament nets entrained less debris, and much less time was spent cleaning nets than during previous efforts. Based upon this selected application of extended gill net sets, it appears that broodstock collection efforts at temperatures up to 15.5°C could be accommodated with minimal increased trauma and risk. Also, capture of adult pallid sturgeon above the Platte River, Nebr. during the prespawn period indicates that the species is present and capable of responding to management actions occurring at or below Gavins Point Dam.

Tracking of fish began immediately after implantation in 2005 and continued through mid-August (fig. B33). Crews tracked fish to document movement and habitat use prior to, during, and after spawning. In 2005 in the lower segment, 47 of 50 individuals were relocated at least once (1–10 locations, mean = 4.9) following implantation. Tracking effort in the lower segment utilized two boats each with a two person crew, tracking on a near daily basis with the goal of locating each fish at least once per week. In the upper segment, 42 of 50 individuals were relocated (1–17 locations, mean = 8.1) following implantation. Relocated shovelnose sturgeon in the lower segment moved an average of 103 RM (166 river kilometer; Rkm) upstream and 35 RM (57 Rkm) downstream. Shovelnose sturgeon from the upper segment moved an average of 35 RM (57 Rkm) upstream and 58 RM (94 Rkm) downstream (fig. B35). One fish was captured by a recreational angler as it moved upstream prior to spawning. Beginning in August 2005, crews began to recover tagged fish. Tagged fish were recovered by drifting trammel nets over the fish's location (recapture success was highly dependent upon flow conditions and fish location). Tracking and recovery efforts continued through December 2005. Of the 100 fish implanted, 20 were recovered. Of those, 15 (75 percent) had spawned successfully (table B5). A manufacturer's defect in the transmitters resulted in the premature battery failure of all tags implanted in 2005. This failure significantly impaired our ability to track and recover sturgeon after the spawning period. All pallid sturgeon transmitters were affected as well.

Tracking crews in 2006 tracked over 13,000 RM (fig. B34), relocating 39 of 50 female shovelnose sturgeon and all pallid sturgeon in the lower segment. In the upper segment, 48 of 50 female shovelnose sturgeon and all pallid sturgeon were relocated. For the 87 shovelnose sturgeon that were relocated, the number of relocations ranged from 1 to 27 with a mean number of relocations of 8.5. The number of relocations for the 10 pallid sturgeon ranged from 1 to 28 with a mean number of 13.3 relocations. Relocated shovelnose sturgeon moved approximately 36.6 RM (58.9 Rkm) upstream and 78.6 RM (126.5 Rkm) downstream. Relocated pallid sturgeon moved an average of 8.9 river miles (13.3 km) upstream and 52.3 RM (84.2 Rkm) downstream (fig. B36). To date, 22 shovelnose sturgeon have been recaptured, 5 from the lower segment and 17 from the upper segment. Three of five (60 percent) shovelnose sturgeon recaptured in the lower segment spawned, while 15 of 17 (88 percent) shovelnose sturgeon from the upper segment spawned (table B6).

Observations from both years indicate that shovelnose sturgeon females that spawn typically move upstream after implantation, stop, and then return downstream after some variable period (for example, figs. B37 to B48). We hypothesize that spawning occurs near the apex, or uppermost point, of the spawning migration. The ability to determine where the apex occurs through manual tracking alone is difficult. A box plot can be used to estimate the confidence boundaries around a particular apex location for each sturgeon tracked (for example, figs. B49 to B60). To determine apex locations with a satisfactory degree of confidence may require daily relocations. The addition of DST data from individual recaptured fish allows additional insight into what the fish's behavior may have been between manual tracking observations (for example, figs. B61 to B72). Large and rapid changes in depth recorded by the DST often occur during periods of rapid movement. Sudden changes in the pattern of depths used over time appear to occur somewhere near the apex of the upstream migration. Female sturgeon that spawn often show a sudden and dramatic change in patterns of depth use, which may be related to spawning (for example, figs. B73 and B74). Sturgeon determined to be non-spawners generally do not exhibit this characteristic movement pattern (for example, B75 to B76). Spawning movements of female shovelnose sturgeon tend to follow a predictable pattern and that females that spawn move upstream, spawning near the apex of their migratory pattern; however, the timing and extent of downstream movement after spawning by shovelnose sturgeon is variable.

Plotting the probable locations of each migration apex along the length of the river results in a scattered pattern with few aggregations. Even though the number of tagged fish was small, on the basis of the pattern of observed movement it seems likely that shovelnose sturgeon spawn at multiple locations within each river segment. Spawning locations of shovelnose sturgeon in the heavily modified Lower Missouri River may be broadly distributed in space. On the basis of movement and recapture data, it seems likely that shovelnose sturgeon spawning occurs over a protracted period and a broad temperature range within our study segments as well.

Evaluations of recaptured fish that had been implanted revealed that female sturgeon, almost without exception, develop moderate to extensive adhesions in response to the surgical incision (fig. B77). Adhesions typically only involve the one ovary but may in some instances involve both ovaries, the gut, and other internal organs, which may be a concern for fish that undergo surgical biopsies in the propagation program and among wild populations of sturgeon where commercial fishers frequently perform invasive egg checks.

The one female pallid sturgeon in reproductive condition lost its transmitter, while the one ripe male pallid sturgeon moved downstream initially after implantation before holding within a three kilometer reach of river for most of the spawning season (figs. B78 and B79). In contrast to the implanted shovelnose sturgeon, most pallid sturgeon were not in reproductive condition and did not exhibit predictable patterns of movement similar to shovelnose sturgeon (for example, figs. B80 to B83).

Additional work is needed to validate observed spawning patterns, to better define actual spawning locations, and to determine whether pallid sturgeon exhibit similar patterns of behavior and habitat use. To accomplish this goal, additional numbers of sturgeon must be implanted, the spatial and temporal resolution of manual observations must be increased, and pallid sturgeon in reproductive condition should be included in the study if basin priorities permit.

Data from 2005 and 2006 are being tabulated and proofed for analysis. The DST data will be analyzed by using a hierarchical Bayesian Markov switching model to predict spawning behavior and success of sturgeon. The model will analyze patterns of depth-use data to evaluate changes in state reflective of behavioral changes associated with spawning events. We will evaluate resource selection of gravid shovelnose sturgeon and nonreproductive pallid sturgeon during the breeding season by using discrete choice modeling within an information-theoretic framework. Discrete choice models calculate the probability of an individual selecting a location as a function of the resource characteristics of that location and all other available locations (Cooper and Millspaugh, 1999). An advantage of using the discrete choice model is that the researcher can define availability separately for each recorded location, which makes it well suited for studies in which characteristics of resources may change over time (for example, depth and velocity). The information theoretic approach evaluates support for an a priori set of user-specified candidate models that contain effects (parameters) related to various hypotheses about the selection of resources (Anderson and Burnham, 2002). An advantage is that simultaneous inferences can be made from multiple sets of competing hypotheses about sturgeon resource selection (for example, depth vs. velocity vs. depth and velocity). For example, we do not understand how and to what degree, if any, resources such as depth, velocity, and substrate drive the selection process of sturgeon during spawning migration, nor do we understand the distances at which sturgeon gather information about those resources when making resource choices. Therefore, we would develop and evaluate candidate models that contain various effects related to those resources at various distances.

Development of Stationary Receiver Network

The receivers and associated housing and power systems were purchased in 2006. Additional work remains to be completed on final installation configurations and the setup and testing of remote communication protocols. Initial attempts at remote communication with all units were successful; however, difficulties with the selected cellular services provided have resulted in delays and reconfigurations of the modem systems. A manufacturer's representative is scheduled to complete a site visit in late January 2007 to assist in the completion of remote setup procedures. Final deployment will be dependent upon water conditions, ice, and agency funding priorities.

Aggregation and Spawning Site Location

The transmitters for this component did not arrive in time for implantation in 2006, and these activities were not completed. We anticipate initiating this work in 2007. The increased number of tagged fish in combination with closer coordination with intensive tracking crews, DIDSON™ crews, and egg and larval crews would result in increased benefits for all related studies.

Intensive Pallid Sturgeon Reproduction Study

Equipment did not arrive in time for implantation in 2006, and all pallid sturgeon in reproductive condition were transferred into the hatchery system for the propagation efforts. This component is scheduled to begin in 2007 if pallid sturgeon can be captured. Crews scheduled by NPGC for this component trained with USGS crews on the use of telemetry systems and assisted in the location of tagged pallid sturgeon and shovelnose sturgeon implanted as part of the extensive sturgeon reproductive study. The NGPC continues to work toward refining procedures and deployment techniques for the application of DIDSON technology to Missouri River applications. The NGPC will provide a report on these activities under separate cover if progress warrants.

Acknowledgments

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Figures and Tables

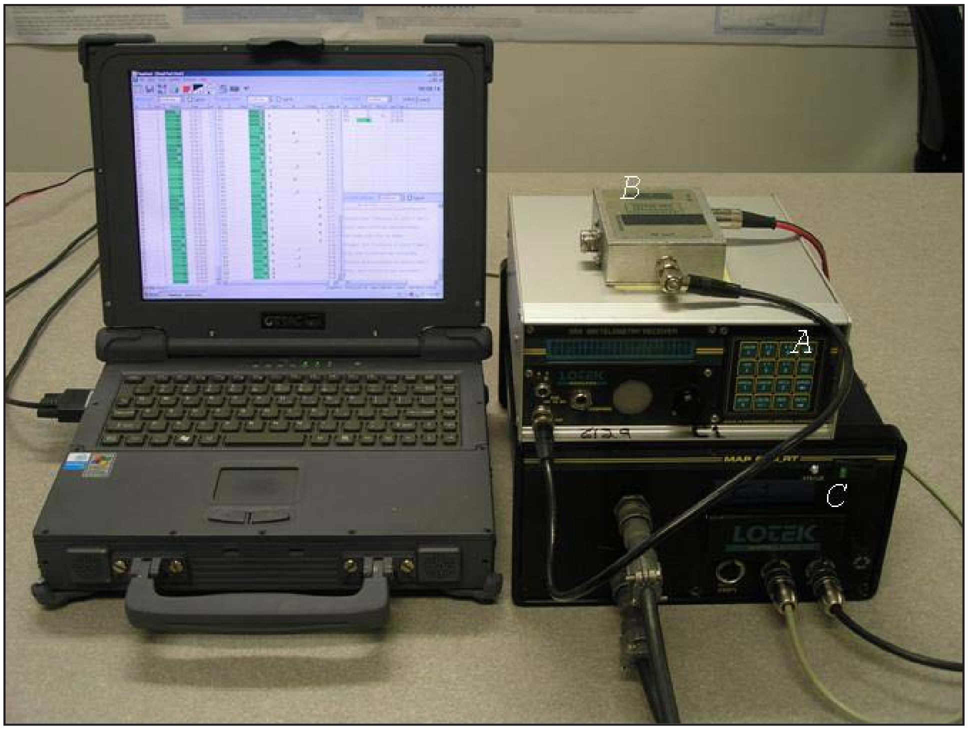


Figure B1. Each tracking vessel typically carries (*A)* a Lotek SRX 600 radio receiver (Lotek Wireless Inc., Newmarket, Ontario, Canada) equipped with (*B*) an acoustic upconverter to detect both radio and ultrasonic signals and (*C*) a dual port Lotek MAP 600 RT digital ultrasonic receiver. The Lotek MAP 600 RT receiver interface runs on a ruggedized field computer.

Figure B2. Lotek (Lotek Wireless Inc., Newmarket, Ontario, Canada) combined acoustic/radio transmitting (CART) tag implanted in shovelnose sturgeon in 2006 (*A*) and data storage tag (DST) implanted in all sturgeon in 2005 and 2006 (*B*). Transmitters implanted in 2005 were acoustic-only tags of similar size but lacking the external antenna.

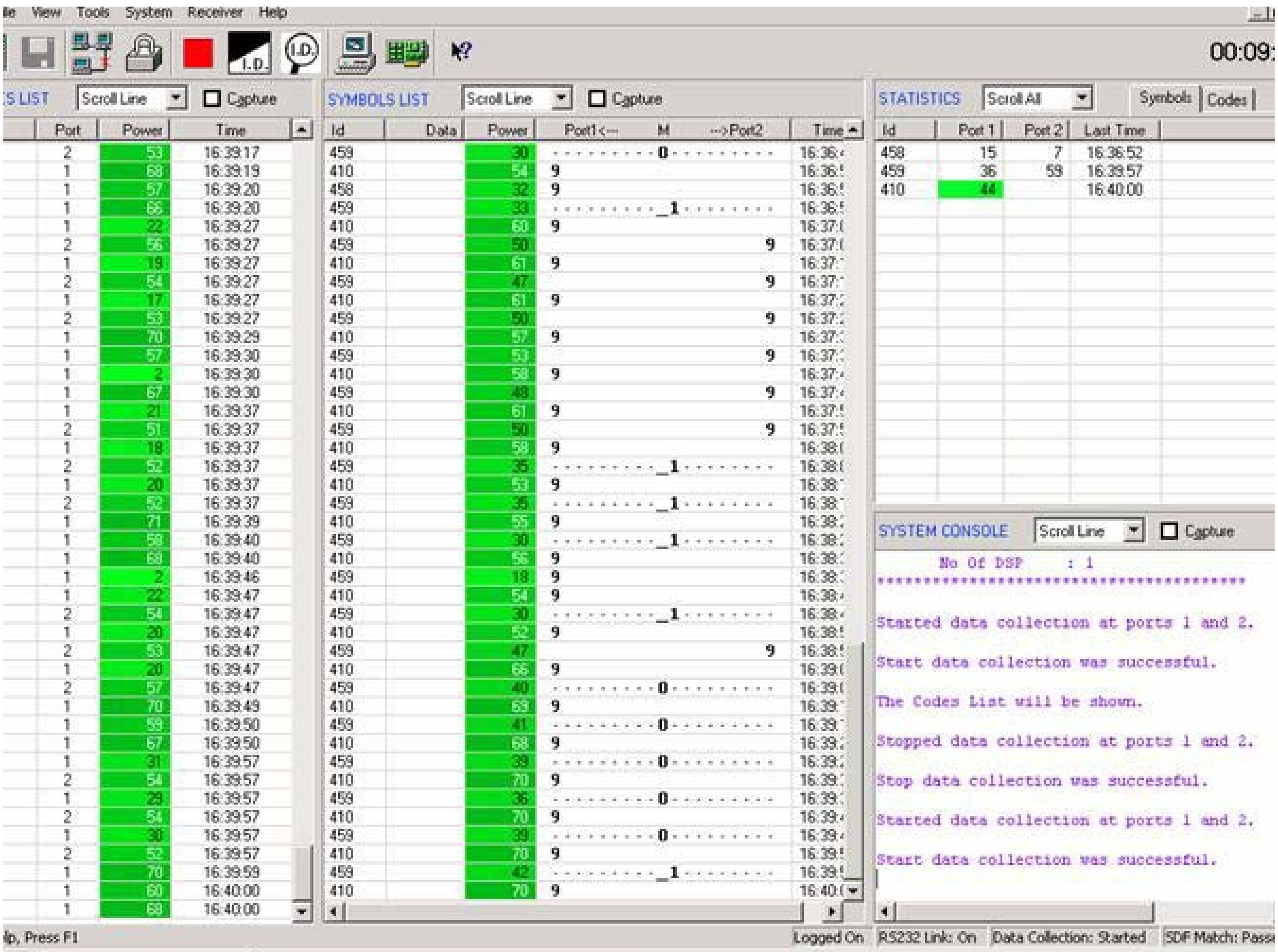


Figure B3. Computer screen image of Lotek MapHost software (Lotek Wireless Inc., Newmarket, Ontario, Canada) showing the simultaneous detection and identification of three transmitters in real-time. Transmitter identity, detection time, signal strength, and relative direction are reported to the operator continually. MapHost software acts both as the control interface for the MAP 600 RT receiver and as the data display.

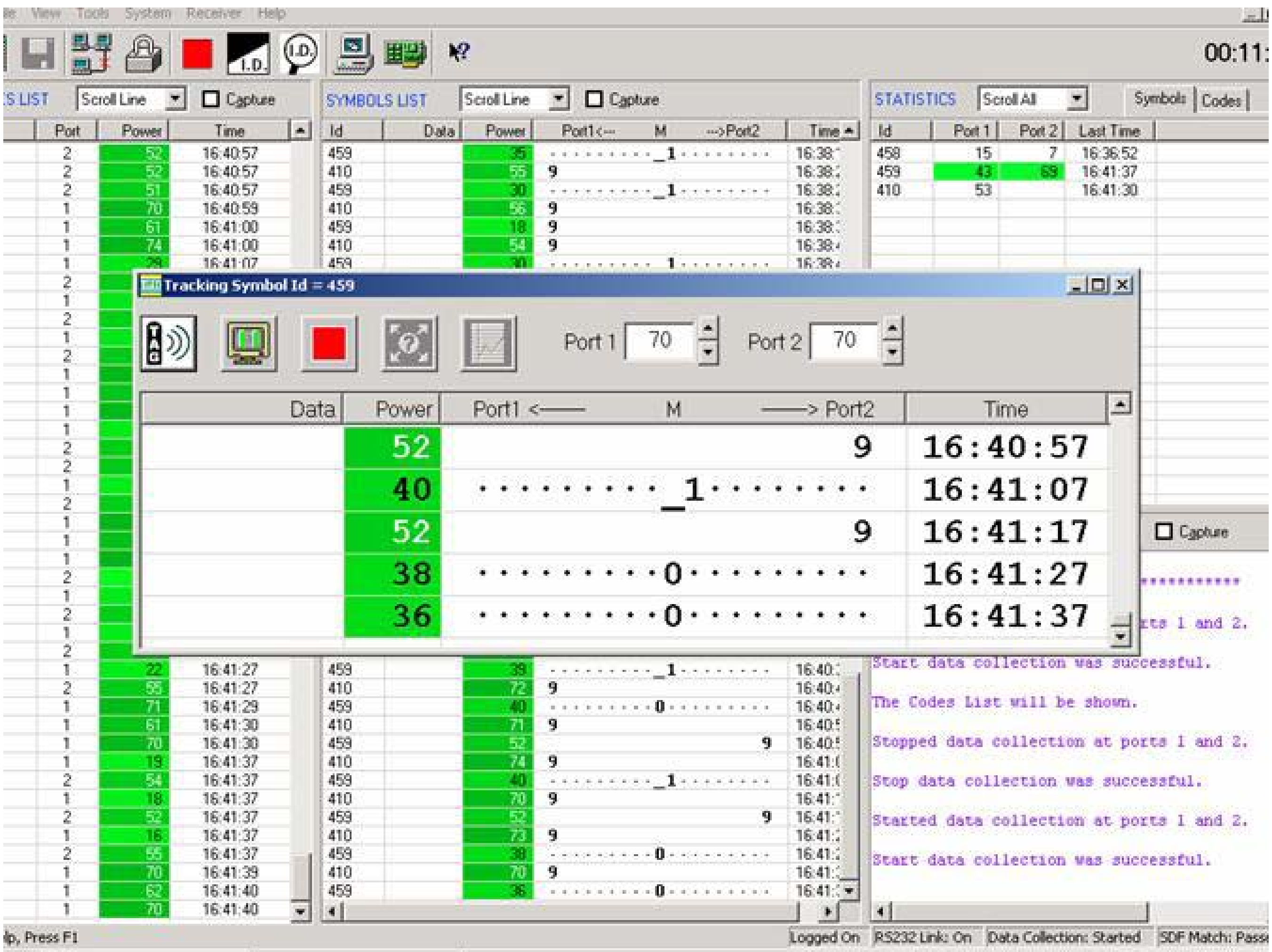


Figure B4. Computer screen image of Lotek MapHost software (Lotek Wireless Inc., Newmarket, Ontario, Canada) during the simultaneous detection three transmitters. The inset window allows the operator to isolate an individual transmitter for tracking regardless of the number of transmitters detected.

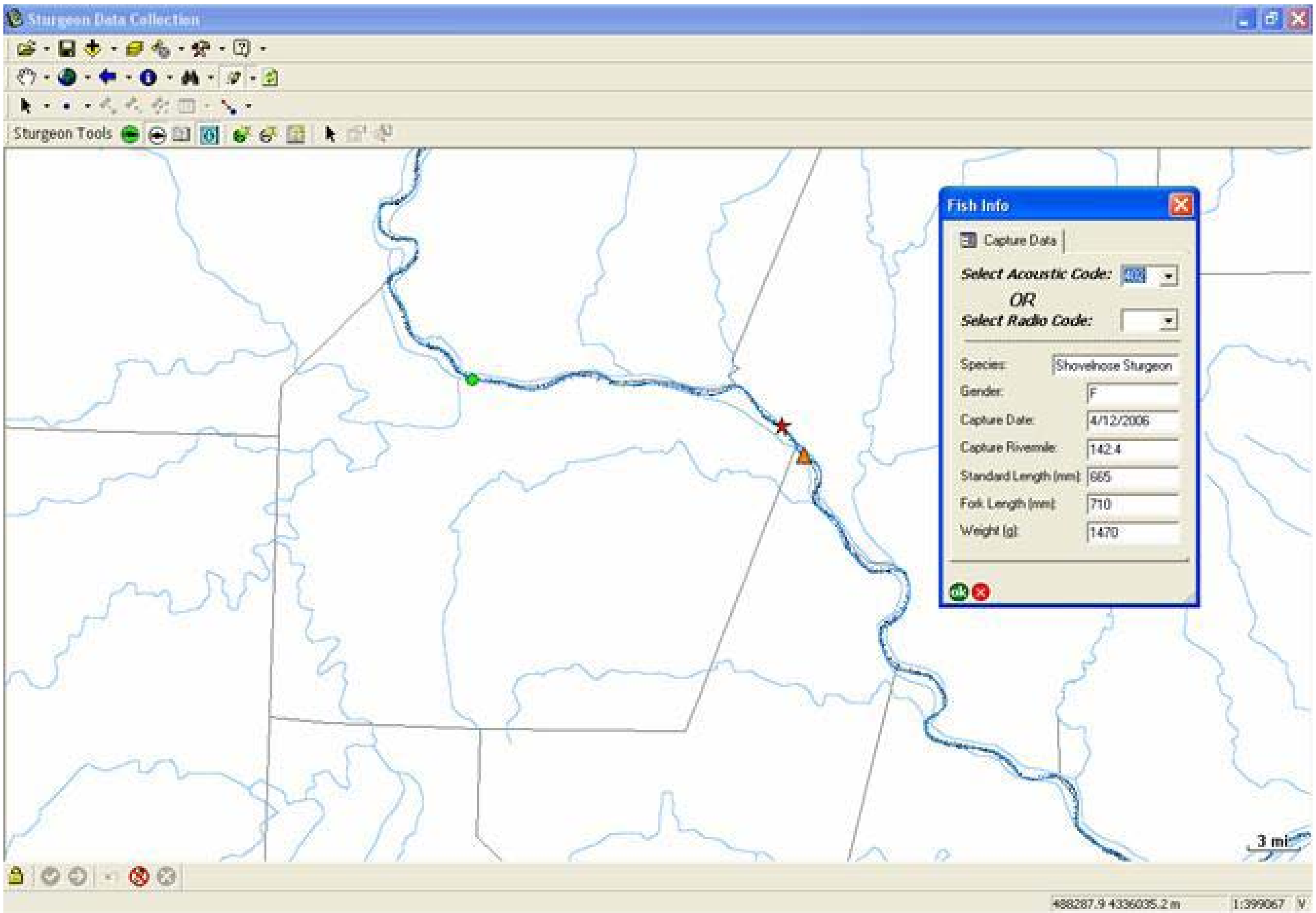


Figure B5. The custom ArcPad™ (ESRI, Inc., Redlands, Calif.) application interface displays ancillary data to aid the users during data collection. Red star indicates sturgeon relocation sites.

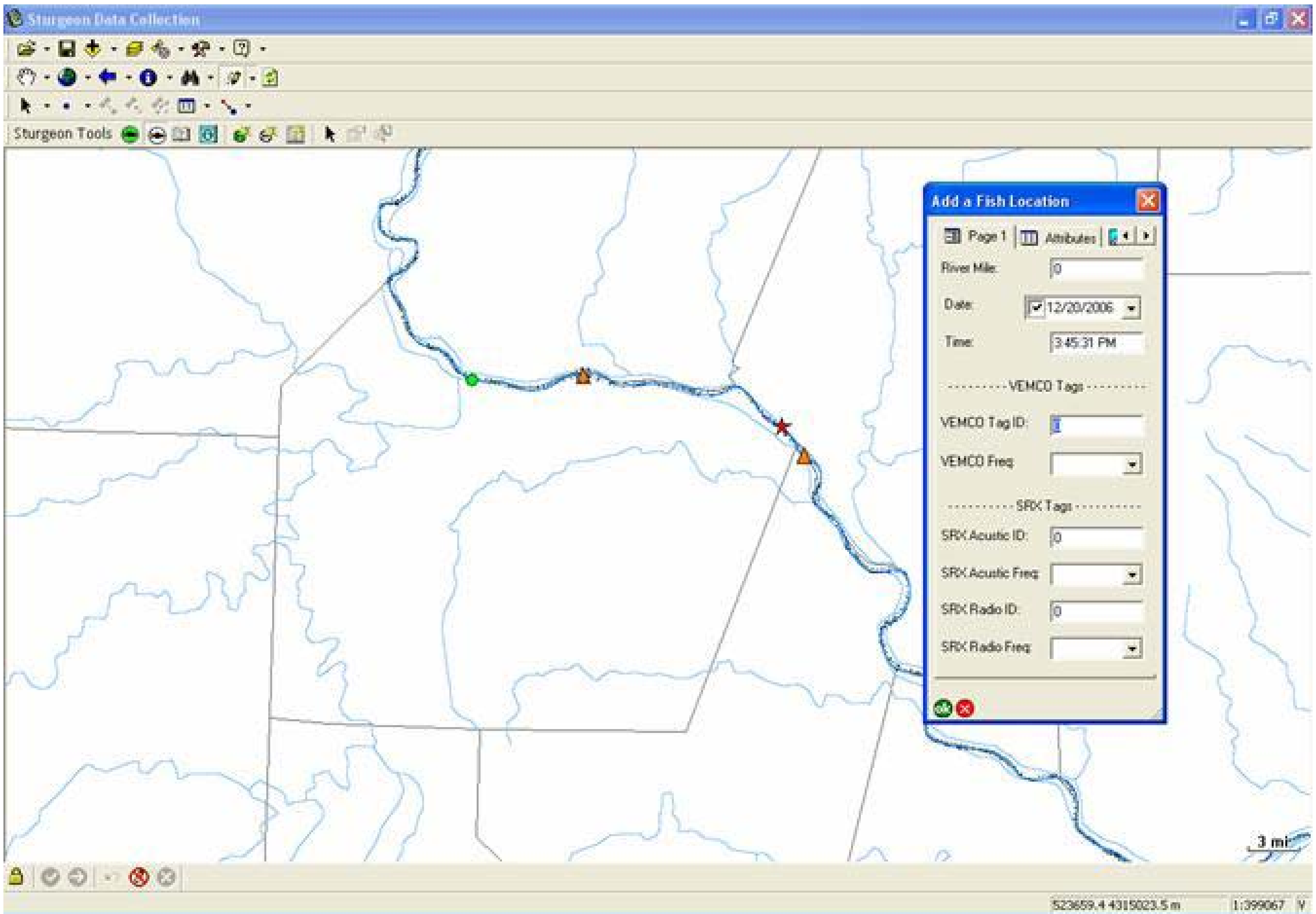


Figure B6. Custom data entry forms in the ArcPad™ (ESRI, Inc., Redlands, Calif.) application streamline and validate data collection. Red star indicates sturgeon relocation sites.

Detailed Summary of Sturgeon Movements

Origin: Lower Segment

Species **Pallid Sturgeon**

FISH ID: *PLS06-001* ***Acoustic Code:*** *522* ***Sex:*** *M*

Date	*Time*	*Temperature*	*River Mile*	*NDays*	*Distance*
4/14/2006 *		18.7	199.6		
5/1/2006	10:33:56 AM	16.3	177.2	17	-22.4
5/2/2006	5:43:39 PM	17.2	177.6	1	0.4
5/5/2006	1:05:54 PM	16.6	178.5	3	0.9
5/9/2006	2:45:00 PM	18.1	177.2	4	-1.3
5/13/2006	9:58:57 AM	16.8	175.1	4	-2.1
5/19/2006	12:57:18 PM	19.9	175.1	6	0
5/21/2006	10:29:50 AM	20.6	171.3	2	-3.8
5/23/2006	11:13:53 AM	20.8	168.5	2	-2.8
5/26/2006	9:41:36 AM	23.9	163.6	3	-4.9
6/2/2006	12:40:23 PM	24.9	152.7	7	-10.9
6/6/2006	11:18:58 AM	26.2	137.3	4	-15.4
6/14/2006	1:24:27 PM	26.1	125.1	8	-12.2

Figure B7. Example of detailed reports available for individual fish produced in a near real time.

Sturgeon Movements Summary

Species **Pallid Sturgeon**

Fish ID: *PLS06-001* ***Acoustic Code:*** *522* ***Sex:*** *M*

Release Date	Release RM	Relocations	Max RM	Last Located	LastRM
4/14/2006	199.6	12	178.5	6/14/2006	125.1

Fish ID: *PLS06-003* ***Acoustic Code:*** *527* ***Sex:*** *F*

Release Date	Release RM	Relocations	Max RM	Last Located	LastRM
5/3/2006	330.2	8	331.9	6/12/2006	331.6

Fish ID: *PLS06-004* ***Acoustic Code:*** *529* ***Sex:*** *F*

Release Date	Release RM	Relocations	Max RM	Last Located	LastRM
5/3/2006	330.2	8	331.1	6/12/2006	328.2

Fish ID: *PLS06-005* ***Acoustic Code:*** *528* ***Sex:*** *M*

Release Date	Release RM	Relocations	Max RM	Last Located	LastRM
5/3/2006	337	8	345.2	6/12/2006	346.2

Fish ID: *PLS06-006* ***Acoustic Code:*** *526* ***Sex:*** *M*

Release Date	Release RM	Relocations	Max RM	Last Located	LastRM
5/3/2006	583.5	10	584.2	6/14/2006	548.1

Figure B8. Example of summary reports that quickly characterize the status of individual fish.

Figure B9. Typical telemetry research vessels designed for use in the lower study segment, including the channelized Lower Missouri River and the Middle and Lower Mississippi River.

Figure B10. Typical research telemetry vessel designed for use in the upper study segment, including the Missouri National Recreational River reach.

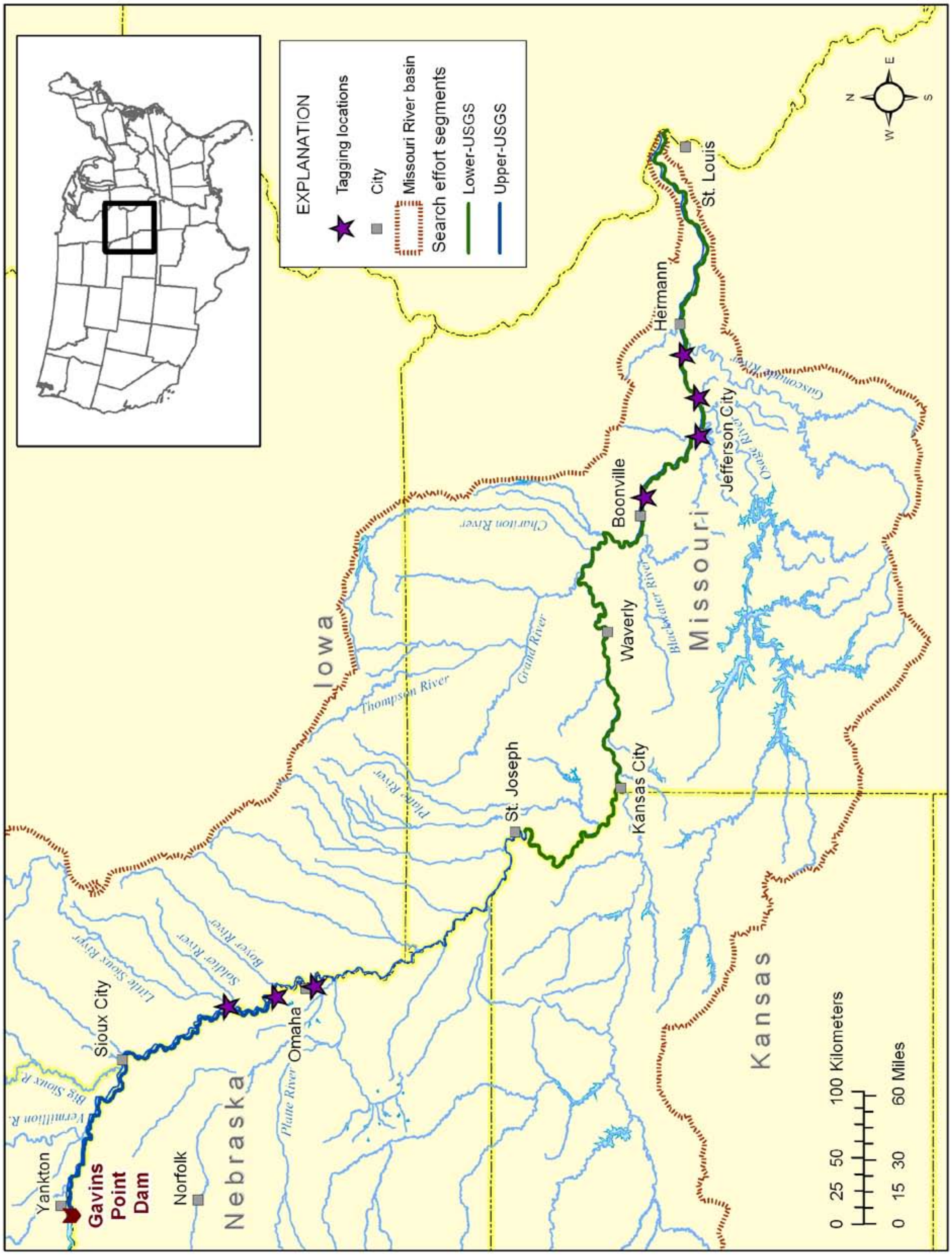


Figure B11. Pallid sturgeon and shovelnose sturgeon tagging locations for 2005 within two geologically and hydrologically distinct segments of the Lower Missouri River.

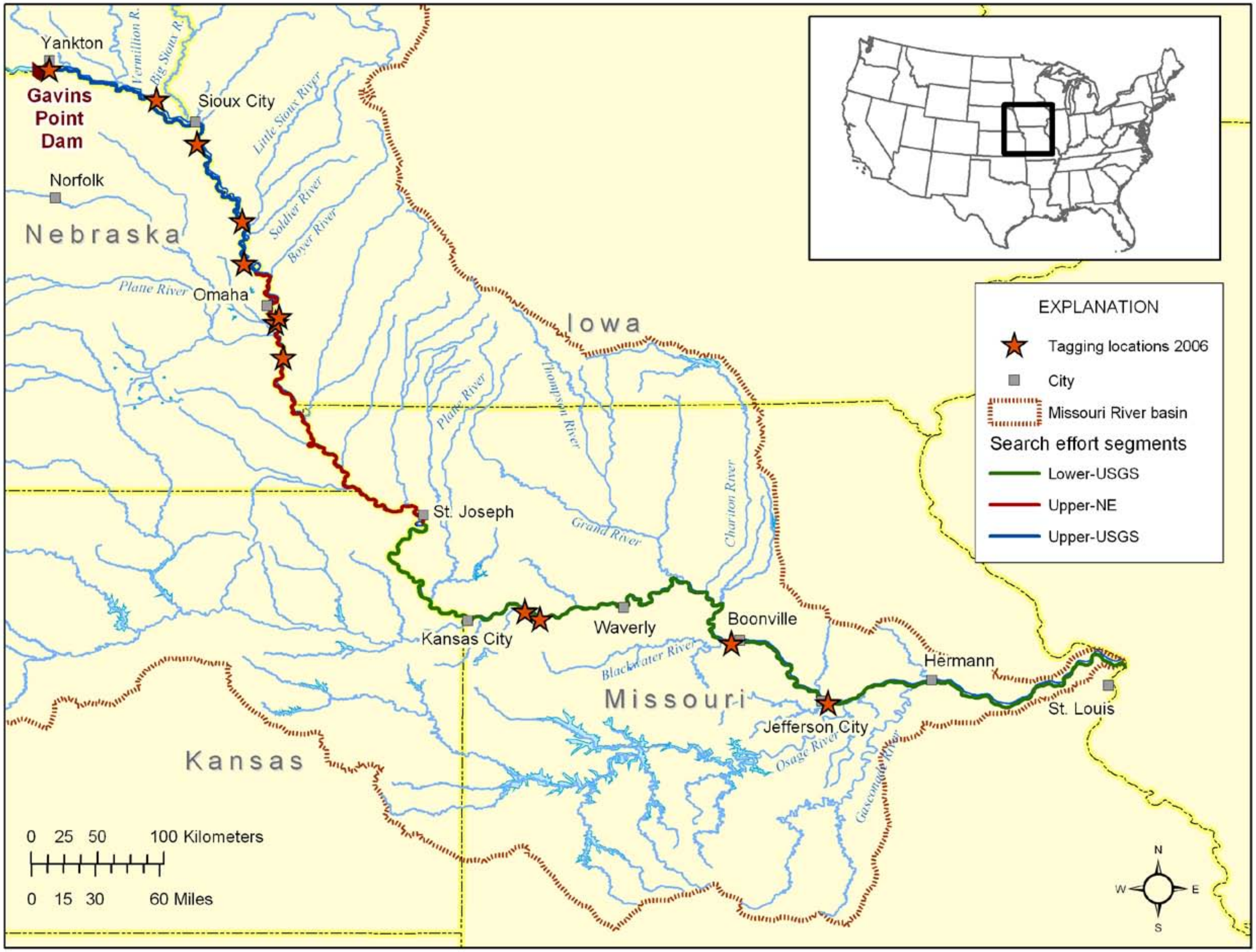


Figure B12. Pallid sturgeon and shovelnose sturgeon tagging locations for 2006 within two geologically and hydrologically distinct segments of the Lower Missouri River.

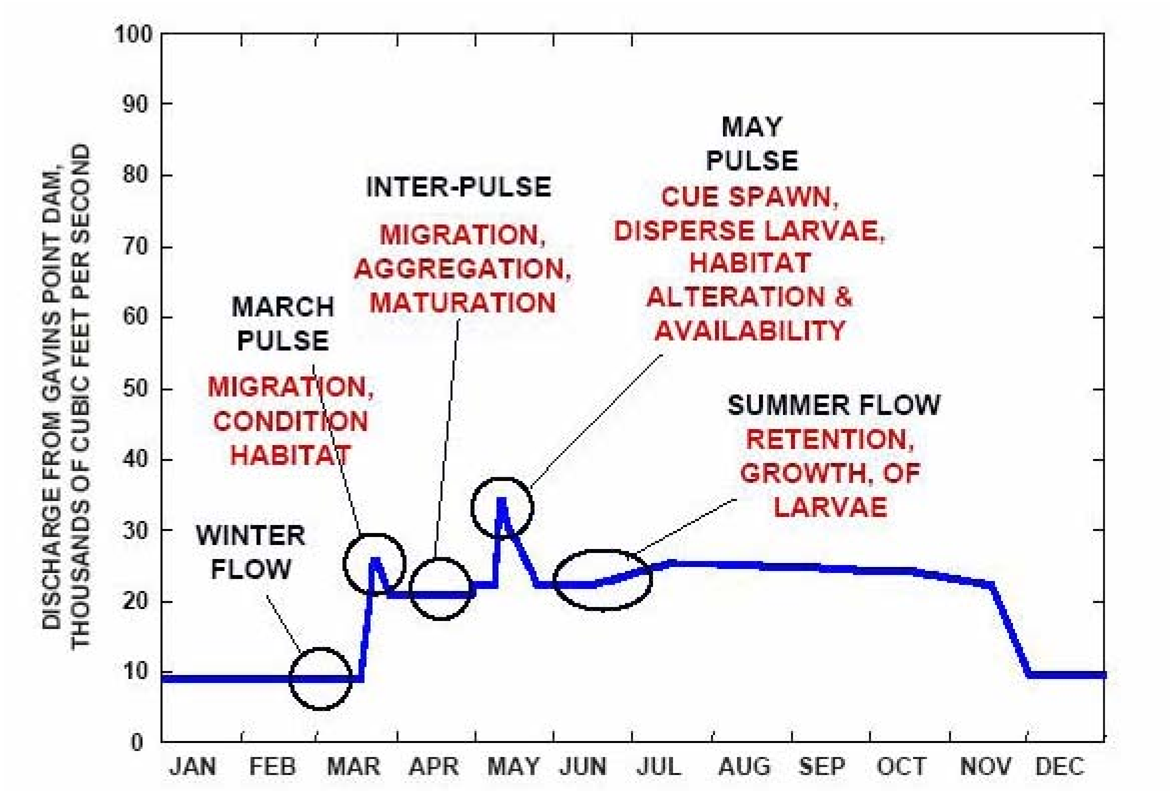


Figure B13. Planned release hydrograph for Gavins Point Dam, assuming median hydrologic conditions in the Missouri River basin, during fiscal year 2006 and 2007 if storage levels are adequate (U.S. Army Corps of Engineers, 2006). Text indicates the hypothesized functions of spring flow pulses as they may relate to reproduction of the pallid sturgeon.

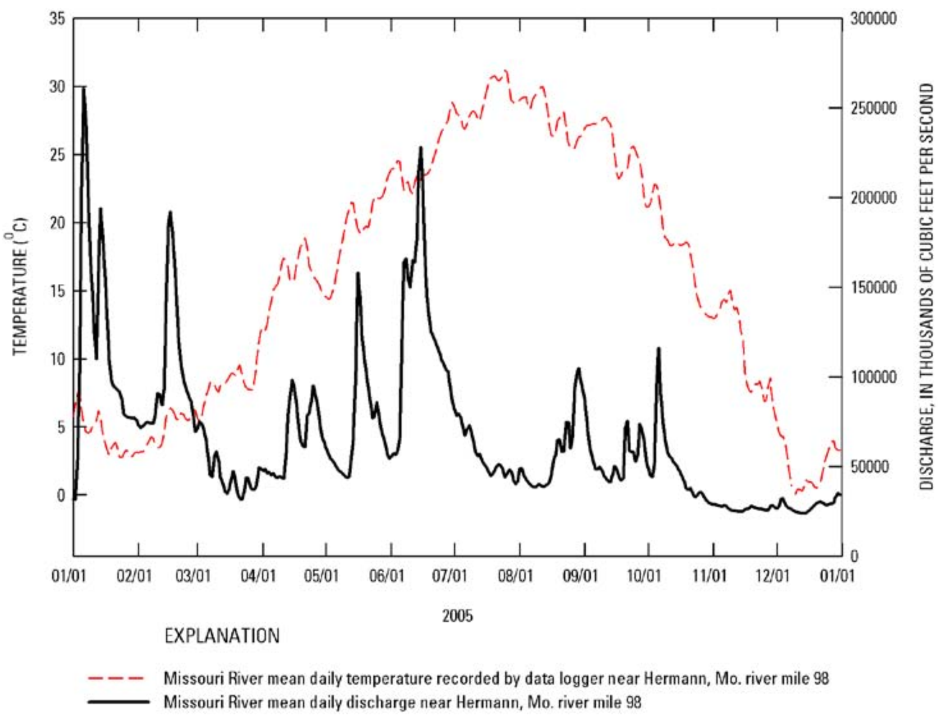


Figure B14. Mean daily temperature recorded by HOBO® Water Temp Pro v2 data loggers (Onset Computer Corporation, Bourne, Mass.) located in the Missouri River near Hermann, Mo., during 2005, and mean daily discharge at U.S. Geological Survey gaging station near Hermann, Mo., during 2005.

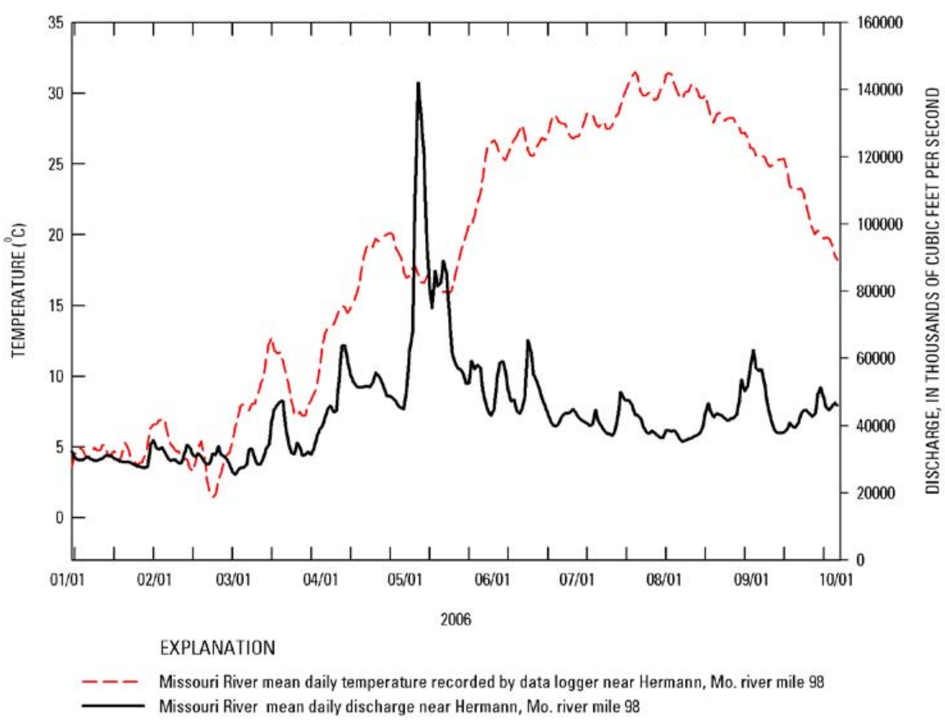


Figure B15. Mean daily temperature recorded by HOBO® Water Temp Pro v2 data loggers (Onset Computer Corporation, Bourne, Mass.) located in the Missouri River near Hermann, Mo., during 2006, and mean daily discharge at U.S. Geological Survey gaging station near Hermann, Mo., during 2006.

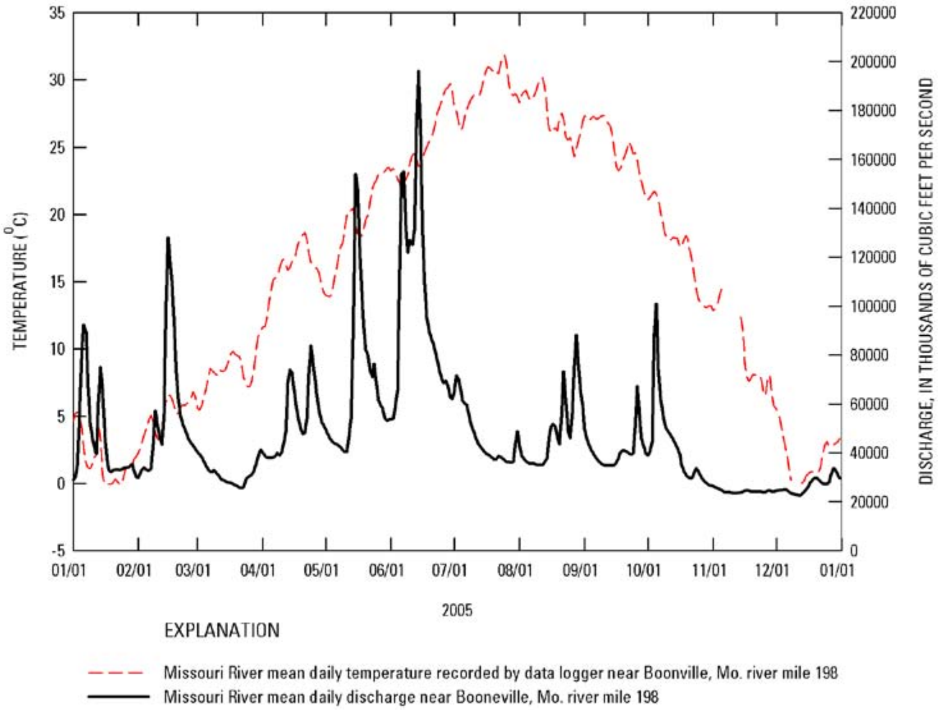


Figure B16. Mean daily temperature recorded by HOBO® Water Temp Pro v2 data loggers (Onset Computer Corporation, Bourne, Mass.) located in the Missouri River near Boonville, Mo., during 2005, and mean daily discharge at U.S. Geological Survey gaging station near Boonville, Mo., during 2005.

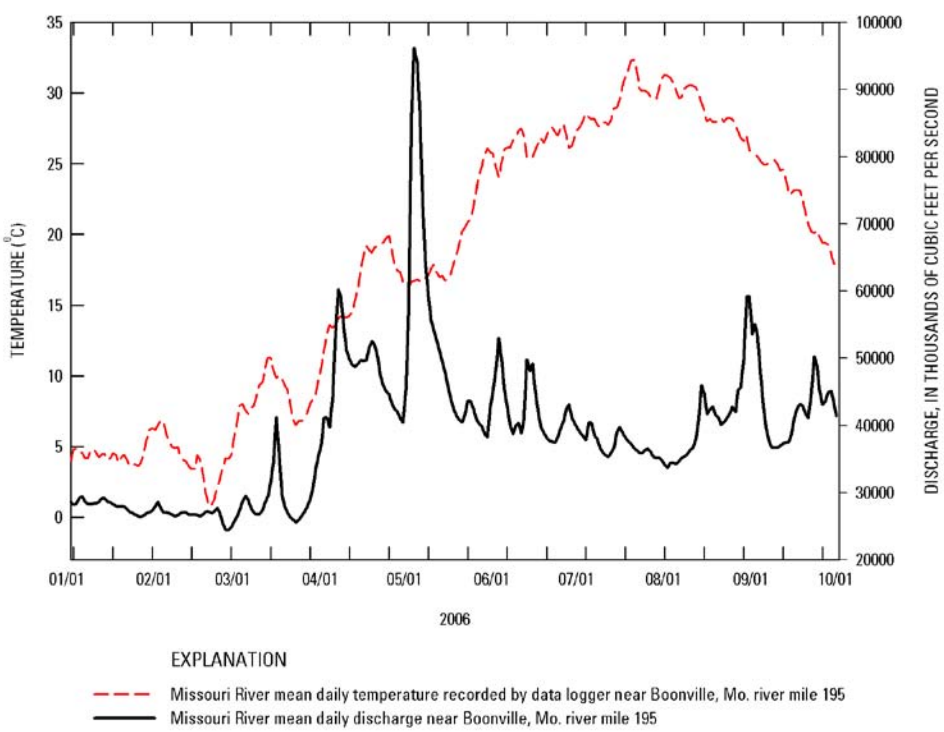


Figure B17. Mean daily temperature recorded by HOBO® Water Temp Pro v2 data loggers (Onset Computer Corporation, Bourne, Mass.) located in the Missouri River near Boonville, Mo., during 2006, and mean daily discharge at U.S. Geological Survey gaging station near Boonville, Mo., during 2006.

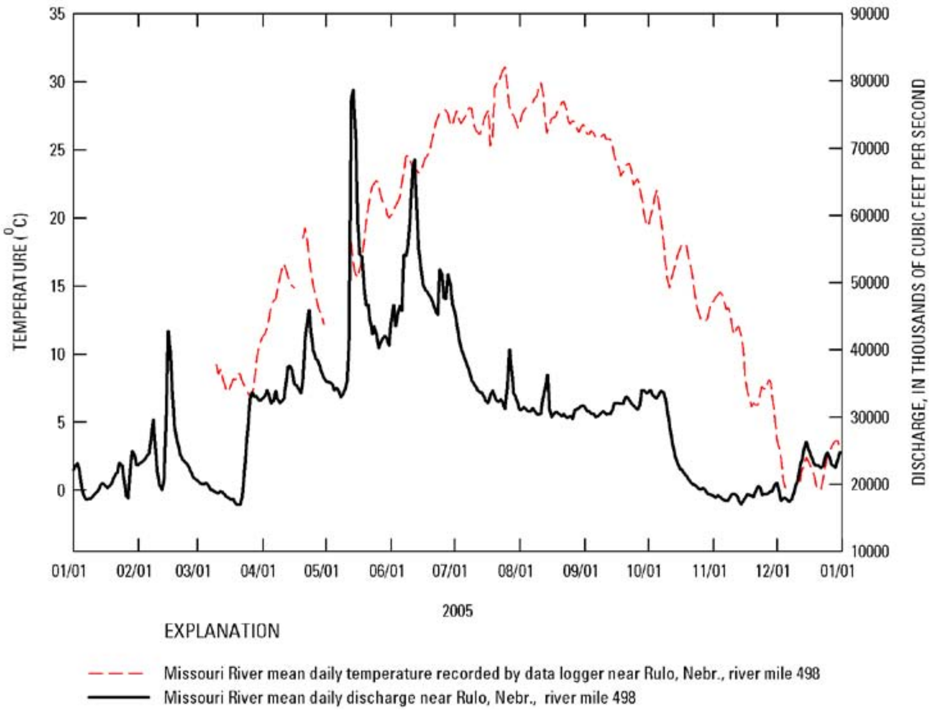


Figure B18. Mean daily temperature recorded by HOBO® Water Temp Pro v2 data loggers (Onset Computer Corporation, Bourne, Mass.) located in the Missouri River near Rulo, Nebr., during 2005, and mean daily discharge at U.S. Geological Survey gaging station near Rulo, Nebr., during 2005.

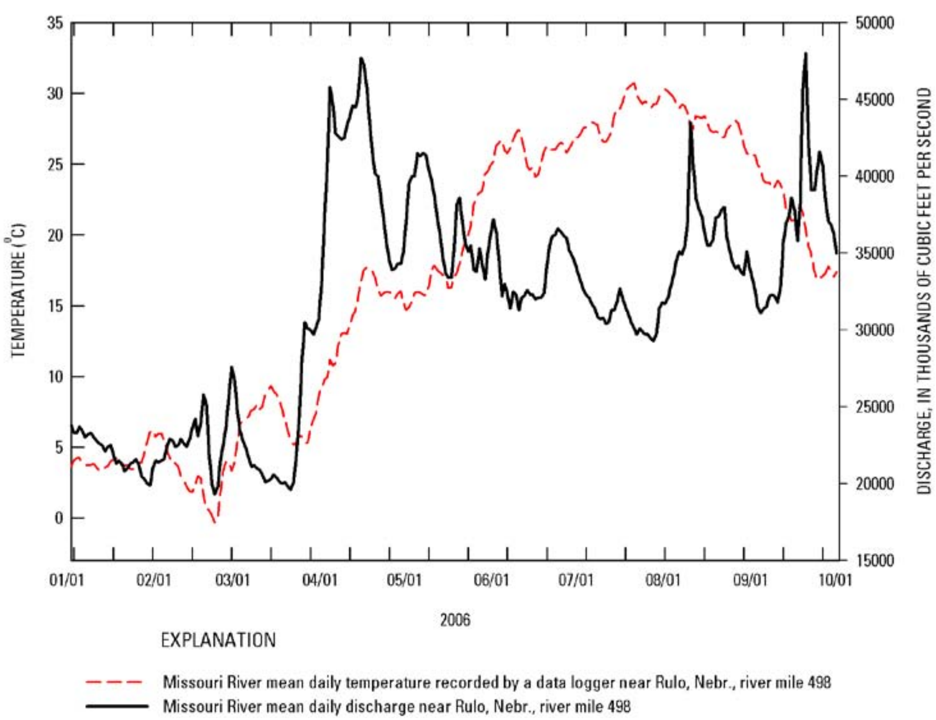


Figure B19. Mean daily temperature recorded by HOBO® Water Temp Pro v2 data loggers (Onset Computer Corporation, Bourne, Mass.) located in the Missouri River near Rulo, Nebr., during 2006, and mean daily discharge at U.S. Geological Survey gaging station near Rulo, Nebr., during 2006.

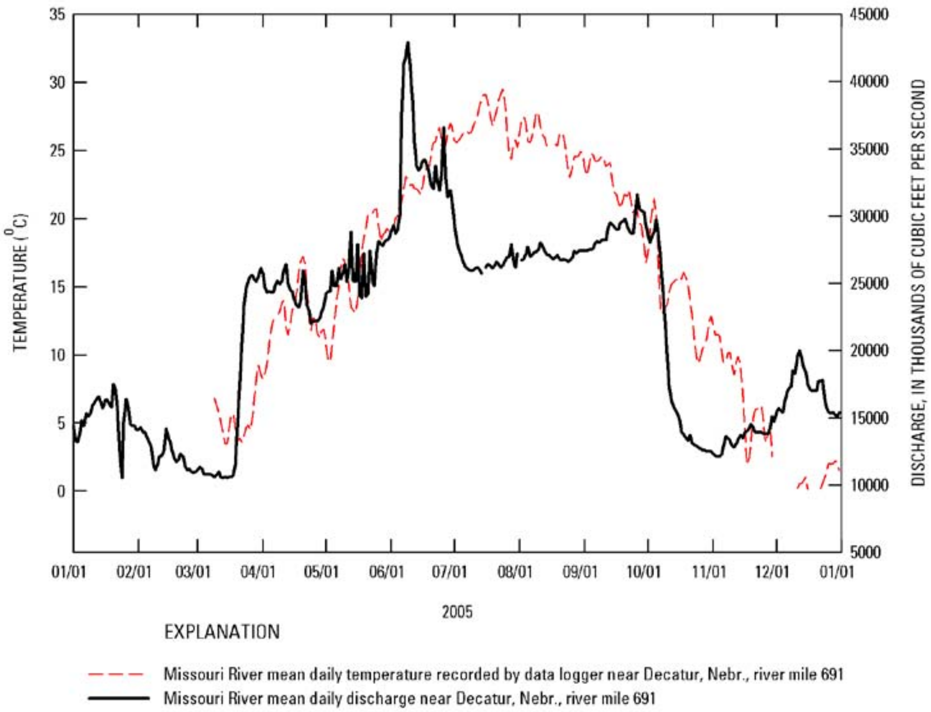


Figure B20. Mean daily temperature recorded by HOBO® Water Temp Pro v2 data loggers (Onset Computer Corporation, Bourne, Mass.) located in the Missouri River near Decatur, Nebr., during 2005, and mean daily discharge at U.S. Geological Survey gaging station near Decatur, Nebr., during 2005.

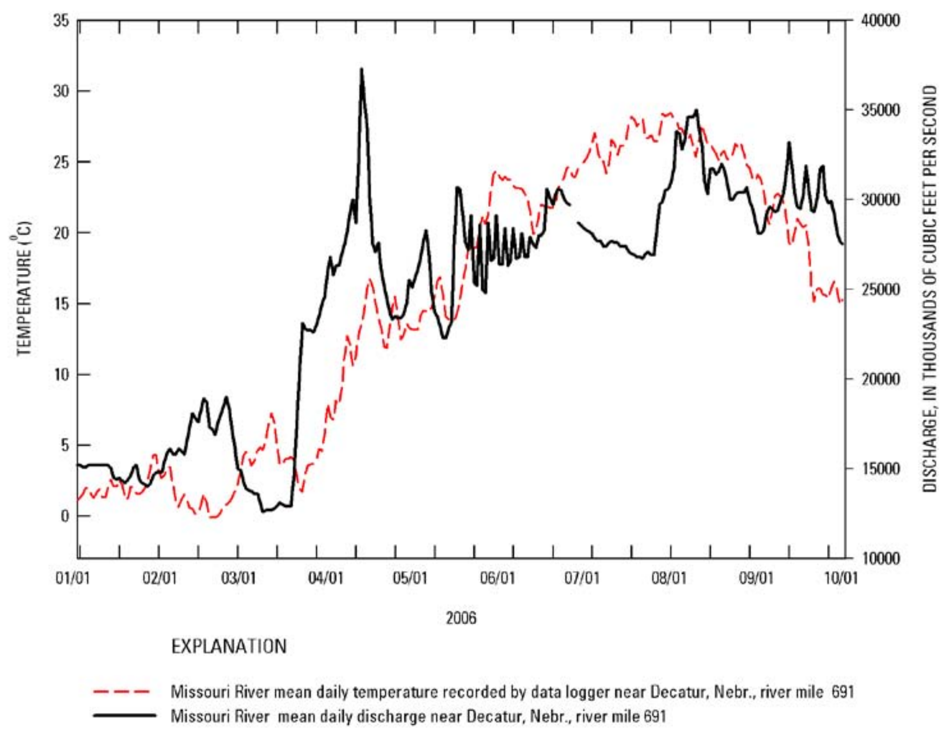


Figure B21. Mean daily temperature recorded by HOBO® Water Temp Pro v2 data loggers (Onset Computer Corporation, Bourne, Mass.) located in the Missouri River near Decatur, Nebr., during 2006, and mean daily discharge at U.S. Geological Survey gaging station near Decatur, Nebr., during 2006.

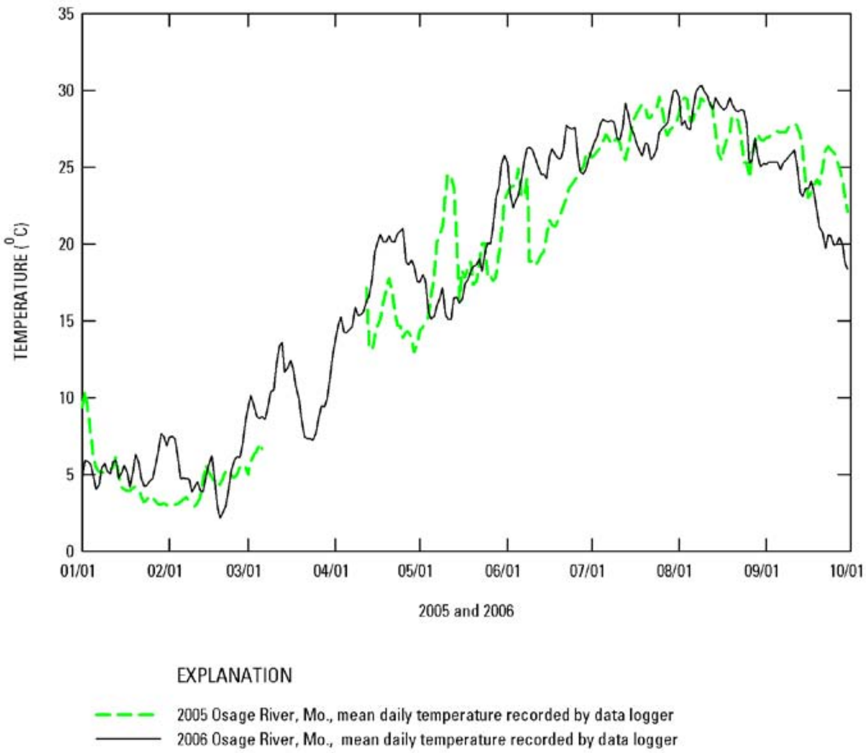


Figure B22. Mean daily temperature recorded by Hobo® Water Temp Pro v2 data loggers (Onset Computer Corporation, Bourne, Mass.) located in the Osage River, Mo., during 2005 and 2006.

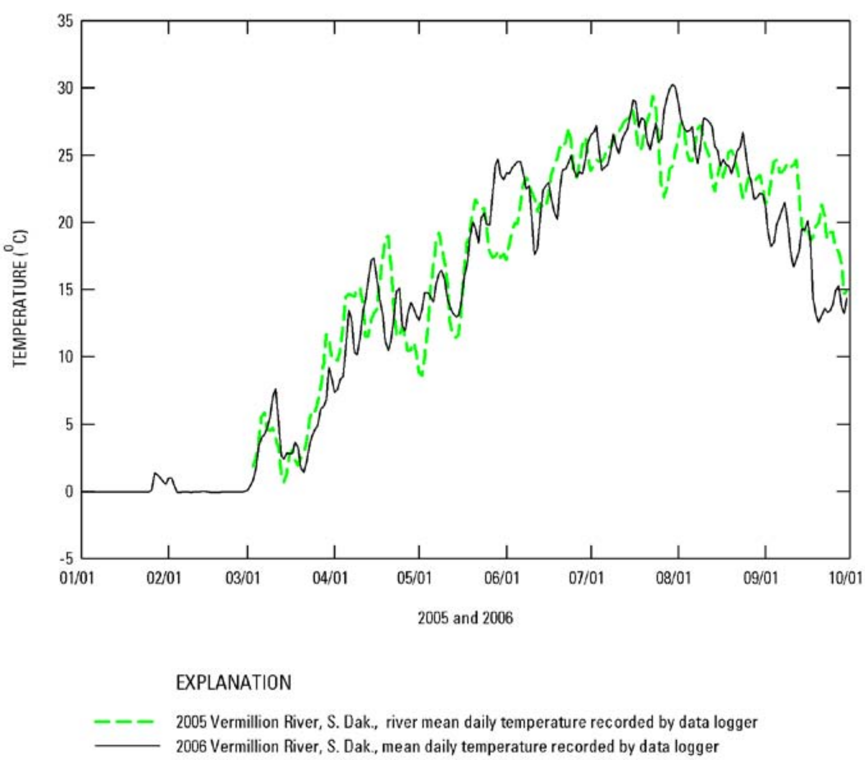


Figure B23. Mean daily temperature recorded by Hobo® Water Temp Pro v2 data loggers (Onset Computer Corporation, Bourne, Mass.) located in the Vermillion River, S. Dak., during 2005 and 2006.

Figure B24. Sturgeon sampling was conducted from open boats in March and April during 2005 and 2006 by using overnight and short-term gill net sets.

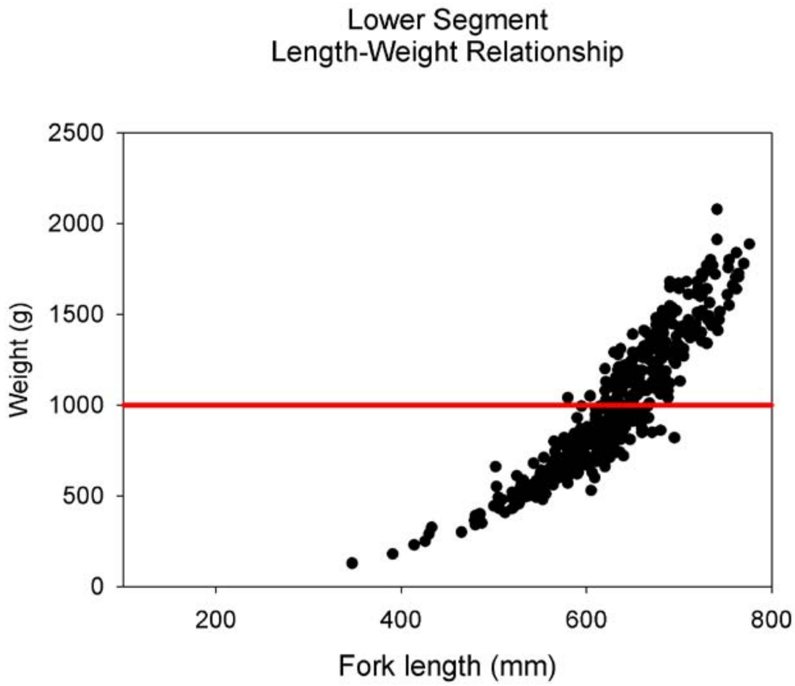


Figure B25. Length-weight relationship for all shovelnose sturgeon collected during April 2006 in the lower study segment of the Lower Missouri River. Only shovelnose sturgeon greater than 1,000 grams were considered as candidates for implantation, indicated by a red line.

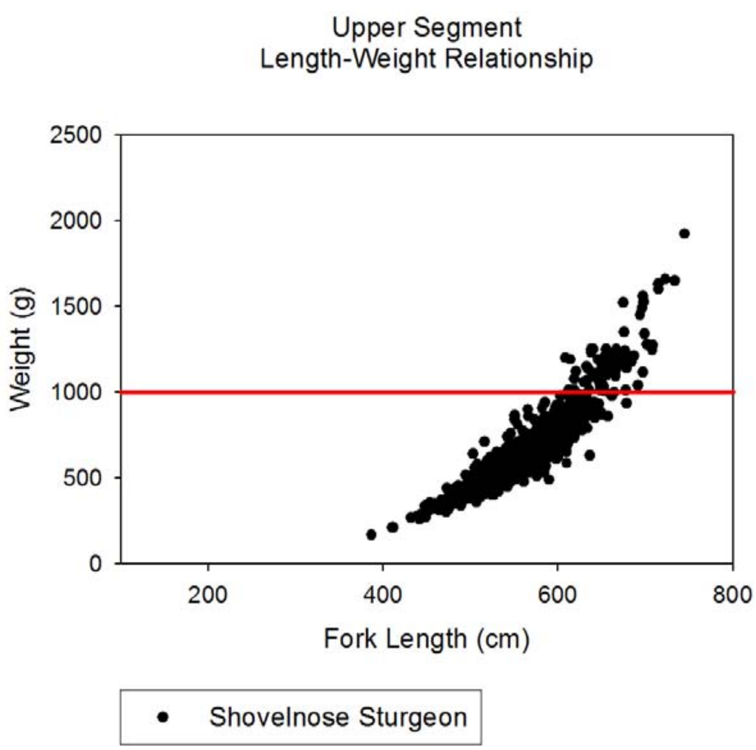


Figure B26. Length-weight relationship for all shovelnose sturgeon collected during April 2006 in the upper study segment of the Lower Missouri River. Only shovelnose sturgeon greater than 1,000 grams were considered as candidates for implantation, indicated by a red line.

Figure B27. Male pallid sturgeon (2.66 kg, 883 mm fork length) in reproductive condition captured at river mile 600.0 in upper study segment of the Missouri River in April 2006 (dorsal view). Fish was unmarked and presumed to be of nonhatchery origin.

Figure B28. Male pallid sturgeon (2.66 kg, 883 mm fork length) in reproductive condition captured at river mile 600.0 in upper study segment of the Missouri River in April 2006 (ventral view). Fish was unmarked and presumed to be of nonhatchery origin.

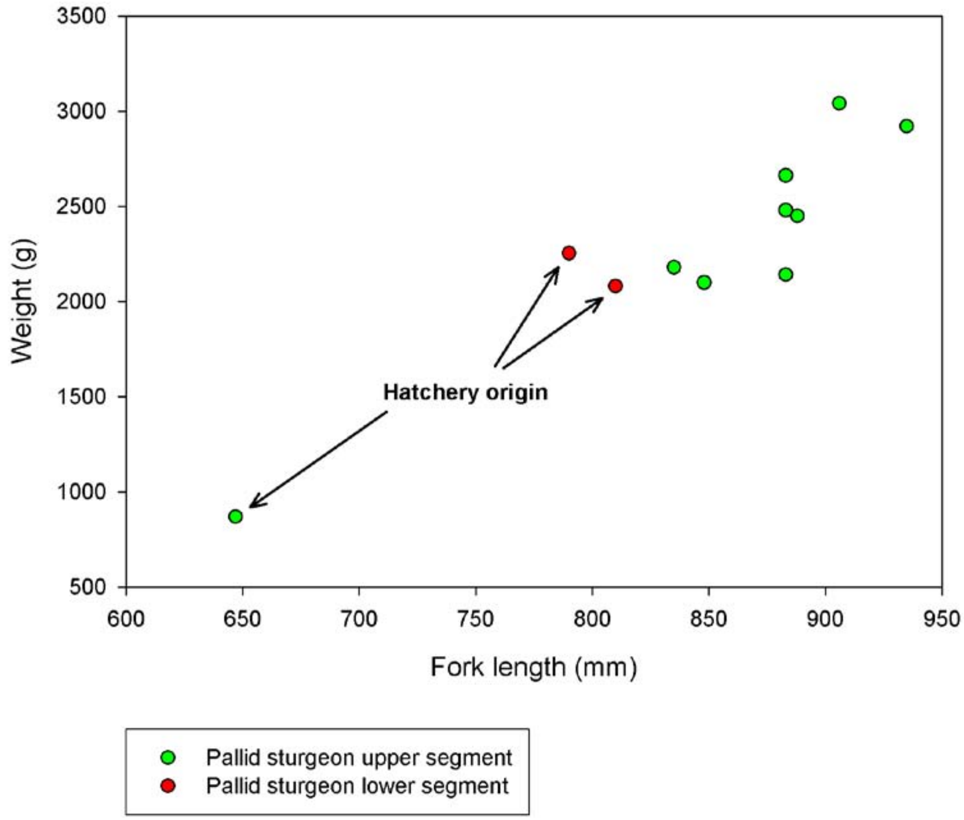


Figure B29. Length-weight relationship for pallid sturgeon collected during April 2006 in the lower and upper study segments of the Missouri River. Three of the twelve pallid sturgeon collected were of hatchery origin.

Figure B30. Sturgeon were weighed, measured, and photographed prior to implantation. This photograph shows a shovelnose sturgeon (lateral view).

Figure B31. Blood samples were taken for reproductive assessment during implantation and again at recapture.

Figure B32. Transmitters and data storage tags were surgically implanted through a single ventral incision. External antennas, when used, exited through a separate abdominal puncture 12–15 cm posterior to the ventral incision.

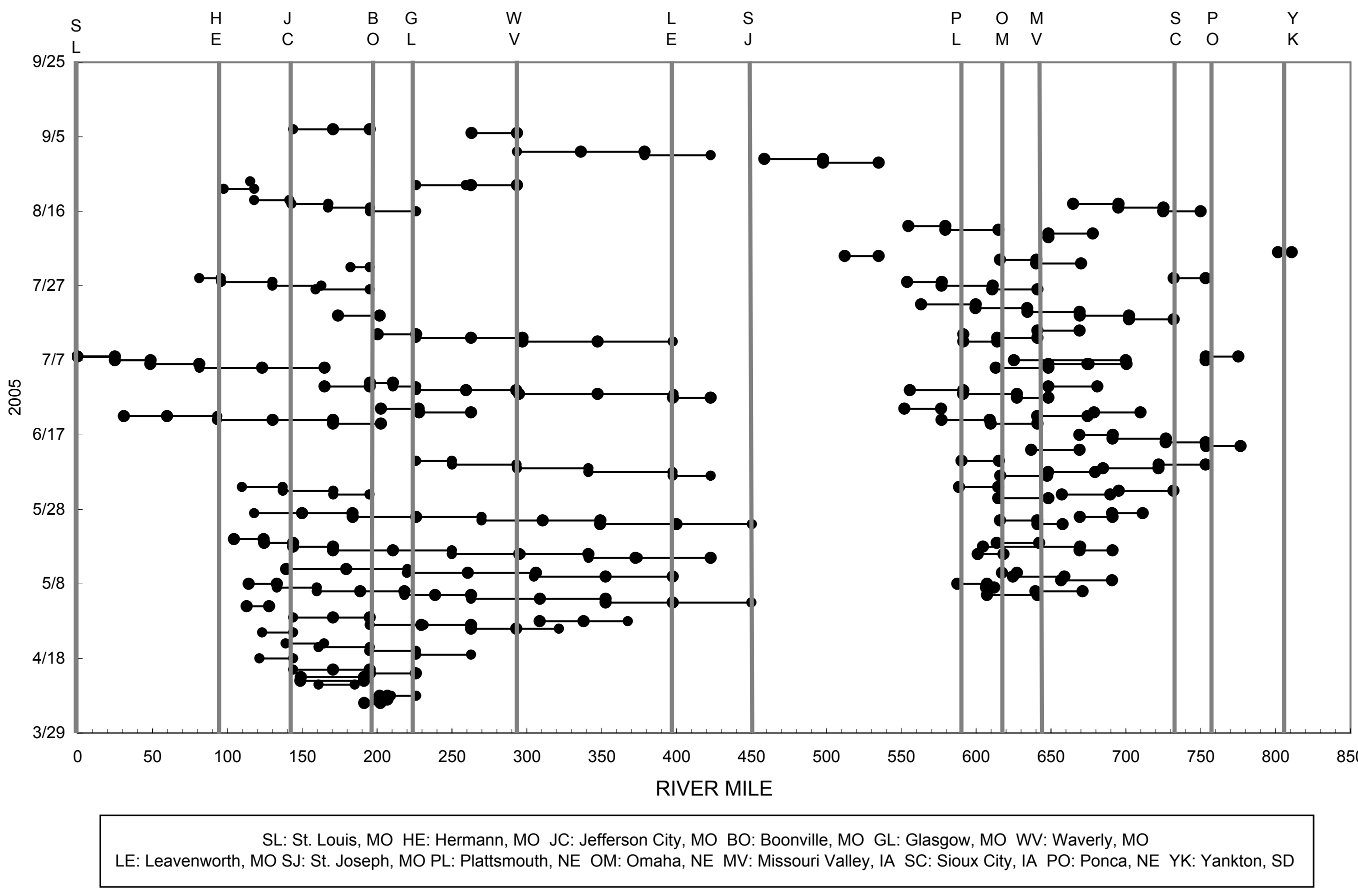
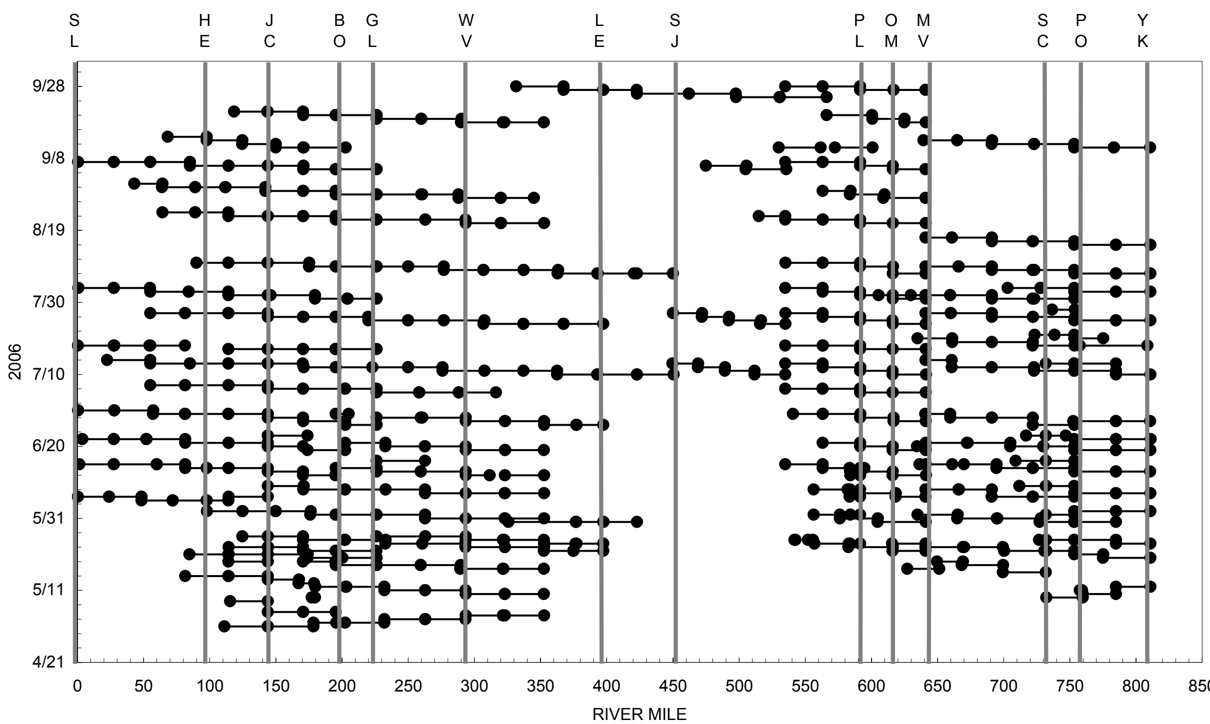


Figure B33. Research vessels' search effort for 2005 for the Lower Missouri River. Each line segment between the black points (starting and stopping location) represents a day's search effort for one vessel.



SL: St. Louis, MO HE: Hermann, MO JC: Jefferson City, MO BO: Boonville, MO GL: Glasgow, MO WV: Waverly, MO
LE: Leavenworth, MO SJ: St. Joseph, MO PL: Plattsmouth, NE OM: Omaha, NE MV: Missouri Valley, IA SC: Sioux City, IA PO: Ponca, NE YK: Yankton, SD

Figure B34. Research vessels' search effort for 2006 for the Lower Missouri River. Each line segment between the black points (starting and stopping location) represents a day's search effort for one vessel.

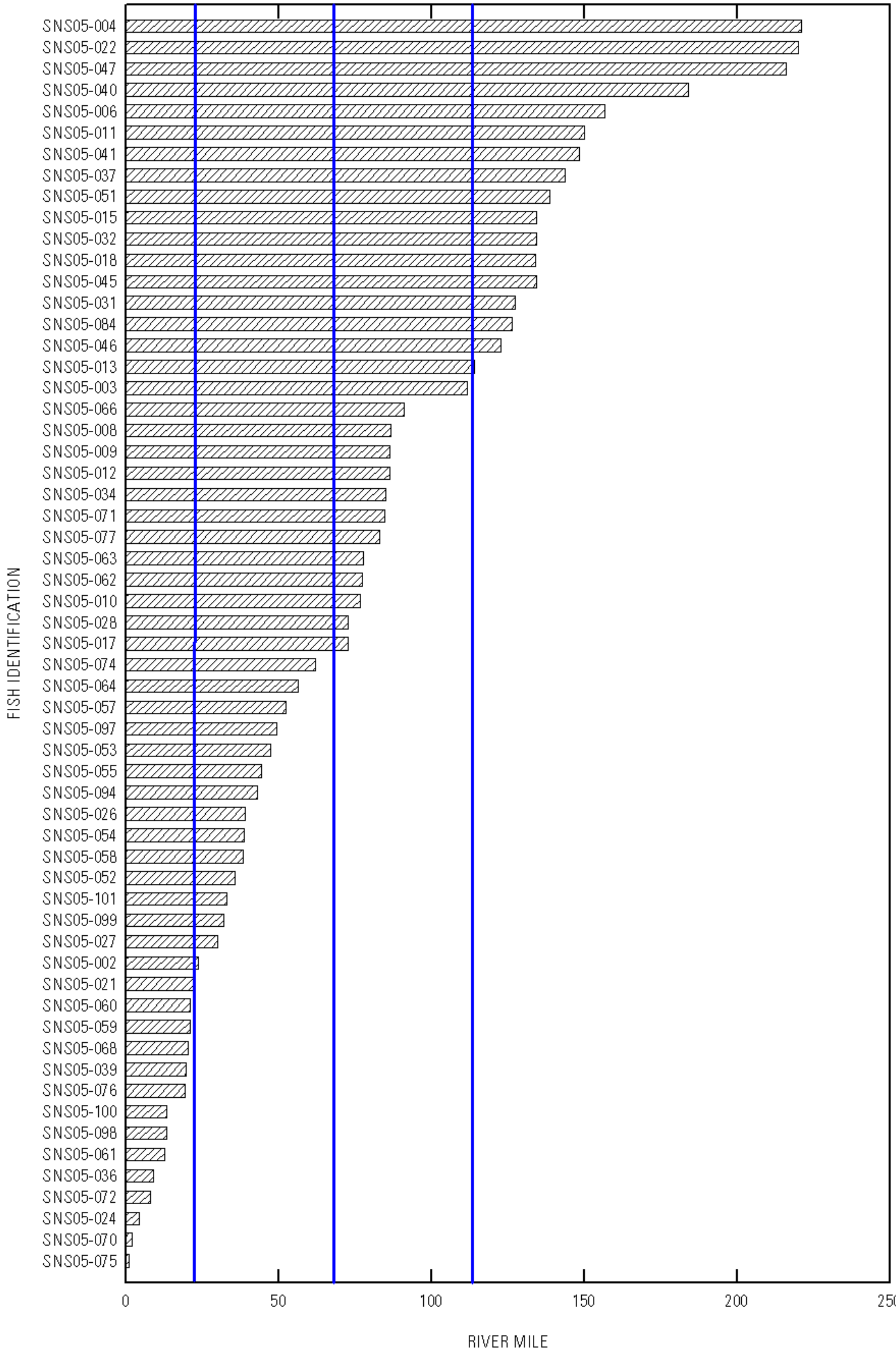


Figure B35. Displacement of 2005 shovelnose sturgeon making an upward migration calculated by subtracting the capture and implantation location from the maximum upstream location.

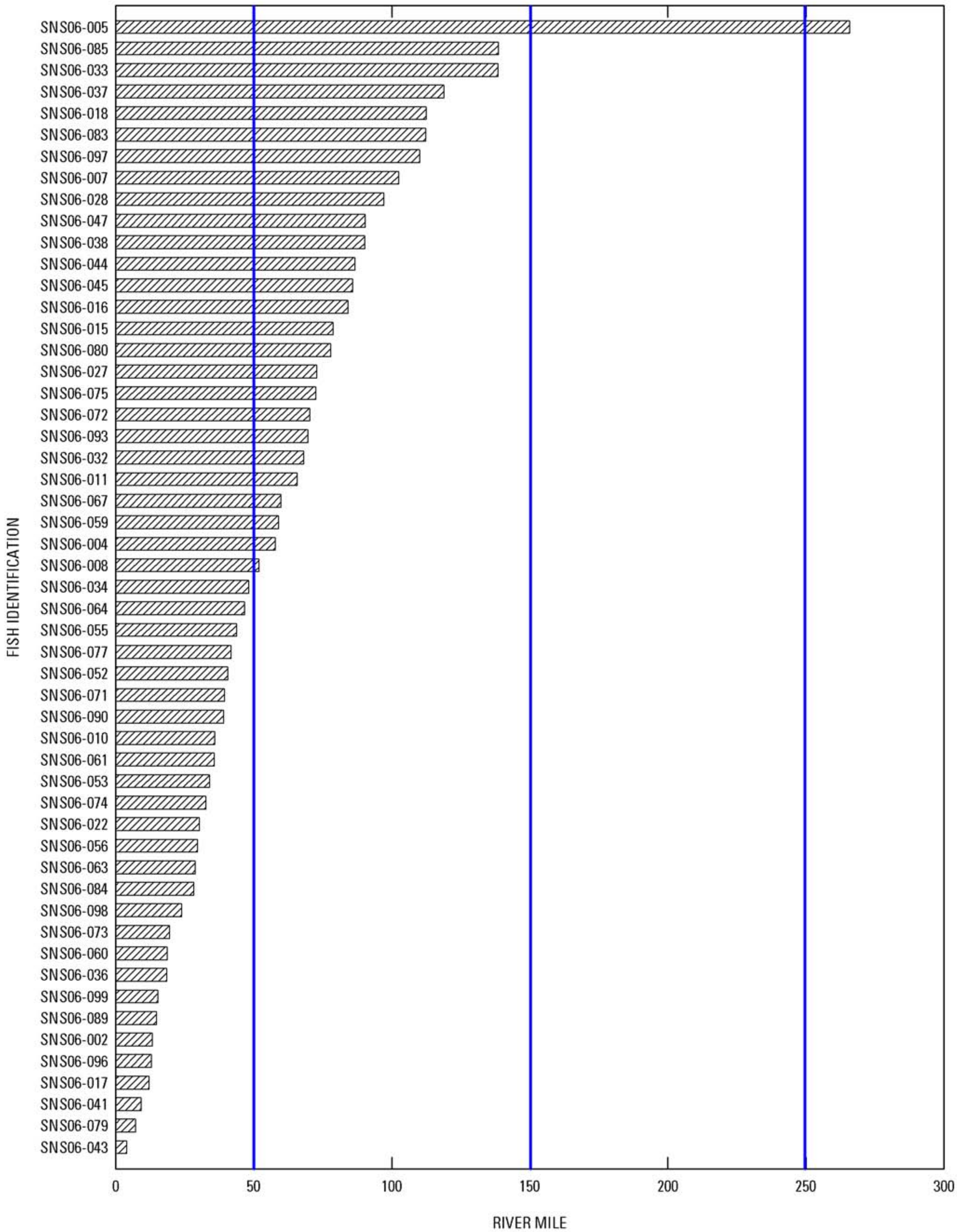


Figure B36. Displacement of 2006 shovelnose sturgeon making an upward migration calculated by subtracting the capture and implantation location from the maximum upstream location.

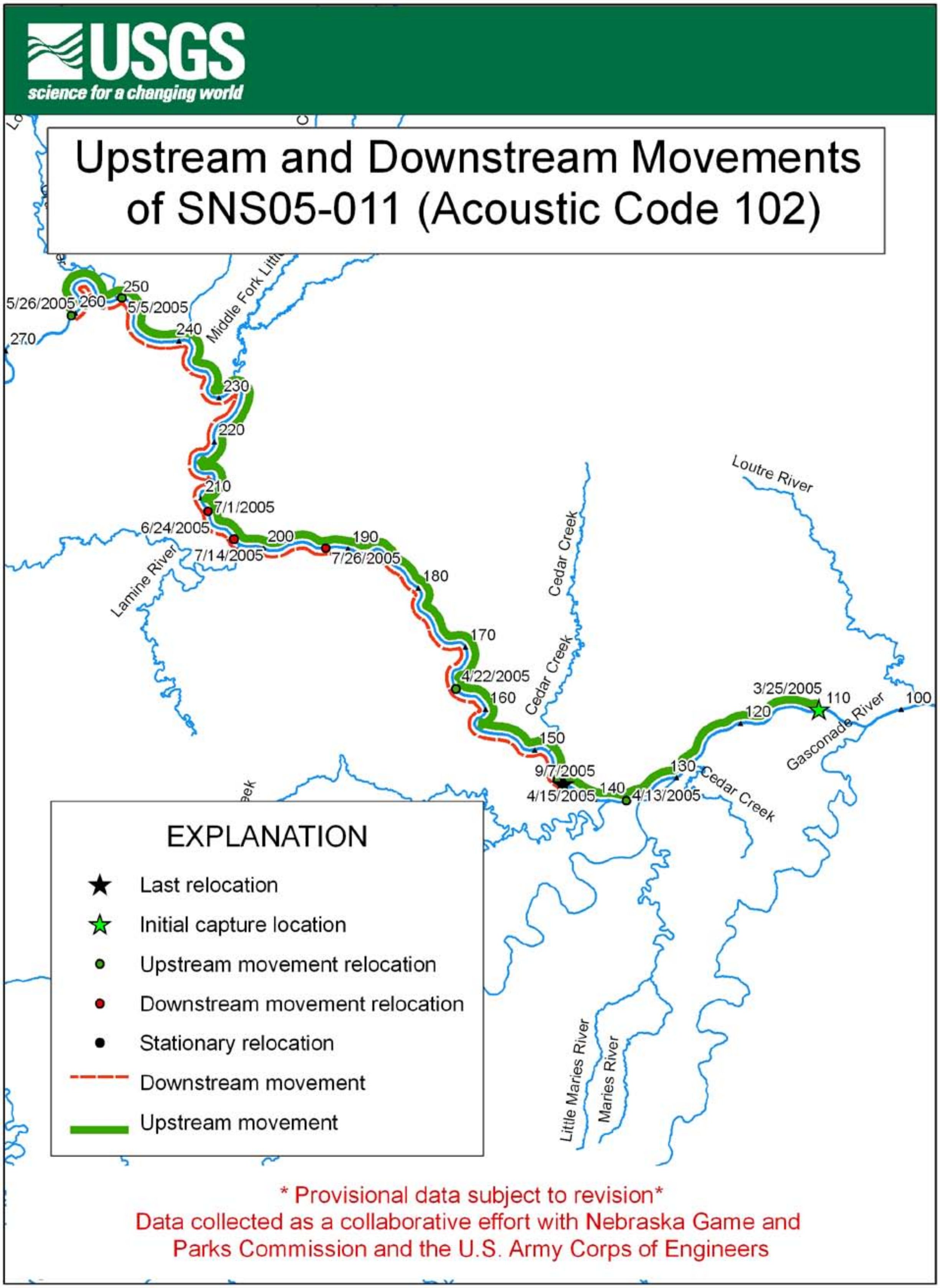


Figure B37. Movement map for shovelnose sturgeon SNS05–011 showing interpolated upstream and downstream movement. Fish was recaptured and did spawn.

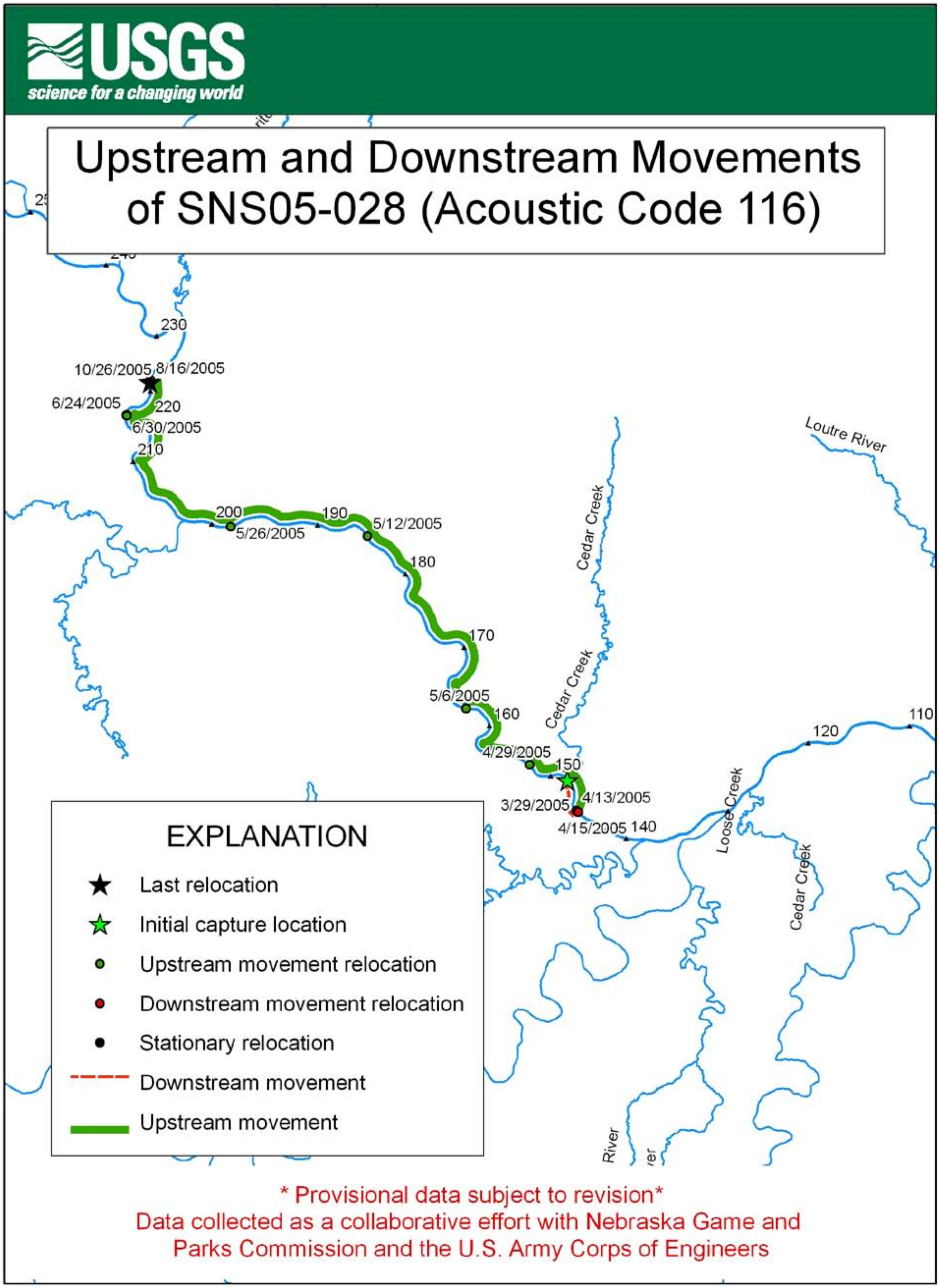


Figure B38. Movement map for shovelnose sturgeon SNS05–028 showing interpolated upstream and downstream movement. Fish was recaptured and did not spawn.

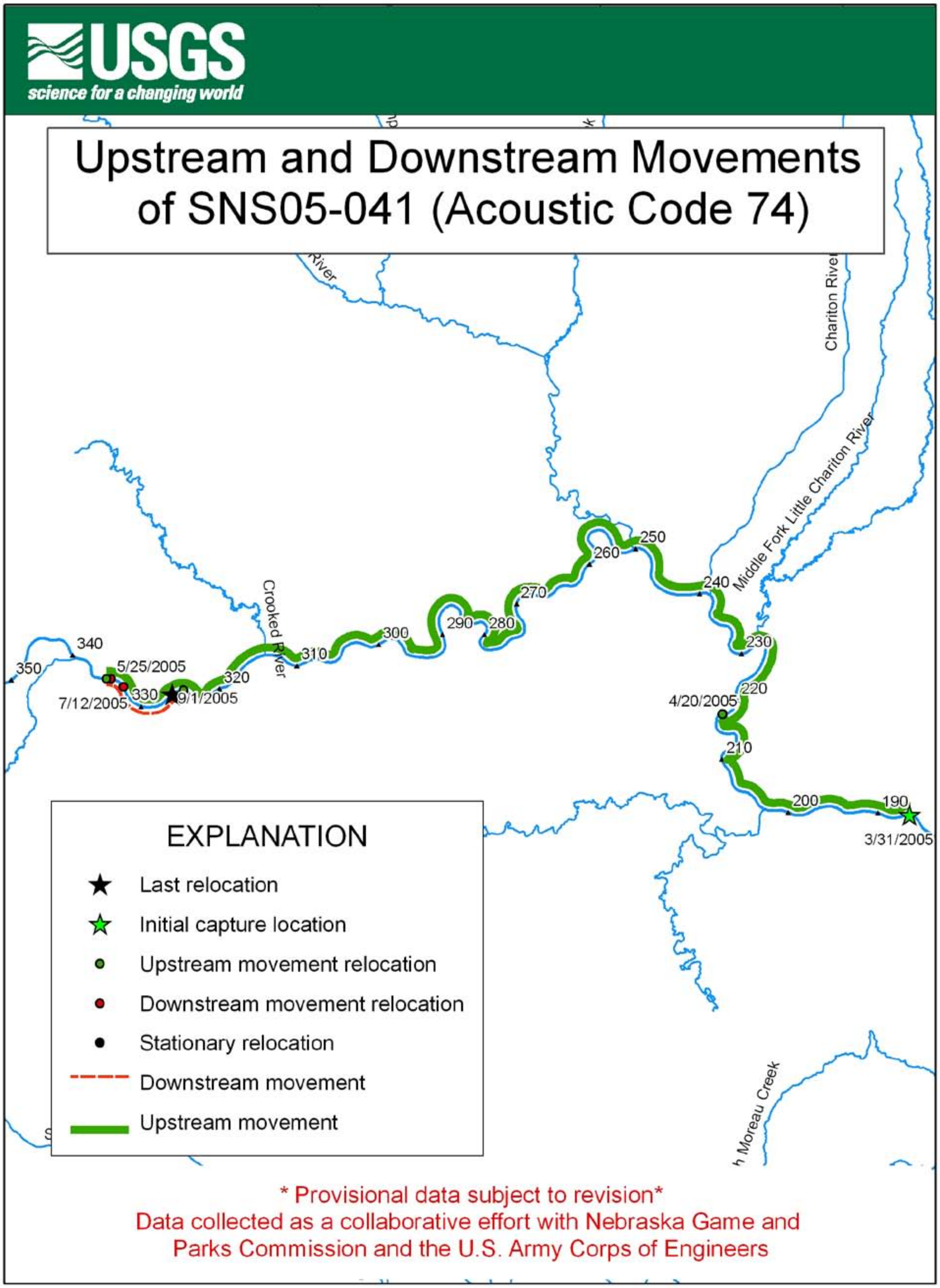


Figure B39. Movement map for shovelnose sturgeon SNS05–041 showing interpolated upstream and downstream movement. Fish was recaptured and did spawn.

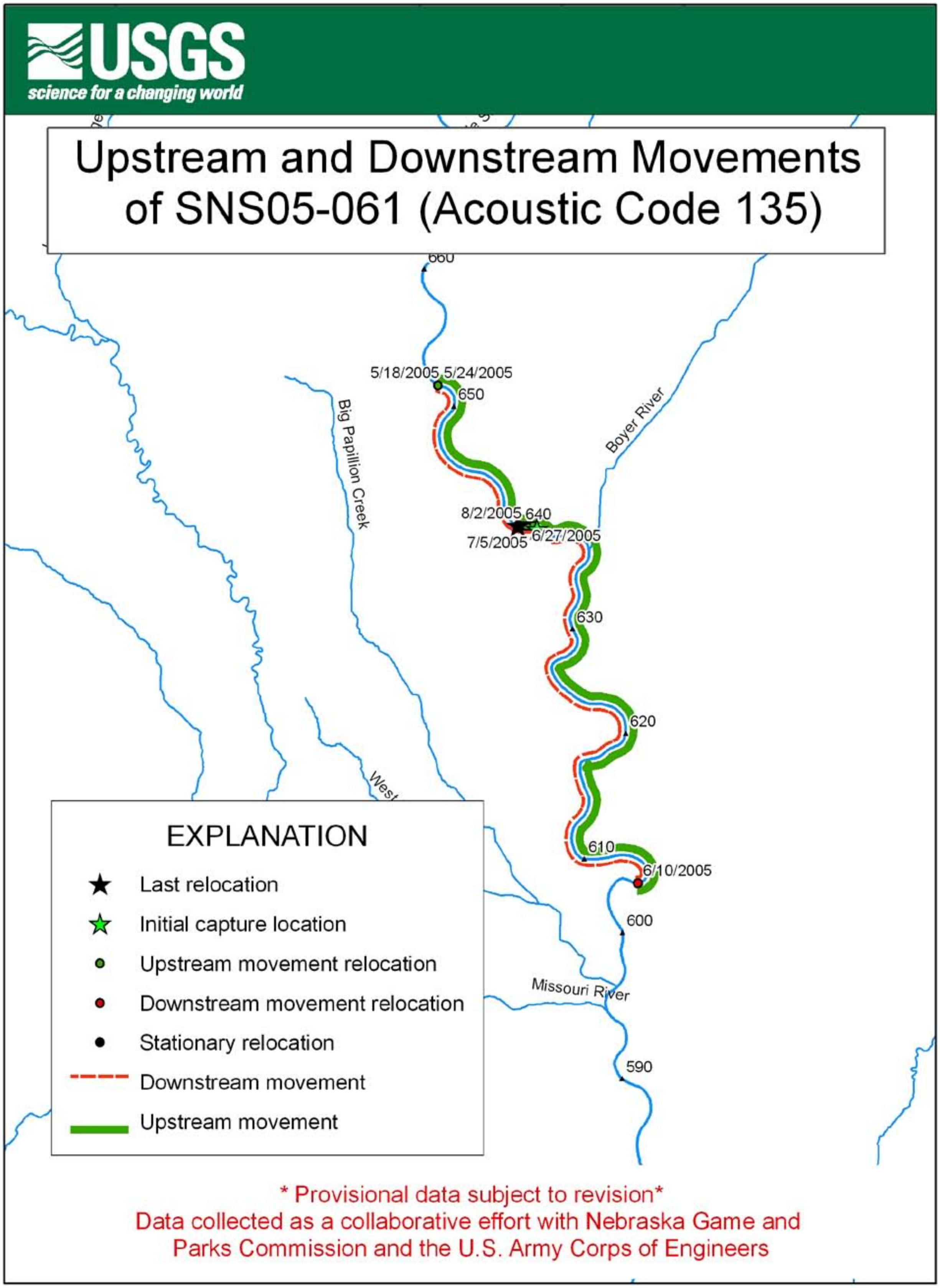


Figure B40. Movement map for shovelnose sturgeon SNS05–061 showing interpolated upstream and downstream movement. Fish was recaptured and did spawn.

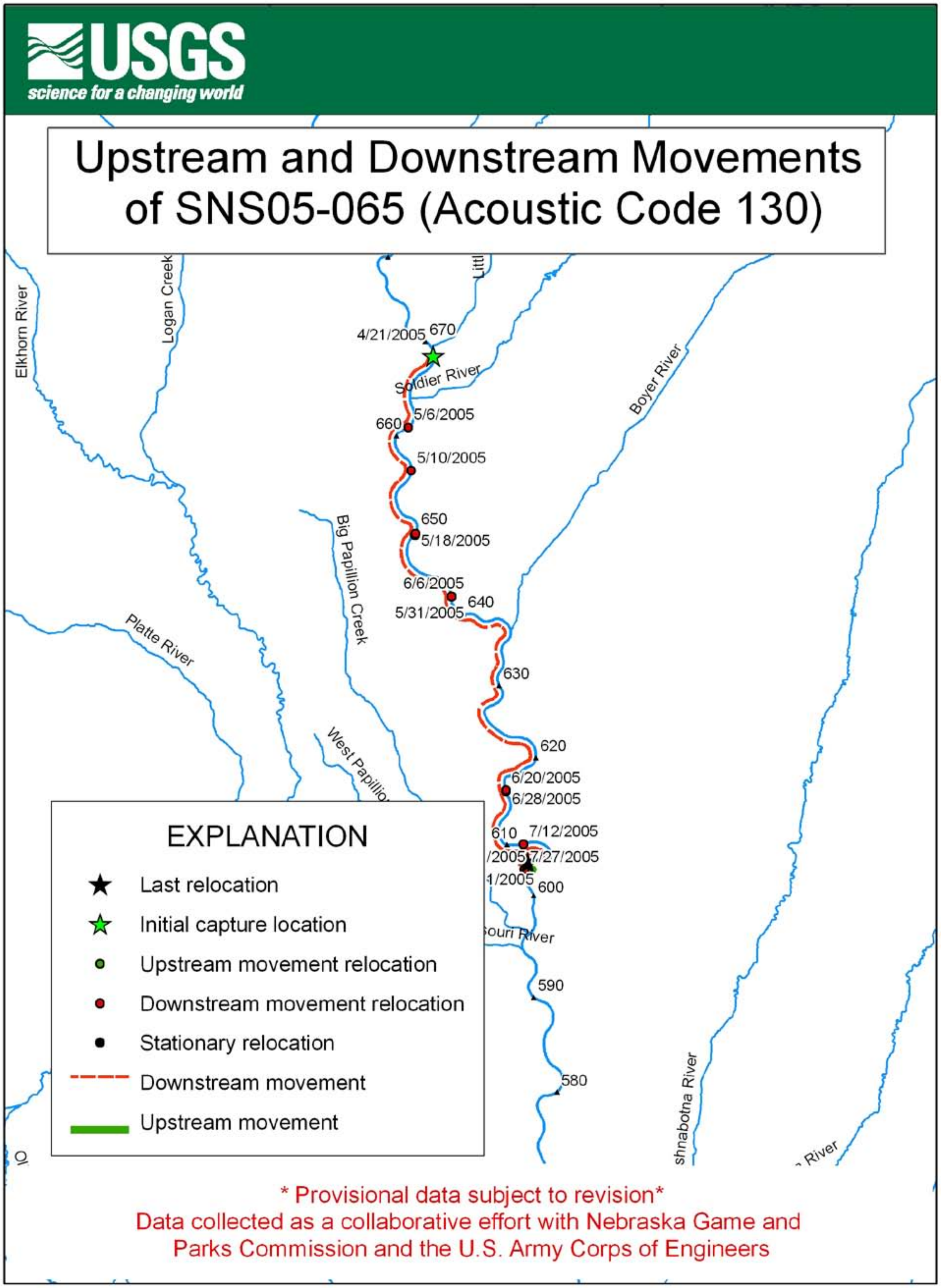


Figure B41. Movement map for shovelnose sturgeon SNS05–065 showing interpolated upstream and downstream movement. Fish was recaptured and did not spawn.

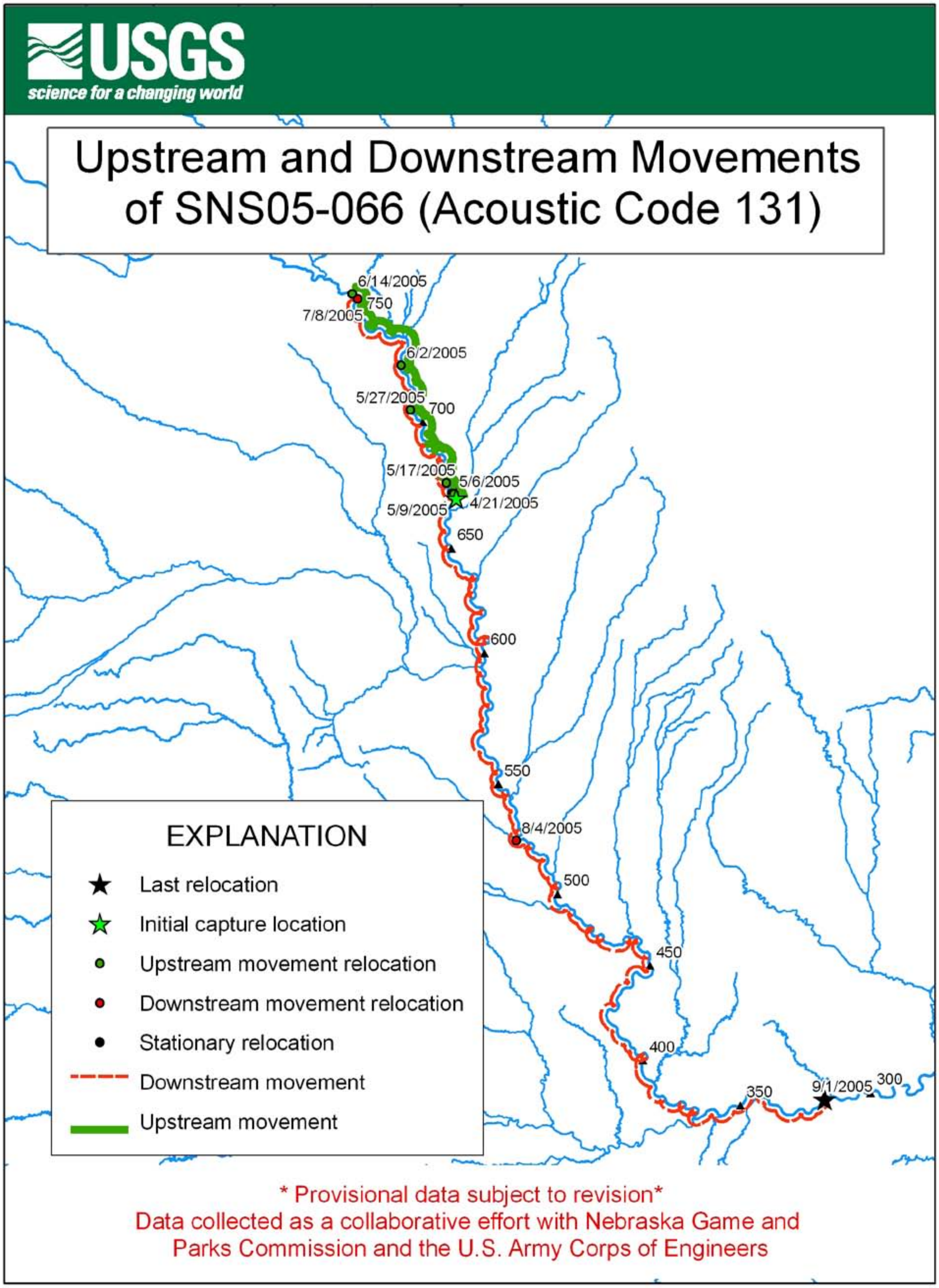


Figure B42. Movement map for shovelnose sturgeon SNS05–066 showing interpolated upstream and downstream movement. Fish was recaptured and did spawn.

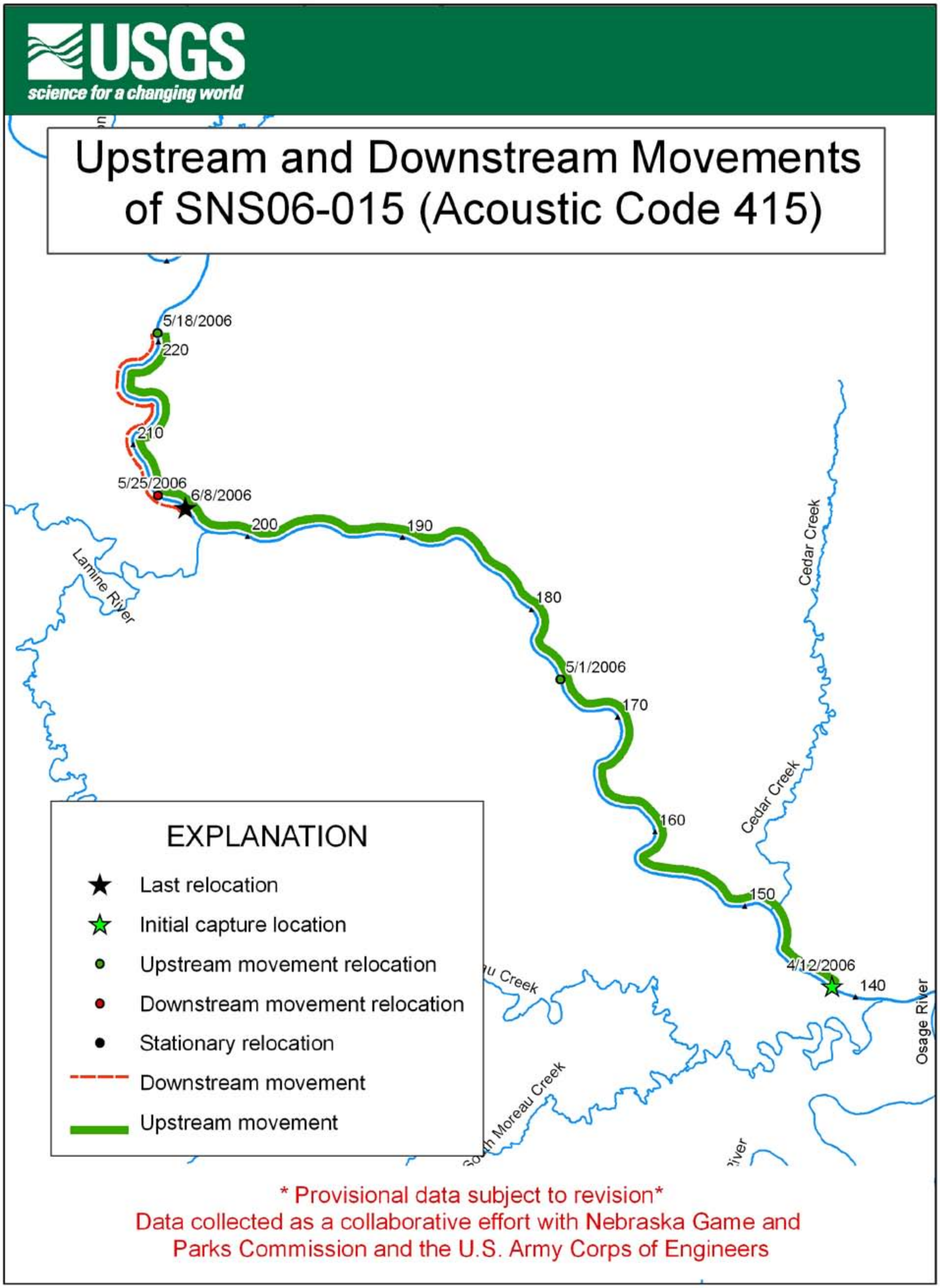


Figure B43. Movement map for shovelnose sturgeon SNS06–015 showing interpolated upstream and downstream movement. Fish was recaptured and did spawn.

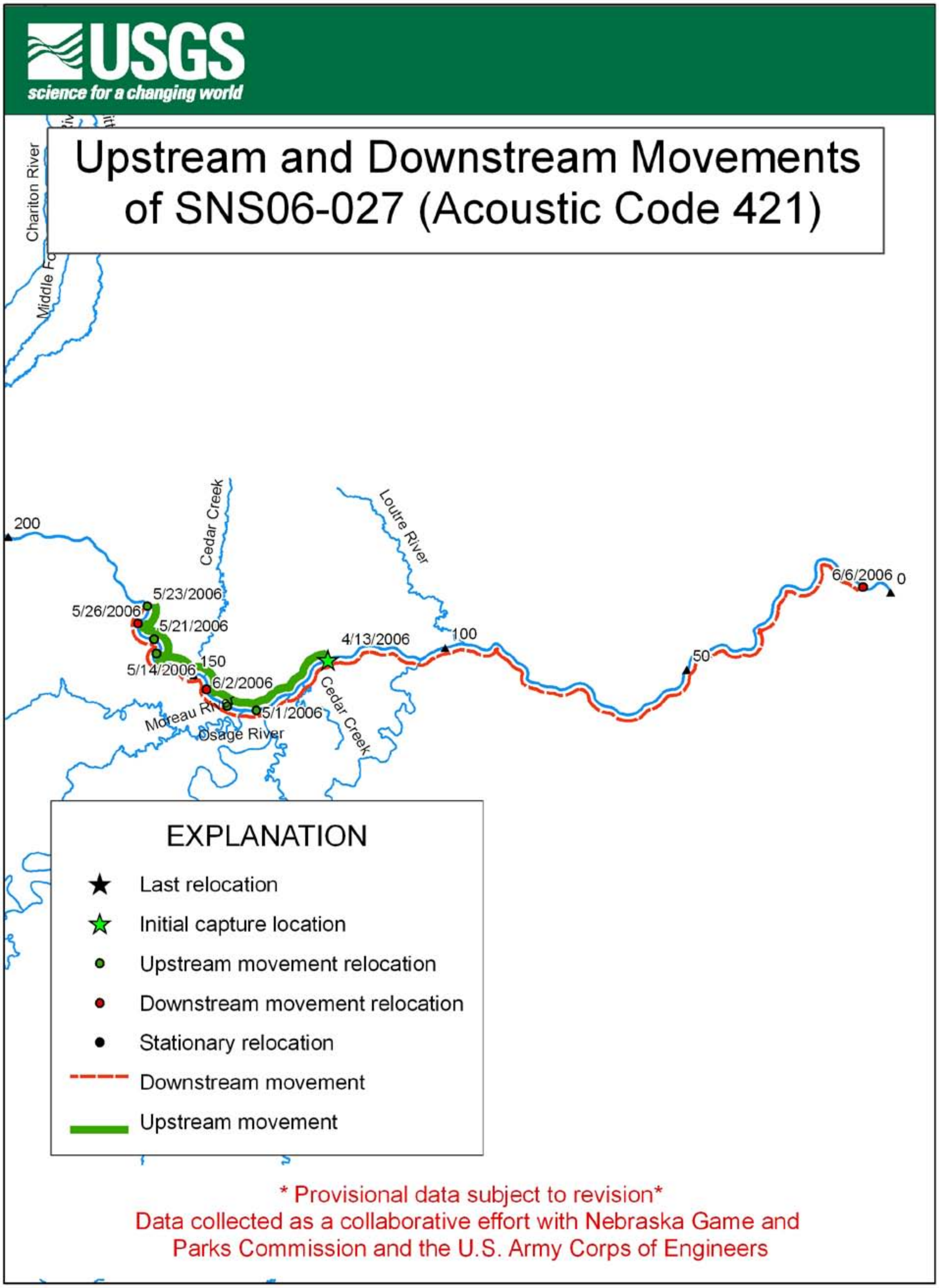


Figure B44. Movement map for shovelnose sturgeon SNS06–027 showing interpolated upstream and downstream movement. Fish was recaptured and did spawn.

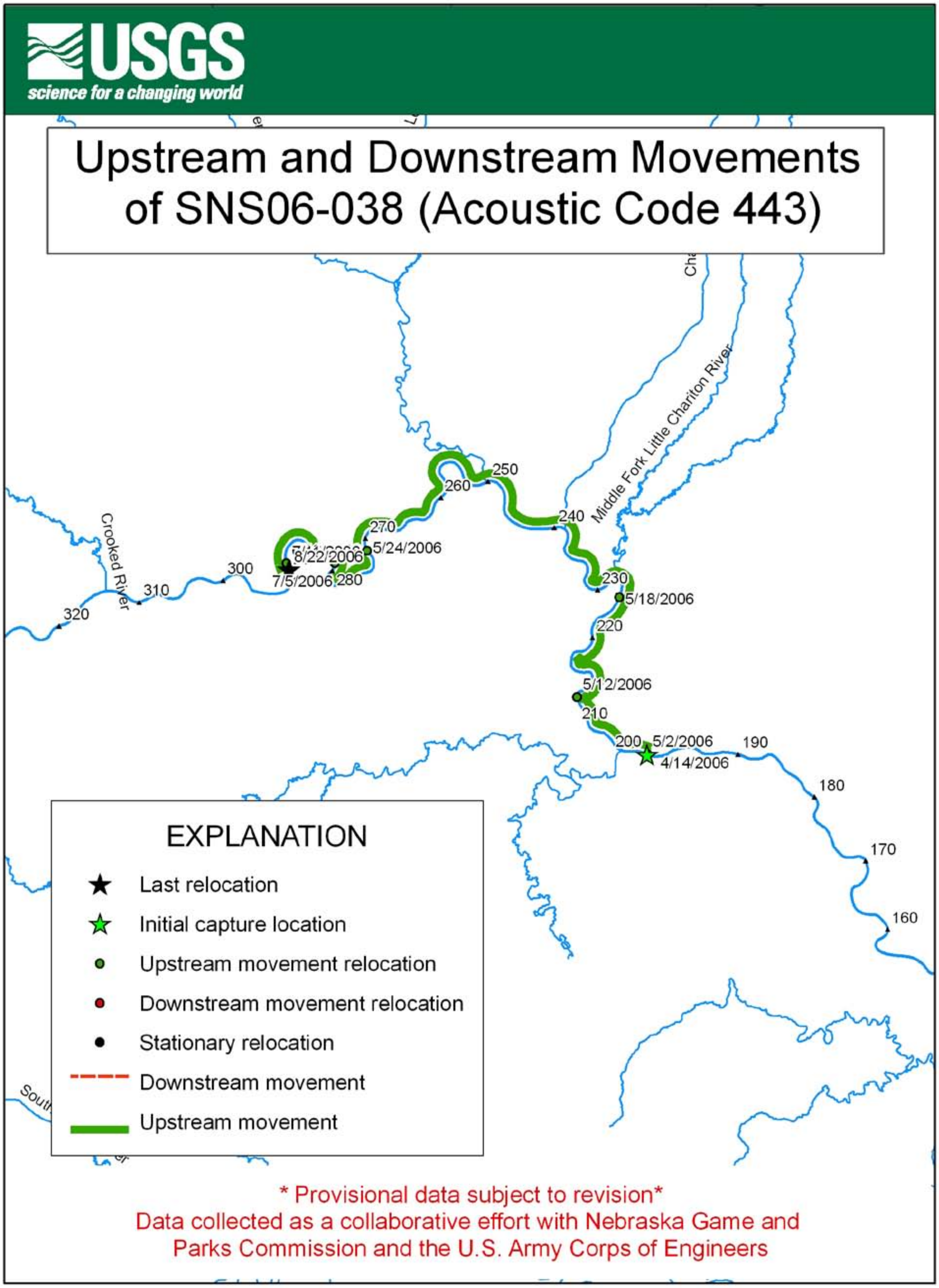


Figure B45. Movement map for shovelnose sturgeon SNS06–038 showing interpolated upstream and downstream movement. Fish was recaptured and did not spawn.

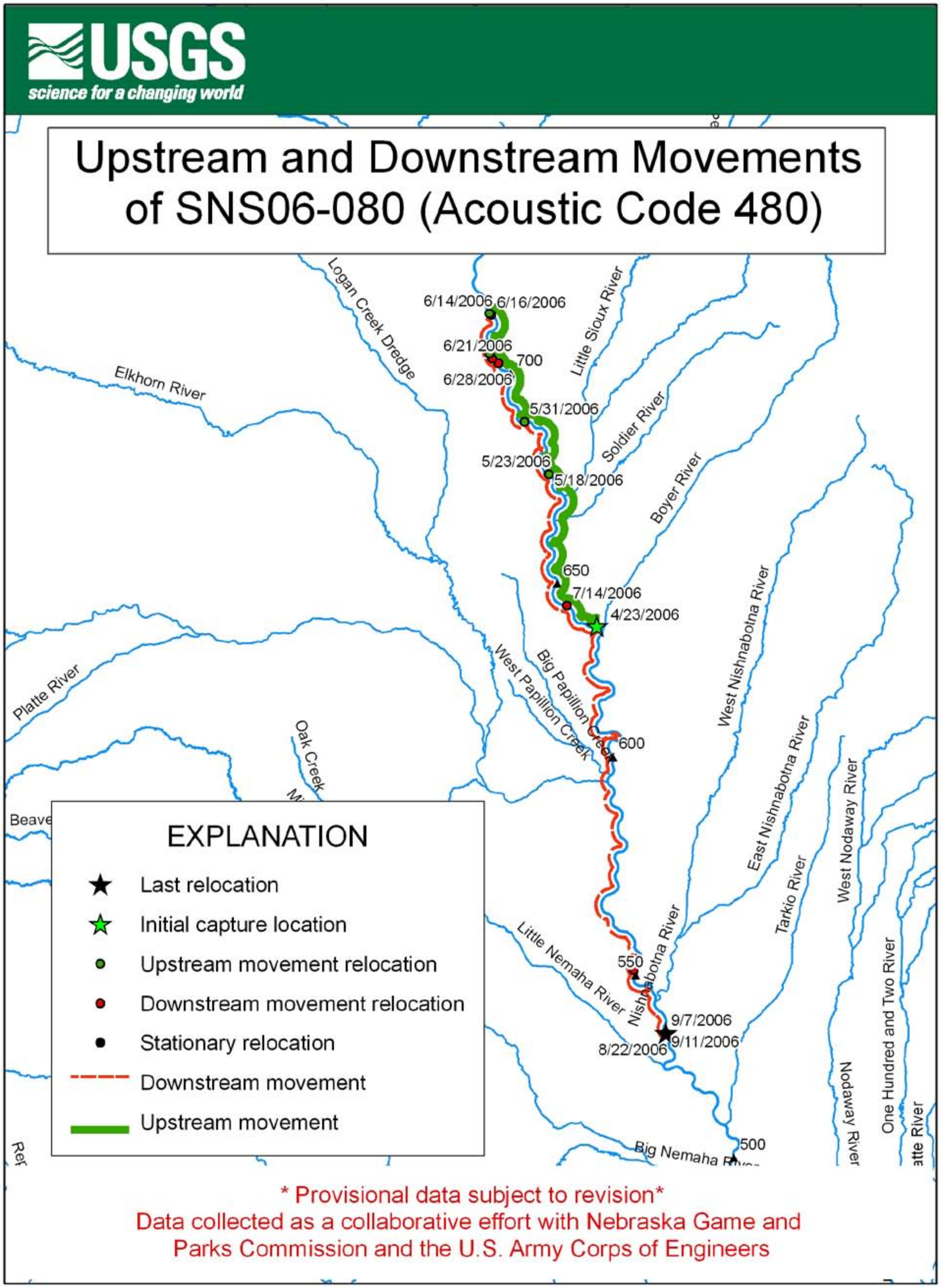


Figure B46. Movement map for shovelnose sturgeon SNS06–080 showing interpolated upstream and downstream movement. Fish was recaptured and did spawn.

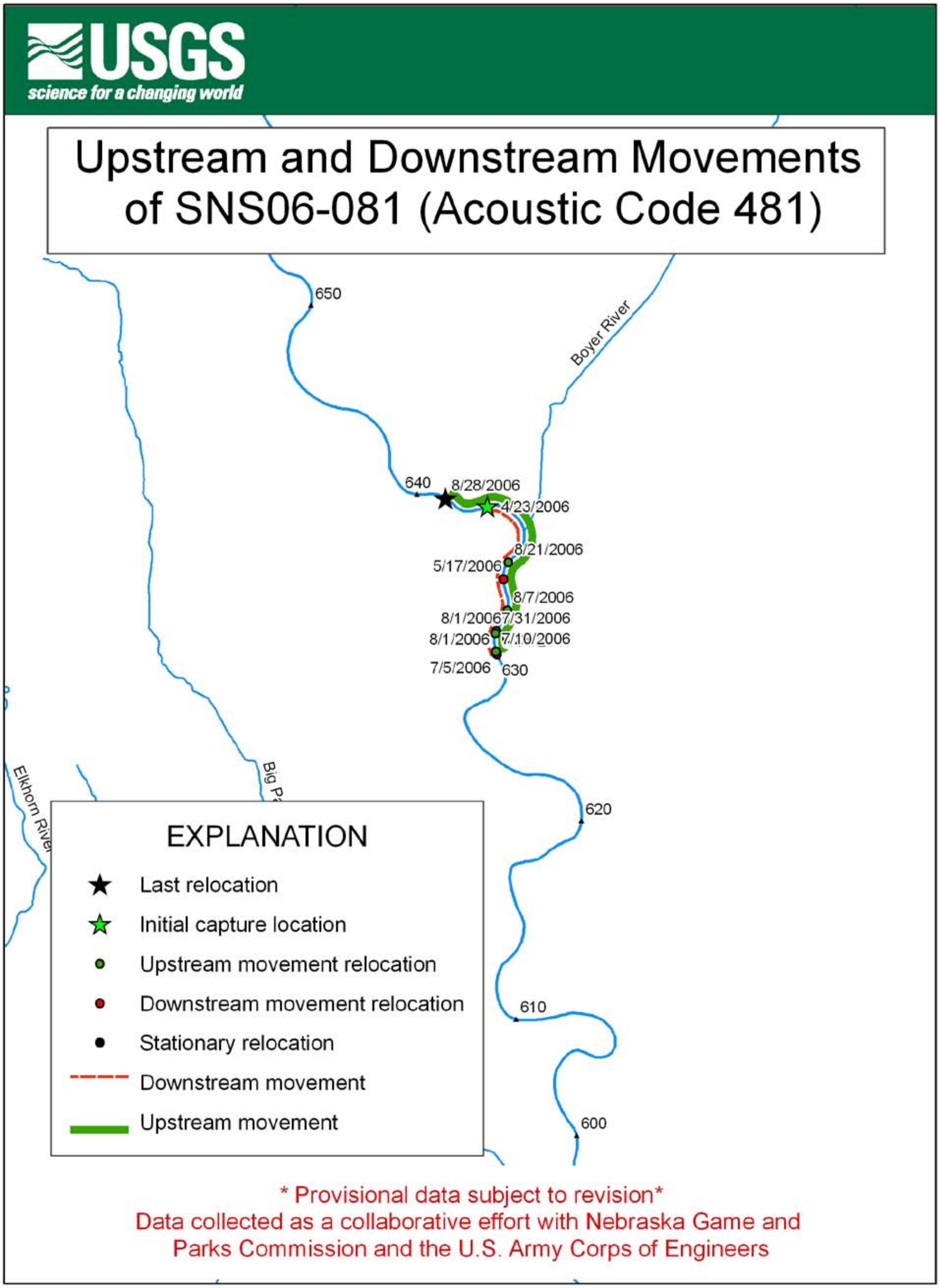


Figure B47. Movement map for shovelnose sturgeon SNS06–081 showing interpolated upstream and downstream movement. Fish was recaptured and did not spawn.

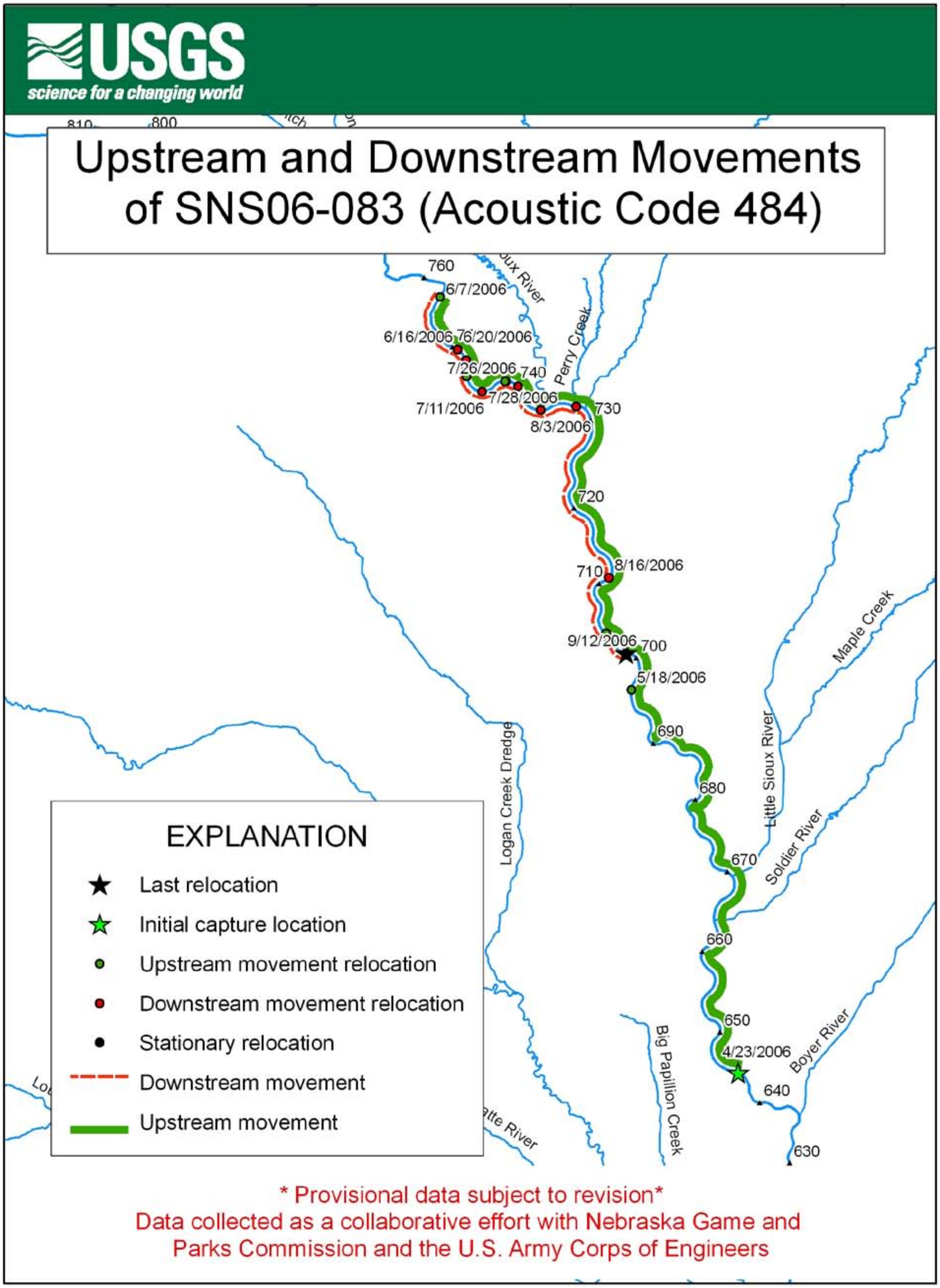


Figure B48. Movement map for shovelnose sturgeon SNS06–083 showing interpolated upstream and downstream movement. Fish was recaptured and did spawn.

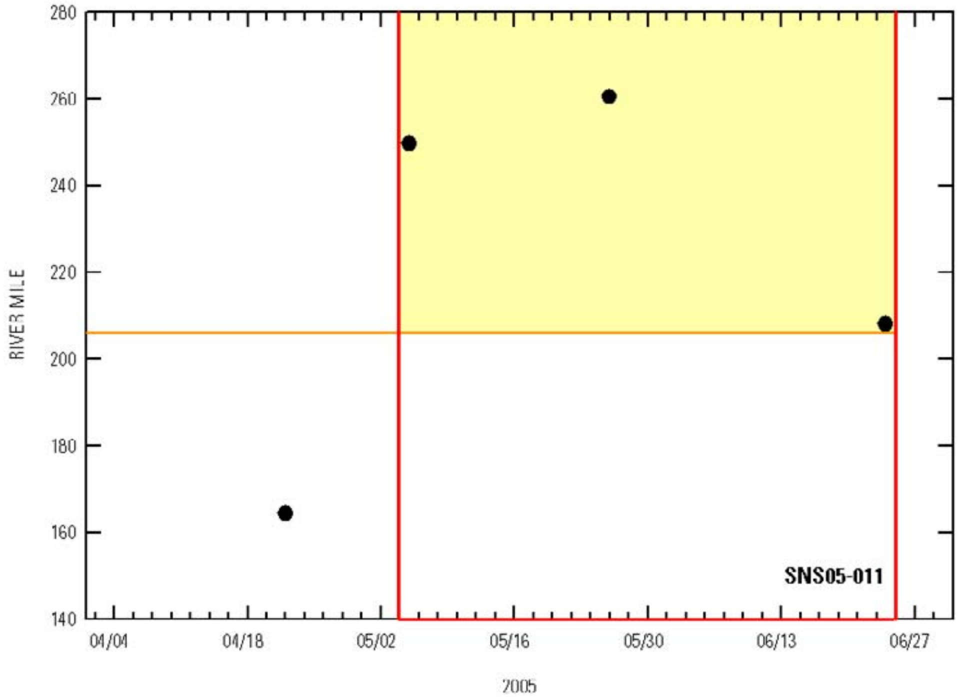


Figure B49. Timing of the maximum upstream location, and locations (indicated by black dots) prior to and following this maximum upstream event for shovelnose sturgeon SNS05–011. Fish was recaptured and did spawn. Red lines indicated approximate time period of spawning. Orange lines indicate approximate location of spawning. The yellow box indicates the range of the approximate time period of spawning and approximate location of spawning.

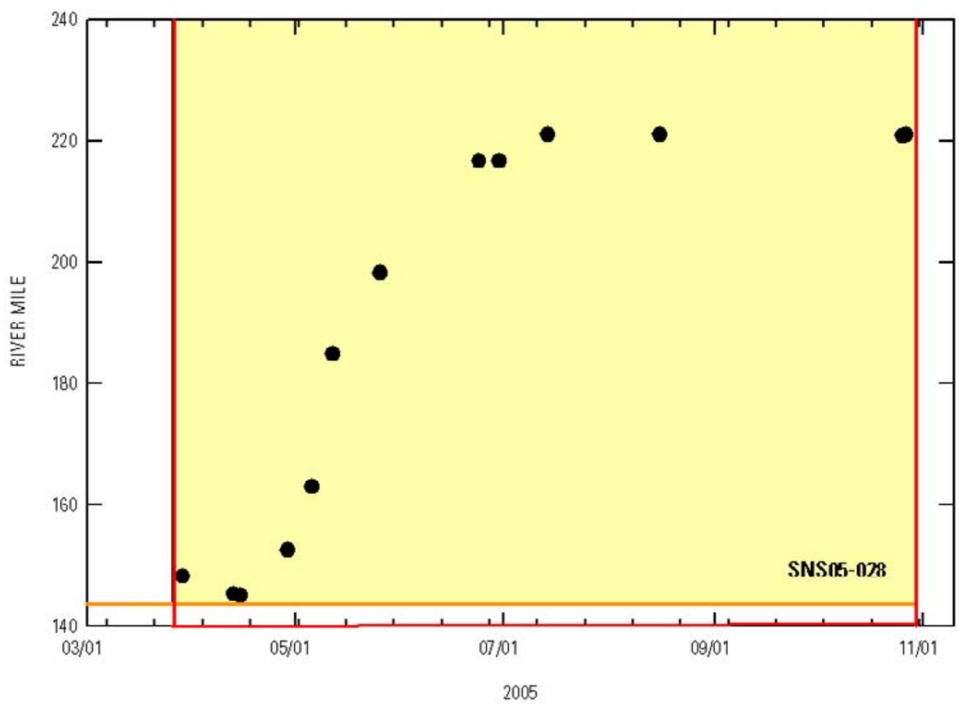


Figure B50. Timing of the maximum upstream location, and locations (indicated by black dots) prior to and following this maximum upstream event for shovelnose sturgeon SNS05–028. Fish was recaptured and did not spawn. Red lines indicated approximate time period of spawning. Orange lines indicate approximate location of spawning. The yellow box indicates the range of the approximate time period of spawning and approximate location of spawning.

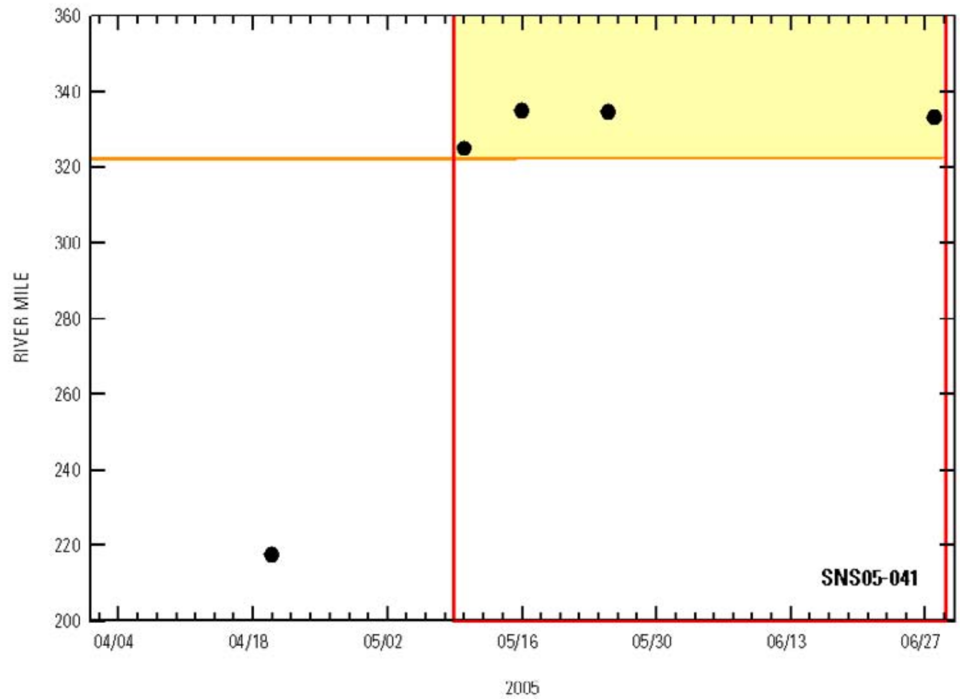


Figure B51. Timing of the maximum upstream location, and locations (indicated by black dots) prior to and following this maximum upstream event for shovelnose sturgeon SNS05–041. Fish was recaptured and did spawn. Red lines indicated approximate time period of spawning. Orange lines indicate approximate location of spawning. The yellow box indicates the range of the approximate time period of spawning and approximate location of spawning.

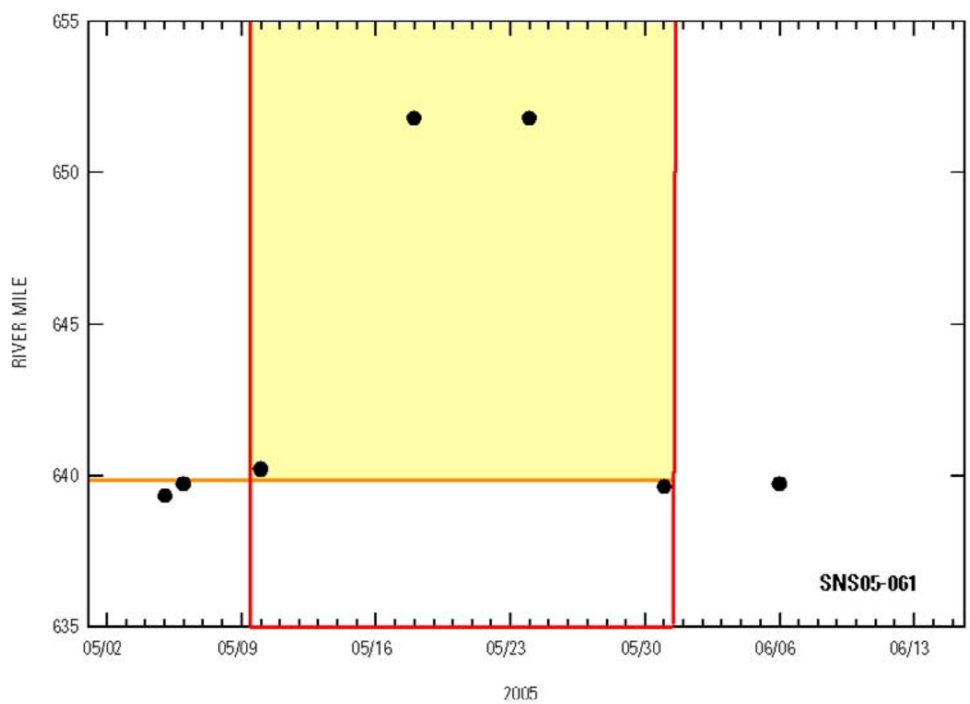


Figure B52. Timing of the maximum upstream location, and locations (indicated by black dots) prior to and following this maximum upstream event for shovelnose sturgeon SNS05–061. Fish was recaptured and did spawn. Red lines indicated approximate time period of spawning. Orange lines indicate approximate location of spawning. The yellow box indicates the range of the approximate time period of spawning and approximate location of spawning.

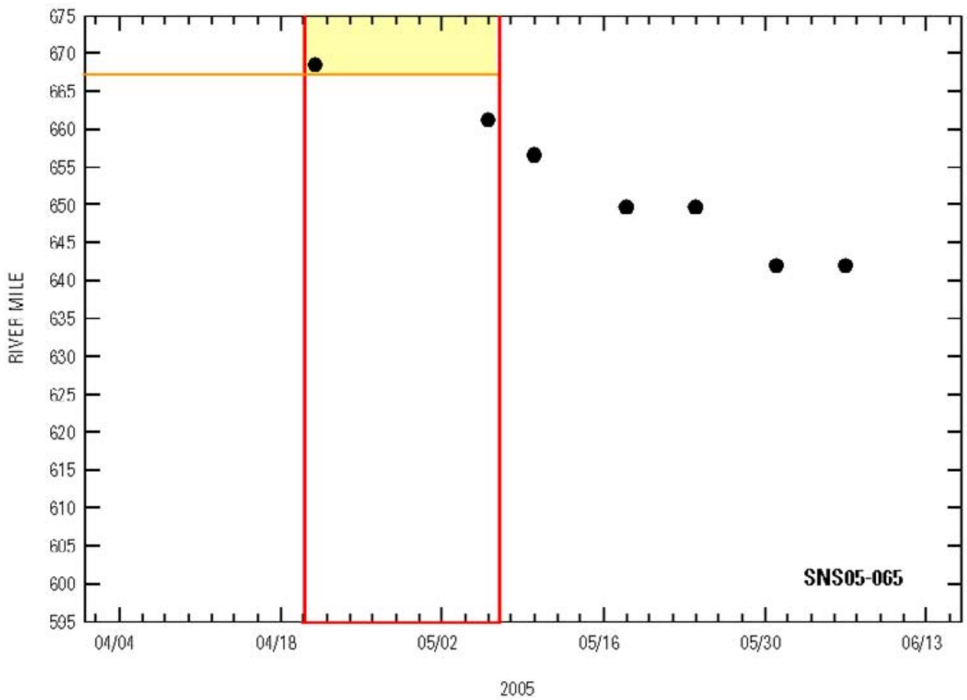


Figure B53. Timing of the maximum upstream location, and locations (indicated by black dots) prior to and following this maximum upstream event for shovelnose sturgeon SNS05–065. Fish was recaptured and did not spawn. Red lines indicated approximate time period of spawning. Orange lines indicate approximate location of spawning. The yellow box indicates the range of the approximate time period of spawning and approximate location of spawning.

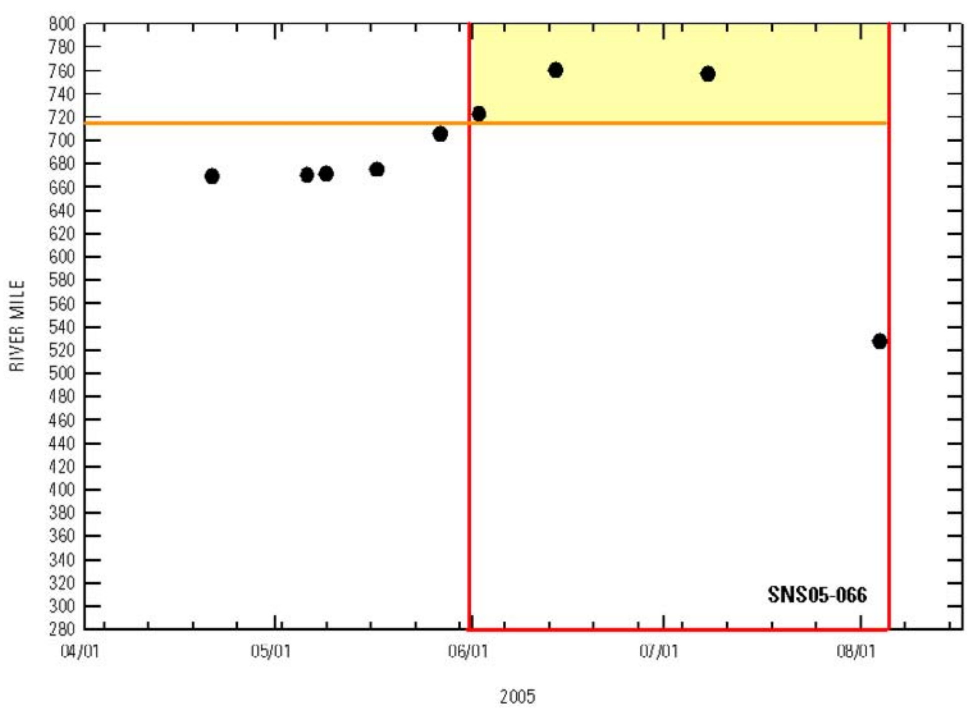


Figure B54. Timing of the maximum upstream location, and locations (indicated by black dots) prior to and following this maximum upstream event for shovelnose sturgeon SNS05–066. Fish was recaptured and did spawn. Red lines indicated approximate time period of spawning. Orange lines indicate approximate location of spawning. The yellow box indicates the range of the approximate time period of spawning and approximate location of spawning.

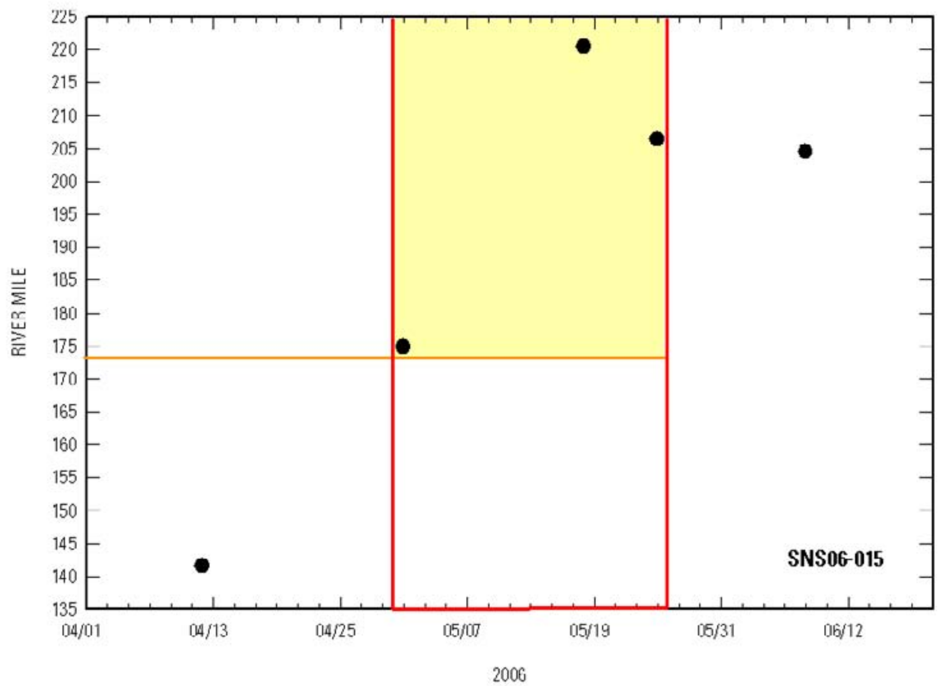


Figure B55. Timing of the maximum upstream location, and locations (indicated by black dots) prior to and following this maximum upstream event for shovelnose sturgeon SNS06–015. Fish was recaptured and did spawn. Red lines indicated approximate time period of spawning. Orange lines indicate approximate location of spawning. The yellow box indicates the range of the approximate time period of spawning and approximate location of spawning.

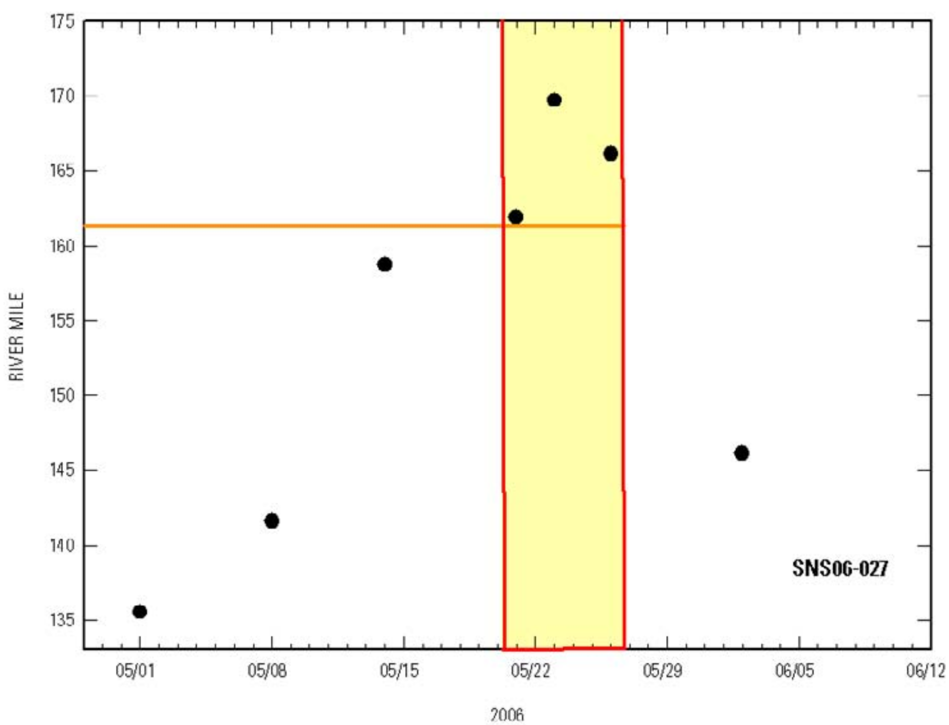


Figure B56. Timing of the maximum upstream location, and locations (indicated by black dots) prior to and following this maximum upstream event for shovelnose sturgeon SNS06–027. Fish was recaptured and did spawn. Red lines indicated approximate time period of spawning. Orange lines indicate approximate location of spawning. The yellow box indicates the range of the approximate time period of spawning and approximate location of spawning.

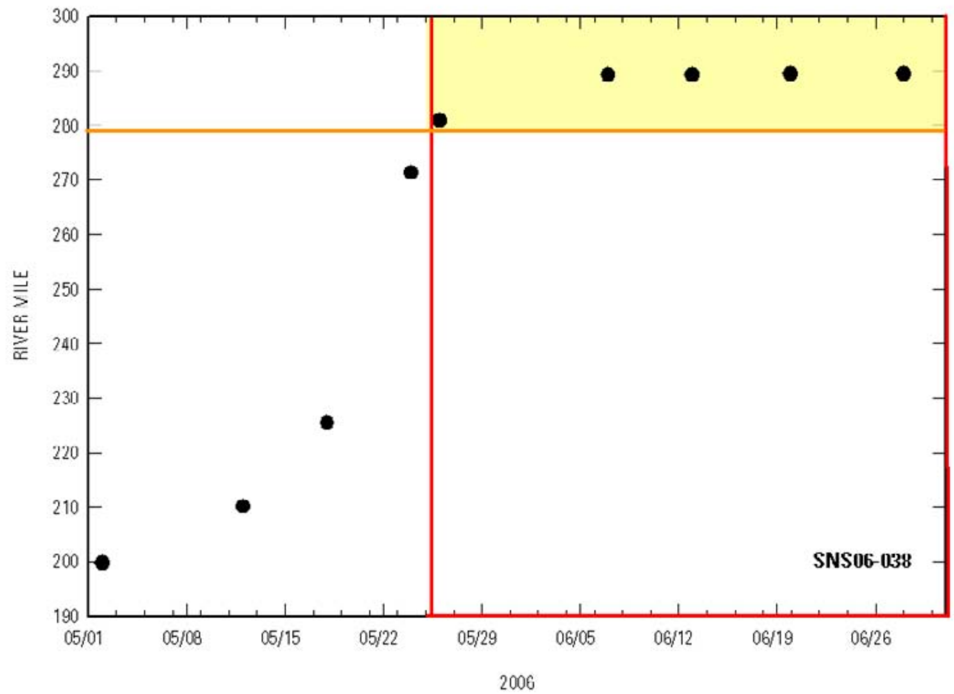


Figure B57. Timing of the maximum upstream location, and locations (indicated by black dots) prior to and following this maximum upstream event for shovelnose sturgeon SNS06–038. Fish was recaptured and did not spawn. Red lines indicated approximate time period of spawning. Orange lines indicate approximate location of spawning. The yellow box indicates the range of the approximate time period of spawning and approximate location of spawning.

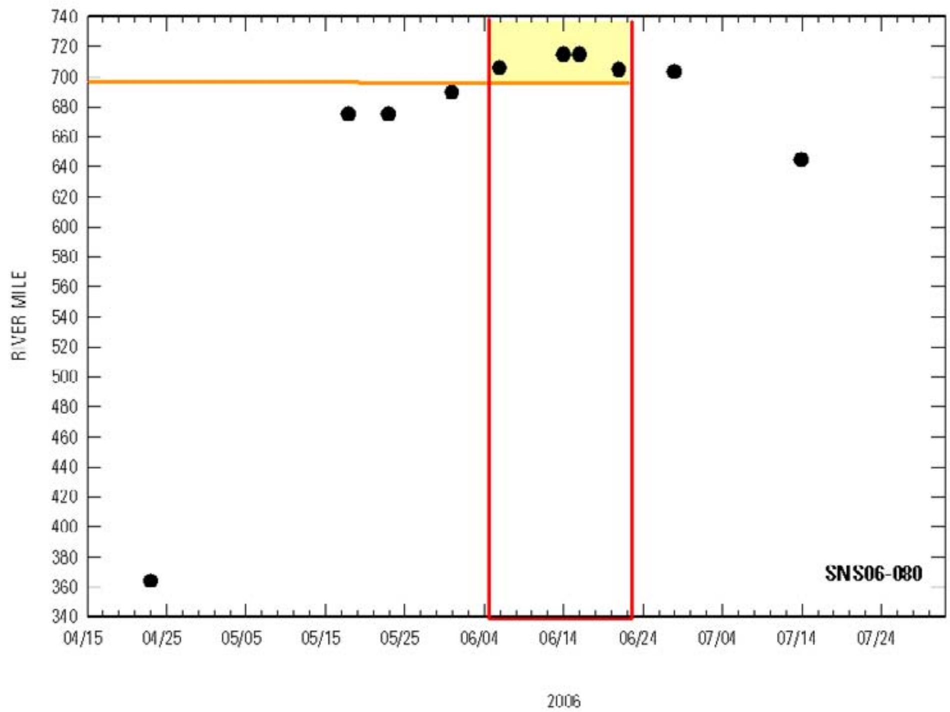


Figure B58. Timing of the maximum upstream location, and locations (indicated by black dots) prior to and following this maximum upstream event for shovelnose sturgeon SNS06–080. Fish was recaptured and did spawn. Red lines indicated approximate time period of spawning. Orange lines indicate approximate location of spawning. The yellow box indicates the range of the approximate time period of spawning and approximate location of spawning.

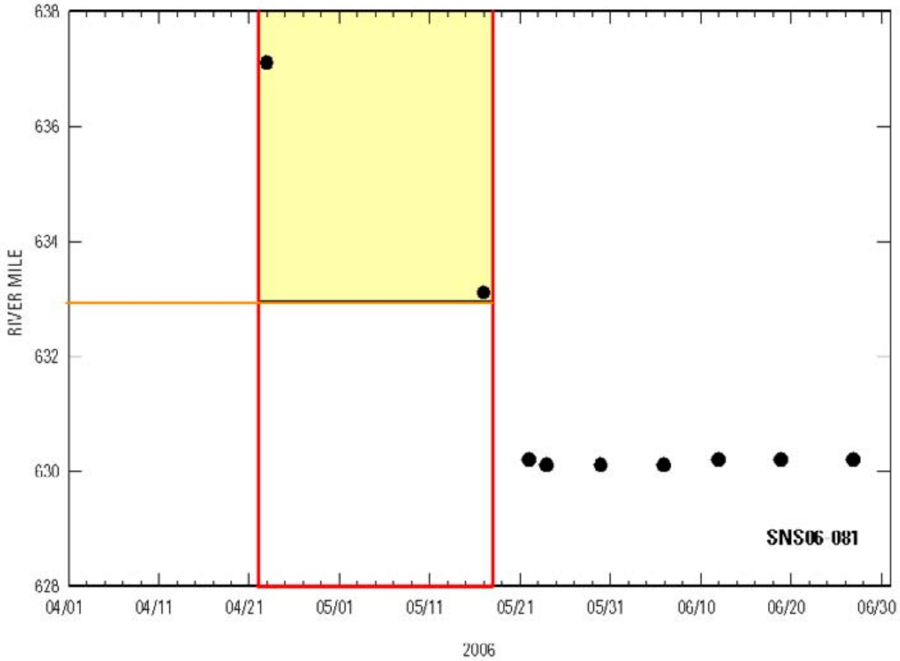


Figure B59. Timing of the maximum upstream location, and locations (indicated by black dots) prior to and following this maximum upstream event for shovelnose sturgeon SNS06–081. Fish was recaptured and did not spawn. Red lines indicated approximate time period of spawning. Orange lines indicate approximate location of spawning. The yellow box indicates the range of the approximate time period of spawning and approximate location of spawning.

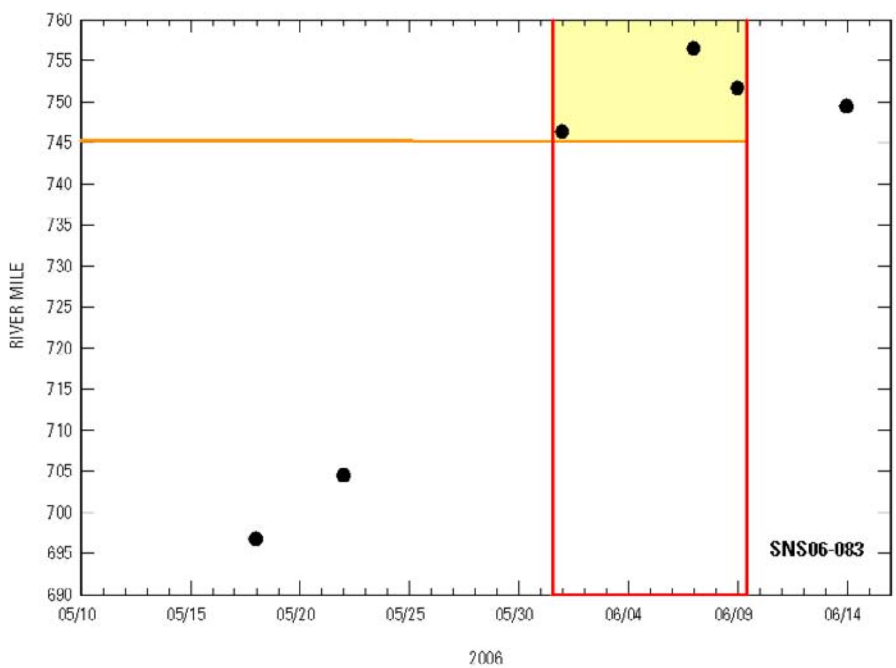


Figure B60. Timing of the maximum upstream location, and locations (indicated by black dots) prior to and following this maximum upstream event for shovelnose sturgeon SNS06–083. Fish was recaptured and did spawn. Red lines indicated approximate time period of spawning. Orange lines indicate approximate location of spawning. The yellow box indicates the range of the approximate time period of spawning and approximate location of spawning.

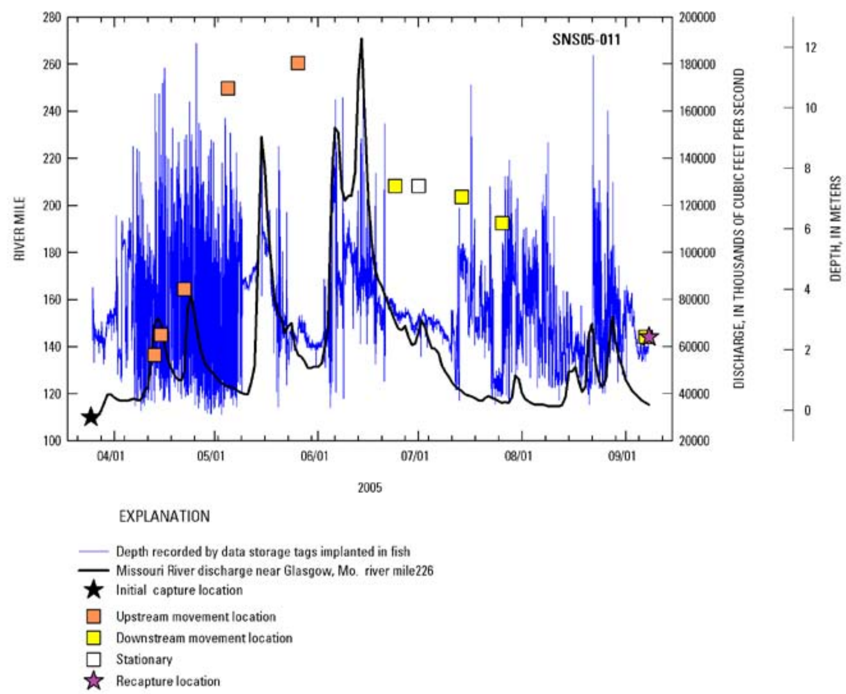


Figure B61. Depths, collected from data storage tag (DST), telemetry relocations, and daily mean temperature and discharge from nearest upstream gage for implanted shovelnose sturgeon SNS05–011. Fish was recaptured and did spawn.

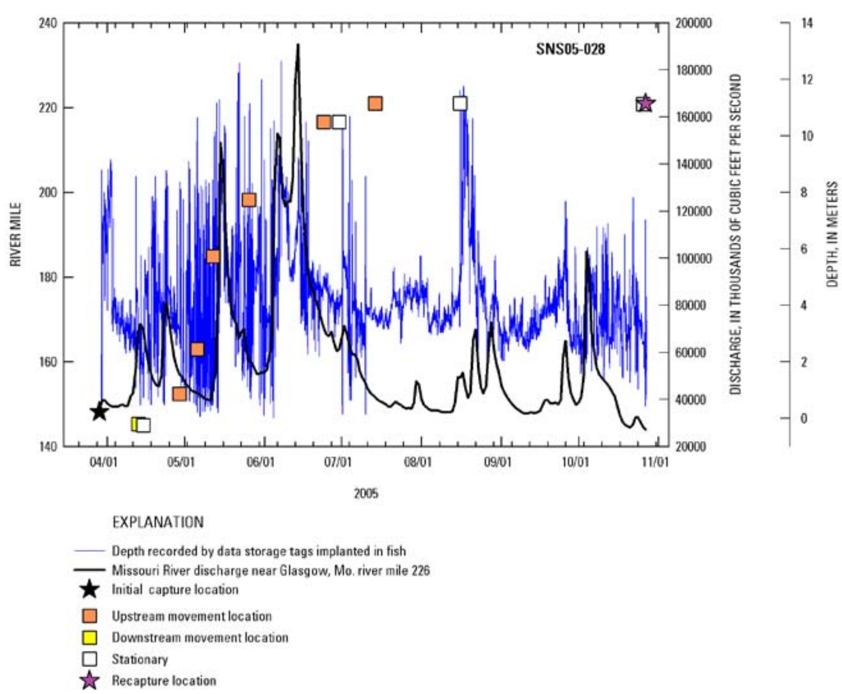


Figure B62. Depths, collected from data storage tag (DST), telemetry relocations, and daily mean temperature and discharge from nearest upstream gage for implanted shovelnose sturgeon SNS05–028. Fish was recaptured and did not spawn.

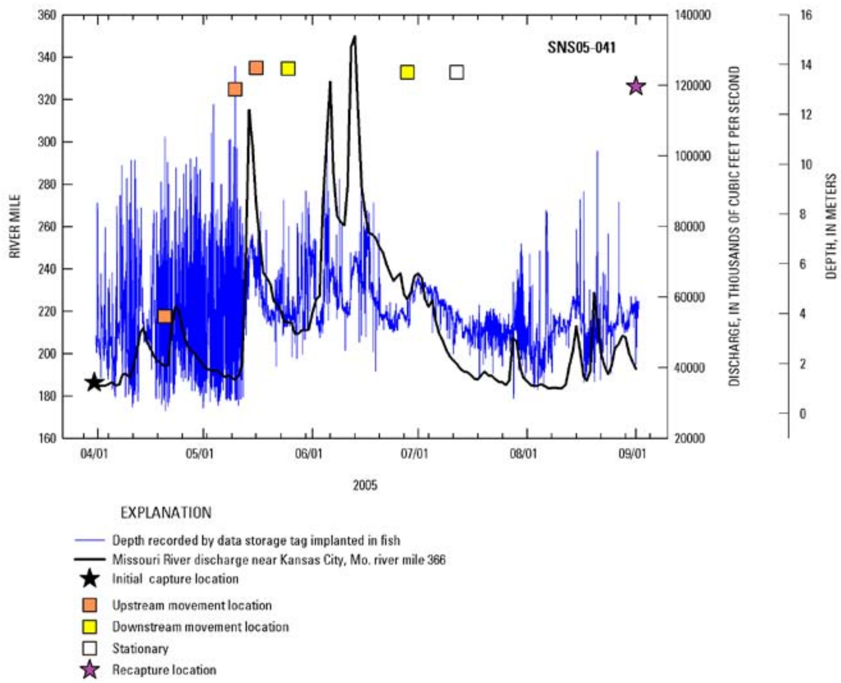


Figure B63. Depths, collected from data storage tag (DST), telemetry relocations, and daily mean temperature and discharge from nearest upstream gage for implanted shovelnose sturgeon SNS05–041. Fish was recaptured and did spawn.

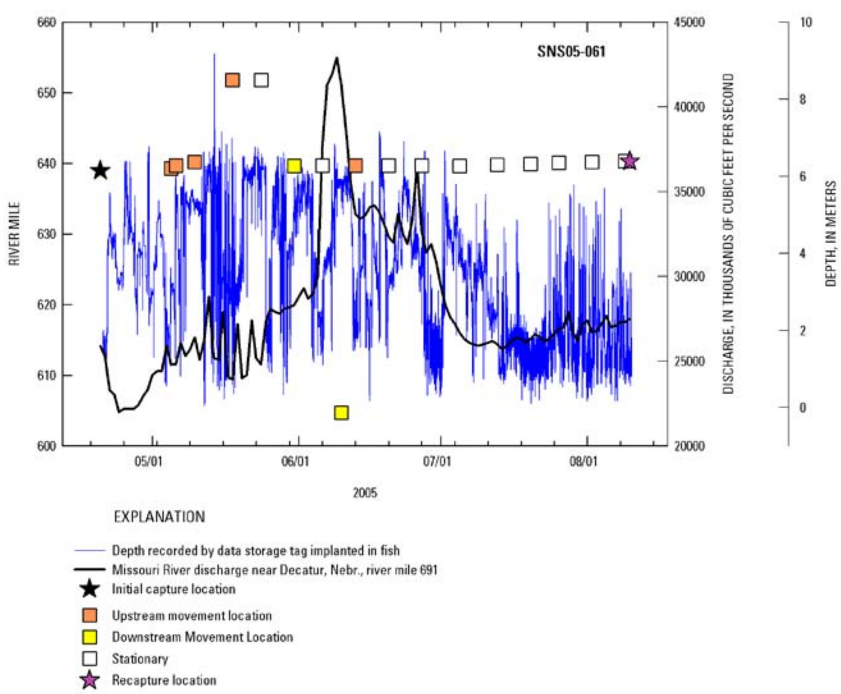


Figure B64. Depths, collected from data storage tag (DST), telemetry relocations, and daily mean temperature and discharge from nearest upstream gage for implanted shovelnose sturgeon SNS05–061. Fish was recaptured and did spawn.

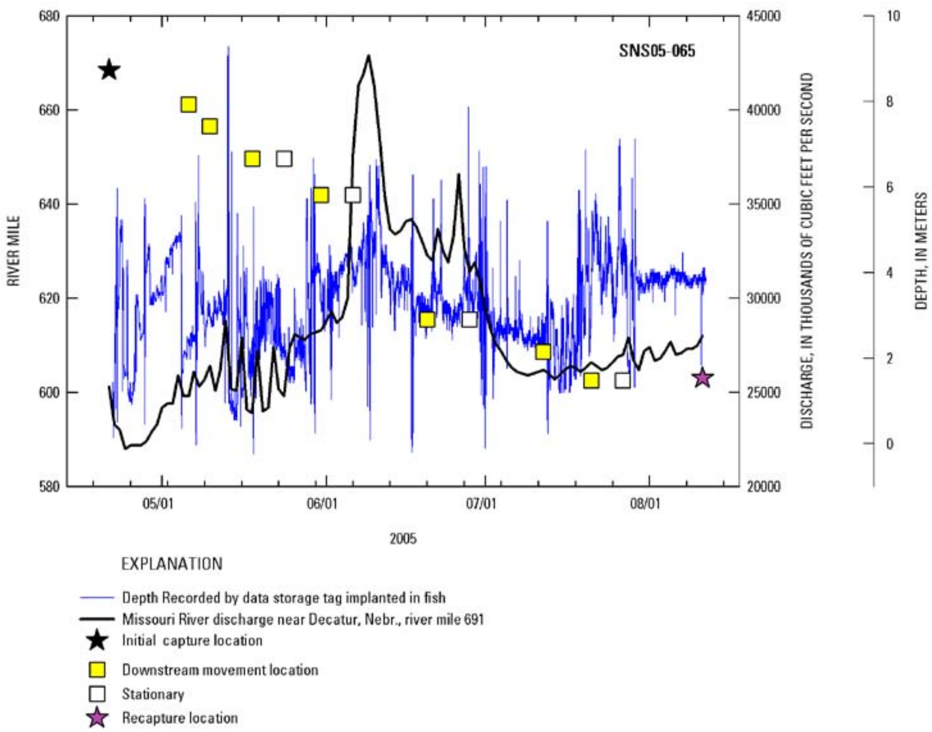


Figure B65. Depths, collected from data storage tag (DST), telemetry relocations, and daily mean temperature and discharge from nearest upstream gage for implanted shovelnose sturgeon SNS05–065. Fish was recaptured and did not spawn.

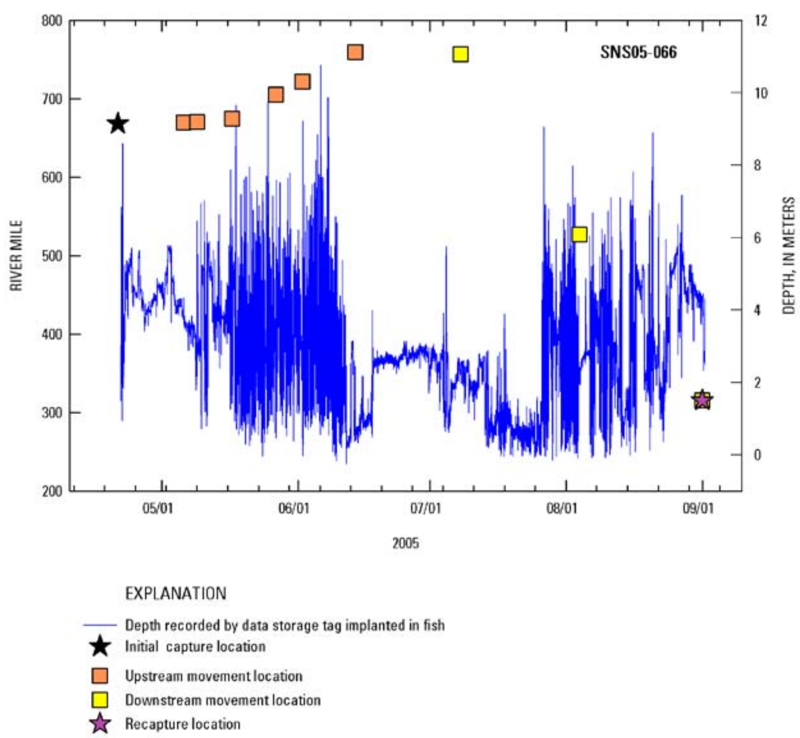


Figure B66. Depths, collected from data storage tag (DST) and telemetry relocations for implanted shovelnose sturgeon SNS05–066. Fish was recaptured and did spawn.

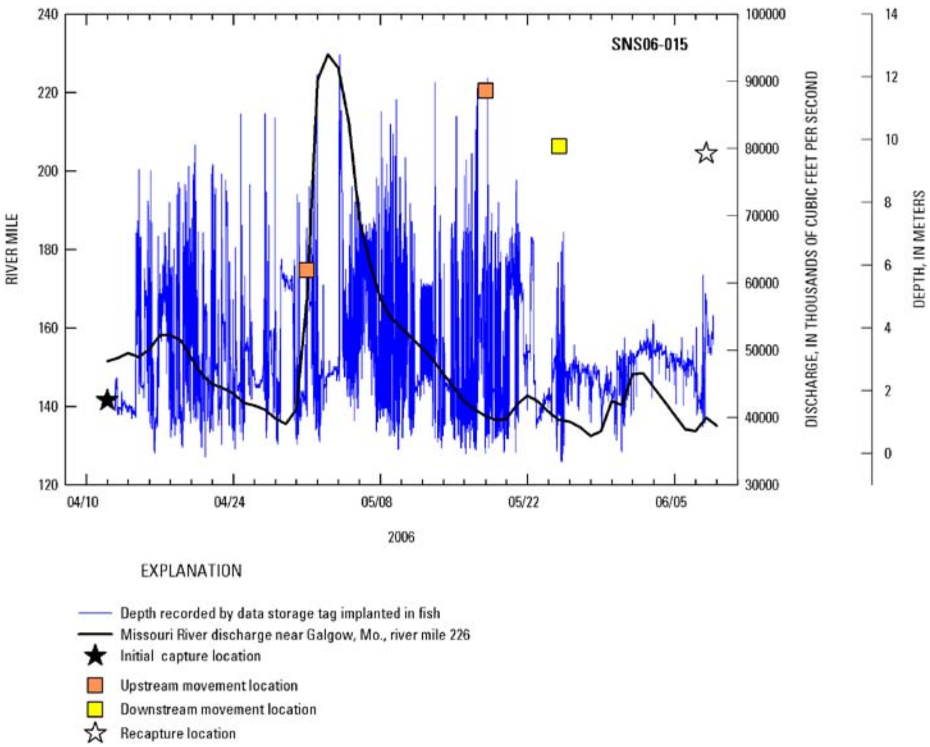


Figure B67. Depths, collected from data storage tag (DST), telemetry relocations, and daily mean temperature and discharge from nearest upstream gage for implanted shovelnose sturgeon SNS06–015. Fish was recaptured and did spawn.

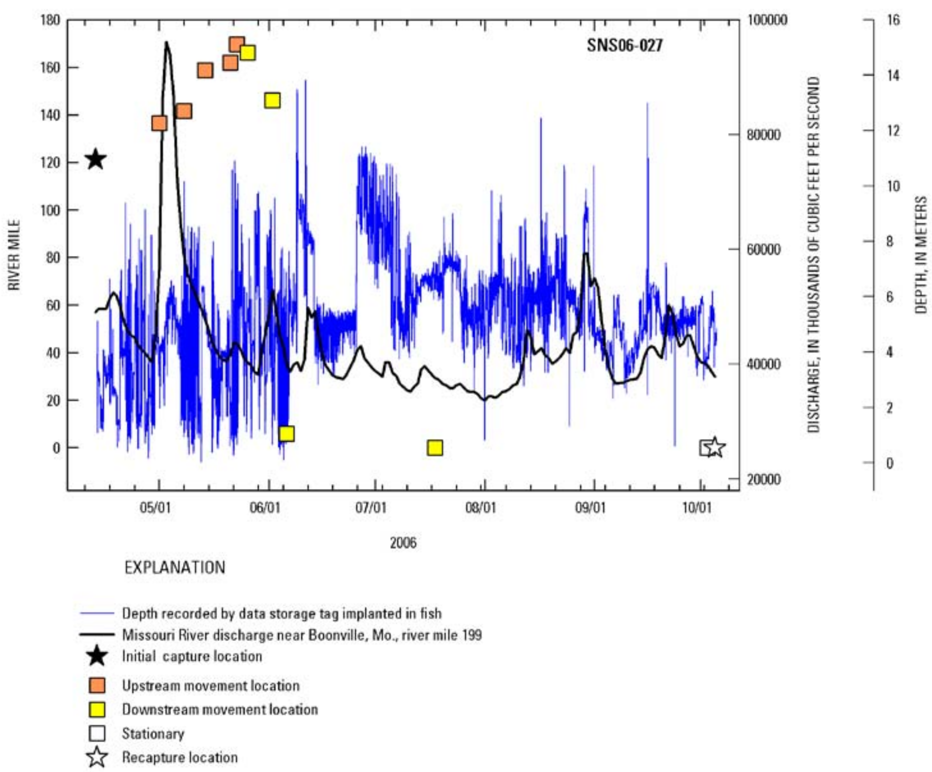


Figure B68. Depths, collected from data storage tag (DST), telemetry relocations, and daily mean temperature and discharge from nearest upstream gage for implanted shovelnose sturgeon SNS06–027. Fish was recaptured and did spawn.

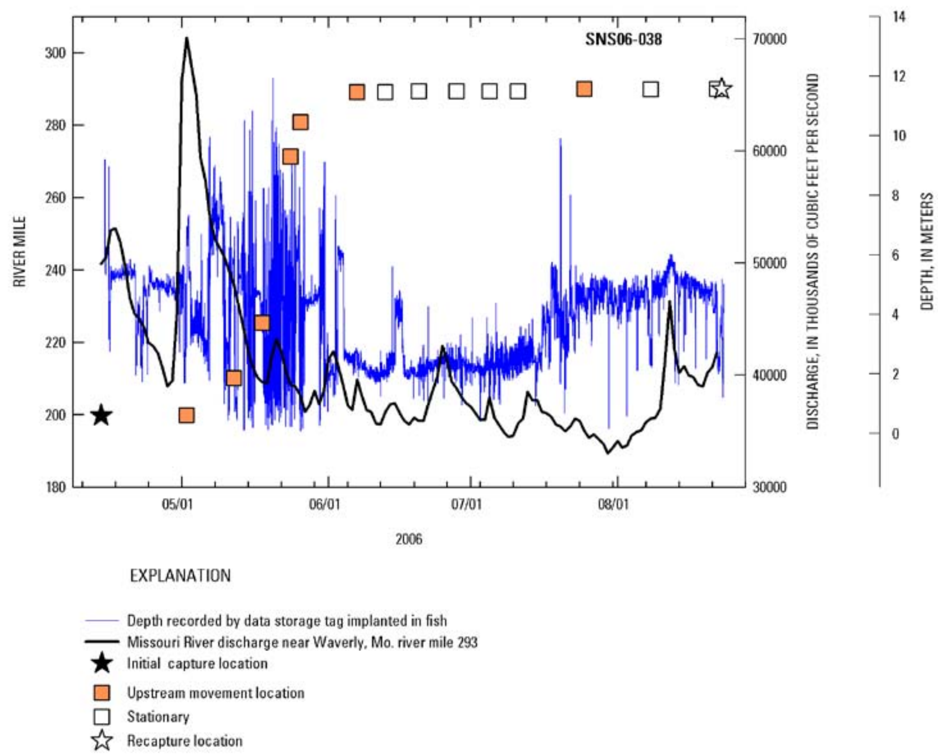


Figure B69. Depths, collected from data storage tag (DST), telemetry relocations, and daily mean temperature and discharge from nearest upstream gage for implanted shovelnose sturgeon SNS06–038. Fish was recaptured and did not spawn.

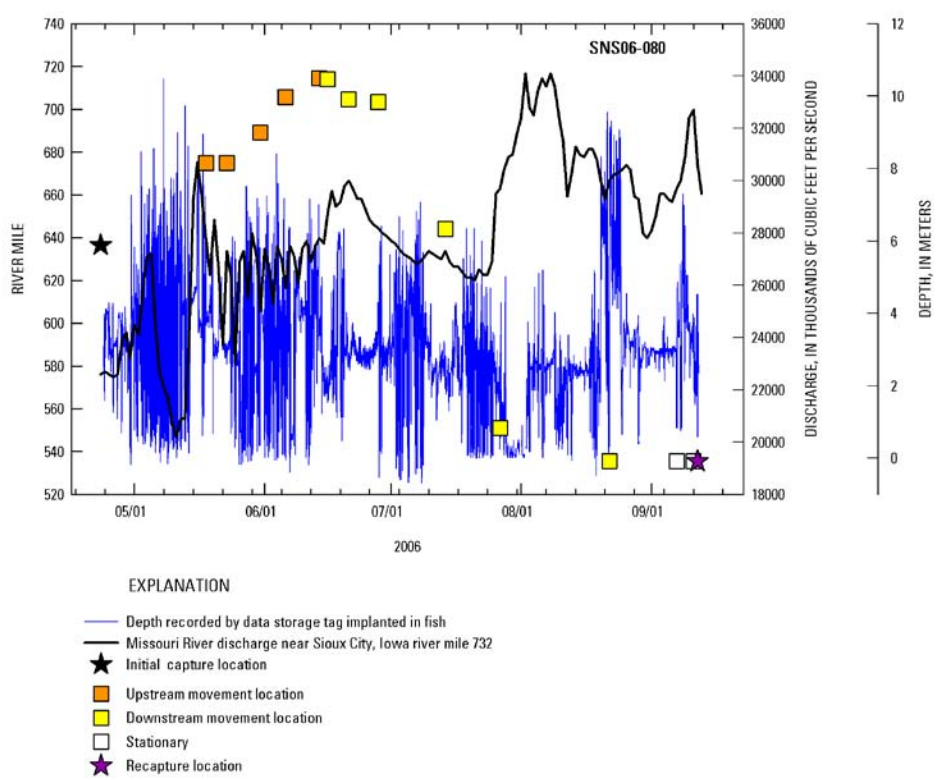


Figure B70. Depths, collected from data storage tag (DST), telemetry relocations, and daily mean temperature and discharge from nearest upstream gage for implanted shovelnose sturgeon SNS06–080. Fish was recaptured and did spawn.

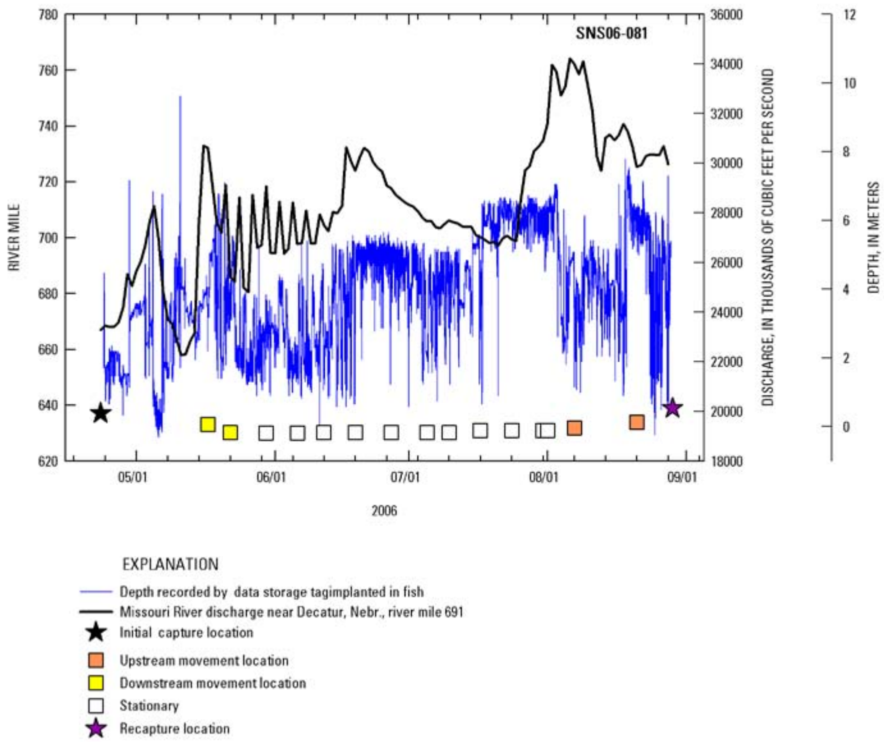


Figure B71. Depths, collected from data storage tag (DST), telemetry relocations, and daily mean temperature and discharge from nearest upstream gage for implanted shovelnose sturgeon SNS06–081. Fish was recaptured and did not spawn.

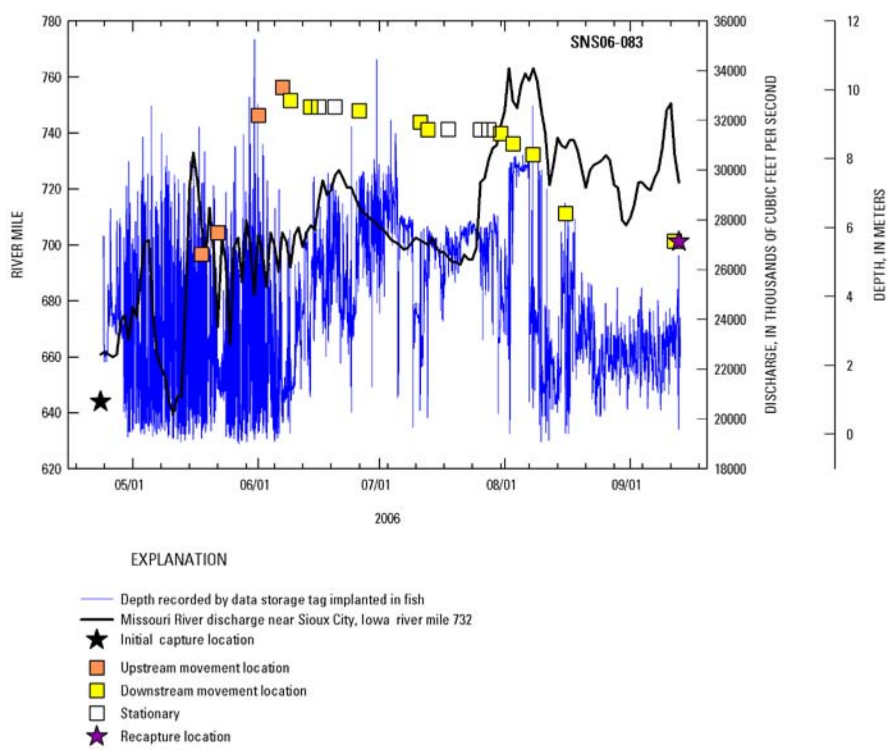


Figure B72. Depths, collected from data storage tag (DST), telemetry relocations, and daily mean temperature and discharge from nearest upstream gage for implanted shovelnose sturgeon SNS06–083. Fish was recaptured and did spawn.

Figure B73. Necropsy of recaptured shovelnose sturgeon. This female had spawned between implantation and recapture. Suture material is still visible in healed incision.

Figure B74. Dissected ovaries removed during necropsy of recaptured shovelnose sturgeon. This female had spawned between implantation and recapture. Note the retained and resorbing oocytes near the location of the transmitter and incision on the ovary nearest the bottom of the photograph. Some adhesion to the abdominal wall was evident.

Figure B75. Necropsy of recaptured shovelnose sturgeon. This female did not spawn. Note the adhesion of the gonad to the abdominal wall present in most implanted females.

Figure B76. Dissected ovaries removed during necropsy of recaptured shovelnose sturgeon. This female did not spawn. The ovaries have become atretic.

Figure B77. Necropsy of recaptured shovelnose sturgeon. This female had spawned between implantation and recapture. Note the significant adhesion of ovarian tissue to the abdominal wall at the incision site and the marked absence of gonadal fat.

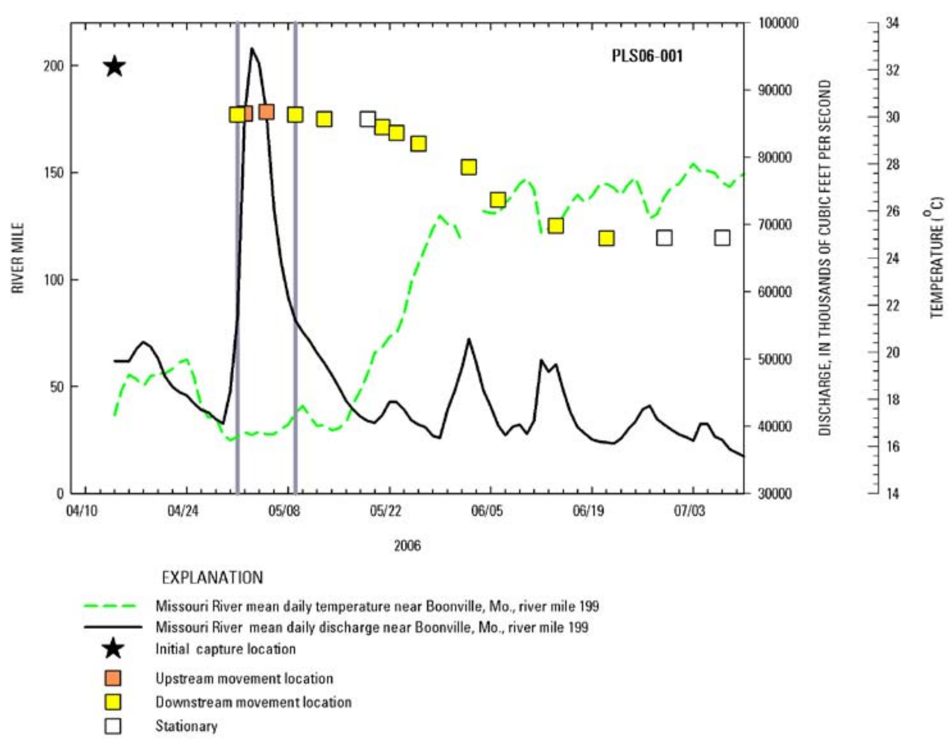


Figure B78. Telemetry relocations and daily mean temperature and discharge from nearest upstream gage for implanted pallid sturgeon PLS06–001. The gray lines denote the only observed upstream movement by this male, coincident with proximity to known coarse substrate deposits during the purported spawning season.

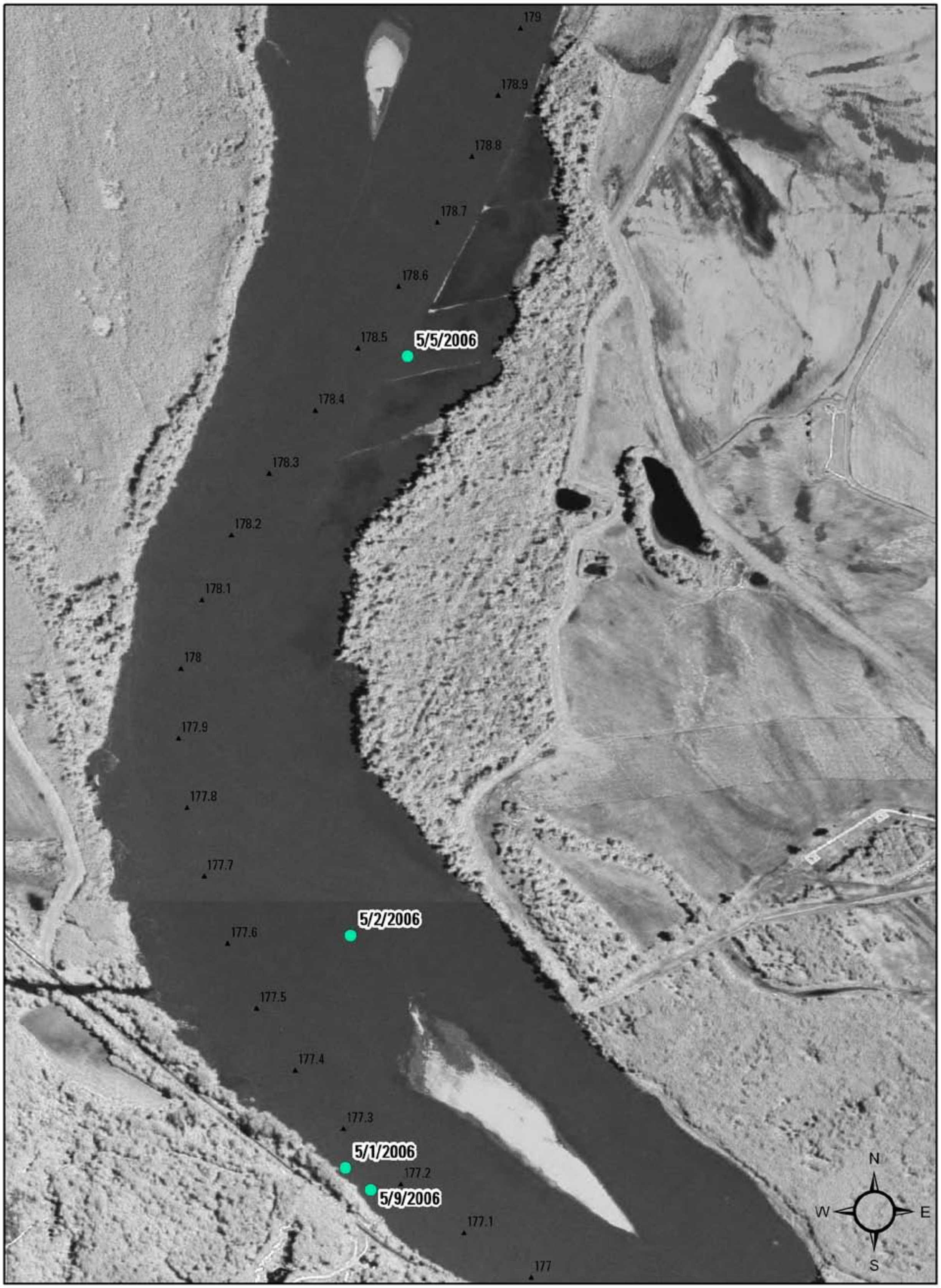


Figure B79. Relocation sites of male pallid sturgeon PLS06–001 during the spawning period during early May 2006. The relocations mapped occur during the shaded period in figure B78. The sturgeon was in reproductive condition when implanted on April 14, 2006, at river mile 199.6.

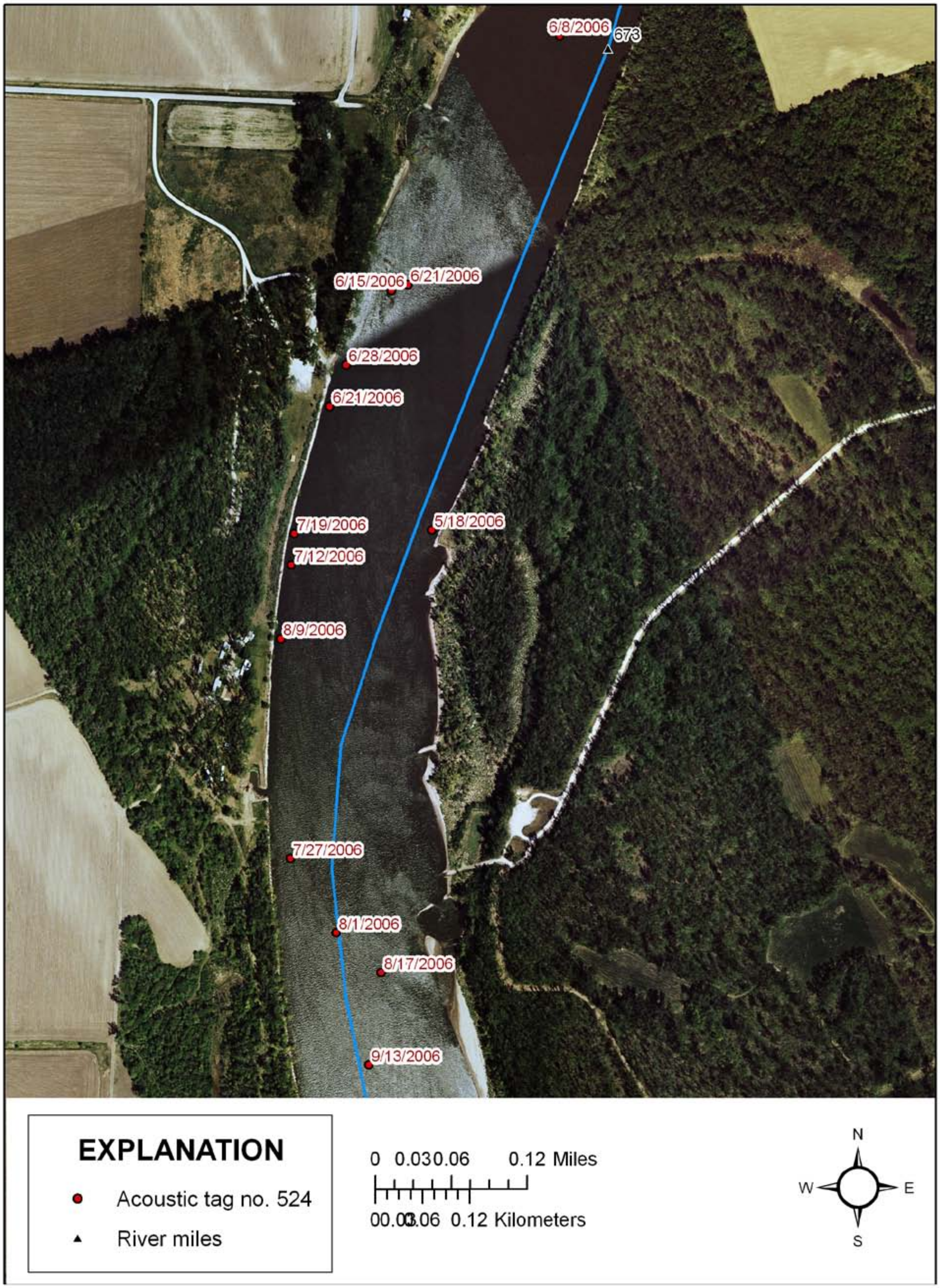


Figure B80. Relocation sites of pallid sturgeon PLS06–009 between river miles 673 and 672 from May 18, 2006, through September 13, 2006. This sturgeon was not in reproductive condition.

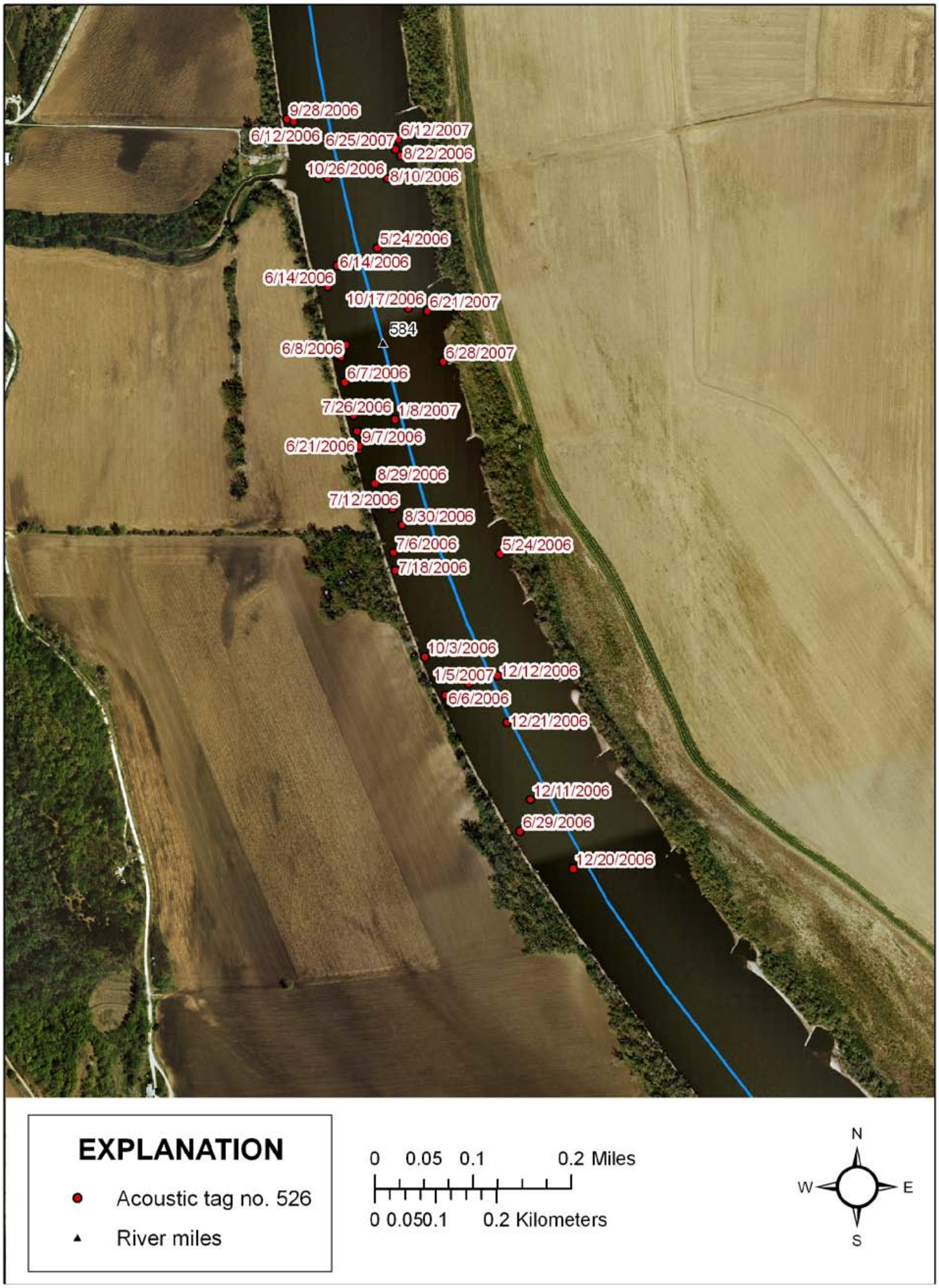


Figure B81. Relocation sites of pallid sturgeon PLS06–006 between river miles 585 and 583 from May 24, 2006, through October 26, 2006. This sturgeon was not in reproductive condition.

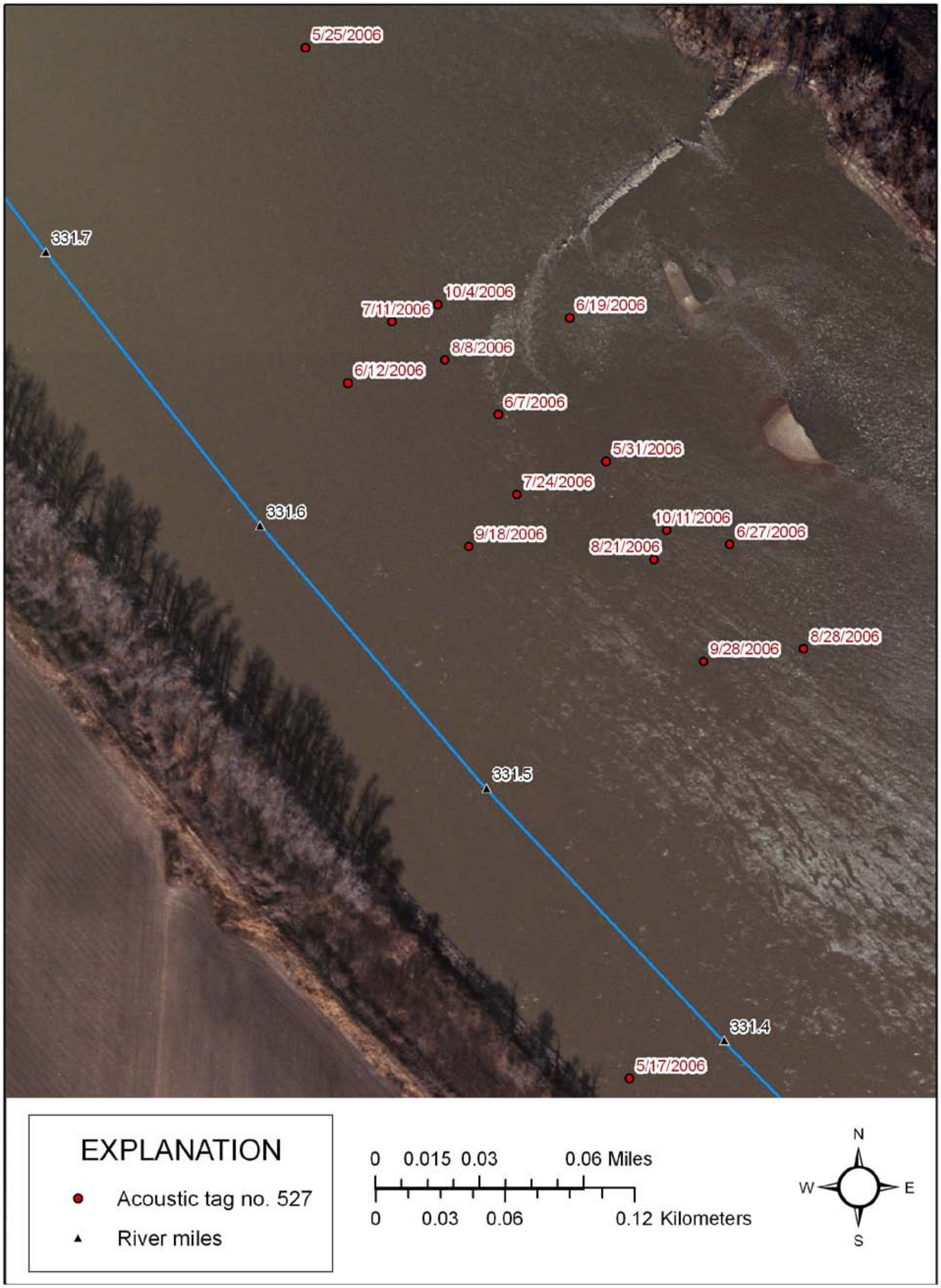


Figure B82. Relocation sites of pallid sturgeon PLS06–003 between river miles 332 and 331 from May 17, 2006, through October 11, 2006. This sturgeon was not in reproductive condition.

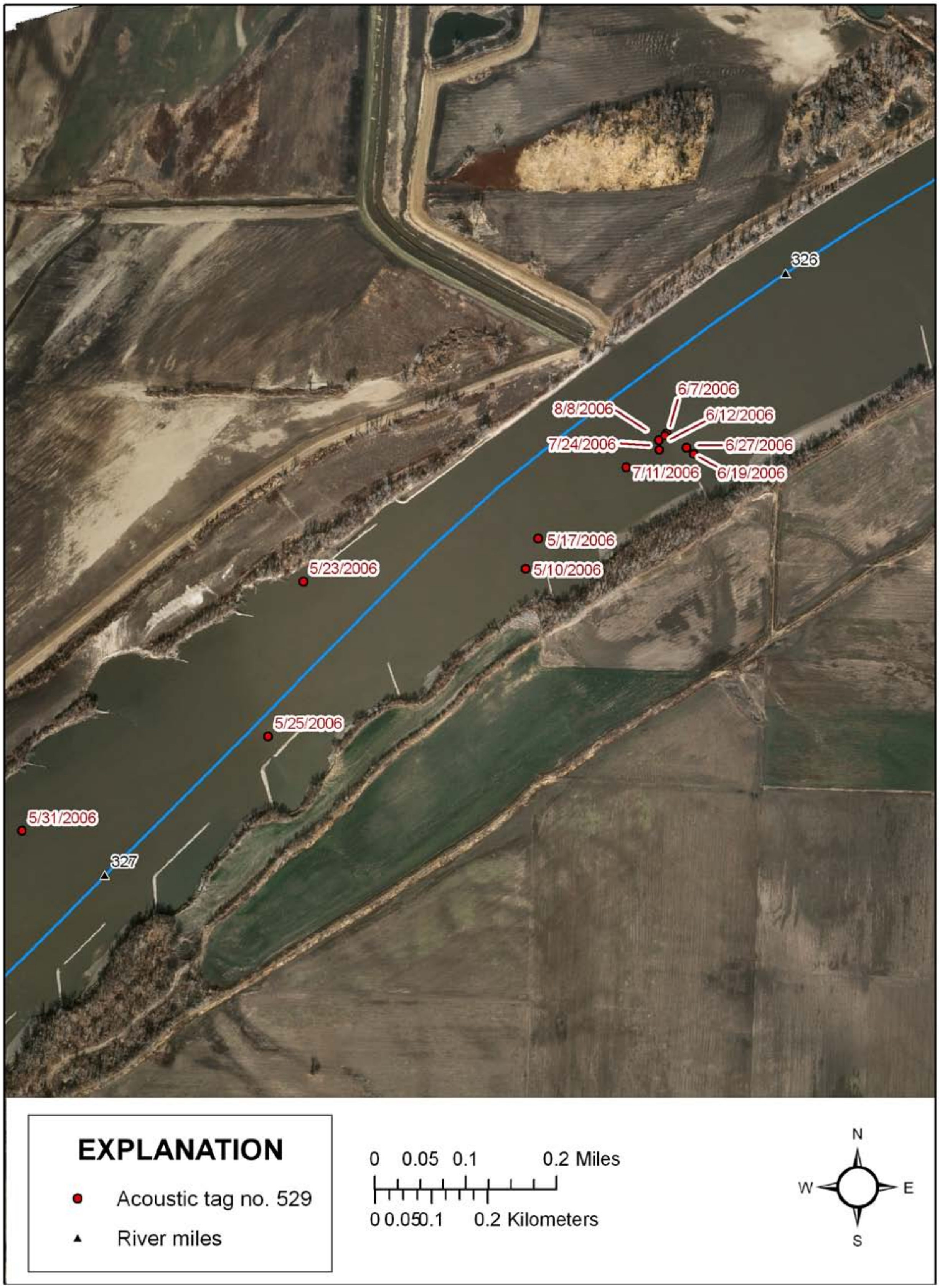


Figure B83. Relocation sites of pallid sturgeon PLS06–004 between river miles 327 and 326 from May 10, 2006, through August 8, 2006. This sturgeon was not in reproductive condition.

Table B1. Shovelnose sturgeon implanted in March–April 2005.

[ID, identification number; mm, millimeter; g, gram; F, female; M, male]

Fish ID	Implantation date	Segment origin	Capture river mile	Sex	Fork length (mm)	Weight (g)	Acoustic code
SNS05–001	3/24/05	Lower	190.1	F	665	1,350	100
SNS05–002	3/24/05	Lower	190.1	F	615	1,050	97
SNS05–003	3/25/05	Lower	188.9	F	732	1,500	30700
SNS05–004	3/24/05	Lower	188.1	F	605	1,050	98
SNS05–005	3/24/05	Lower	191.4	F	693	1,500	99
SNS05–006	3/24/05	Lower	192.2	F	617	1,050	96
SNS05–007	3/24/05	Lower	192.0	F	638	1,050	95
SNS05–008	3/25/05	Lower	110.5	F	628	1,100	101
SNS05–009	3/25/05	Lower	110.3	F	659	1,300	31200
SNS05–010	3/25/05	Lower	110.3	F	658	1,150	103
SNS05–011	3/25/05	Lower	110.3	F	638	1,000	102
SNS05–012	3/25/05	Lower	111.7	F	674	1,250	30400
SNS05–013	3/25/05	Lower	111.7	F	695	1,250	104
SNS05–014	3/25/05	Lower	111.7	F	655	1,250	94
SNS05–015	3/29/05	Lower	142.4	F	714	1,760	105
SNS05–016	3/29/05	Lower	142.4	F	673	1,300	107
SNS05–017	3/29/05	Lower	142.2	F	705	1,680	30000
SNS05–018	3/29/05	Lower	142.2	F	623	1,130	106
SNS05–019	3/29/05	Lower	146.4	F	648	1,410	29500
SNS05–020	3/29/05	Lower	142.4	F	668	1,260	111
SNS05–021	3/29/05	Lower	146.4	F	688	1,170	110
SNS05–022	3/29/05	Lower	146.4	F	674	1,530	29700
SNS05–023	3/29/05	Lower	147.6	F	684	1,700	31100
SNS05–024	3/29/05	Lower	147.6	F	704	1,490	113
SNS05–025	3/29/05	Lower	147.4	F	718	1,590	112
SNS05–026	3/29/05	Lower	147.4	F	663	1,140	114
SNS05–027	3/29/05	Lower	147.6	F	653	1,260	118
SNS05–028	3/29/05	Lower	148.2	F	683	1,630	116
SNS05–029	3/29/05	Lower	148.0	F	703	1,610	117
SNS05–030	3/29/05	Lower	147.4	F	624	1,200	115
SNS05–031	3/29/05	Lower	148.2	F	678	1,270	109
SNS05–032	3/30/05	Lower	186.7	F	634	1,800	30200
SNS05–033	3/30/05	Lower	185.7	F	671	1,250	72
SNS05–034	3/30/05	Lower	182.8	F	672	1,100	71

Table B1. Shovelnose sturgeon implanted in March–April 2005.—Continued

[ID, identification number; mm, millimeter; g, gram; F, female; M, male]

Fish ID	Implantation date	Segment origin	Capture river mile	Sex	Fork length (mm)	Weight (g)	Acoustic code
SNS05–035	3/30/05	Lower	185.7	F	611	1,070	69
SNS05–036	3/30/05	Lower	186.7	F	621	1,010	76
SNS05–037	3/30/05	Lower	185.1	F	629	1,100	30100
SNS05–039	3/31/05	Lower	186.4	F	709	1,730	73
SNS05–040	3/31/05	Lower	187.4	F	688	1,330	75
SNS05–041	3/31/05	Lower	186.4	F	685	1,340	74
SNS05–042	3/31/05	Lower	187.4	F	716	1,740	70
SNS05–043	4/01/05	Lower	130.2	F	589	1,040	92
SNS05–044	4/01/05	Lower	129.0	F	654	1,210	90
SNS05–045	4/01/05	Lower	126.6	F	717	1,600	30500
SNS05–046	4/01/05	Lower	126.6	F	709	1,810	108
SNS05–047	4/01/05	Lower	127.4	F	663	1,061	87
SNS05–048	4/01/05	Lower	126.7	F	718	2,100	77
SNS05–049	4/05/05	Lower	126.7	F	685	1,470	89
SNS05–050	4/05/05	Lower	126.3	F	718	1,950	84
SNS05–051	4/05/05	Lower	124.9	F	674	1,470	80
SNS05–052	4/19/05	Upper	635.9	F	628	1,010	140
SNS05–053	4/19/05	Upper	638.4	F	693	1,460	141
SNS05–054	4/19/05	Upper	638.4	F	659	1,170	142
SNS05–055	4/19/05	Upper	638.3	F	756	1,670	136
SNS05–056	4/19/05	Upper	638.3	F	604	1,100	30300
SNS05–057	4/19/05	Upper	637.1	F	630	1,060	143
SNS05–058	4/20/05	Upper	641.3	F	620	1,030	139
SNS05–059	4/20/05	Upper	638.7	F	674	1,250	138
SNS05–060	4/20/05	Upper	639.0	F	679	1,170	137
SNS05–061	4/20/05	Upper	639.0	F	613	1,020	135
SNS05–062	4/20/05	Upper	638.7	F	622	1,100	134
SNS05–063	4/21/05	Upper	668.5	F	659	1,110	31400
SNS05–064	4/21/05	Upper	668.5	F	745	1,550	133
SNS05–065	4/21/05	Upper	668.5	F	650	1,010	130
SNS05–066	4/21/05	Upper	668.5	F	687	1,370	131
SNS05–067	4/28/05	Upper	609.3	F	695	1,500	119
SNS05–068	4/28/05	Upper	610.1	F	683	1,190	120
SNS05–069	4/28/05	Upper	609.4	F	794	1,870	29800

Table B1. Shovelnose sturgeon implanted in March–April 2005.—Continued

[ID, identification number; mm, millimeter; g, gram; F, female; M, male]

Fish ID	Implantation date	Segment origin	Capture river mile	Sex	Fork length (mm)	Weight (g)	Acoustic code
SNS05–070	4/28/05	Upper	609.3	F	666	1,230	121
SNS05–071	4/28/05	Upper	609.3	F	720	1,570	29900
SNS05–072	4/28/05	Upper	609.4	F	685	1,470	122
SNS05–073	4/28/05	Upper	609.8	F	625	1,010	123
SNS05–074	4/28/05	Upper	610.1	F	638	1,130	124
SNS05–075	4/28/05	Upper	610.1	F	658	1,010	125
SNS05–076	4/28/05	Upper	609.3	F	643	1,190	30900
SNS05–077	4/28/05	Upper	609.4	F	653	1,150	126
SNS05–078	4/28/05	Upper	609.8	F	643	1,190	127
SNS05–079	4/28/05	Upper	610.1	F	565	1,000	128
SNS05–080	4/28/05	Upper	609.4	F	597	1,000	129
SNS05–081	4/28/05	Upper	609.3	F	605	980	132
SNS05–082	4/28/05	Upper	609.8	F	647	1,270	30600
SNS05–083	4/28/05	Upper	610.1	F	643	1,190	144
SNS05–084	4/28/05	Upper	609.8	F	663	1,000	145
SNS05–085	4/28/05	Upper	610.1	F	620	1,100	146
SNS05–086	4/28/05	Upper	609.4	F	625	970	147
SNS05–087	4/28/05	Upper	609.8	F	640	1,120	148
SNS05–088	4/28/05	Upper	607.4	F	693	1,450	31000
SNS05–089	4/28/05	Upper	607.4	F	688	1,430	31300
SNS05–090	4/28/05	Upper	607.4	F	640	1,200	78
SNS05–091	4/28/05	Upper	607.4	F	616	1,060	79
SNS05–092	4/28/05	Upper	607.2	F	635	1,070	88
SNS05–093	4/28/05	Upper	607.2	F	658	1,330	91
SNS05–094	4/28/05	Upper	607.2	F	641	1,070	93
SNS05–095	4/29/05	Upper	607.7	F	662	1,150	29600
SNS05–096	4/29/05	Upper	607.7	F	639	1,100	81
SNS05–097	4/29/05	Upper	607.7	F	683	1,260	82
SNS05–098	4/30/05	Upper	614.2	F	660	1,210	30800
SNS05–099	4/30/05	Upper	614.2	F	632	1,130	85
SNS05–100	4/30/05	Upper	614.2	F	655	1,110	83
SNS05–101	4/30/05	Upper	614.2	F	620	1,080	86

Table B2. Pallid sturgeon implanted in 2005.

[mm. millimeter; g, gram; U, unknown; F, female; M, male]

Implantation date	Segment origin	Capture river mile	Sex	Fork length (mm)	Weight (g)	Acoustic code
4/07/2005	Lower	131.2	U	774	2,000	164
4/08/2005	Lower	181.0	U	715	1,230	170
5/04/2005	Lower	Weldon Springs, Mo.	F	765	1,410	178
5/04/2005	Lower	Weldon Springs, Mo.	M	645	950	179
7/01/2005	Upper	Unknown	U	675	1,530	165
7/01/2005	Upper	Unknown	U	935	3,120	166
7/01/2005	Upper	Unknown	F	930	2,910	167
7/01/2005	Upper	Unknown	F	729	1,350	171
7/01/2005	Upper	Unknown	U	800	2,000	172
9/22/2005	Lower	Hartsburg, Mo.	M	960	3,710	177

Table B3. Shovelnose sturgeon implanted in April 2006.

[ID, identification number; mm. millimeter; g, gram; F, female; M, male]

Fish ID	Implantation date	Segment origin	Capture river mile	Sex	Fork length (mm)	Weight (g)	Acoustic code	Radio code
SNS06–001	4/12/06	Lower	142.7	F	650	1,250	401	11
SNS06–002	4/12/06	Lower	142.4	F	710	1,470	402	12
SNS06–003	4/12/06	Lower	142.7	F	735	1,440	403	13
SNS06–004	4/12/06	Lower	143.2	F	697	1,520	405	15
SNS06–005	4/12/06	Lower	142.7	F	721	1,650	404	14
SNS06–006	4/12/06	Lower	144.5	F	720	1,200	406	16
SNS06–007	4/12/06	Lower	146.0	F	700	1,290	407	17
SNS06–008	4/12/06	Lower	145.8	F	700	1,670	408	18
SNS06–009	4/12/06	Lower	146.0	F	730	1,640	409	19
SNS06–010	4/12/06	Lower	144.5	F	770	1,780	410	20
SNS06–011	4/12/06	Lower	140.6	F	724	1,724	411	21
SNS06–012	4/12/06	Lower	143.0	F	697	1,378	412	22
SNS06–013	4/12/06	Lower	140.6	F	621	1,130	413	23
SNS06–014	4/12/06	Lower	141.6	F	685	1,300	414	24
SNS06–015	4/12/06	Lower	141.6	F	668	1,240	415	25
SNS06–016	4/12/06	Lower	141.6	F	672	1,360	416	26

Table B3. Shovelnose sturgeon implanted in April 2006.—Continued

[ID, identification number; mm. millimeter; g, gram; F, female; M, male]

Fish ID	Implantation date	Segment origin	Capture river mile	Sex	Fork length (mm)	Weight (g)	Acoustic code	Radio code
SNS06–017	4/12/06	Lower	142.7	F	675	1,360	417	27
SNS06–018	4/13/06	Lower	122.4	F	650	1,390	430	40
SNS06–019	4/13/06	Lower	126.8	F	671	1,370	429	39
SNS06–020	4/13/06	Lower	123.1	F	653	1,149	428	38
SNS06–021	4/13/06	Lower	124.4	F	776	1,886	427	37
SNS06–022	4/13/06	Lower	124.3	F	703	1,433	426	36
SNS06–023	4/13/06	Lower	124.3	F	637	1,309	425	35
SNS06–024	4/13/06	Lower	128.3	F	633	1,120	424	34
SNS06–025	4/13/06	Lower	128.3	F	709	1,390	423	33
SNS06–026	4/13/06	Lower	128.4	F	668	1,300	422	32
SNS06–027	4/13/06	Lower	121.3	F	724	1,602	421	31
SNS06–028	4/13/06	Lower	121.9	F	722	1,495	420	30
SNS06–029	4/13/06	Lower	121.9	F	661	1,261	419	29
SNS06–030	4/13/06	Lower	125.0	F	734	1,800	418	28
SNS06–031	4/14/06	Lower	201.1	F	690	1,650	450	60
SNS06–032	4/14/06	Lower	201.1	F	683	1,430	449	59
SNS06–033	4/14/06	Lower	197.1	F	720	1,510	448	58
SNS06–034	4/14/06	Lower	199.8	F	725	1,520	447	57
SNS06–035	4/14/06	Lower	199.6	F	662	1,410	446	56
SNS06–036	4/14/06	Lower	196.3	F	700	1,330	445	55
SNS06–037	4/14/06	Lower	199.3	F	675	1,480	444	54
SNS06–038	4/14/06	Lower	199.8	F	660	1,190	443	53
SNS06–039	4/14/06	Lower	191.7	F	659	1,298	442	52
SNS06–040	4/14/06	Lower	190.8	F	634	1,027	441	51
SNS06–041	4/14/06	Lower	193.6	F	648	1,190	440	50
SNS06–042	4/14/06	Lower	191.3	F	706	1,414	439	49
SNS06–043	4/14/06	Lower	191.8	F	643	1,183	438	48
SNS06–044	4/14/06	Lower	193.6	F	636	1,070	437	47
SNS06–045	4/14/06	Lower	191.3	F	761	1,703	436	46
SNS06–046	4/14/06	Lower	190.8	F	664	1,088	435	45
SNS06–047	4/14/06	Lower	190.8	F	665	1,308	434	44
SNS06–048	4/14/06	Lower	191.3	F	725	1,703	433	43
SNS06–049	4/14/06	Lower	191.3	F	741	2,078	432	42

Table B3. Shovelnose sturgeon implanted in April 2006.—Continued

[ID, identification number; mm. millimeter; g, gram; F, female; M, male]

Fish ID	Implantation date	Segment origin	Capture river mile	Sex	Fork length (mm)	Weight (g)	Acoustic code	Radio code
SNS06–050	4/14/06	Lower	191.8	F	683	1,491	431	41
SNS06–051	4/19/06	Upper	736.5	F	745	1,923	451	61
SNS06–052	4/19/06	Upper	737.5	F	661	1,137	451	62
SNS06–053	4/19/06	Upper	741.0	F	621	1,120	453	63
SNS06–054	4/19/06	Upper	736.5	F	649	1,011	454	64
SNS06–055	4/19/06	Upper	740.6	F	638	1,250	455	65
SNS06–056	4/19/06	Upper	739.1	F	612	1,010	456	66
SNS06–057	4/19/06	Upper	740.1	F	651	1,050	457	67
SNS06–058	4/19/06	Upper	738.6	F	631	970	458	68
SNS06–059	4/19/06	Upper	723.0	F	723	1,660	459	69
SNS06–060	4/19/06	Upper	738.8	F	715	1,630	460	70
SNS06–061	4/20/06	Upper	738.6	F	609	1,200	461	71
SNS06–062	4/20/06	Upper	742.9	F	715	1,600	462	72
SNS06–063	4/20/06	Upper	743.1	F	644	1,100	463	73
SNS06–064	4/20/06	Upper	746.7	F	619	1,080	464	74
SNS06–065	4/21/06	Upper	606.7	F	697	1,560	465	75
SNS06–066	4/21/06	Upper	600.0	F	709	1,660	466	76
SNS06–067	4/21/06	Upper	610.2	F	650	1,025	467	77
SNS06–068	4/21/06	Upper	600.2	F	640	1,250	468	78
SNS06–069	4/21/06	Upper	600.0	F	677	1,240	469	79
SNS06–070	4/22/06	Upper	599.0	F	666	1,090	470	80
SNS06–071	4/22/06	Upper	595.4	F	614	1,190	471	81
SNS06–072	4/22/06	Upper	598.8	F	667	1,250	472	82
SNS06–073	4/22/06	Upper	598.3	F	651	1,160	473	83
SNS06–074	4/22/06	Upper	595.4	F	645	1,100	474	84
SNS06–075	4/22/06	Upper	598.3	F	655	1,140	475	85
SNS06–076	4/22/06	Upper	599.6	F	653	1,030	476	86
SNS06–077	4/22/06	Upper	599.6	F	619	1,010	477	87
SNS06–078	4/23/06	Upper	637.1	F	646	1,075	478	88
SNS06–079	4/23/06	Upper	644.0	F	659	1,230	479	89
SNS06–080	4/23/06	Upper	636.6	F	675	1,165	480	90
SNS06–081	4/23/06	Upper	637.1	F	650	1,065	481	91
SNS06–082	4/23/06	Upper	634.2	F	709	1,275	482	92

Table B3. Shovelnose sturgeon implanted in April 2006.—Continued

[ID, identification number; mm. millimeter; g, gram; F, female; M, male]

Fish ID	Implantation date	Segment origin	Capture river mile	Sex	Fork length (mm)	Weight (g)	Acoustic code	Radio code
SNS06–083	4/23/06	Upper	644.0	F	684	1,180	484	94
SNS06–084	4/23/06	Upper	638.7	F	675	1,210	485	95
SNS06–085	4/23/06	Upper	644.2	F	630	1,060	486	96
SNS06–086	4/23/06	Upper	643.8	F	667	1,130	487	97
SNS06–087	4/23/06	Upper	6.38.7	F	678	1,180	488	98
SNS06–088	4/23/06	Upper	649.0	F	633	1,150	489	99
SNS06–089	4/24/06	Upper	651.0	F	694	1,450	490	100
SNS06–090	4/24/06	Upper	650.9	F	655	1,220	491	101
SNS06–091	4/24/06	Upper	651.1	F	640	1,110	492	102
SNS06–092	4/24/06	Upper	651.0	F	696	1,490	493	103
SNS06–093	4/24/06	Upper	651.1	F	646	1,190	494	104
SNS06–094	4/24/06	Upper	658.4	F	676	1,205	495	105
SNS06–095	4/24/06	Upper	658.5	F	655	1,250	496	106
SNS06–096	4/24/06	Upper	657.5	F	708	1,245	497	107
SNS06–097	4/24/06	Upper	658.5	F	698	1,525	498	108
SNS06–098	4/24/06	Upper	656.4	F	656	1,100	499	109
SNS06–099	4/24/06	Upper	657.2	F	676	1,350	501	111
SNS06–100	4/24/06	Upper	658.5	F	679	1,140	500	110

Table B4. Pallid sturgeon implanted in 2006.

[ID, identification number; mm. millimeter; g, gram; F, female; M, male]

Fish ID	Implantation date	Segment origin	Capture river mile	Sex	Fork length (mm)	Weight (g)	Acoustic code	Radio code
PLS06–002	4/12/06	Lower	141.1	F	790	2,253	521	131
PLS06–001	4/14/06	Lower	199.6	M	810	2,000	522	132
PLS06–007	5/2/06	Upper	806.5	M	740	1,452	502	112
PLS06–010	5/2/06	Upper	671.5	F	860	2,903	523	133
PLS06–009	5/2/06	Upper	675.0	F	788	2,359	524	134
PLS06–008	5/2/06	Upper	757.5	M	975	3,357	525	135
PLS06–006	5/3/06	Upper	583.5	M	936	3,338	526	136
PLS06–003	5/3/06	Lower	330.0	M	1060	4,445	527	137
PLS06–005	5/3/06	Lower	342.2	M	NA	3,311	528	138
PLS06–004	5/3/06	Lower	321.2	M	940	2,948	529	139
PLS06–011	10/2/06	Upper	657.4	F	885	2,280	530	140
PLS06–012	10/2/06	Upper	654.5	M	878	2,160	531	141
PLS06–013	10/2/06	Upper	649.5	M	890	2,505	533	143
PLS06–014	10/2/06	Upper	724.5	M	860	2,310	534	144
PLS06–015	10/2/06	Upper	600.0	M	875	3,010	535	145
PLS06–016	10/2/06	Upper	610.2	F	930	3,130	536	146

Table B5. Gravid female shovelnose sturgeon implanted in 2005 and subsequently recaptured.

[ID, identification number; mm. millimeter; g, gram]

Fish ID	Implantation date	Implantation river mile	Recapture date	Recapture river mile	Recapture fork length (mm)	Recapture weight (g)	Spawn
SNS05–011	3/25/05	110.3	9/08/05	144.1	635	850	Spawn
SNS05–028	3/29/05	148.2	10/27/05	221.0	682	1,370	Nonspawn
SNS05–041	3/31/05	186.4	9/01/05	326.2	675	980	Spawn
SNS05–052	4/19/05	635.9	8/12/05	587.8	616	780	Spawn
SNS05–060	4/20/05	639.0	9/15/05	622.2	667	990	Spawn
SNS05–061	4/20/05	639.0	8/10/05	640.3	604	870	Spawn
SNS05–062	4/20/05	638.7	8/11/05	658.2	625	920	Spawn
SNS05–063	4/21/05	668.5	9/13/05	668.6	652	960	Spawn
SNS05–064	4/21/05	668.5	9/14/05	694.0	738	1,330	Spawn
SNS05–065	4/21/05	668.5	8/11/05	603.1	641	870	Nonspawn
SNS05–066	4/21/05	668.5	9/01/05	315.7	682	1,130	Spawn
SNS05–071	4/28/05	609.3	10/04/05	686.5	720	1,200	Incomplete
SNS05–074	4/28/05	610.1	8/12/05	564.6	627	880	Spawn
SNS05–075	4/28/05	610.1	7/27/05	604.6	659	990	Nonspawn
SNS05–076	4/28/05	609.3	9/01/05	618.6	715	1,540	Incomplete
SNS05–085	4/28/05	610.1	8/31/05	439.6	610	790	Spawn
SNS05–094	4/28/05	607.2	10/05/05	646.0	630	770	Spawn
SNS05–099	4/30/05	614.2	10/05/05	643.3	622	850	Spawn
SNS05–101	4/30/05	614.2	8/31/05	616.4	609	780	Spawn
SNS05–096	4/29/05	607.7	8/16/06	Kansas River	629	780	Spawn

Table B6. Gravid female shovelnose sturgeon implanted in 2006 and subsequently recaptured.

[ID, identification number; mm. millimeter; g, gram]

Fish ID	Implantation date	Implantation river mile	Recapture date	Recapture river mile	Recapture fork length (mm)	Recapture weight (g)	Spawn
SNS06–010	4/12/06	144.5	9/06/06	177.5	758	1,536	Nonspawn
SNS06–015	4/12/06	141.6	6/08/06	204.5	659	960	Spawn
SNS06–018	4/13/06	122.4	6/09/06	232.0	650	1,154	Spawn
SNS06–027	4/13/06	121.3	10/05/06	000.0	715	1,352	Spawn
SNS06–038	4/14/06	199.8	8/23/06	289.9	650	1,058	Nonspawn
SNS06–052	4/19/06	737.5	10/11/06	733.8	656	1,026	Spawn
SNS06–053	4/19/06	741.0	9/28/06	362.0	616	808	Spawn
SNS06–055	4/19/06	740.6	10/31/06	734.5	643	1,215	Spawn
SNS06–058	4/19/06	738.6	8/03/06	707.4	632	870	Spawn
SNS06–059	4/19/06	723.0	10/02/06	686.6	718	1,430	Spawn
SNS06–061	4/20/06	738.6	5/31/06	773.4	612	950	Spawn
SNS06–063	4/20/06	743.1	8/03/06	680.9	642	852	Incomplete
SNS06–071	4/22/06	595.4	10/12/06	335.7	602	735	Spawn
SNS06–080	4/23/06	636.6	9/12/06	535.4	659	918	Spawn
SNS06–081	4/23/06	637.1	8/28/06	638.8	647	1,022	Nonspawn
SNS06–083	4/23/06	644.0	9/13/06	701.2	674	854	Spawn
SNS06–085	4/23/06	644.2	10/11/06	737.4	626	818	Spawn
SNS06–090	4/24/06	650.9	11/07/06	563.7	652	975	Spawn
SNS06–093	4/24/06	651.1	11/01/06	541.9	647	1,170	Spawn
SNS06–096	4/24/06	657.5	11/01/06	518.0	697	955	Spawn
SNS06–098	4/24/06	656.4	9/26/06	491.3	652	790	Spawn
SNS06–099	4/24/06	657.2	6/01/06	671.7	670	1,060	Spawn

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Rolla, MO 65401
For more information concerning this publication, contact:
Director
U.S. Geological Survey
Columbia Environmental Research Center
4200 New Haven Road
Columbia, MO 65201
(573) 875–5399
Or visit the Columbia Environmental Research Center website at:
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Reproductive Physiology of Missouri River Gravid Pallid Sturgeon and Shovelnose Sturgeon During the 2005 and 2006 Spawning Seasons

By Diana M. Papoulias, Mandy L. Annis, Aaron J. DeLonay, and Donald E. Tillitt

Chapter C of

Factors Affecting the Reproduction, Recruitment, Habitat, and Population Dynamics of Pallid Sturgeon and Shovelnose Sturgeon in the Missouri River

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Reproductive Physiology of Missouri River Gravid Pallid Sturgeon and Shovelnose Sturgeon During the 2005 and 2006 Spawning Seasons

By Diana M. Papoulias, Mandy L. Annis, Aaron J. DeLonay, and Donald E. Tillitt

Abstract

In a natural, unaltered river, the location and timing of sturgeon spawning will be dictated by the prevailing environmental conditions to which the sturgeon have adapted. A goal of the Comprehensive Sturgeon Research Program (CSRP; see chap. A) at the U.S. Geological Survey Columbia Environmental Research Center is to identify where, when, and under what conditions shovelnose sturgeon (*Scaphirhynchus platorynchus*) and pallid sturgeon (*S. albus*) spawn in the altered Missouri River so that those conditions necessary for spawning success can be defined. One approach to achieving this goal is to exploit what is known about fish reproductive physiology to develop and apply a suite of diagnostic indicators of readiness to spawn. In 2005 and 2006, gravid shovelnose sturgeon and a limited number of pallid sturgeon were fitted with transmitters and tracked on their spawning migration. A suite of physiological indicators of reproductive state such as reproductive hormones and oocyte development were measured. These same measurements were made on tissues collected from additional fish, presumably migrating to spawn, that were not tagged or tracked. The data presented here indicating the sturgeons' readiness to spawn are to be evaluated together with their behavior and the environmental conditions. The U.S. Army Corps of Engineers (ACOE) Sturgeon Response to Flow Modification (SRFM; see chap. A) study, initiated in 2006, provides additional opportunities to experimentally evaluate the sturgeon reproductive response indicators relative to changes in flow. In this chapter, we report progress made on identifying and developing the physiological indicators and summarize 2 years' worth of indicator data collected thus far.

Introduction

The timing of spawning for seasonally spawning fish is generally believed to have evolved in synchrony with the seasonal hydrologic and environmental conditions that provide the best possible chance of survival for offspring (Balon, 1975; Munro and others, 1990). Historically, North American sturgeon (*Acipenser spp.* and *Scaphirhynchus spp.*) have been reported to spawn from spring to midsummer depending on latitude and water temperature (lake sturgeon [*Acipenser fulvescens*]: Eddy and Surber, 1947; pallid sturgeon [*Scaphirhynchus albus*]: Forbes and Richardson, 1920; shovelnose sturgeon *[S.platorhynchus]*: Christenson, 1975; green sturgeon [*A. medirostris*]: Van Eenennam and others, 2005; shortnose sturgeon (*A. brevirostrum*]: Taubert, 1980; Atlantic sturgeon [*A. oxyrhynchus*]: Van Enennaam and others, 1996; and Gulf sturgeon [*A. oxyrhynchus desotoi*]: Fox and others, 2000. During the spawning season, specific environmental cues can trigger or be associated with the physiological changes in the fish that result in spawning activity: migration, aggregation, courtship, ovulation, oviposition, and fertilization (fig. C1). Although the biochemical, physiological, and behavioral events are generally synchronized, they can become decoupled with the result that spawning is unsuccessful (Dettlaff and others, 1993).

The objective of this study was to evaluate the reproductive readiness of shovelnose and pallid sturgeon and their spawning success relative to prevailing environmental conditions by using physiological indicators. This research is intended to support ongoing work (see other chapters of this report) to identify when and where shovelnose and pallid sturgeon spawn and to better define the environmental factors necessary for completion of the reproductive cycle through completion of spawning in the Lower Missouri River.

Approach

Photoperiod, temperature, and flow are the primary factors that cue the reproductive physiology of most fishes. Physiological and morphological measurements allow scientists to evaluate the response 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. Reproductive assessment prior to a telemetry study and again at recapture provides information on the reproductive readiness of the fish and subsequently whether spawning was successful or resulted in oocyte follicles being resorbed. Moreover, assessment of the physiological status of captured wild sturgeon allows for an understanding of the environmental factors necessary for successful completion of the reproductive cycle. Our approach was to assess the reproductive condition of sturgeon prior to their spawning migration, 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 discharge, temperature, and day length (Comprehensive Sturgeon Research Program [CSRP] task 2.2). Fish were primarily collected in two geographical areas with distinct hydrographs to allow for comparisons of the effect of hydrograph on spawning (Spring Rise Flow Modification [SRFM] 1.c.i). Limited additional fish samples were collected in a third area in 2005 (the Yellowstone River) as a proof of concept of the relationships among upstream migration, temperature, and physiological indicators.

Readiness to spawn was assessed by using the polarization index (PI), the progesterone assay, and blood reproductive hormones (Dettlaff and others, 1993; Wildhaber and others, 2006). Spawning success was evaluated on the basis of visual and microscopic inspection of gonads and blood reproductive hormones (Wildhaber and others, 2006). As a gravid female progresses towards spawning, the germinal vesicle (GV) of the oocyte gets closer to the animal pole. Sometime during the migration of the GV to the animal pole (generally estimated as a PI of <0.07), the hormonal system is cued that ovulation may proceed. The fish has reached maturational competence at this time. When conditions are suitable, the final stages of maturation commence such that specific hormones (luteinizing hormone and maturation-inducing hormone) are released, causing germinal vesicle breakdown (GVBD) followed by ovulation. The concentrations of sex hormones also change during the course of migration, final maturation, ovulation, and spawning. Estrogen and testosterone are typically high when migration begins and decrease at different rates through spawning. Additionally, some hormones, such as cortisol, reflect the degree of stress the fish is experiencing, and their increase has been correlated with changes in sex hormone levels and failure to spawn.

In addition to estrogen and testosterone, several other blood hormone measurements can indicate readiness to spawn or may be useful in interpreting why spawning did not occur. Measurement of the gonadotropin luteinizing hormone (LH) and the maturation-inducing hormone (MIH) can provide more precise estimates of when spawning will occur. Reagents to readily measure these hormones in sturgeon are not available, thus an additional objective of this work is to make the necessary reagents (CSRP task 2.1). The reagents will then be used to measure these additional hormones in the archived blood collected from sturgeon in these studies. Cortisol is an indicator of acute stress and has been measured in most blood samples collected in these studies; however, interpretation of the values has been difficult because reference values have been lacking. Therefore, an additional set of laboratory experiments were designed in 2006 to provide basal (low) and stressed (high) reference values of cortisol for comparison to values obtained in studies.

Study Areas

Yellowstone River

Movements of shovelnose sturgeon have been monitored in the Yellowstone River and in the Missouri River upstream and downstream of the Yellowstone River confluence (Recovery Priority Management Area 2 (RPMA)) for the last 3 years as part of the Fort Peck Flow Modification Biological Data Collection Plan (Dr. Pat Braaten, U.S. Geological Survey, Fort Peck Project Office, written commun. 2004; Dave Fuller, Montana Fish, Wildlife and Parks, Fort Peck, written commun., 2004). Results from this ongoing study indicate that shovelnose sturgeon primarily overwinter in the Missouri River, but during spring, some individuals of this population migrate into the Yellowstone River to spawn, while others spawn in the Missouri River downstream from Fort Peck Dam. As part of the ongoing Fort Peck project, 60 shovelnose sturgeon fitted with transmitters are tracked and relocated at weekly intervals from April through July. In 2005, tissue samples were collected from fish that were randomly captured weekly as field crews tracked tagged sturgeon migrating up the Yellowstone River.

Missouri River (RM 0–200)

In 2005 and 2006, data were collected from fish used in the tracking study at the time of tag implantation and then again from any tagged fish that were later recaptured. Fish for the 2005 tracking study were collected from river mile (RM) 110 to 192, between Morrison, Mo. and Boonville, Mo. In 2005, additional data were also collected from fish caught by a commercial fisherman in the Missouri River near Hartsburg, Mo. Fish for the 2006 tracking study were collected from RM 121 to 200, between Chamois, Mo. and slightly above Boonville, Mo. In 2006, additional data were also collected between RM 10 (just above the confluence with the Mississippi River) and RM 192 from fish captured as part of the U.S. Army Corps of Engineers (USACE) population assessment program.

Missouri River (RM 365–870)

In 2005 and 2006, data were collected from fish used in the tracking study at the time of tag implantation and then again from any tagged fish that were later recaptured. Fish for the 2005 tracking study were collected from RM 607 to RM 668, between Bellevue, Nebr., and the River Sioux, Iowa. Fish for the 2006 tracking study were collected from RM 596 to RM 747, between Plattsmouth, Nebr. and just below Ponca, Nebr. In 2006, additional data were also collected from fish captured as part of the USACE population assessment program in one reach above Gavins Point Dam (RM 831 to RM 870) and two reaches below the dam (from RM 754 to RM 811 and from RM 367 to RM 750).

Methods and Procedures

Tissue Collection

Blood and ovarian biopsies were collected from fish used in the telemetry study (see chap. 2) from the lower (n = 50) and the upper (n = 50) study areas in 2005 and 2006 upon implantation and again upon recapture (lower: n = 3, 2005, and n = 5, 2006; upper: n = 16, 2005, and n = 17, 2006). During 2006, blood and sometimes ovarian tissue were also collected from a reach above Gavins Point Dam, two reaches in the upper study area, and one reach in the lower study area (table C1).

In 2005, additional blood and ovary samples (n = 25), were obtained from fish provided by a local fishermen in the lower study area from mid-April through June. Also in 2005, a proof of concept test was conducted in Montana to demonstrate the validity and performance of the physiological measurements as indicators of readiness to spawn using shovelnose sturgeon captured during ongoing studies in the Yellowstone River (Dr. Pat Braaten, oral. commun.). Weekly, the group of fish associated with fish being tracked was subsampled, and ovarian tissue and blood were collected from a total of 26 gravid females.

Blood was collected from the caudal vein by using a heparinized syringe. Blood samples were kept on wet ice until centrifugation at 3,500 revolutions per minute (rpm) for 10 minutes. Plasma was transferred to 1.8-mL cryogenic vials, and quick frozen in dry ice, and then stored in a -80°C freezer until steroid extraction and analysis. Ovarian biopsy tissue was collected by making a small incision in the abdomen. Eggs and tissue were removed by using a disposable pipette. The incision was closed with one suture using absorbable suture material. Other fish were euthanized prior to biopsy. Biopsy samples were either preserved in 10 percent neutral buffered formalin (NBF) for determination of PI and for histology or were placed in Ringer's solution at river temperature for the progesterone assay.

Hormone Extraction and Analysis for 17 β-Estradiol, 11-Ketotestosterone, and Testosterone

The plasma samples for reproductive hormone analysis were extracted by using diethyl ether to separate the steroids from the binding proteins. The steroid-containing ether phase was quick frozen, and the resulting supernatant was placed in a 30°C water bath and evaporated under nitrogen. The steroid residues were then reconstituted in phosphate buffered saline pH 7.0 with 1 percent gelatin (PBSG). Extracted, reconstituted samples were stored at -20°C until assayed.

Extraction efficiency was determined by spiking the plasma with a known concentration of tritiated steroid. The spiked sample then underwent the extraction procedure as described above, with a subsample of the diethyl ether supernatant taken for radioactive analysis. An additional scintillation vial containing a spike was also analyzed. The resulting radioactive count was calculated for recovery rate by comparing the recovered radioactive values to that of the known spike. A laboratory average was determined by averaging the recovery rates of several extractions to obtain an average of 95 percent, 98 percent, and 97 percent for estradiol, 11-ketotestosterone, and testosterone, respectively. These values were applied to the derived steroid data to correct sample steroid values for efficiency of extraction.

Estradiol (E2), 11-ketotestosterone (11-KT), and testosterone (T) were assayed by using the radioimmunoassay (RIA) method (McMaster and others, 1992). Each steroid was assayed independently. Steroid concentration was determined through competition of the steroid in the standard or sample and a constant volume of radiolabeled steroid for a fixed titer of antibody. The E2 antibody was purchased from Sigma-Aldrich (St. Louis, Mo.), Dr. Tim Gross (U.S. Geological Survey Florida Integrated Science Center) donated the 11-KT antibody, and the T antibody was purchased from MP Biomedical (Solon, Ohio). PerkinElmer (Wellesley, Mass.) supplied radiolabeled steroids for both E2 and T, with 11-KT being purchased from Amersham Biosciences (Piscataway, N.J.). Test tubes containing the antibody, radiolabeled steriod, and extracted sample or standard were incubated overnight at 4 °C. A chilled solution of dextran-coated activated charcoal in PBSG (0.4 percent dextran, 0.625 percent charcoal) was added and allowed to incubate before centrifugation at 0 °C for 20 minutes at 2,800 rpm. A portion of the resulting supernatant was added to a scintillation vial containing 5 mL of scintillation cocktail (EcoLume®). A scintillation count was performed with the resulting values indicating the amount of antibody bound to labeled steroid, which is inversely proportional to the amount of free steroid in the sample. A standard curve of a serial dilution of E2, 11-KT, and T standards (Sigma-Aldrich, St. Louis, Mo.) was used to allow calculation of steroid concentrations in the unknown samples.

Cortisol Analysis

Plasma samples for cortisol analysis were shipped overnight on dry ice to Dr. Grant Feist (Oregon State University, Corvallis, Oreg.). Cortisol analysis followed procedures outlined in Redding and others (1984).

Quality Assurance Procedures and Assay Performance Characteristics

Samples in all assays were run in duplicate and included measurement of blanks which were subtracted from all absorbance values. Estradiol sensitivity was 887 pg/mL at 80 percent binding and 13 pg/mL at 20 percent binding. 11-ketotestosterone sensitivity was 83 pg/mL and 1 pg/mL at 20 percent and 80 percent binding, respectively. Testosterone sensitivity at 80 percent binding was 8 pg/mL and 336 pg/mL at 20 percent binding. Cross-reactivities of the antibodies used in these assays with other similar steroids are reportedly less than10 percent according to the vendors (for E2 and T) and Sepulveda (2002) for 11-KT. Estradiol intra-assay variation was 11 percent, and interassay variation was 3 percent. 11-ketotestosterone intra-assay variation was 8 percent and interassay variation was 13 percent. Testosterone intra-assay variation was 1 percent, and interassay variation was 13percent. The assay was validated for measurement of E2, T, and 11-KT by verifying that serial dilutions of sample were parallel to a standard curve. E2 had a slope of 0.81, with a slope of 0.80 for 11-KT and a slope of 0.87 for T. These values were obtained from the regression of hormone measured and concentration of hormone added to a plasma sample.

Polarization Index and Progesterone Activation Assay

At time of implantation, oocytes were sampled to calculate PI and to determine whether GVBD could be hormonally induced *in vitro* (Dettlaff and others, 1993). Ten oocytes were preserved in 10 percent NBF for the PI measurement, and another 25 oocytes were placed in Ringers solution in a Petri dish to which progesterone was added (Sigma-Aldrich, St. Louis, Mo.). After 24 hours of incubation at 19 °C, oocytes were preserved in 10 percent NBF followed by PI measurement to determine if GVBD had taken place.

Histology

Histological analysis was conducted on the ovarian tissue of the sturgeon to accurately determine stage of maturity, presence of GVBD, and spawning success in recaptured fish. Samples were preserved and processed according to methods outlined by Blazer and Dethloff (2000). Briefly, after an initial fixation of 48 hours in 10 percent NBF, samples were transferred through a series of rinses to 70 percent ethanol (EtOH). The samples were stored in the 70 percent EtOH until analysis was performed. Routine processing of tissue involved trimming into small pieces, dehydration through a series of alcohols followed by immersion in an organic solvent, and then infiltration with paraffin. Paraffin blocks containing the tissues were cut into 5-µm slices. Sections were taken at three different depths to ensure that the microscopic evaluations were representative of the entire tissue. These sections were placed on glass slides, allowed to dry, and then deparaffinized. The slides were stained with hematoxylin and eosin (Luna, 1968) and viewed with a light microscope.

Development of an LH (GTH II) Antibody and LH Assay

Luteinizing hormone is one of two gonadotropic hormones among the suite of reproductive hormones controlling oocyte follicle development. During germinal vesicle migration at approximately a PI of 0.07 or less, and when the fish has reached maturational competency, LH will increase. Currently, there are no available assays to measure shovelnose sturgeon LH because a specific antibody to shovelnose LH is required and has not been developed.

Luteinizing hormone is produced in the pituitary. Thus, as a first step in development of an assay to measure LH, 400 shovelnose whole brains were collected from gravid female shovelnose sturgeon for isolation and recovery in 2004. Shovelnose sturgeon were sacrificed by first calming the fish in icy water and then quickly severing the head. Brains with pituitaries were removed and immediately placed on dry ice. Samples were stored at -80 °C until they were shipped to ProteinX Lab, Inc. (Sorrento, Calif.) for purification of LH. ProteinX generally followed the methods of Swanson and others (1991), Mañanós and others (1997), and Lin and others (2004) with some modifications with the goal of obtaining a sample of LH with 95 percent purity and characterized by reverse phase high-performance liquid chromatography (rpHPLC) showing the alpha and beta subunits.

From the outset it was recognized that this would be a difficult project because of the very small amounts of protein of interest in the tissues. The criteria for identifying the protein were based on known facts from other fish species: a pituitary from a mature sturgeon might contain approximately 30 µg of protein, the size of the protein is about 40–50 kilo Daltons (kD), there are two subunits of 12–24 kD that are noncovalently bound, and under acidic conditions LH could be dissociated and separated on a C18 rpHPLC column.

The effort began with a small-scale purification by using only 6–8 of the 400 brains and using three different columns (ion exchange column (Mono Q), sizing column (sucrose 12), and hydrophobic interaction column [(HIC) (resource Phenyl)] followed by monitoring and characterization for LH by using SDS gel electrophoresis rpHPLC (Vydac column #218TP54, Grace, Deerfield, Ill.). Detection sensitivity was expected to be around 0.5–1 µg/mL on SDS and rpHPLC. Subsequent separations used a TSK gel ODS-120T C18 column (SigmaAldrich, St. Louis, Mo.) with slightly better resolution than the Vydac column used initially.

Freeze-dried samples from purifications were resuspended with 0.5 mL mQ H_20 and spun briefly. Resuspended samples were stored at 4°C until bioassay. Bioassay involved exposing shovelnose sturgeon vitellogenic oocytes *in vitro* to approximately 1 µg protein of each sample (although results were expected to be relative since actual protein concentrations were known to vary widely) and measuring the estradiol produced. Samples that resulted in oocytes producing the most estradiol were further fractioned through gradient elution. Bands corresponding to likely LH based on mass were cut from gels and submitted for protein sequencing by using mass spectrometry finger printing at the Proteomics Center at the University of Missouri, Columbia, Mo.

A second approach to developing an LH assay was to clone and sequence the shovelnose sturgeon LH beta subunit gene. The C-terminal sequence was used to develop a synthetic peptide conjugated to a carrier protein for antibody development (Querat and others, 2000; Hervitz and others, 2005).

Identification of the Maturation Inducing Hormone (MIH) and Development of an MIH Assay

Maturation-inducing hormone stimulates the oocyte to resume meiosis (identified by GVBD) during the final phases of oocyte maturation just prior to ovulation. The production of MIH is triggered by an increase in LH. Procedures generally followed Webb (1999). Briefly, wild gravid female shovelnose sturgeon were induced to ovulate, and pieces of the ovary were collected for *in vitro* production of MIH. Incubation media containing MIH was analyzed by using HPLC and eluted fractions containing identified peaks and then were tested in an *in vitro* bioassay to determine the most active fraction to induce GVBD.

Development of Cortisol Reference Values for Shovelnose Sturgeon

Wild-caught mature female and male shovelnose sturgeon were captured from the Missouri River in 2006 and subjected to various stressors to establish reference values for cortisol. Basal cortisol levels were measured in fish every 3 hours for 24 hours for a baseline unstressed condition. Stressors included holding fish out of the water for a short period of time, driving the fish while in a tank in the back of a truck for 1 hour, and stimulation with adrenocorticotropic hormone. Blood for all stress tests was collected by using a catheter inserted into the caudal vein to minimize stress from repeated blood collections. Procedures for measuring cortisol were as described above.

Results

Yellowstone River

Figure C2 shows the results obtained from fish (n = 25) that were randomly captured weekly as field crews tracked tagged sturgeon migrating up the Yellowstone River during the summer reproductive period. Polarization index, E2, T, and 11-KT all decrease over the course of the movement, although each parameter shows a slightly different pattern.

Missouri River (RM 0–200)

Polarization Index

The majority of fish implanted in 2005 had PIs of 0.15–0.20 (fig. C3), while the majority of fish implanted in 2006 had PIs of 0.10–0.15 (fig. C4). The PIs of fish collected randomly throughout the spawning season near Hartsburg, Mo. in 2005 did not show a clear trend (fig. C5). The PIs of fish collected randomly during 2006 were initially low in May but then increased through June (fig. C6).

Progesterone Assay

Slightly more fish tagged in 2006 compared with those tagged in 2005 had reached maturational competency as indicated by 100 percent GVBD (figs. C7 and C8).

Hormones

In general, and as expected, all hormones decreased from initial levels at implantation of tags (table C2). Twenty-five samples remain to be analyzed from the 2006 tracking study. Hormone results for the additional samples from fish caught near Hartsburg, Mo. in 2005 and between RM 0 and RM 195 can be found in appendix C1 (note that 11 samples remain to be analyzed).

Histology

Histological analysis of the ovarian tissue of the three recapatured fish from 2005 indicated that one fish resorbed many of its follicles. Analyses for ovarian tissue at time of implantation, randomly sampled, or recaptured for 2005 and 2006 fish are pending.

Missouri River (RM 365–870)

Polarization Index

The majority of fish implanted in 2005 had PIs of 0.15–0.20 (fig. C9), while the majority of fish implanted in 2006 had PIs of 0.15 (fig. C10). The PIs of fish collected randomly throughout the spawning season from the reach above Gavins Point Dam and the two other reaches downstream of the dam tended to decrease over time (fig. C11).

Progesterone Assay

Slightly more fish tagged in 2006 compared with those tagged in 2005 (fig. C12) had reached maturational competency as indicated by 100 percent GVBD (fig. C13). By mid-May most of the fish caught in the river reach immediately below Gavins Point Dam had reached maturational competency as indicated by the number of fish with 100 percent GVBD (fig. C14)

Hormones

In general, and as expected, all hormones decreased from initial levels at implantation of tags (table C3). Twenty-one samples remain to be analyzed from the 2006 tracking study. Hormone results for the additional samples from fish caught between RM 365 and RM 875 can be found in appendix C1 (note that 231 samples remain to be analyzed).

Histology

Three of sixteen tissue samples from 2005 recaptured fish indicated that many eggs were not ovulated and were resorbed. Histological analyses for ovarian tissue at time of implantation, randomly sampled, or recaptured for 2005 and 2006 fish are pending.

Development of Hormone Indicators

LH (Gonadotropin II)

The low level of LH in the tissue has made it very difficult to isolate the protein. After hundreds of purifications, several samples likely to contain LH were obtained and tested in an *in vitro* bioassay for activity. Sample G3 was identified as having the greatest activity (fig. C15). Sample G3 was a relatively pure fraction from a step elution off of the ion exchange column containing—a couple of micrograms of protein. Subsequently, the sample was further fractionated by gradient elution, and fractions 2 and 4 were picked up. Fraction 4 was a good representative of sample G3 however, a concern with sample G3 was that the molecular weight was smaller than expected, 1315 kD, and separated on SDS without reductants (fig. C16). Before proceeding further, bands from fraction 4 were submitted for quick sequencing involving a solution digest, followed by matrix assisted laser desorption/ionization mass spectrometry (MALDI MS). We got no matches that indicated that the protein was LH.

Subsequently, we have attempted to separate pituitaries from remaining brain tissue. The pituitaries have been resubmitted to Protein X (September 2006), and they are again attempting to isolate LH. We have also begun to try another approach by cloning and sequencing the shovelnose sturgeon LH beta subunit gene by using the C-terminal sequence to develop a synthetic peptide conjugated to a carrier protein for antibody development (fig. C17). Currently, an antibody is being made to the conjugated synthetic LH peptide by Abraxis LLC (Westminister, Pa.).

MIH

Eluted fractions corresponding to resolved peaks and likely to contain MIH based on incorporation of tritiated progesterone have been prepared and are ready to be exposed *in vitro* to late stage vitellogenic oocyte follicles to assess GVBD (fig. C18).

Cortisol

Results of blood cortisol analysis of laboratory stress experiments were received in mid-December 2006 and are being evaluated.

Summary

Initial work in the Yellowstone River demonstrated that telemetered and tracked fish physiologically cycle in a predictable pattern on their spawning migration up river based on hormone and egg measurements. Data for the 2005 and 2006 Missouri River tracking study provided information at the beginning and, if fish were recaptured, at the end of the spawning period. These data will be useful in assessing why a given fish may not have spawned and the readiness to spawn relative to environmental conditions. The additional 2006 dataset from untracked sturgeon will allow us to more closely evaluate spawning readiness together with behavior and environmental conditions during the reproductive period. These data are especially useful when we evaluate responses to different flow patterns whether they are during the same year but in different geographic areas or in different years. Reference values for evaluating cortisol levels and stress in shovelnose sturgeon will soon be available. Encouraging progress is being made to provide reagents and assays to measure additional and more proximal indicators of readiness to spawn, allowing us to further narrow the window for when and where sturgeon spawning is occurring.

Acknowledgments

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Figures and Tables

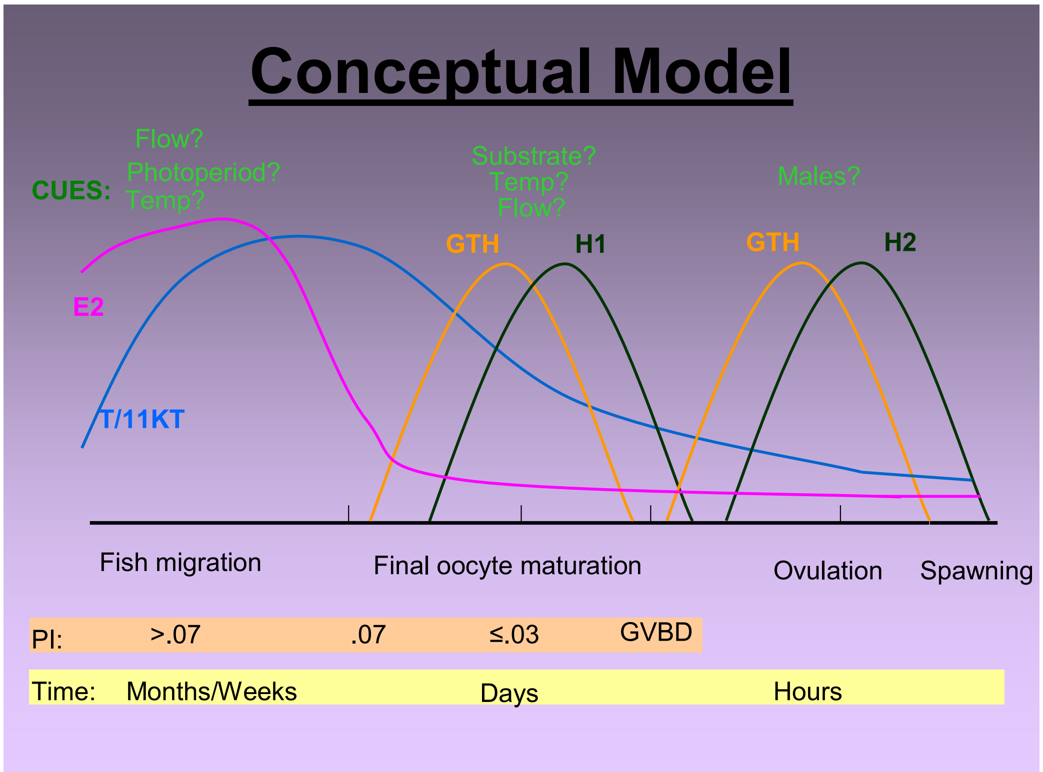

Figure C1. Conceptual model of environmental cues, the physiological indicators they may affect (gonadotropin=GTH, H1=hormone, H2=hormone, T=testosterone, 11KT=11-ketotestosterone, E2=17 β-Estradiol, PI=polarization index, GVBD=germinal vesicle breakdown), and the corresponding reproductive stage of sturgeon.

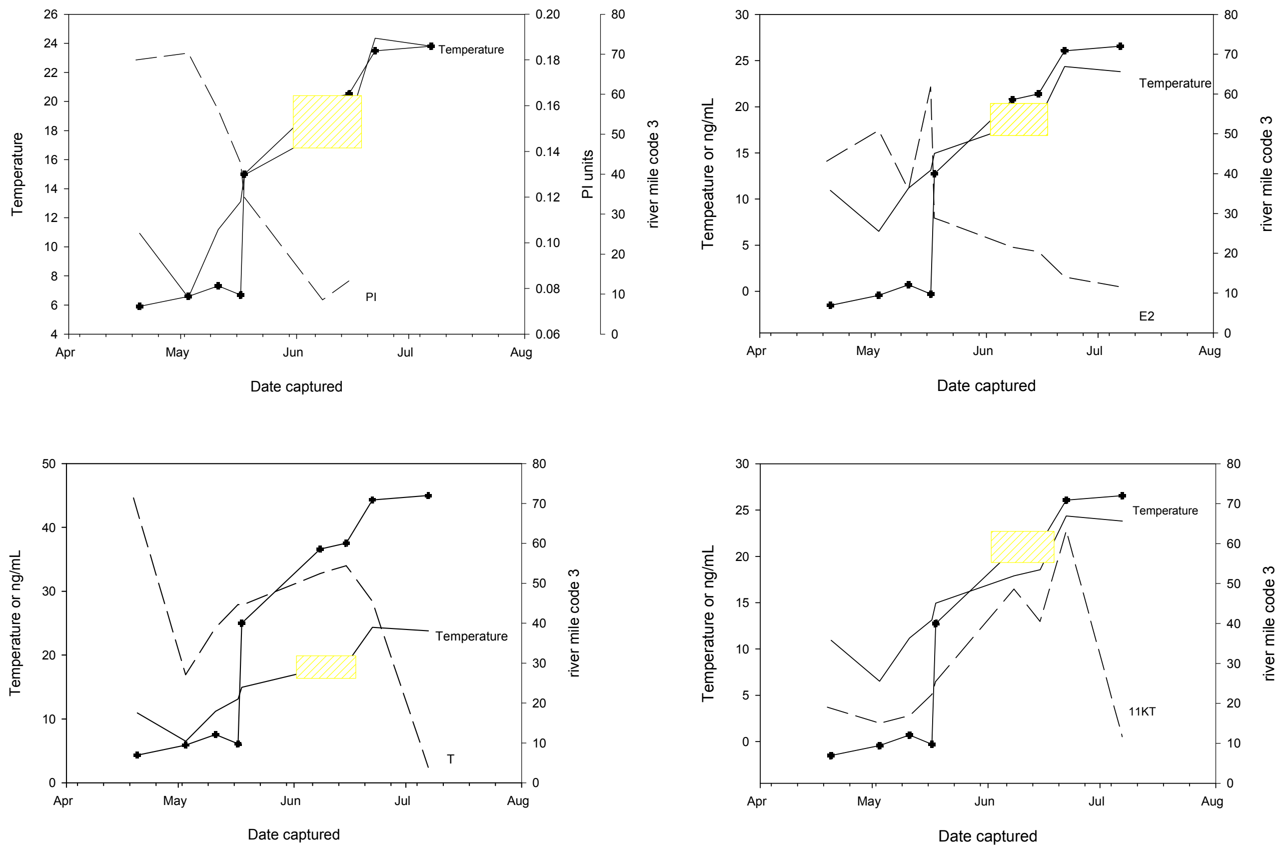

Figure C2. (*A–D*) The results obtained when a single fish is repeatedly sampled in 2005 as it moves upstream (up the Yellowstone R.) during the summer months. Polarization index (PI), 17 β-Estradiol (E2), Testosterone (T), and 11-ketotestosterone (11KT) all decrease over the course of the movement, although each parameter shows a slightly different pattern. The yellow box shows the temperature at which spawning is thought to occur.

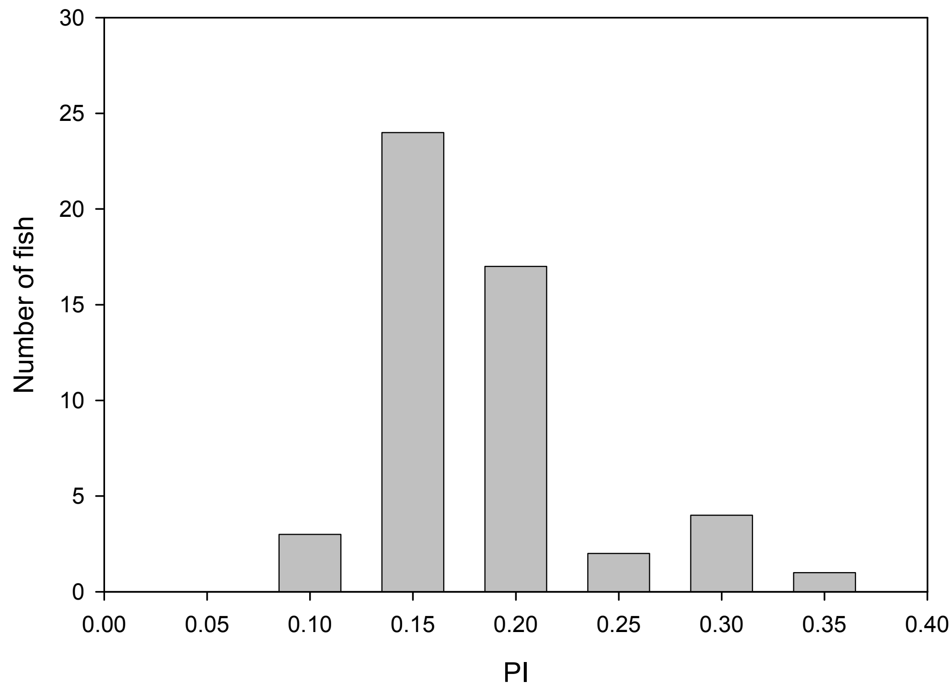

Figure C3. Frequency distribution of Polarization Index (PI) values for fish collected from Missouri River river miles 0 to 200 and implanted with transmitters in 2005.

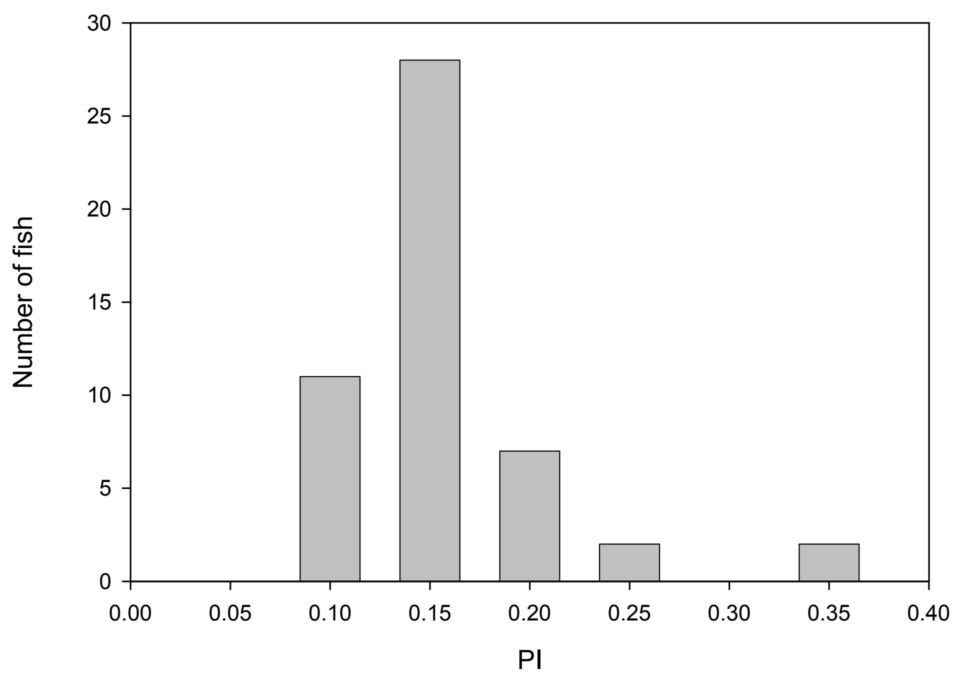

Figure C4. Frequency distribution of Polarization Index (PI) values for fish collected from Missouri River river miles 0 to 200 and implanted with transmitters in 2006.

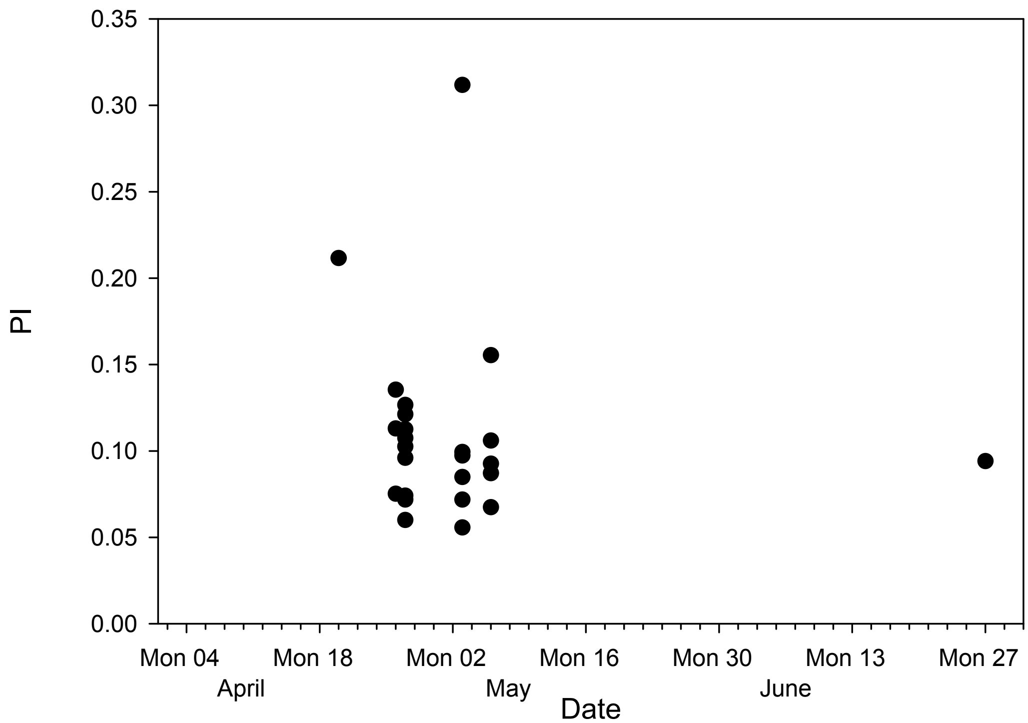

Figure C5. Polarization Index (PI) values of fish collected from the Missouri River from April to June 2005 near Hartsburg, Mo.

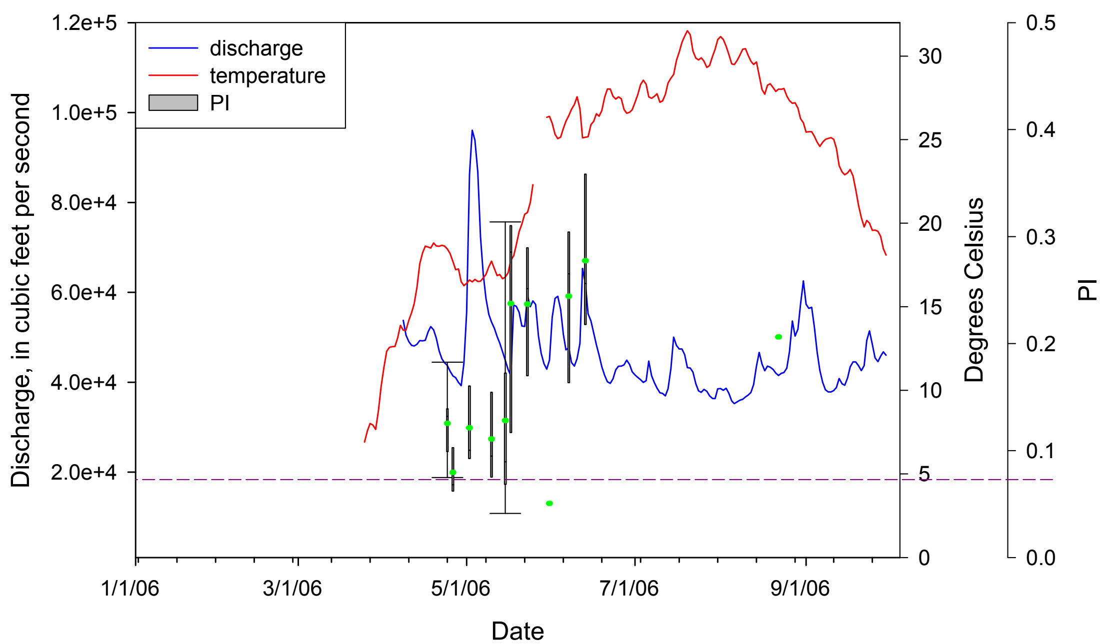

Figure C6. Polarization Index (PI) values for fish caught randomly during 2006 between Missouri River river miles 0 and 195. Green dots indicate mean values. Dotted purple line shows the PI value (0.07) at which maturational competence is estimated to occur.

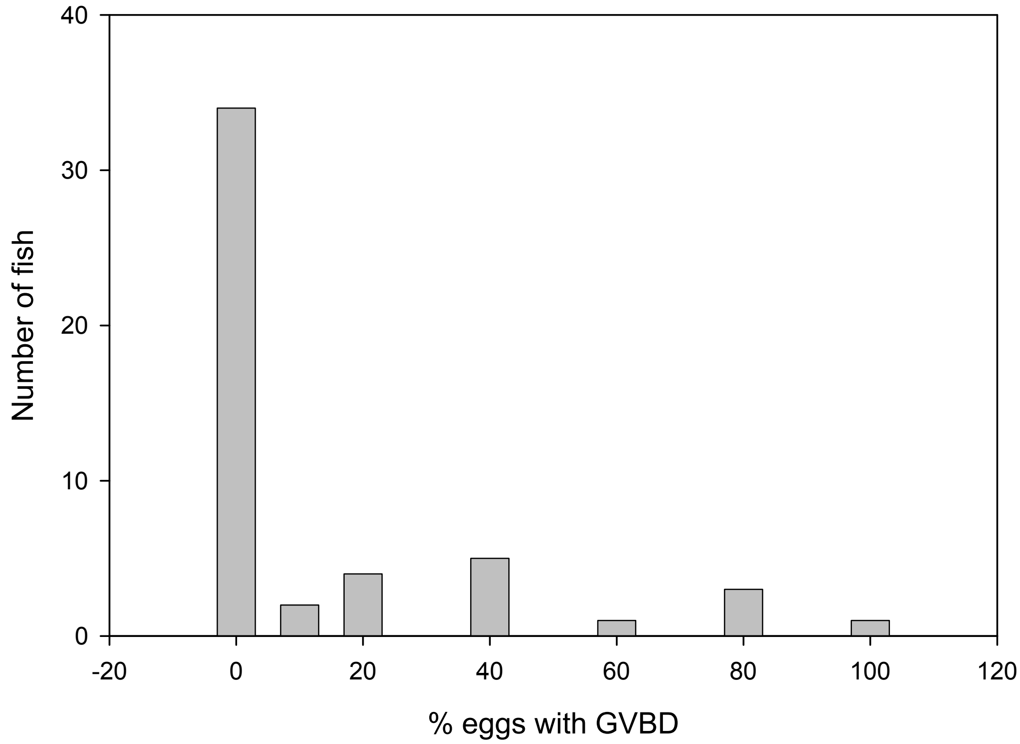

Figure C7. The number of fish and the percentage of each fish's eggs that showed germinal vesicle breakdown (GVBD) in the progesterone assay for fish collected from Missouri River river miles 0 to 200 and implanted with transmitters in 2005.

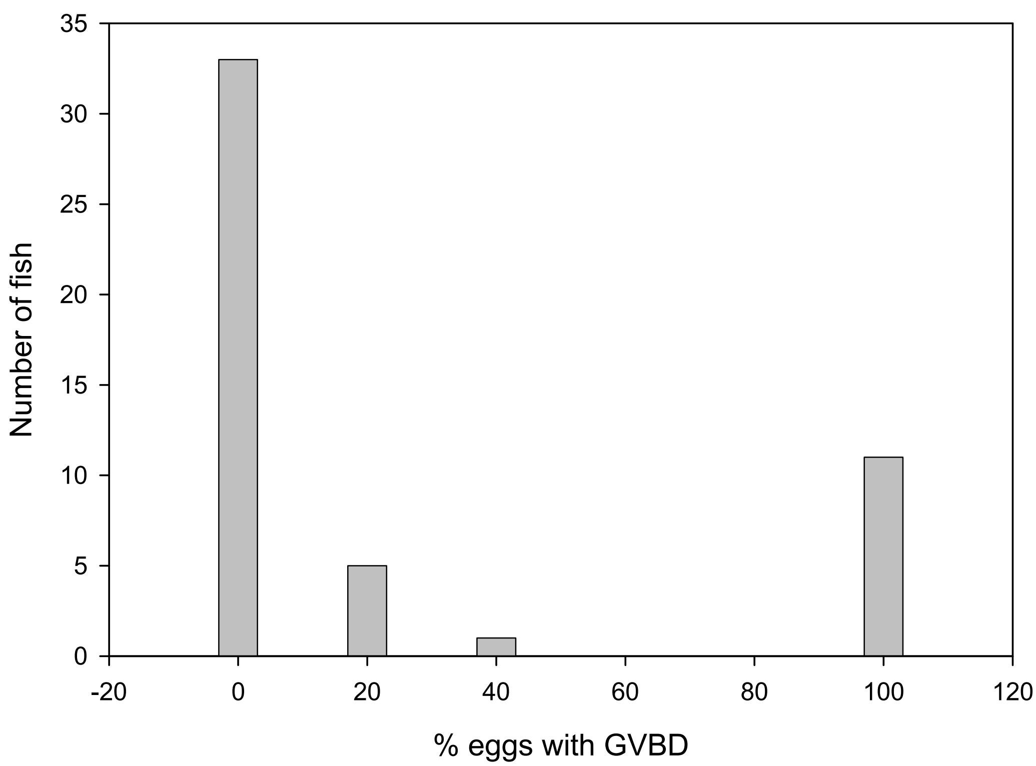

Figure C8. The number of fish and the percentage of each fish's eggs that showed germinal vesicle breakdown (GVBD) in the progesterone assay for fish collected from Missouri River river miles 0 to 200 and implanted with transmitters in 2006.

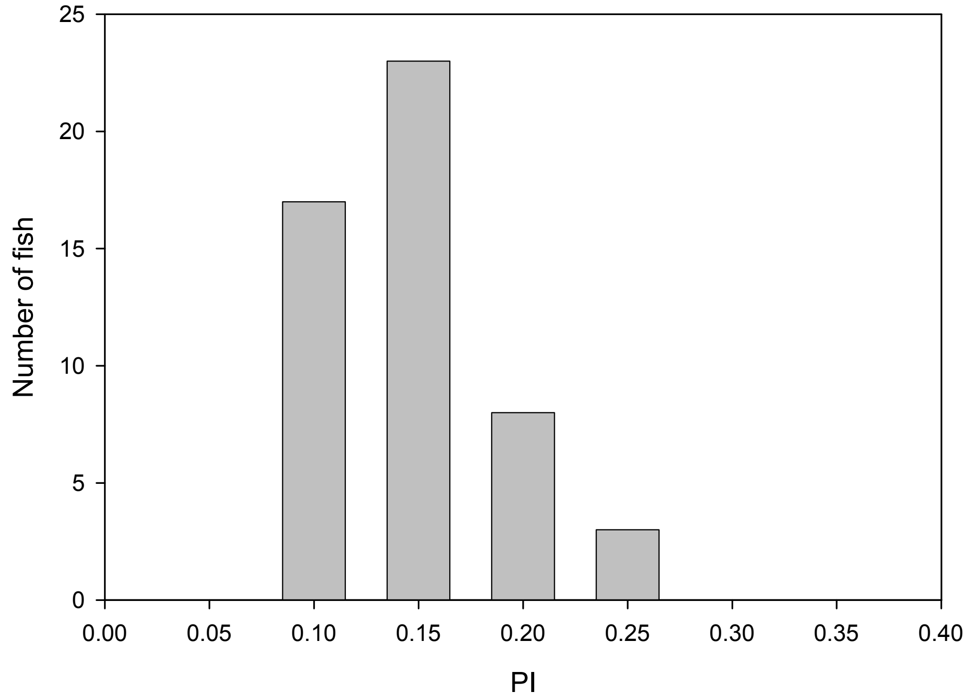

Figure C9. Frequency distribution of polarization Index (PI) values for fish collected from Missouri River river miles 365 to 870 and implanted with transmitters in 2005.

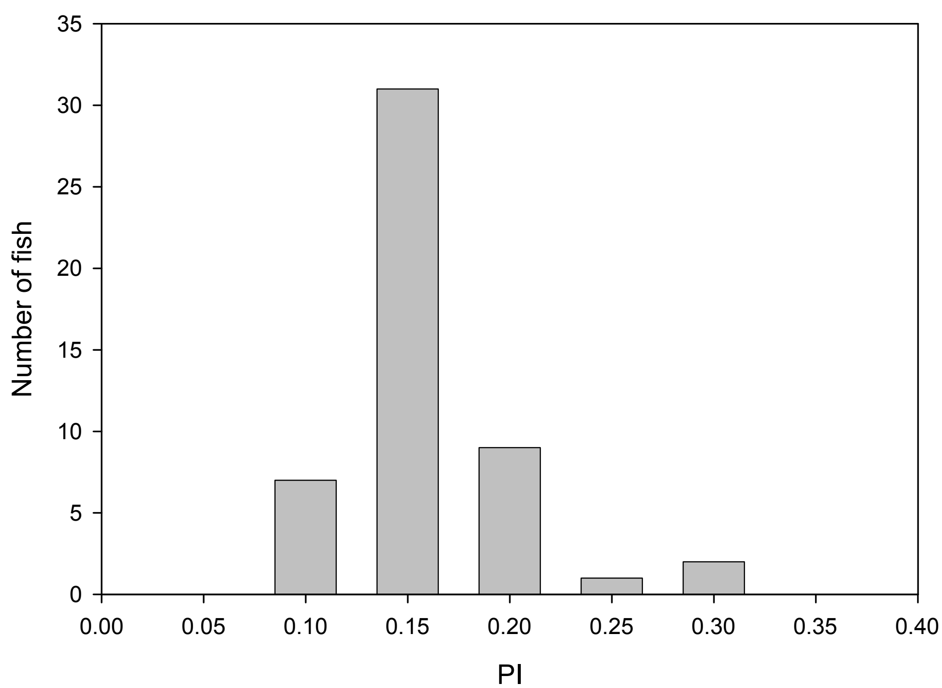

Figure C10. Frequency distribution of polarization index (PI) values for fish collected from Missouri River river miles 365 to 870 and implanted with transmitters in 2006.

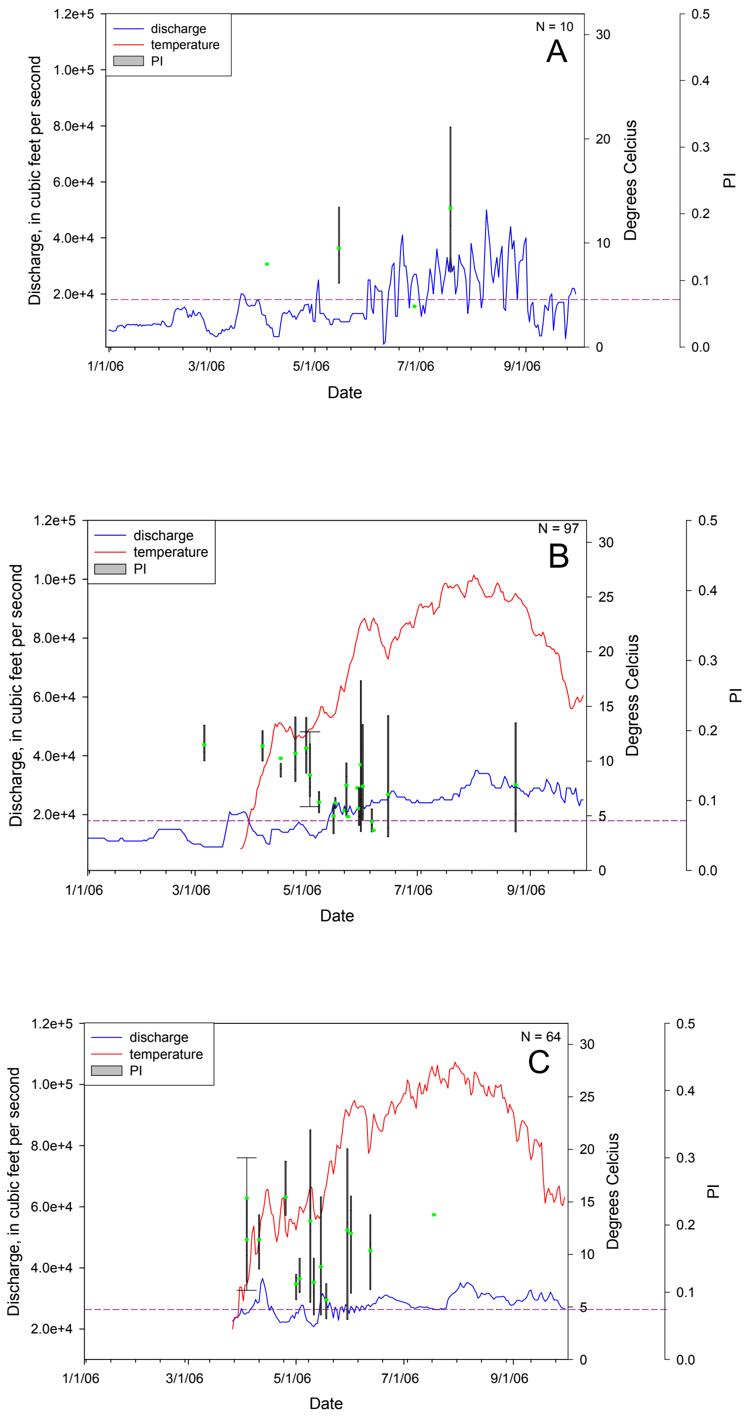

Figure C11. Polarization Index (PI) values for fish caught randomly during 2006 between Missouri River river miles 870 and 830 (*A*), river miles 755 and 810 (*B*), and river miles 365 and 750 (*C*). Green dots indicate mean values. Dotted purple line shows the PI value (0.07) at which maturational competence is estimated to occur. The total number of fish sampled (N) is indicated in the upper right corner of the graph.

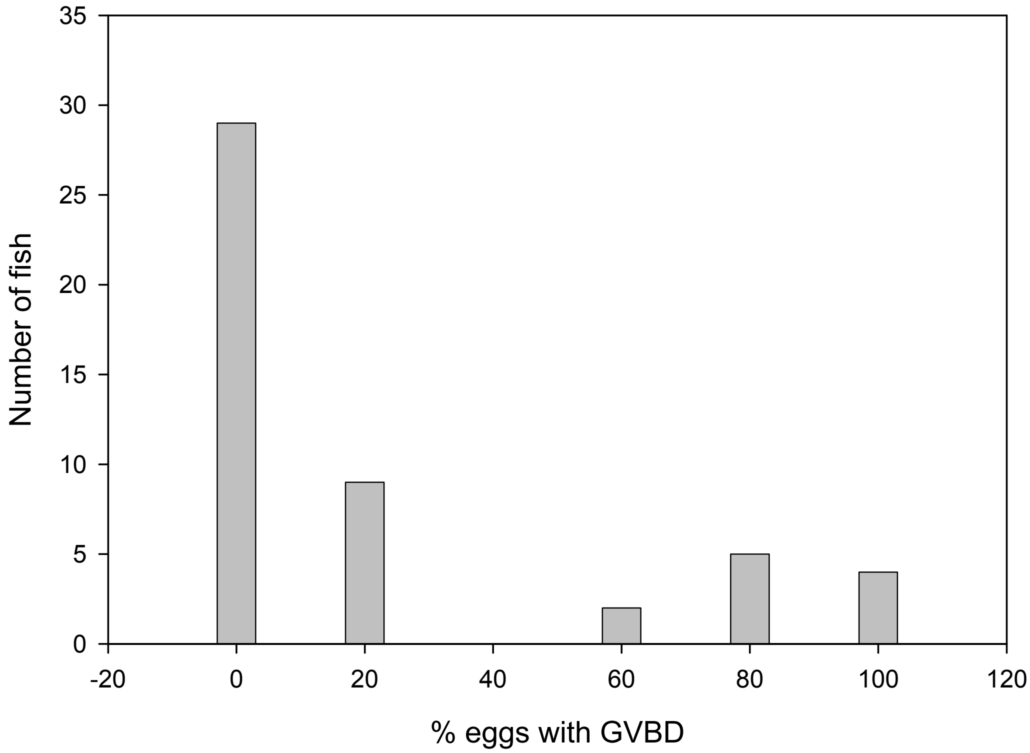

Figure C12. The number of fish and the percentage of each fish's eggs that showed germinal vesicle breakdown (GVBD) in the progesterone assay for fish collected from Missouri River river miles 365 to 870 and implanted with transmitters in 2005.

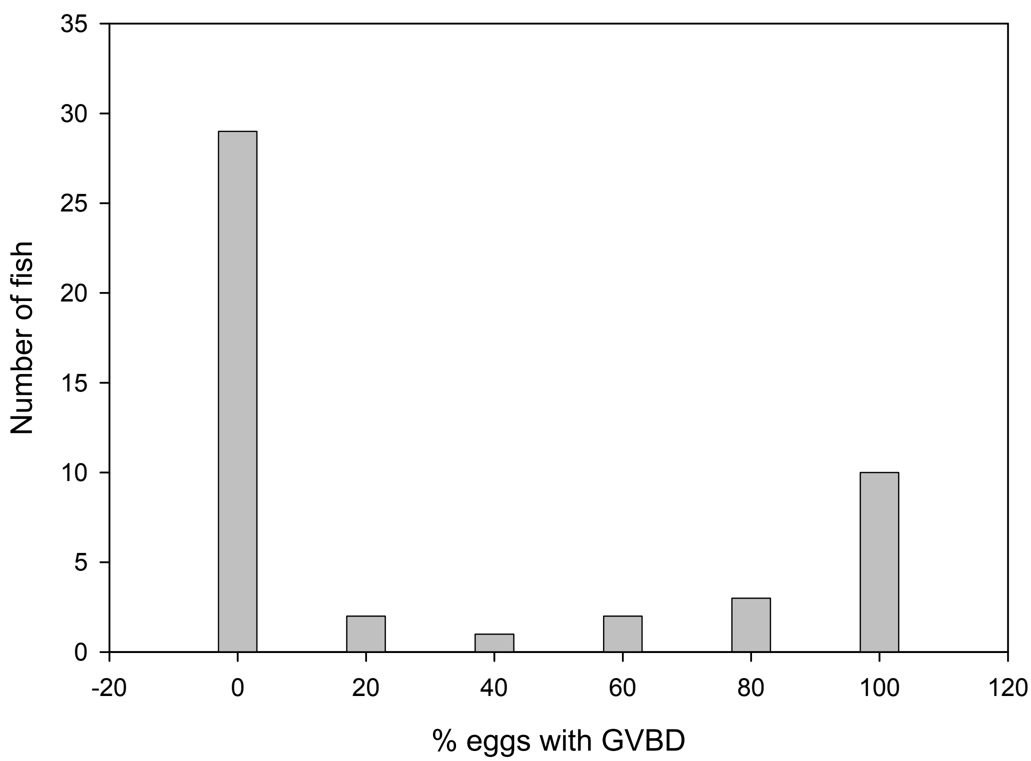

Figure C13. The number of fish and the percentage of each fish's eggs that showed germinal vesicle breakdown (GVBD) in the progesterone assay for fish collected from Missouri River river miles 365 to 870 and implanted with transmitters in 2006.

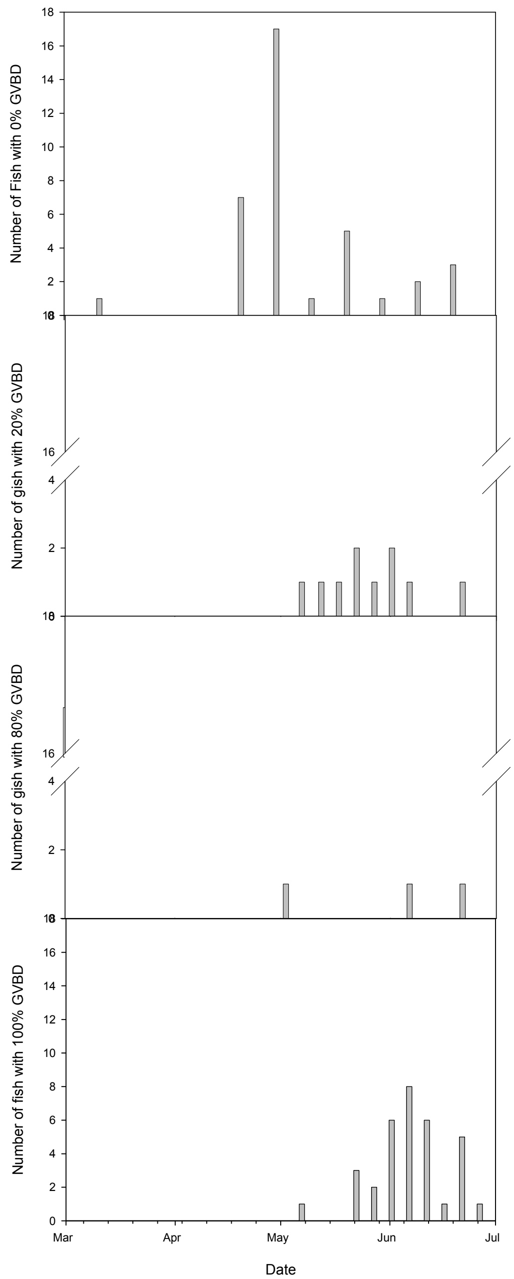

Figure C14. The number of fish and the percentage of each fish's eggs that showed germinal vesicle breakdown (GVBD) in the progesterone assay for fish collected from the Missouri River between river miles 870 and 830 in 2006.

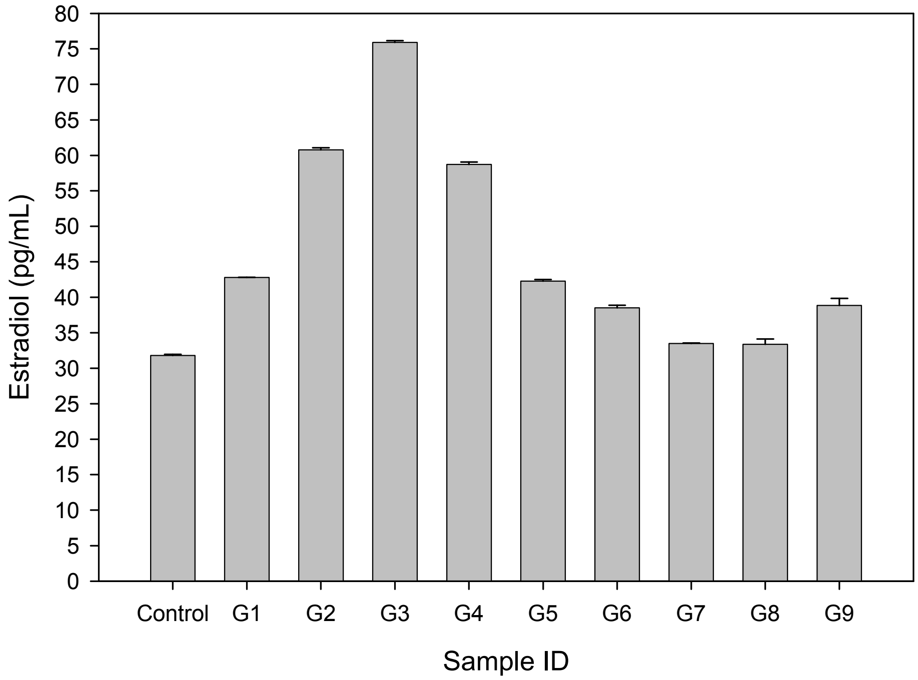

Figure C15. 17 β-estradiol produced by vitellogenic shovelnose sturgeon oocytes exposed to various samples thought to contain luteinizing hormone (LH).

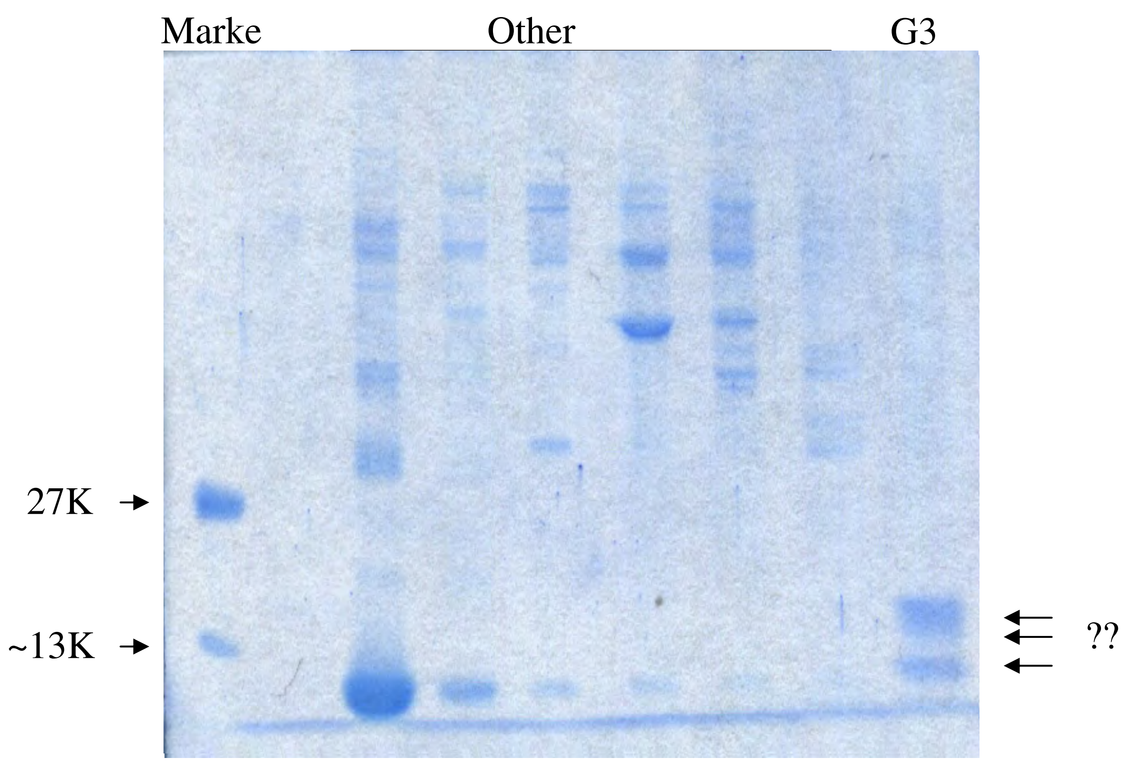

Figure C16. An sodium dodecyl (lauryl) sulfate-polyacrylamide (SDS) electrophoresis gel showing the G3 sample (see fig. C15) and three bands near the front line possibly representing the luteinizing hormone (LH) complex.

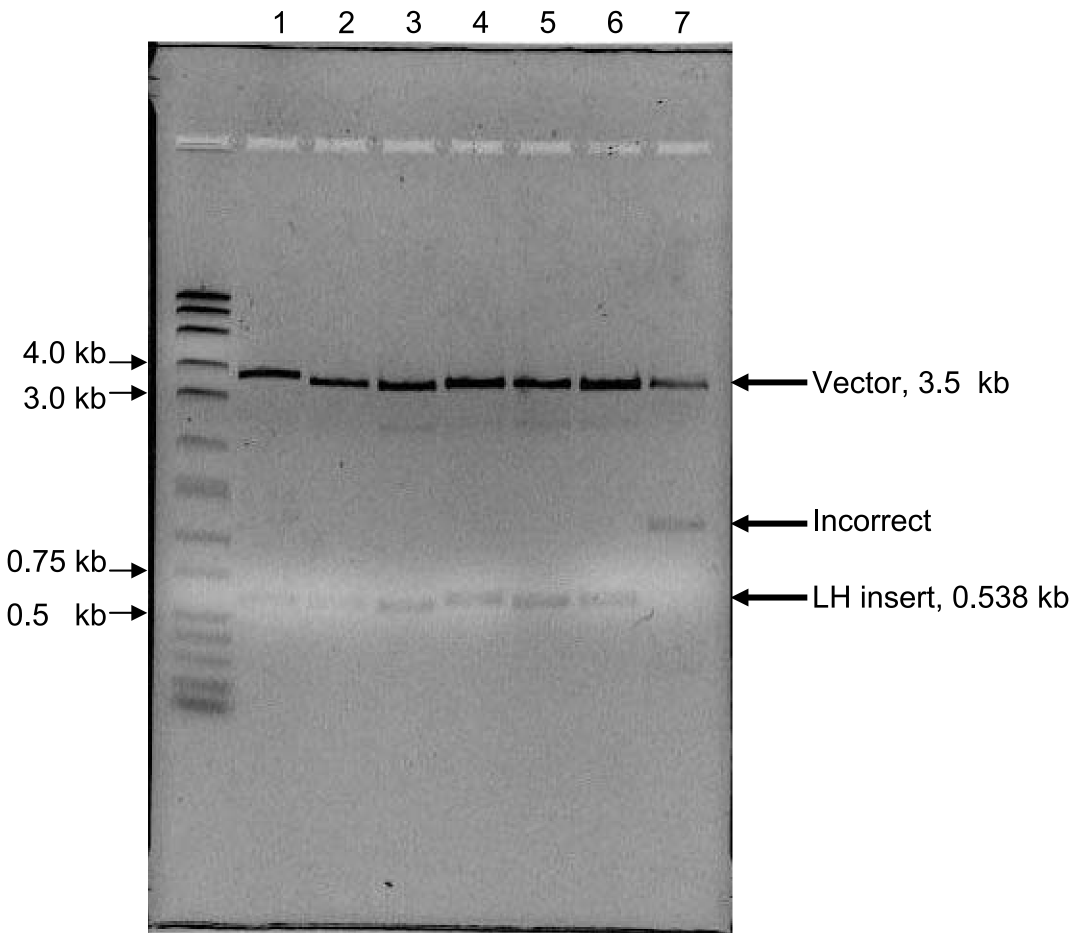

Figure C17. A 1.0 percent agarose gel of an EcoRI digest (restriction enzyme) of miniprep DNA for shovelnose sturgeon luteinizing hormone (LH). Clones 1 and 6 have the correct LH insert; clone 7 has an incorrect insert. Clones 3 and 4 were chosen for sequencing.

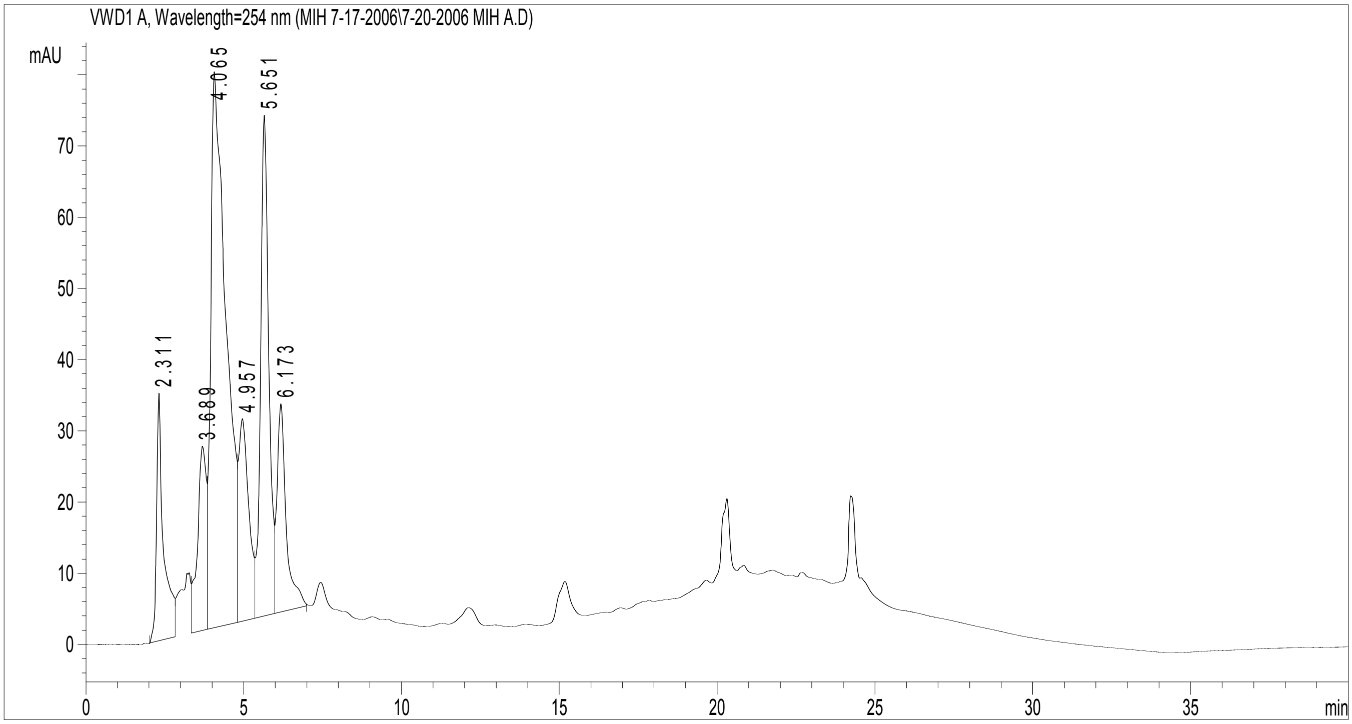

Figure C18. Chromatogram of incubation media collected after incubation of oocyte follicles during the final phases of oocyte maturation. Peaks indicate potential maturation-inducing compounds.

Table C1. Blood and biopsy samples collected during 2006 from sturgeon captured in the Missouri River.

	Number of samples	
River reach (river miles)	**Plasma**	**Biopsy**
870–830	80	10
810–755	119	103
750–365	180	62
195–0	132	60
Total	**511**	**235**

Table C2. Means ± standard deviation and ranges (in parantheses) of 17 β-estradiol, 11-ketotestosterone, testosterone, and cortisol from gravid female sturgeon collected from river miles 0–200 of the Missouri River in 2005 and 2006.

[Sampling occurred during implantation and then again if the fish were recaptured. pg/mL, picograms per milliliter; AP, analysis pending]

Year	Time point	17 β-Estradiol (pg/mL)	11-Ketotestorone (pg/mL)	Testosterone (pg/mL)	Cortisol (ng/mL)
2005	Implantation	7722 ± 5999 (969–22896)	1599 ± 1983 (412–13563)	13462 ± 5306 (3199–23153)	19 ± 8 (6–48)
	Recapture	167 ± 49 (23–134)	148 ± 41 (119–176)	1728 ± 855 (92–2467)	7 ± 4 (3–12)
2006	Implantation	7017 ± 10106 (164–40991)	2655 ± 1921 (236–6915)	13175 ± 7766 (2198–34009)	24 ± 13 (6–69)
	Recapture	AP	AP	AP	AP

Table C3. Means ± standard deviation and ranges (in parantheses) of 17 β-estradiol, 11-ketotetosterone, testosterone, and cortisol from gravid female sturgeon collected from river miles 365–870 of the Missouri River in 2005 and 2006.

[Sampling occurred during implantation and then again if the fish were recaptured. pg/mL, picograms per milliliter; AP, analysis pending]

Year	Time Point	17 β-Estradiol (pg/mL)	11-Ketotestosterone (pg/mL)	Testosterone (pg/mL)	Cortisol (ng/mL)
2005	Implantation	3678 ± 3289 (531–17221)	3341 ± 3262 (201–13592)	10865 ± 7961 (892–33567)	40 ± 27 (9–148)
	Recapture	248 ± 124 (150–640)	244 ± 383 (65–1327)	1342 ± 533 (588–2665)	12 ± 9 (1–41)
2006	Implantation	11515 ± 15584 (236–58648)	3159 ± 2877 (295–11288)	17569 ± 7999 (2443–31038)	AP
	Recapture	103 ± 15 (92–113)	20 ± 0 (20–20)	132 ± 47 (165–98)	AP

Appendixes C1 and C2

Appendix C1. Hormone values for fish randomly caught in 2005 in the Missouri River near Hartsburg, Mo.

[pg/mL, picograms per liter; NA, data not available].

Sample	Estradiol (pg/mL)	11-Ketotestosterone (pg/mL)	Testosterone (pg/mL)
1	24	6,919	22,195
2	165	7,578	16,881
3	103	2,319	NA
4	63	1,351	NA
5	15	5,462	NA
6	7	873	78
7	10	10,483	989
8	8	2,523	262
9	29	11,972	520
10	15	9,106	889
11	NA	4,481	8,994
12	NA	7,613	16,650
13	NA	3,711	13,353
14	509	1,299	219
15	24	2,074	5,196
16	40	10,457	20,393
17	47	3,781	7,622
18	101	5,201	14,258
19	912	663	6,787
20	210	871	4,971
21	124	2,092	8,863
22	12	8,626	16,650
23	58	1,823	5,724
24	NA	1,219	6,335
25	NA	1,408	4,958

Appendix C2. Hormone values for fish randomly caught in 2006 in the Missouri River in one reach above Gavins Point Dam and three reaches below Gavins Point Dam.

[pg/mL, picograms per liter; RM, river mile]

Sample	17 β-Estradiol (pg/mL)	11-Ketotestosterone (pg/mL)	Testosterone (pg/mL)
	RM 750-811		
23	149	214	1,570
46	8,087	764	17,177
79	1,131	311	8,514
80	10,131	4,987	24,982
82	36,891	2,481	18,179
90	8,710	1,318	15,672
151	39,519	517	10,460
185	46,583	589	14,493
256	3,683	808	14,685
264	6,651	4,875	21,766
265	37,761	3,845	23,876
279	9,108	2,212	14,152
293	19,821	4,186	23,308
296	1,412	8,105	19,345
317	7,528	4,238	23,603
331	7,173	4,876	22,121
346	743	5,956	25,371
352	7,363	5,322	26,624
364	1,104	7,047	28,827
370	3,875	4,146	15,980
389	3,587	5,784	24,356
389	2,543	6,034	24,841
412	22,855	5,037	26,840
433	7,881	1,614	13,641
435	17,222	2,624	15,789
444	176	6,284	20,185
459	13,169	5,246	20,797
468	26,827	2,982	25,779
708	3,928	4,787	26,917
744	174	10,699	34,192
757	130	5,798	18,980
763	1,909	5,898	25,119
771	1,620	4,957	19,534
912	18,422	3,121	21,689
926	19,384	2,978	17,734
973	58,887	4,400	22,765
974	12,759	6,595	25,867
975	4,931	1,881	13,097
978	3,289	6,671	16,949
2825	1,658	6,925	27,623

Appendix C2. Hormone values for fish randomly caught in 2006 in the Missouri River in one reach above Gavins Point Dam and three reaches below Gavins Point Dam.—Continued

[pg/mL, picograms per liter; RM, river mile]

Sample	17 β-Estradiol (pg/mL)	11-Ketotestosterone (pg/mL)	Testosterone (pg/mL)
23004	951	5,340	22,559
23021	142	10,017	26,628
23039	1,684	6,745	24,382
23043	7,028	8,052	25,991
23045	16,381	4,526	16,700
23046	2,073	8,813	30,656
23196	27,235	7,323	15,818
23503	3,248	6,229	25,633
23507	975	4,772	17,160
23509	1031	5,498	24,483
23516	328	5,581	5,541
23519	24,087	1,741	11,638
23550	369	10,826	31,969
23575	131	6,581	4,383
23604	2,820	6,423	26,112
23605	16,522	2,847	23,540
23606	1,928	4,810	25,485
23610	1,249	9,681	25,541
23618	12,408	5,755	19,297
23626	1,280	9,370	26,729
23635	5,189	7,777	26,221
23680	118	10,285	30,017
24023	453	7,294	20,786
24040	172	8,935	22,173
24053	175	35	23,993
24247	13,783	6,488	28,943
24249	130	275	218
RM 367.5-750			
1815	2,401	1,924	13,753
1822	8,190	1,648	14,214
1823	14,515	1,190	11,354
1824	109	318	5,676
1878	10,829	1,425	11,994
1881	366	743	6,760
1882	7,793	554	4,902
1884	11,176	1,183	9,213
1886	3,649	2,746	17,934
1888	125	1,701	184
1890	18,767	2,801	20,519
1897	155	50	715
1898	17,274	1,140	14,184

Appendix C2. Hormone values for fish randomly caught in 2006 in the Missouri River in one reach above Gavins Point Dam and three reaches below Gavins Point Dam.—Continued

[pg/mL, picograms per liter; RM, river mile]

Sample	17 β-Estradiol (pg/mL)	11-Ketotestosterone (pg/mL)	Testosterone (pg/mL)
1922	893	1,714	12,171
1923	3691	7,236	24,660
1942	27,764	1,396	10,857
1944	42,269	4,236	23,581
1946	27,409	2,630	19,013
1947	1,310	1,991	11,824
1948	214	10,782	34,819
1949	170	340	3,637
2080	116	2,251	14,806
2222	27,305	7,783	12,346
2238	7,684	19	16,877
2362	2,035	1,099	10,406
2372	2,794	4,207	23,184
2397	5,017	311	6,296
2482	291	156	726
2502	115	4,821	26,775
2517	10,203	1,188	13,819
2614	14,214	3,173	20,366
2623	133	46	1,012
2685	127	277	2200
2698	1,688	1,026	12,423
2871	455	7,128	26,137
2872	117	157	1,869
2873	11,767	809	10,022
2934	332	7,869	25,467
2981	135	7,532	35,210
2984	169	3,422	686
2986	500	133	11,687
4182	1,167	3,266	18,261
10070	23,477	1,284	13,689
10076	280	4,015	22,318
10076	200	449	9,413
10077	112	140	1,245
10092	225	589	9,439
10096	199	58	406
10097	125	1,019	7,401
10098	25,843	3,547	21,359
10229	175	9,247	34,847
10509	169	8,498	30,719
10540	6,457	6,433	25,124
10603	115	78	802

Appendix C2. Hormone values for fish randomly caught in 2006 in the Missouri River in one reach above Gavins Point Dam and three reaches below Gavins Point Dam.—Continued

[pg/mL, picograms per liter; RM, river mile]

Sample	17 β-Estradiol (pg/mL)	11-Ketotestosterone (pg/mL)	Testosterone (pg/mL)
10604	11,574	2,258	16,826
10605	604	1,873	10,417
10619	1,485	5,600	23,876
10638	9,519	5,238	23,423
10640	468	7,141	25,371
10641	377	6,051	21,175
10651	116	293	199
10652	159	5,178	22,888
10655	234	8,410	23,108
10656	228	9,262	4,536
10672	9,896	4,546	21,926
10753	159	6,868	27,842
11317	207	364	6,707
11323	137	11,201	23,955
12003	103	190	2,905
12007	4,561	3,778	18251
12571	119	51	1,785
12579	10,323	1,805	12,848
8047	172	11,564	28,776
8048	127	10,196	24305
8049	127	10,382	20,362
8101	5,644	9,043	30,647
8104	172	445	3,978
8106	130	11,761	32,840
8109	159	4,697	22,570
8111	114	9,611	30,005
8112	136	9,051	38,092
8113	137	1,768	14,731
8114	227	26	448
8115	142	9,598	29,931
8116	138	69	1,482
8117	137	7,451	26,945
8118	103	37	536
8119	15,265	8,306	34,704
8120	120	9,676	32,960
8121	122	11,061	34,027
8122	160	10,451	33,755
8123	15,548	781	12,119
8124	38,983	2,442	21,878
8125	34,641	3,704	22,604
8126	157	111	2,652

Appendix C2. Hormone values for fish randomly caught in 2006 in the Missouri River in one reach above Gavins Point Dam and three reaches below Gavins Point Dam.—Continued

[pg/mL, picograms per liter; RM, river mile]

Sample	17 β-Estradiol (pg/mL)	11-Ketotestosterone (pg/mL)	Testosterone (pg/mL)
8127	152	218	5,254
8128	132	1,063	16,369
8129	152	9,124	26,553
8145	250	165	3,527
8146	140	10,050	32,318
8149	20,635	4,254	24,415
8150	126	8,473	29,328
8161	181	225	8,316
8162	3,630	1,709	22,915
8163	1,584	185	6,781
8164	199	9,885	28,670
8165	136	31	555
8167	18,522	672	555
8168	25,676	598	25,748
8169	120	8,467	12,143
8170	177	122	5,501
8171	27,836	1,451	30,943
8172	100	9,186	15,326
8175	5,809	295	10,676
8185	160	93	3,523
8186	124	42	748
8187	134	881	748
8188	125	55	15,183
8189	100	3,318	1,288
8190	90	2,951	28,565
8192	132	1,333	16,523
8193	148	80	13,450
8194	88	2,334	15,871
8196	108	71	1,045
8526	130	10,965	27,350
8527	112	10,500	28,387
8528	16,486	5,955	23,420
8530	15,000	7,071	21,159
8531	25,884	9,197	33,299
8534	114	16	174
8535	152	168	1,496
8536	149	9,677	20,383
8537	5,877	9,472	32,659
8692	154	455	212
8693	13,587	3,058	19,656
8695	147	11,694	30,382

Appendix C2. Hormone values for fish randomly caught in 2006 in the Missouri River in one reach above Gavins Point Dam and three reaches below Gavins Point Dam.—Continued

[pg/mL, picograms per liter; RM, river mile]

Sample	17 β-Estradiol (pg/mL)	11-Ketotestosterone (pg/mL)	Testosterone (pg/mL)
8697	2,924	422	8,141
8698	134	32	388
RM 0-250			
5128	13,591	1,216	13,096
5218	18,382	1,498	13,907
5221	131	9,814	29,761
5272	25,965	3,581	18,498
5333	649	7,618	22,933
5334	16,743	5,098	26,424
5335	2,889	5,013	20,071
5408	483	5,974	21,149
5439	6,929	1,000	8,621
5441	44,750	4,049	18,674
5444	25,705	5,349	19,162
5449	15,083	3,609	19,795
5450	73,315	7,020	24,937
5648	412	3,065	8,422
5650	152	6,317	22,018
5778	14,188	3,948	15,149
5778	27,139	4,108	15,982
5783	33,682	6,479	22,217
5853	41,124	7,037	20,419
5867	16,880	5,654	26,162
5874	18,272	2,156	13,840
15038	132	419	10,359
15045	17,395	1,680	13,543
15406	4,006	8,106	27,488
15417	989	4,696	18,253
15425	115	27	134
15432	37,147	2,064	27,989
15434	3,101	3,592	18,565
15436	391	9,833	36,029
15438	49,519	2,388	19,419
15440	51,756	4,511	21,292
15445	39,434	5,960	28,215
15458	9,907	1,660	7,752
15458	11,248	1,987	7,848
15494	169	258	4,646
15495	15,978	1,004	10,867
15499	66,942	1,075	8,357
15500	17,095	451	8,858

Appendix C2. Hormone values for fish randomly caught in 2006 in the Missouri River in one reach above Gavins Point Dam and three reaches below Gavins Point Dam.—Continued

[pg/mL, picograms per liter; RM, river mile]

Sample	17 β-Estradiol (pg/mL)	11-Ketotestosterone (pg/mL)	Testosterone (pg/mL)
15711	20,106	4,244	22,114
16416	1,088	5,259	2,244
16460	1,449	6,978	28,896
16466	437	6,960	26,566
16474	3,221	797	5,669
16763	1,927	2,609	17,670
16800	3503	1,979	15,899
16875	5,821	9,522	29,734
17312	10,681	9,535	941
17313	107	53	171
CR002	122	4,973	7,549
CR003	150	2,468	24,505
CR004	201	4,768	7,010
CR006	15,142	3,486	10,908
CR007	146	4,848	16,549
CR008	140	8,247	29,422
CR011	124	6,757	10,874
CR012	98	3,986	26,922
CR013	19,420	2,387	5,285
CR014	205	2,408	11,573
CR015	1,315	4,944	6,390
CR016	475	2,382	7,826
CR020	1,057	2,918	8,296
CR021	45,369	442	2,833
CR022	17,313	612	4,258
CR023	22,054	2,165	16,216
CR026	207	1,053	3,660
CR035	233	2,802	4,561

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For more information concerning this publication, contact:
Director
U.S. Geological Survey
Columbia Environmental Research Center
4200 New Haven Road
Columbia, MO 65201
(573) 875–5399
Or visit the Columbia Environmental Research Center website at:
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The Roles of Physical Habitat in Reproduction and Survival of Pallid Sturgeon and Shovelnose Sturgeon in the Lower Missouri River, Progress 2005–06

By Robert B. Jacobson, Harold E. Johnson, Joanna M. Reuter, and
Caroline M. Elliott

Chapter D of

Factors Affecting the Reproduction, Recruitment, Habitat, and Population Dynamics of Pallid Sturgeon and Shovelnose Sturgeon in the Missouri River

Edited by Carl E. Korschgen

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The Roles of Physical Habitat in Reproduction and Survival of Pallid Sturgeon and Shovelnose Sturgeon in the Lower Missouri River, Progress 2005–06

By Robert B. Jacobson, Harold E. Johnson, Joanna M. Reuter, and Caroline M. Elliott

Abstract

This report documents progress on three related components of habitat assessments in the Lower Missouri River during 2005–06. The habitat-use component links this research directly to sturgeon ecology research described in other chapters. The habitat availability and habitat dynamics assessments provide physical context for the ecological research. Results from 2005 to 2006 indicate that the methods developed to assess habitat use, quality, quantity, and dynamics are appropriate and sufficiently accurate to address critical questions about sturgeon habitat on the Lower Missouri River. Preliminary analysis of habitats occupied by adult female shovelnose sturgeon indicates that migrating sturgeon do not select for depth but seem to select for lower than reach-averaged velocities and higher than reach-averaged velocity gradients. Data collected to compile, calibrate, and validate multidimensional hydraulic models in probable spawning reaches appear to be sufficient to support the modeling objectives. Monitoring of selected channel cross sections and long profiles multiple times during the year showed little change at the upstream-most reach over the range of flows measured during 2006, likely because of channel stability associated with an armored bed. Geomorphic changes documented at monitoring cross sections increased with distance downstream. Hydroacoustic substrate-class parameters documented systematic changes with discharge and with hydraulic environment across the channel. Similarly, bed velocity varied predictably with discharge and hydraulic environment, indicating its potential as an indicator of bedload sediment transport. Longitudinal profiles showed substantial downstream movement of dunes over the monitored discharges, as well as substantial within-year variability in dune size. Observations of geomorphic change during the moderate flow range of 2006 support the hypothesis that the magnitude of flow modifications under consideration on the Lower Missouri River will be sufficient to transport sediment and potentially modify spawning habitats.

Background

Intensive management of the Missouri River (fig. D1) for navigation, flood control, and power generation has resulted in substantial physical changes to the river corridor (Ferrell, 1993; 1996; Galat and Lipkin, 2000; Jacobson and others, 2004b; Jacobson and Galat, 2006). Other factors, such as agricultural pesticides, nutrient runoff, and increasing discharge of domestic and industrial effluents, also may have affected the aquatic biota and the ecological health of the Missouri River basin (Tockner and Stanford, 2002). In addition, recent proliferation of introduced and non-indigenous species has further threatened to diminish the ecological integrity of the river ecosystem (Pflieger, 1997; Galat and others, 2005). Cumulatively, these changes in flow, physical habitat, water quality, and biota have been implicated in the decline of important components of the Missouri River's native fish assemblage (Funk and Robinson, 1974; Hesse and others, 1989; Hesse and Sheets, 1993). The most notable and conspicuous of these is the decline of sturgeon species native to the Missouri River basin.

Physical habitat has been central to recovery strategies on the Missouri River. The U.S. Army Corps of Engineers is charged with altering operations of the Missouri River Main Stem Reservoir System, operation and maintenance of the Missouri River Bank Stabilization and Navigation Project, and operation of the Kansas River Reservoir System to remove a jeopardy opinion for the endangered pallid sturgeon (*Scaphirhynchus albus*) (U.S. Fish and Wildlife Service, 2003), largely through manipulations of physical habitat. Interdisciplinary compilations of research needs for pallid sturgeon recovery have also emphasized physical habitat. A research-needs workshop in 2004 (Quist and others, 2004) developed priorities that were subsequently prioritized by the Middle Basin Pallid Sturgeon Recovery Work Group (Middle Basin Pallid Sturgeon Recovery Work Group, 2005). Three top-ranked research needs from the working group were related to spawning and early-life-stage physical habitats:

- Locate, quantify, and characterize pallid sturgeon spawning sites, and quantify spawning frequency and behavior.
- Locate, define, characterize, and quantify pallid sturgeon juvenile and rearing habitats.
- Determine habitat use by larval pallid sturgeon.

Research needs specific to flow modification responses also were deliberated by experts, stakeholders, and managers in a series of basin-wide meetings (plenary group process) during summer 2005. The plenary group articulated hypotheses relating spring pulses to habitat availability and quality:

- Spring flow pulses may act to "condition" spawning substrate by transporting sediment and cleaning it of silt and sand.
- Spring flow pulses may act to make spawning habitat available to reproductive fish by inundating habitat patches or changing patch hydraulics.
- Spring flow pulses may affect rate and distance of larval drift.

Based on the statements of research priorities, this study addresses the roles of physical habitat in reproduction and survival of sturgeon in the Missouri River. Physical habitat in this context is defined as the joint spatial and temporal distribution of depth, velocity, substrate, turbidity, temperature, and other related variables; at the reach scale, physical habitat is typically described as measures of depth, velocity, and substrate (Gordon and others, 1992; Reuter and others, 2003).

The research described here is a task within a series of coordinated studies being conducted by the U.S. Geological Survey's (USGS) Columbia Environmental Research Center (CERC) and collaborating agencies on factors affecting the reproduction and survival of pallid sturgeon and shovelnose sturgeon (*S. platorynchus*) in the Missouri River. The overarching project is the Comprehensive Sturgeon Research Project (CSRP) and is organized as a matrix of life-stage components and tasks that address ecosystem and population processes (fig. D2). Flow-manipulation experiments are included conceptually within CSRP as an approach to developing field data under relatively controlled experimental conditions; these efforts are addressed in part under a coordinated project called the Sturgeon Response to Flow Modification (SRFM) project. Progress in habitat studies under both CSRP and SRFM are described in this chapter.

The CSRP approach recognizes that any life stage of sturgeon could be a bottleneck in their reproduction and survival; however, technical experts in the Missouri River basin have consistently identified spawning and early-life stages as priorities because of the vulnerability of populations to disturbances during early-life stages (Quist and others, 2004; Middle Basin Pallid Sturgeon Recovery Work Group, 2005). Accordingly, the priorities of this study and coordinated CSRP studies are to understand the factors affecting spawning first, followed by factors affecting larval and juvenile fish habitats (fig. D3).

Reproductive Ecology of Missouri River Sturgeon

Evidence from various monitoring efforts suggests that recruitment of pallid sturgeon to the adult population is limited or nonexistent throughout most of the Missouri River (U.S. Fish and Wildlife Service, 2000). In contrast, the closely related shovelnose sturgeon is reproducing, and some recruitment is occurring in the Missouri River (Moos, 1978; Keenlyne, 1997). Locations of spawning and the relative suitability of spawning conditions for both of these sturgeon species in the Lower Missouri River are not known. In addition, the specifics of the reproductive physiology and spawning behavior of both species are not well documented.

The effect of hydrology on spawning has not been described for either shovelnose sturgeon or pallid sturgeon, but fishery biologists speculate that spawning runs are somewhat dependent on river flow (Becker, 1983; Keenlyne and Jenkins, 1993; U.S. Fish and Wildlife Service, 2000). Migrations of shovelnose sturgeon into smaller streams, presumably for spawning, have been reported (Becker, 1983) but, similar use of small tributaries by pallid sturgeon has not been documented. The sequence of spawning behavior from migration and aggregation at the spawning site through egg deposition has not been documented for either the shovelnose sturgeon or pallid sturgeon. The timing, periodicity, and location of spawning events in relation to the physical habitat variables have not been documented. This information is critical for designing habitat alterations and flow modifications to promote reproduction and survival of young sturgeon.

Spawning areas of other North American sturgeon species are usually characterized by coarse or hard substrates, with variable depths and velocities. White sturgeon, *Acipenser transmontanus* (Scott and Crossman, 1973; Parsley and others, 2002); green sturgeon, *A. medirostris* (Houston, 1988); shortnose sturgeon, *A. brevirostrum* (Taubert, 1980; Buckley and Kynard, 1985); Atlantic sturgeon, *A. oxyrinchus oxyrinchus* (Scott and Crossman, 1973); Gulf sturgeon, *A. oxyrinchus desotoi* (Fox and others, 2002); and lake sturgeon, *A. fulvescens* (Scott and Crossman, 1973; LaHaye and others, 1992; Bruch and Binkowski, 2002) spawn primarily over gravel, cobble, boulder, bedrock, or other hard surfaces. Little is known, however, about the specific substrate preferences of spawning pallid and shovelnose sturgeon. Pallid sturgeon and shovelnose sturgeon have been assumed to spawn in relatively rapid current over coarse substrate in, or adjacent to, the main river channel (Becker, 1983; Mayden and Kuhajha, 1996). Knowledge of the location and type of substrate preferred by spawning pallid and shovelnose sturgeon would allow biologists to locate adult fish during the spawning season, estimate the population of reproductive adults, monitor spawning activity and relative success, and assess habitat preferences and suitability during the spawning period.

Potential postspawn controls on sturgeon survival are also poorly understood. To survive, sturgeon eggs must be deposited on suitable substrate, without either being covered with sediment or being dislodged as a result of bedload transport. Recently, hypotheses have been developed that white sturgeon eggs drift with the current after spawning and may need to be deposited in riparian vegetation patches downstream from the site of spawning (Coutant, 2004). If applicable to Missouri River sturgeon, this theory would require relatively high flows during spawning and specific spatial organization of spawning and egg-incubation habitat patches. Water quality may also be critical at this stage.

After hatching, larval sturgeon drift and migrate downstream for 8–13 days. While they lack swimming ability, their transport and fate are determined mainly by river hydraulics. Distance of drift and the types of habitats encountered by the larvae are key variables that may influence their survivability. In particular, the fate of larvae may be very different if they remain in the central thread of high-velocity current or are advected or diffused into marginal, slow-water areas with different mixes of food sources, water quality, and potential predators (Braaten and Fuller, in press).

Physical Habitat Concepts

The goal of this research is to determine the physical habitat requirements for pallid and shovelnose sturgeon reproduction and survival in the Missouri River. Habitat is conventionally defined as the place or a set of places where a fish, a fish population, or a fish assemblage finds suitable environmental features to survive and reproduce (Orth and White, 1999). Because Missouri River sturgeon migrate long distances during their lives, habitat assessments need to consider a broad suite of places within the river system (fig. D3). The more restricted definition of physical habitat is the three-dimensional structure in which riverine organisms live; time (frequency, duration, sequence, rate of change) adds a critical fourth dimension (Gordon and others, 1992). Water depth, flow velocity, and substrate are the three main characteristics of physical habitat that are usually evaluated. Water temperature and turbidity typically are also strongly associated with depth and flow velocity.

Physical aquatic habitat results from interaction of water with the morphology of the stream channel and adjacent flood plain (Jacobson and Galat, 2006). Flow regime describes the quantity and temporal variation of water flows. Flow regimes can be assessed independent of channel form by considering biologically important measures of flow variability (Poff and others, 1997; Richter and others, 1997; Richter and others, 2003). River channel form determines how the water is distributed across the channel, thereby creating the spatial distribution of depth, velocity, and substrate. Form can also be independently assessed by using measures of channel morphology. Putting form and flow together to achieve an integrated spatial and temporal assessment of habitat availability generally requires a hydrodynamic modeling approach (Bowen and others, 2003). Hydrodynamic modeling is especially critical for understanding the spatial and temporal organization of habitat patches that may determine reproductive success at the reach scale (Coutant, 2004; Jacobson and Galat, 2006; Johnson and others, 2006).

Historical Alteration, Lower Missouri River

The channel form and flow regime of the Lower Missouri River have been substantially altered to promote economic development but at the expense of fish and wildlife habitat (National Research Council, 2002). The Lower Missouri River (generally defined as the Missouri River downstream of Gavins Point Dam at Yankton, S. Dak., fig. D1) drains 1,300,000 km^2 at its mouth (U.S. Army Corps of Engineers, 1998). Engineering of the Lower Missouri River began in the 1830s with clearing, snagging, and bank stabilization to improve conditions for steamboat navigation. Most of the river's engineering structures date from the Missouri River Bank Stabilization and Navigation Project, first authorized in the River and Harbor Act of 1912 (37 Stat. 201) and followed by an additional six acts of Congress in 1917 (40 Stat. 250), 1925, 1927, 1930 (46 Stat. 918), 1935 (PL 74–109), and 1945 (59 Stat. 10) (Ferrell, 1996). Wing dikes and revetments have stabilized the riverbank, and narrowed and focused the thalweg to maintain a self-dredging navigation channel from Sioux City, Iowa, 1,200 km downstream to St. Louis, Mo. (fig. D4). These engineering structures have created a narrow, swift, and deep channel from what was historically a shallow, shifting, braided river, resulting in the loss of as much as 400 km^2 of river-corridor habitats (Funk and Robinson, 1974; Hesse and Sheets, 1993; National Research Council, 2002; Galat and others, 2005).

Recognition of the scope of habitat loss has increased interest in rehabilitating parts of the Missouri River to help recover native biota (Latka and others, 1993). The U.S. Army Corps of Engineers began implementing the Missouri River Fish and Wildlife Mitigation Project (Mitigation Project) in 1986. Initial authorization for mitigation along the Lower Missouri River was for 194.7 km^2; an additional 480.2 km^2 were authorized in 1999 (U.S. Army Corps of Engineers, 2004a). Following the very large flood of 1993, numerous landowners sold their flood-damaged lands to the U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, and other Government agencies for conservation purposes.

The river has been regulated since 1954 by the Missouri River Reservoir System, the Nation's largest reservoir system, with nearly 93 km^3 of storage (U.S. Army Corps of Engineers, 2004b). The system is managed for multiple purposes including maintenance of navigation flows, flood control, hydropower, public water supply, recreation, and fish and wildlife resources. A historical perspective on hydrologic changes

(Galat and Lipkin, 2000) documents substantial alteration to the annual hydrograph below the reservoirs, with generally decreased spring pulses and increased summer low flows (fig. D5). The intensity of hydrologic alteration diminishes downstream from the dams as minimally regulated tributaries enter the Missouri River. The lower 590 km downstream of the Kansas River confluence has a notably altered hydrograph, particularly with respect to low flows, but has regained substantial variability, as shown at Hermann, Mo. (fig. D5).

Objectives and Scope

The general objectives of this study are to develop a predictive understanding of the roles of physical habitat in reproduction and survival of sturgeon in the Missouri River. Addressing this objective requires coordination with biological studies to define the linkages between physical habitat processes and biological responses. In the short term—a 3–5-year time frame—the emphasis is on understanding the physical processes that determine spawning and early-life-stage habitats. Our specific objectives are as follows:

1. Quantify physical habitat parameters associated with sturgeon spawning, successful egg maturation, and larval drift at the reach scale.
2. Quantify the sensitivity of spawning and early-life-stage habitats to variations in discharge, especially related to managed ecological flows.
    - A. Refine understanding of spawning habitat by quantifying spatial and temporal organization of habitat patches and quantifying gradients between patches at the reach scale.
    - B. Assess hydrodynamic modeling errors associated with varying bed roughness and bed deformation in the context of ecological information needs.
    - C. Evaluate methods to address larval drift by scaling models upward to the segment scale.
3. Evaluate the role of sediment transport in altering quantity and quality of habitat for spawning and early-life stages. Emphasis in this objective is on the “conditioning” of spawning patches and processes that affect survival of adhered eggs.

This chapter is intended to document progress in data collection efforts during 2005 and 2006 to address the three objectives listed above. We provide illustrations of representative data and some very limited interpretations. More comprehensive interpretations will be included in final project reports.

General Approach

This research is generally field based, combining measurements and modeling of physical habitat with biological understanding of habitat use. Hydroacoustic, Global Positioning System (GPS), and lidar survey methods are used to measure habitats, monitor geomorphic change, and compile, calibrate, and validate digital hydrodynamic models. Linkages to biotic responses are established through collaborations with coordinated studies on sturgeon physiology, ecology, and distributions (chaps. A, B, C, E). Additional understanding about the contribution of water quality to sturgeon habitat is provided by coordinated water-quality monitoring (chap. F).

Emphasis during 2005–06 has been on spawning habitat. If spawning habitat does not prove to be a unique bottleneck to sturgeon reproduction and survival, emphasis in later years will shift toward larval drift and rearing habitats.

To communicate more effectively with stakeholders, managers, and other scientists working on the Lower Missouri River, we use a mix of U.S. customary units and International System of Units (SI) units of measure in this chapter. For locations along the river and for discharges, we use the customary units of river mile (RM) and cubic feet per second. Reach-scale hydraulic variables—current velocity and depth—are in SI units of meters per second and meters.

Research Components

Component 1—Habitat Use

Principal Investigators

- Robert B. Jacobson
- Joanna M. Reuter
- Caroline M. Elliott

Specific Objectives

The objective of the habitat-use component is to quantify characteristics of prespawning, spawning, and early-life-stage habitats used by pallid and shovelnose sturgeon. The following discussion focuses on habitat as determined primarily from movements of 200 acoustically tagged, reproductively ready female shovelnose sturgeon; a few pallid sturgeon were also included in the study in 2006 (chap. B). Research activities during 2005–06 focused on adult sturgeon use of prespawning, spawning, and postspawning habitats.

Approach/Methods

Habitat-use studies depend substantially on telemetry data developed in the coordinated CSRP (task 1) project (chap. B, fig. D2). Ongoing radioacoustic telemetry studies involve the tagging of shovelnose and pallid sturgeon that are known to be in reproductive condition. Sturgeon were tagged in the downstream river segment between the Grand River, Mo. and the Osage River, Mo. and in the upstream river segment between the Big Sioux River, S. Dak. and the Platte River, Nebr. Telemetry was used to relocate the sturgeon periodically. Sturgeon locations were provided as Universal Transverse Mercator (UTM) coordinates accurate to within 2 m.

Two methods, based on fish locations, were used to select river reaches for physical habitat assessment. In the first method, a location was randomly selected from the previous day's sturgeon locations. Randomly selected locations are best suited for unbiased assessments of habitat use and availability (Millspaugh and Marzlugg, 2001). The second selection method utilized telemetry or behavioral observations that indicated that one or more of the tagged female sturgeon might be spawning. These potential spawning locations were preferentially selected without randomization because of their likely importance in defining spawning habitats. Also, pallid sturgeon relocations were selected without randomization at times, in order to validate similarity between shovelnose and pallid sturgeon habitat-use patterns. In addition, nonrandomized sites were mapped when randomization was not possible because of fluctuations in discharge, threat of severe weather, or other logistical constraints. Habitat mapping was not attempted if the discharge changed more than 10 percent between the time that a sturgeon was located and the time that the hydroacoustic survey could begin. Mapping was completed between April and August in 2005 and between May and July in 2006.

A mapping reach was defined as a complete river bend-crossover-bend or crossover-bend-crossover sequence roughly centered on the sturgeon location. The intent was to assess all macrohabitats available to the sturgeon. Reaches generally ranged from1,500 m to 3,000 m in length with 3,000 m being the maximum reach length that could be mapped during a single day. Sampling transects extended from bank to bank of the river perpendicular to general flow direction at 20- and 40-m intervals downstream of Rulo, Nebr. and 15- and 30-m intervals upstream of Rulo, Nebr. Five transects upstream and five transects downstream of the sturgeon location were mapped at the smaller transect spacing (15 or 20 m). Also, a longitudinal profile to define bedform dimensions was collected from upstream to downstream, following the thalweg along the entire reach. Commensurate with the accuracy of sturgeon locations, the hydroacoustic mapping was georeferenced with real-time Differential Global Positioning System (DGPS) data to submeter accuracy of northing and easting. Hydroacoustic mapping included high-resolution single-beam echosounding and acoustic bed-material classification. Three-dimensional flow velocities were measured with an acoustic Doppler current profiler. Selected sites were also mapped with high-resolution side-scan sonar to provide a complementary qualitative picture of spawning habitats. Except as discussed below, established USGS CERC protocols and standard methods were used (Elliott and others, 2004; Jacobson and others, 2004a; Jacobson and others, 2004b; Oberg and others, 2005) to produce depth, velocity, and substrate maps with 5-m cells that can be queried to determine averages and measures of variability of depth, velocity, and substrate or combinations of these characteristics.

Progress During 2005–06

During 2006, hydroacoustic data were collected, and maps were constructed for 28 reaches representing 73.6 km, bringing the 2005–06 total to 116 reaches and 305.5 km (figs. D6 to D11; tables D1, D2). Discounting overlapping reaches, 251.7 km, or nearly one-fifth of the Lower Missouri River (from Gavins Point Dam to the mouth), was mapped at least once as a part of the sturgeon habitat-use assessment in 2005 and 2006. Reaches have been mapped in each of the major river segments. In 2006 we increased the number of reaches in the Gavins segment (fig. D1), where mapping is logistically more difficult because of the prevalence of shallow water. Mapping in the Gavins, Ponca, and Big Sioux segments (fig. D1) was also complicated by rapidly varying flows from May to June (fig. D12). The rapidly varying flows made it difficult to map reaches on the day after sturgeon were relocated while also meeting the criterion that discharges should be within the range of plus or minus10 percent.

Four of the 2006 reaches were selected for more intensive study beyond the usual depth, velocity, and substrate maps. At these sites, we collected side-scan sonar data for qualitative interpretation (for example, figs. D7, and D11). These reaches are considered potential spawning reaches based on sturgeon movements in 2005 and presence of coarse, hard substrate (Laustrup and others, 2007).

Data Processing and Map Production

Grids of depth, velocity, and substrate have been generated for habitat-use data collected in 2005 and 2006 (for example, figs. D6, D8, D10). Some of the map-making protocols were refined for 2006 data processing. Derived grids (including slope, velocity gradient, and terrain classification) have also been prepared from the basic depth and velocity maps; these derived grids yield additional information and in some cases show less sensitivity to discharge. Development of terrain-classification methods is ongoing, and additional work remains to refine the protocols to scale terrain units to channel size.

Depth and Derived Grids

Depth maps for 2005 and 2006 were generated by using standard protocols (Elliott and others, 2004; Jacobson and others, 2004a; Jacobson and others, 2004b; Oberg and others, 2005). The depth maps were used to create derived grids including slope (approximating topographic slope) and a form of relative depth classification (fig. D13). The relative depth classification categorizes the reach based on the elevation of a cell compared to that in the surrounding area; this classification is based on the idea of the topographic position index and the Benthic Terrain Modeler (Lundblad and others, 2006). Combining slope and relative depth classifications yields four terrain classes: crests (bars), depressions (thalweg and deep holes), slopes (>5°), and flat areas. These terrain classes are relatively insensitive to changes in discharge, potentially providing a way to infer some basic habitat information for sturgeon relocations that fall within a mapped reach but at a different discharge. We are currently evaluating the discharge sensitivity of this classification approach and its effectiveness as a mesohabitat indicator; further refinement of this technique is possible as spatial metrics are scaled to river size.

Velocity and Derived Grids

Velocity grid maps in 2006 were generated by using a streamlined approach of standard methods using a Python script that calls ArcGIS kriging routines (ESRI, Redlands, Calif.). A slightly different method that yielded nearly equivalent results was used in 2005. In addition to the velocity maps, we created derived maps of velocity gradients. These gradient maps can be used to test hypotheses about sturgeon preference for high-velocity-gradient zones (Johnson and others, 2006).

Substrate

In 2006, two different models of RoxAnn instruments (Sonavision Ltd., Aberdeen, Scotland) were used to collect substrate data; one instrument also was used during 2005. In order to produce comparable maps from the two instruments, we developed new protocols for substrate classification. The new approach classifies substrate point-by-point and utilizes the values of E1(roughness) and E2 (hardness) at the point as well as the local variability of these parameters to classify substrate into three generalized categories. A calibration reach was mapped with both instruments. Side-scan sonar and substrate sampling were used for ground truthing. This new method was applied to generate a set of substrate maps for all 2005 and 2006 habitat-use datasets with available RoxAnn data.

Data Summary and Analysis

For targeted sturgeon locations, we have extracted values from habitat maps at each sturgeon relocation point and in its vicinity. Point values have been acquired from grids for depth, velocity, substrate, depth classification, velocity gradient, and slope of depth (an example is shown in fig. D9). Summary statistics are being compiled within a circular region surrounding the sturgeon points for various radii (fig. D14). The spatial summary statistics for continuous-value data (including depth, velocity, slope, and velocity gradient) are minimum, maximum, mean, and standard deviation. For discrete-value data (including substrate and terrain classification), summary statistics include the amount of each class in the zone of interest. Although additional analysis is necessary, these data indicate a tendency for sturgeon to select lower than reach-averaged velocities and higher than reach-averaged velocity gradients. There is no apparent selection for depths.

In general, reaches were mapped in response to the relocation of a sturgeon, but many mapped reaches contained additional sturgeon relocation points (nontargeted sturgeon locations) from different time periods or discharges. For nontargeted sturgeon locations in mapped reaches, the hydroacoustic maps may still provide useful information about habitat if the nontargeted sturgeon were relocated at a time when discharge was similar to the map date.

To address the question of what habitat parameters can be inferred for nontargeted sturgeon and over what range of discharge, we are using an existing two-dimensional hydrodynamic model of the Missouri River near the junction with the Lamine River (Johnson and others, 2006) to assess sensitivity of habitat parameters to changes in discharge, assuming constant topography. Initial assessment indicates that terrain classification, depth gradient, and velocity gradient are less sensitive to changes in discharge than to depth and velocity themselves. The results from components 2 and 3, (this chapter) will yield further information about sensitivity of habitat to hydrologic and geomorphic changes.

Sensitivity analyses will be used to determine over what range of discharge and over what period of time the maps are reasonably valid for extraction of habitat parameters for nontargeted sturgeon. It appears that some parameters will be valuable over a wider range of discharge than others. This method yields a hierarchical scheme for determining habitat parameters for sturgeon relocations, shown conceptually in table D3.

We have also combined reach-scale depth and velocity data to generalize habitat characteristics at the segment scale. Based on these data summaries, distinctive signatures emerge for each main segment of the river (figs. D15, D16). For example, the depth histograms tend to be bimodal for reaches in the lower segments of the river. Simpler, single-peaked histograms describe the upper segments, with increasingly shallow peak values progressing upstream from the Big Sioux segment to the Gavins segment.

Habitat Selection Modeling

In addition to the geomorphically based analyses of these data, we are working with collaborators at CERC and the University of Missouri to analyze the spatial associations between fish locations and habitat availability (fig. D2). This analysis compares habitat measures at the sturgeon relocation points (habitat use) with habitat at randomly selected points in the mapped reaches (habitat availability). The data that we provide will be used to support testing of hypotheses in an information-theoretic framework (Millspaugh and Marzlugg, 2001; Burnham and Anderson, 2002).

Plans for 2007

Efforts in 2007 will be divided between collecting new data and analyzing the substantial existing dataset. The primary emphasis for new data collection will be to map identified spawning sites as determined by coordinated telemetry studies. For spawning sites, we will collect side-scan sonar data in conjunction with the standard depth, velocity, and substrate data.

We will continue to summarize and analyze existing reach-scale data from the hydroacoustic maps to explore information content at multiple scales. This analysis will include development of depth-based habitat diversity indices and refinement of the terrain-classification approach. Analysis will include subdividing and aggregating data over multiple scales of classification. This analysis will address the extent to which habitat availability can be generalized from microhabitat measures (depth, velocity, and substrate) to mesohabitat (such as terrain classes, inside/outside bend classes, and classes based on spatial relations to engineering structures) and macrohabitat (bend-crossover, reach, and segment) scales. If relations exist, microhabitat features may be inferred from readily available geographic information system-scale data. Based on the timing and position of sturgeon relocations relative to the hydroacoustic maps, a hierarchy of habitat parameters may be inferred (table D3); the most detail is available for those sturgeon found on habitat maps at similar discharges and in close temporal proximity to the hydroacoustic map date, but some basic information may be inferred for all sturgeon relocation points. Results from the habitat availability portion of the study (components 2 and 3, this chapter) will help to assess the extent to which it is valid to infer mapped parameters for point data at times and discharges different from the conditions of the hydroacoustic map date. During 2007, we will continue to collaborate with University of Missouri colleagues to provide information needed for statistical models of habitat selection. In 2007, we will draft a peer-reviewed USGS series report documenting habitat-use data and interpreting implications of these data with regard to river management activities.

Component 2 — Habitat Availability

Principal Investigators

- Robert B. Jacobson
- Harold E. Johnson
- Richard Wilson
- Benjamin J. Dietsch

Specific Objectives

The objective of the habitat-availability component is to assess sensitivity of spawning and early-life-stage habitat availability to discharge variation, with emphasis on assessing the range of flows that may be considered under environmental flow management (U.S. Fish and Wildlife Service, 2000; 2003; U.S. Army Corps of Engineers, 2004b).

Approach/Methods

Habitat simulation is the most widely used tool worldwide for assessment of ecological responses to river management (Tharme, 2003). The use of two or three dimensional hydrodynamic models allows quantification of spatial attributes of habitat, including diversity (Reuter and others, 2003; Pasternack and others, 2004), gradients between habitat units (Crowder and Diplas, 2006; Johnson and others, 2006), patch dynamics (Bowen and others, 2003), and patch persistence (Bovee and others, 2004).

Habitat simulation studies generally have been limited in how well they capture physical habitat availability because they have assumed a fixed bed, as most models lack the ability to model sediment transport and channel evolution. This is a minor problem for low-flow studies or studies on rivers with immobile beds, but substantial limitations exist for studies that consider the ecological effects of flows that are capable of transporting bed material because the models do not account for changing channel boundary conditions (geometry and flow resistance) during individual flow events or over seasons. New understanding of sediment transport at scales relevant to habitat (Schmeeckle and Nelson, 2003) and hydrodynamic-modeling code that can simulate bed evolution (Barton and others, 2005; McDonald and others, 2005) are contributing to progress toward overcoming the assumption of a fixed bed. The sand bed of the Lower Missouri River is subject to transport and change over the range of flows considered in this study. Therefore, hydrodynamic models which incorporate bed evolution may be necessary to simulate habitat availability. Hence, this project seeks to assess the errors and uncertainties inherent in modeling with and without bed evolution.

Models of natural systems are generally classified as those that are used to predict and those that are used to increase understanding (Kirkby, 1996). The focus of this project component is to use hydrodynamic models to increase understanding of what is suitable spawning and early-life-stage habitat for the Missouri River sturgeon and the sensitivity of habitat to flow variation. The modeling effort is exploratory and intended to elucidate relations between sturgeon and their environment.

Reach Selection

During 2006 we began to evaluate habitat availability in four reaches (Yankton, Kensler’s Bend, Little Sioux, and

Miami study sites) that are representative of probable spawning locations for sturgeon in the Lower Missouri River (fig. D1). These reaches were selected on the basis of two criteria: each reach (1) has patches of coarse, hard substrate thought to be preferred spawning substrate (Laustrup and others, 2007) and/or (2) was the upstream apex of movement of a female shovelnose that completely spawned in 2005. For three of the four reaches, evidence is strong that spawning occurred somewhere within the reach. The fourth reach at Yankton, S. Dak., lacked data confirming spawning activity in 2005 (although spawning activity was confirmed during 2006, chap. E), but it has the most extensive deposit of gravel-cobble substrate identified on the Lower Missouri River (Laustrup and other, in press). Additional reaches may be added in subsequent years as additional fish location data are collected. The 2006 work was the first year of a 2-year effort needed to complete the first phase of validated modeling for the four reaches. Habitat-availability reaches were selected and delineated to include replicates of macrohabitats (at least one complete bend-cross-over-bend sequence) and to insure that probable spawning areas were included (fig. D17).

Reach-Scale Data Collection

Each habitat-availability reach was mapped completely for depth, velocity, and substrate at a relatively high discharge (although substantially less than bankfull). This dataset was used to compile base bathymetric data and to provide high-flow velocity calibration data. Compilation mapping was based on 20-m transect intervals. Data were collected with a precision depth sounder, a 1,200 kHz acoustic Doppler current profiler, a substrate classifier, and Real-Rime Kinematic Global Positioning System (RTK-GPS) by using established USGS habitat-mapping protocols (Elliott and others, 2004; Jacobson and others, 2004a; Gaeuman and Jacobson, 2005; 2006). Terrestrial RTK-GPS surveys were completed along cross sections to reach the top of bank and to define engineering structures. Terrestrial lidar data is available for the Yankton and Kensler’s Bend reaches and will be assessed for its utility in supplementing hydroacoustic surveys. Photogrammetrically derived digital elevation data from 2000, gridded at 5-m intervals, are available from the U.S. Army Corps of Engineers (Northwestern Division, Omaha, Nebr.) in all four reaches to supplement overbank elevation data. Hydroacoustic elevation data have been merged with terrestrial surveys and either lidar data or the photogrammetric digital elevation data to create mass-point datasets for continuous surface mapping of the channel and flood plain elevations, extending over the bank to include the nominal 5-year recurrence flood plain.

Calibration/Validation Collection

Discharge, velocity, depth, substrate class, and channel-bottom elevation data were collected on a subset of approximately 30 randomly selected transects (also used in component 3, this chapter) at a range of discharges. Each calibration/validation survey included a replicate longitudinal profile. Longitudinal profiles provided bedform dimensions for estimating boundary roughness parameters as well as water-surface profiles. These data will be used for calibration and validation of the hydrodynamic model and for defining relations between stage and discharge in each reach. Additional discharge and longitudinal profile data will be collected in the reach as needed to compile stage-discharge curves for modeling.

Progress During 2006

During 2006, a full-reach, bathymetric survey was conducted for the Yankton, Kensler’s Bend, Little Sioux, and Miami reaches (figs. D18 to D21). Hydroacoustic depth, velocity, and substrate data were gathered along transects spanning the width of the river from bank to bank at 20-meter intervals. A terrestrial survey with RTK-GPS includes top of bank, control structure, and other topographic points. We created mass points for a computational mesh for a multidimensional hydraulic model, the Multi-Dimensional Surface Water Modeling System, MD-SWMS (McDonald and others, 2005) by combining the bathymetry and terrestrial surveys with available Digital Elevation Model or lidar data (figs. D22 to D25). An example of an initial computational mesh for the Kensler’s Bend reach is shown in figure D26. Depth-averaged velocity maps of each reach will be used for comparison with model output at specific discharges (figs. D27 to D30). Four to five other bathymetric surveys during the year (table D4) were completed on the randomly selected transects to provide model calibration and validation through recording of water-surface elevations, bedform dimensions, bathymetry, and velocity measurements (fig. D31).

Plans for 2007

Calibration/validation data will be edited and analyzed to document sensitivity of depth, velocity, and substrate class availability to changing discharge. A subset of the calibration/validation data will be used to calibrate a multidimensional hydrodynamic model that uses the MD-SWMS program. The remainder of the calibration/validation data will be used to validate model performance in terms of depth, velocity distributions, and water-surface elevations. Model performance will be validated with water-surface elevations and velocity distributions.

Results from the hydrodynamic models will be explored to evaluate habitat sensitivity to discharge variations and sensitivity of suspected habitat classes to modeling procedure emphasizing patch dynamics and areas of high hydraulic gradients (Bowen and others, 2003; Bovee and others, 2004; Crowder and Diplas, 2006; Johnson and others, 2006) (fig. D32).

We anticipate that the modeling process will be iterative. As more precise measures of spawning habitat selection become apparent (component 1, this chapter), we will update how model results are analyzed and perhaps increase resolution in critical parts of the models. Model results also will be used to interpolate flow fields spatially and over varying discharges to provide reach- and mesohabitat-scale visualization of flow structure. Model results will help to improve understanding of factors that create effective habitat for the fish, including characteristic scales, patch shapes, and patch adjacency. Because of the reach-scale definition of the hydrodynamic models, results will show a variety of habitat patches that may relate to other ecosystem components important to sturgeon reproduction and survival, including patches used by prey or predator fishes and patches involved in drift of larvae.

A generic problem with hydrodynamic models in sand-bed rivers is systematic and nonsystematic deformation of the bed morphology and flow resistance over time and with changing discharge. Monitoring data (described in component 3, this chapter) will be used to assess the variation of bed morphology with discharge, to help quantify the effects of a deforming bed on model errors, and to assess how bed changes vary among reaches. In addition, monitoring data will be used to explore how well bed-evolution capabilities of the model code can simulate transient bed evolution.

During 2007 we will also begin to explore the use of model results to evaluate drift dynamics, with emphasis on calculating reach averaged transit times and probabilities of neutrally buoyant particles passing from the main current into marginal, slow-velocity areas. Comparisons among reaches will illustrate the relative roles of natural and engineered channel morphologies in retaining or passing larval fish.

Data from the model runs will be analyzed statistically to explore changes in habitat availability with discharge. Model results will be imported into a geographic information system database to allow spatial analyses. Spatial relations among habitat patches will be analyzed statistically by using FRAGSTATS (McGarigal and Marks, 1995) to assess factors such as edge length, adjacency, and patch shape.

Model results will be analyzed during 2007 and published in a peer-reviewed USGS series report in 2008.

Component 3—Habitat and Geomorphic Dynamics

Principal Investigators

- Robert B. Jacobson
- Harold E. Johnson
- Richard Wilson

Specific Objectives

The relations between geomorphic dynamics and habitat quality and quantity will be assessed through monitoring and measurement of channel morphology, substrate, and measures of sediment transport in the four reaches identified in component 2 (this chapter). The specific objective is to evaluate effects of sediment transport over a range of discharges to assess the role of flow modifications and natural flow events in modifying habitats.

Approach/Methods

A randomly selected subset of 30 transects (the same set used for calibration/validation measurements, component 2, this chapter) was resurveyed by using RTK-GPS hydroacoustic mapping protocols to evaluate change in the cross section shape and area, change in substrate conditions, and change in velocity structure (figs. D33 to D36). Random selection of transects is essential for unbiased estimates of how much area of the reach is affected by geomorphic changes. Also, selection of a subset of the transects was necessary to allow completion of surveys during transient flow events; surveys were completed during 1 day. Four or five surveys were performed in 2006 to assess geomorphic changes and sediment transport associated with a range of discharges. Surveys were coordinated with planned flow modifications (U.S. Army Corps of Engineers, 2006) (fig. D37). In the two downstream reaches, the planned flow modifications were much diminished relative to natural variation. The cross sections were randomly selected once, and the original set of randomly selected cross sections was resurveyed to assess change.

The randomly selected cross sections were surveyed with RTK-GPS-controlled hydroacoustic methods and by using USGS CERC protocols. Terrestrial RTK-GPS surveys extended the hydroacoustic surveys from the water's edge to at least 5 m beyond the top of the bank. The precision of RTK-GPS allows for comparisons of elevation changes between surveys. Simultaneous collection of RTK-GPS-controlled acoustic Doppler current profiler (ADCP) data provided current-velocity data and bed-velocity measurements (Gaeuman and Jacobson, 2005; 2006). RoxAnn acoustic bed-classification methods were used for substrate typing, which allowed assessment of bed material changes as a function of discharge. Cross sections made with an ADCP were also processed to yield discharges.

In addition to the transect surveys, a longitudinal profile was collected during each survey. The longitudinal profile was used to document bedform changes as a result of flow changes and to quantify bedform dimensions. As an experiment in sediment transport assessment, a short—approximately 500–800 m—section of the longitudinal profile was resurveyed after approximately 2.5–3 hours and used for one-dimensional bedload transport estimates by bedform differencing in the two lower (Little Sioux and Miami) reaches (Simons and others, 1965).

Velocities, bedform dimensions, and water-surface profiles collected during these surveys will also be used for calibration and validation of hydrodynamic models in component 2 (this chapter).

Progress During 2006

Thirty to thirty-three transects per reach were processed to obtain bed elevation, substrate parameters (E1, roughness, and E2, hardness), and bed-velocity data. Bed elevation from each survey was compared to determine cross-sectional area change (examples in figs. D38 to D41). Transects in the Yankton reach were notable for their lack of change over the range of flows that occurred during 2006. In contrast, most transects in the other reaches downstream showed substantial geomorphic changes, indicating that the range of flows occurring during 2006 were capable of altering bed morphology in those reaches.

Substrate parameters (E1 and E2) were measured on each transect to address evolution of the channel bed types before, during, and after flow changes. Calibration and validation of RoxAnn data are continuing through 2007. Substrate classification from RoxAnn parameters is based on typical E1 and E2 distributions for the major bed-material types of the Lower Missouri River (fig. D42) This classification differs substantially from previously used supervised and unsupervised statistical classification procedures (Elliott and others, 2004). Our simplest derived classification is based on uniform low values for both E1 and E2 (silt and mud), low E1 combined with spatially variable E2 (sand and sand dunes), and highly variable E1 and E2 (rough substrate including cobble, gravel, and revetment). Typical RoxAnn data for two transects it the Miami reach demonstrate that substrate parameters vary measurably with discharge and across the channel (figs. D43 and D44). Preliminary analysis indicates that the highest flows measured (about 47,000 ft^3/s) resulted in a softer bed in the center of the channel, suggesting either a flush of fine sediment or a moving bed (which typically has low E1 and E2 values).

Data obtained with an ADCP were processed with both bottom track and GPS positioning to allow for calculation of bed velocities (examples shown in figs. D45, D46). These examples indicate that calculated bed velocities increase as expected during higher flows and indicate the proportion of the cross section affected by transport.

Photography was used to document substrate changes at points along a subset of the terrestrial RTK-GPS surveys. The photographs were taken within a scaled frame at the first survey before navigation season, and after the last postnavigation survey. This photography was done to document visual evidence of substrate change within the area of the river bank that would be inundated during ecological flows but exposed at lower flows. The photographs taken at the Miami surveys show that deposition occurred in this specific part of the reach, although in the Little Sioux reach, erosion was typical (fig. D47). Together, these results indicate that the range of flows evaluated during 2006 has the potential to alter substrate quality by transporting sediment.

Longitudinal profiles were collected for comparison at all four reaches (sample profiles in figs. D48 and D49). Longitudinal profiles collected during the four to five surveys also provide information on bed mobility and bedform dimensions (fig. D50). Typical dune bedform wavelengths are 4–7 m and heights are 0.2–0.6 m. In addition, at the Little Sioux and Miami reaches an experimental short profile was surveyed 3.5–4 hours after the first survey (figs. D48, and D49). The long and short profiles from each survey were analyzed to calculate sediment transport rate by bedform differencing (Simons and others, 1965). Computer code to analyze these data has been written and tested. The one-dimensional transport rate for dune migration shown in figure D49, for example, is equivalent to a flux of approximately 0.1 kg/s/m (unit width) at a discharge of 24,500 ft^3/s. One-dimensional transport rates calculated by using this procedure will be used to assess relative transport rates among reaches and as functions of discharge, thereby providing a measure of relative sensitivity of sediment transport to flow modifications.

Plans for 2007

For 2007, each reach will be resurveyed at least four times during the year with the intent of documenting effects of a wider range of flows and of isolating planned flow modifications, if they occur. Results of surveys will be used to assess geomorphic sensitivity to discharge and to evaluate hydrodynamic model errors that would arise if bed evolution and bedform roughness are not taken into account. Results will also be compared with runs of hydrodynamic models simulating bed evolution to evaluate the extent to which bed-evolution simulations capture actual geomorphic changes (component 2, this chapter).

A peer-reviewed USGS series, peer report documenting habitat and geomorphic change for each of the four sites will be prepared in 2007.

Summary

This report documents progress on three related components of habitat assessments in the Lower Missouri River during 2005–06. The habitat components consist of habitat use, habitat availability, and habitat and geomorphic dynamics. The habitat-use component links this research directly to sturgeon ecology research described in chapters B, C, and E. In turn, the habitat availability and dynamics assessments are intended to provide physical context for the ecological research and to provide a physical component to eventual population modeling (Bajer and Wildhaber, in press). Complementary water-quality components of habitat are described in chapter F.

Results from 2005 to 2006 indicate that the methods developed to assess habitat use, quality, quantity, and change are appropriate and sufficiently accurate to address critical questions about sturgeon habitat on the Lower Missouri River. Preliminary analysis of habitats occupied by adult female shovelnose sturgeon indicates that migrating and post-spawn sturgeon do not select for depth but seem to select for lower than reach-averaged velocities and higher than reach-averaged velocity gradients. Data collected to compile, calibrate, and validate multidimensional hydraulic models in probable spawning reaches appear to be sufficient to support the modeling objective. Monitoring of selected channel cross sections and long profiles showed little change at the Yankton reach over the range of flows measured during 2006. This lack of change is likely due to channel stability associated with the armored bed in this degraded segment of the river. Documented geomorphic change increased with distance downstream. RoxAnn substrate parameters documented systematic changes with discharge and with hydraulic environment across the channel. Similarly, bed velocity varied predictably with discharge and hydraulic environment, indicating its potential as an indicator of bedload sediment transport. Longitudinal profiles showed substantial downstream movement of dunes over the monitored discharges, as well as substantial within-year variability in dune size. Observations of geomorphic change during the moderate flow range of 2006 support the hypothesis that the magnitude of flow modifications under consideration on the Lower Missouri River will be sufficient to transport sediment and potentially modify spawning habitats.

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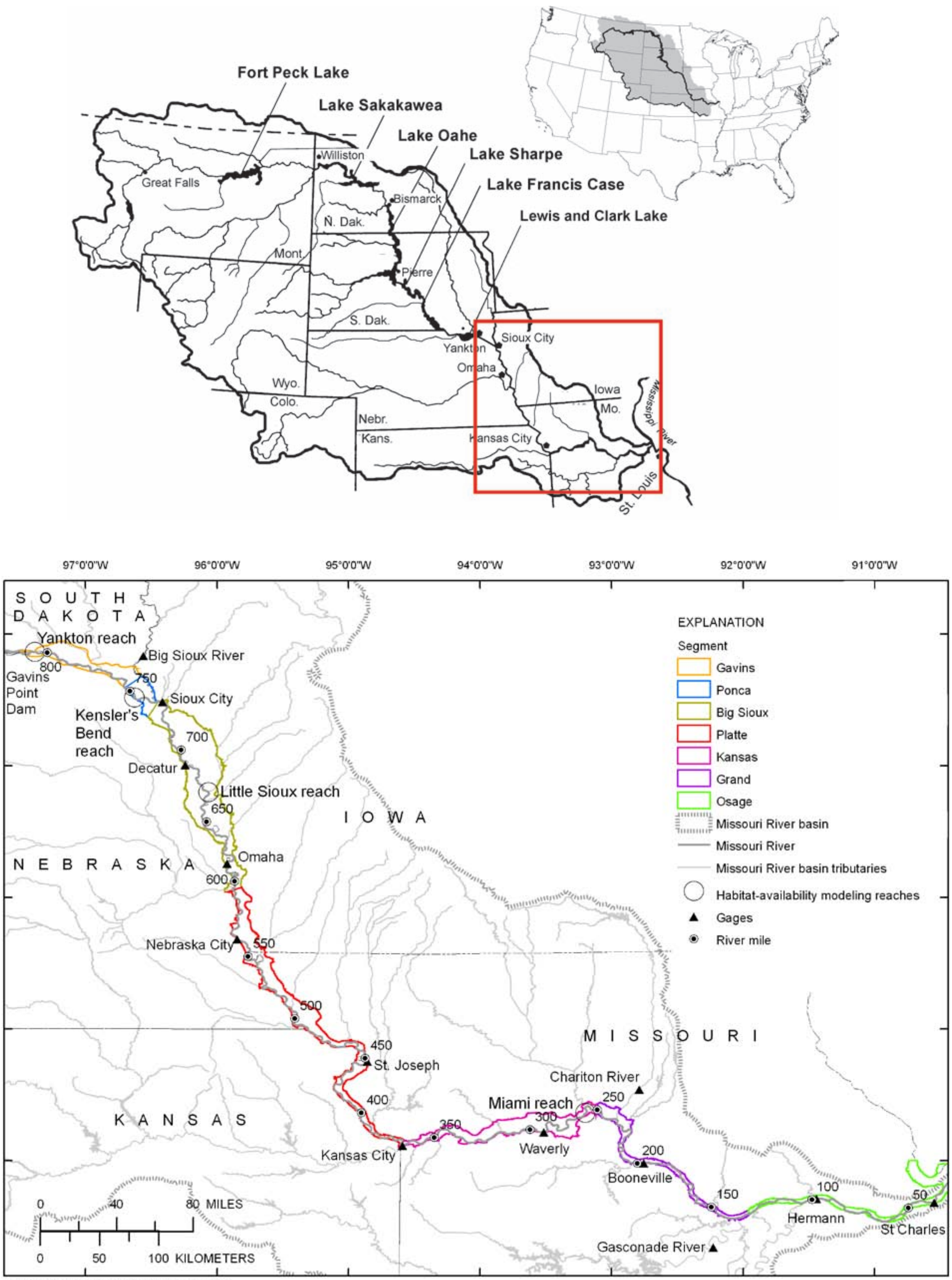
Figures and Tables



Base data from the National Atlas, 2006,
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Figure D1. Missouri River basin and Lower Missouri River showing locations of stream gages, habitat-availability modeling reaches, and Missouri River segments.

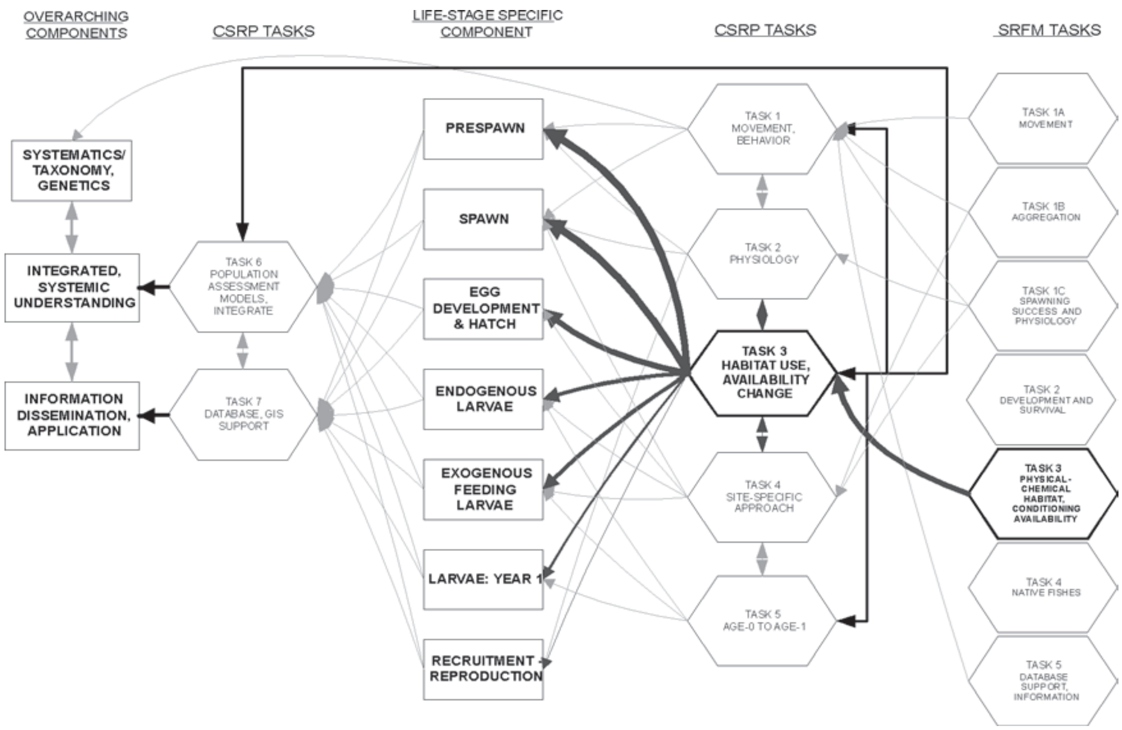


Figure D2. Diagram showing relations of Comprehensive Sturgeon Research Project (CSRP) tasks to life-stage components of pallid sturgeon, and relations of Sturgeon Response to Flow Modification (SRFM) tasks to CSRP. Information flow (curvilinear lines) from task 3 of CSRP (this study) are illustrated with weights commensurate with sequence of emphasis; in the early parts of this project, emphasis has been on prespawning and spawning, but emphasis will shift to larval and juvenile habitats over time. A subset of intertask arrows (rectilinear lines) are shown here, linking task 3 to other CSRP tasks. The double-headed arrows indicate two-way, iterative interaction among tasks, a feature that is essential to developing the comprehensive understanding of factors affecting sturgeon reproduction and survival in the Lower Missouri River.

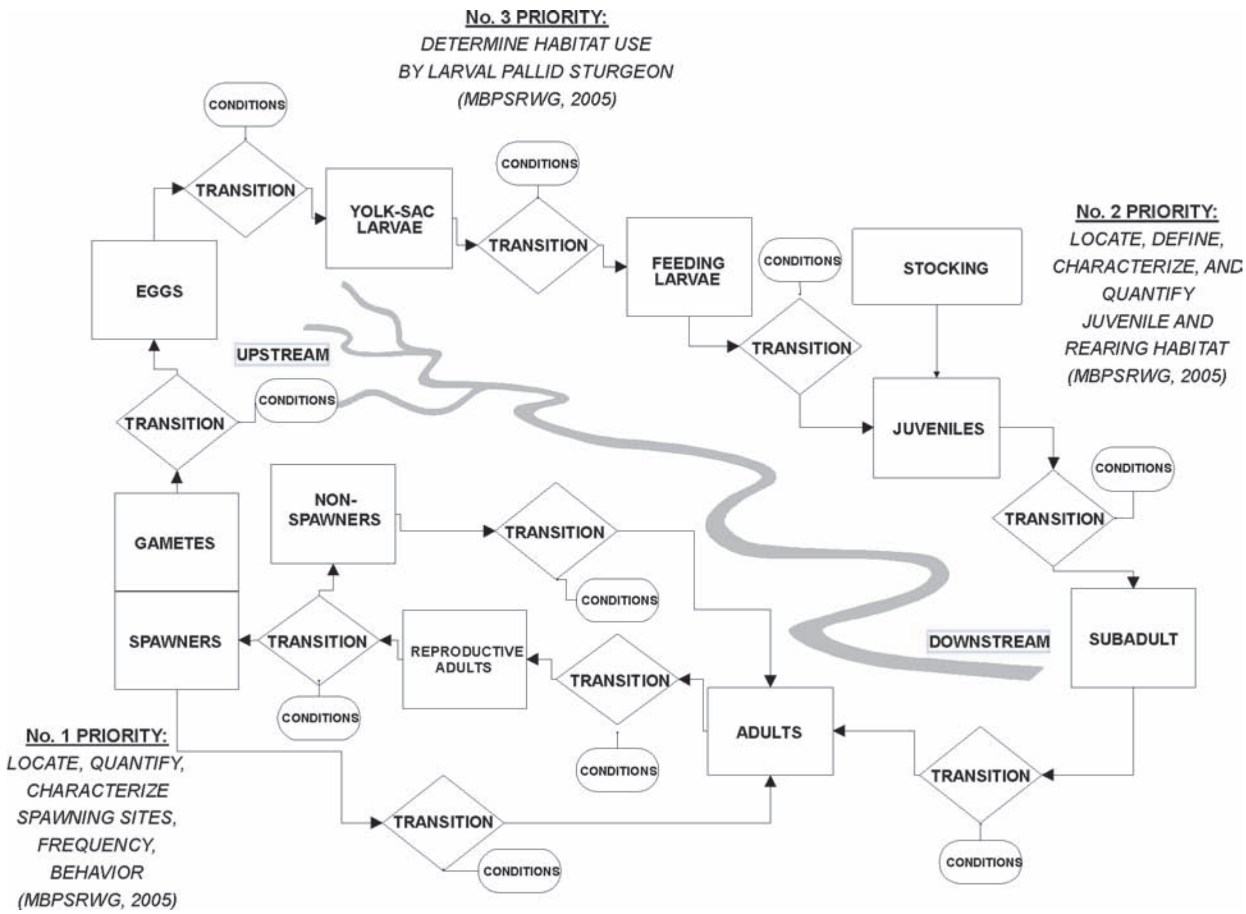


Figure D3. Conceptual model of sturgeon life stages and migration, Lower Missouri River. Priorities are those listed by the Middle Basin Pallid Sturgeon Recovery Work Group (2005) based on the assessment of research priorities in Quist (2004).

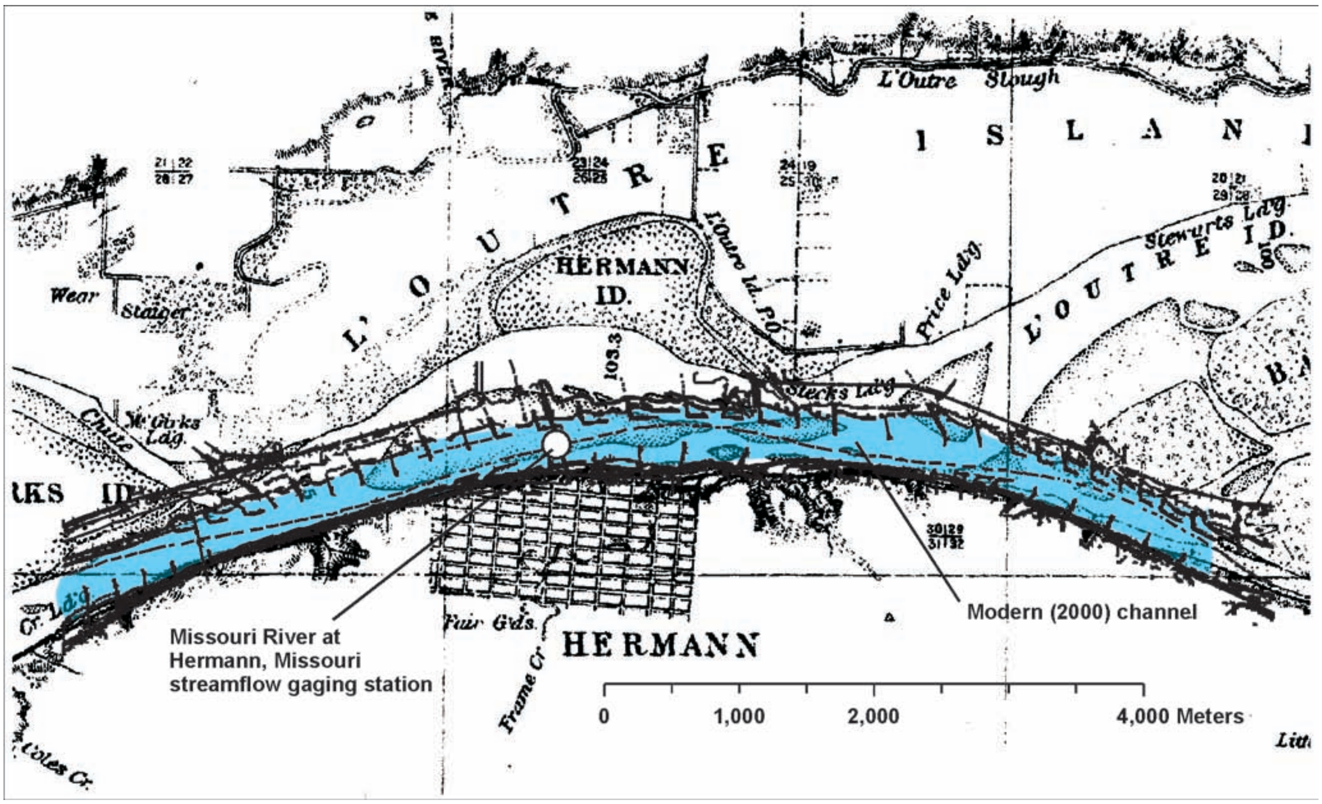


Figure D4. Modern (2000) and historical (1894) channel maps, Lower Missouri River at Hermann, Mo..

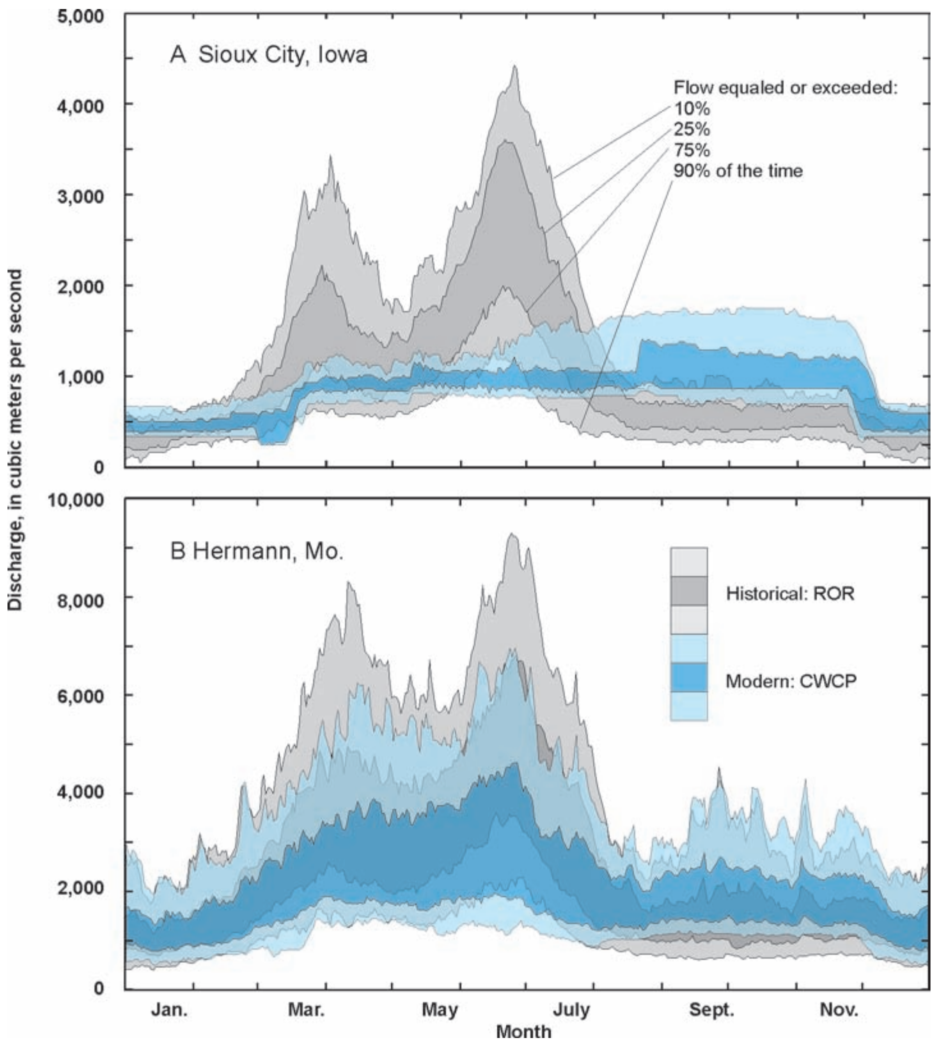


Figure D5. Duration hydrographs illustrating effects of flow regulation, Lower Missouri River. Daily flow duration for 100 years of daily data; note differences in discharge scales. (*A*) Missouri River at Sioux City, Iowa. (*B*) Missouri River at Hermann, Mo. ROR, run-of-the-river simulation model; CWCP, current water control plan simulation model, operational control plan 1967 to April 2004.

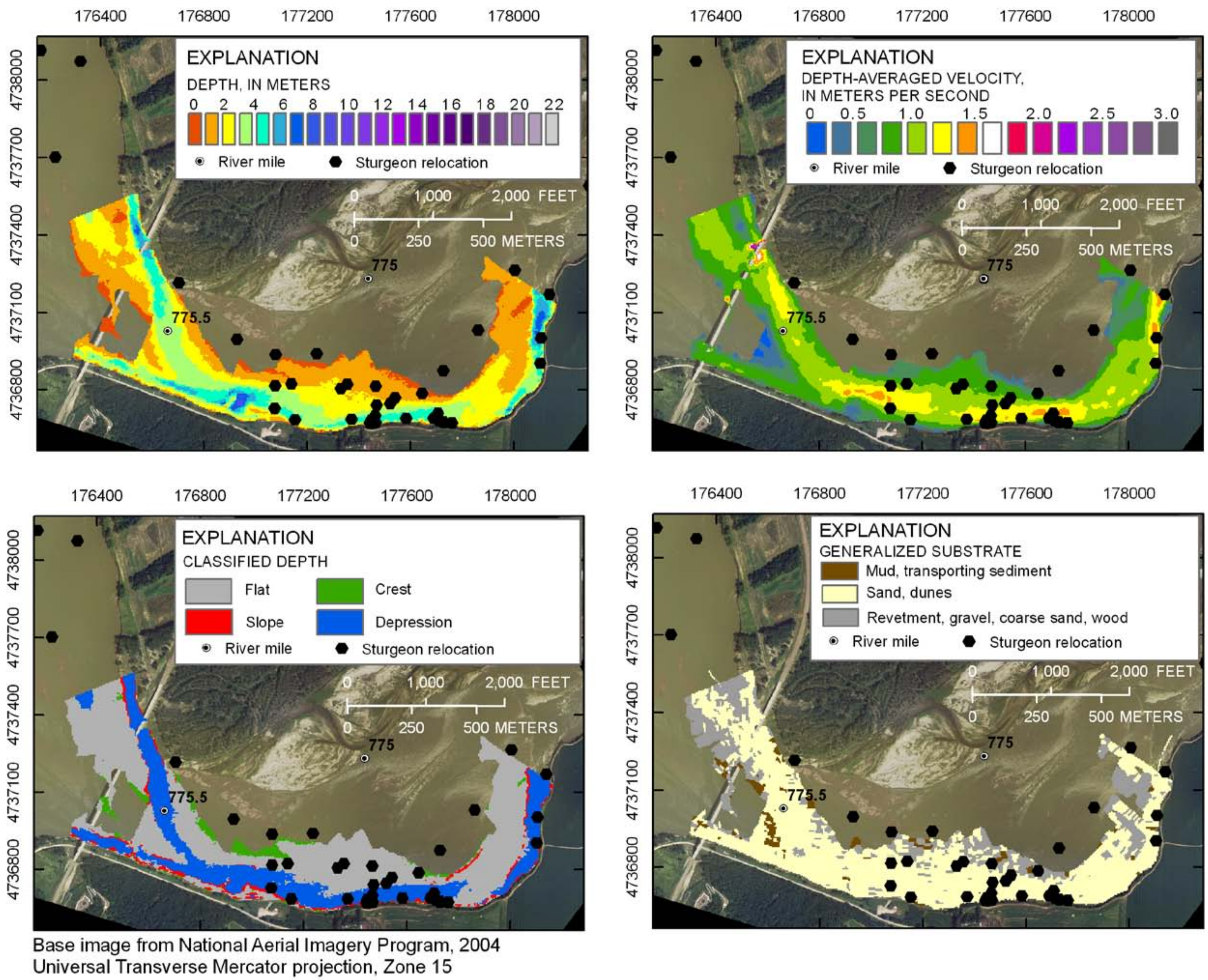


Figure D6. Maps of depth, velocity, terrain classification, and substrate for Mulberry Bend, Gavins segment, mapped on May 30 and 31, 2006, at a discharge of approximately 21,000 ft^3/s.

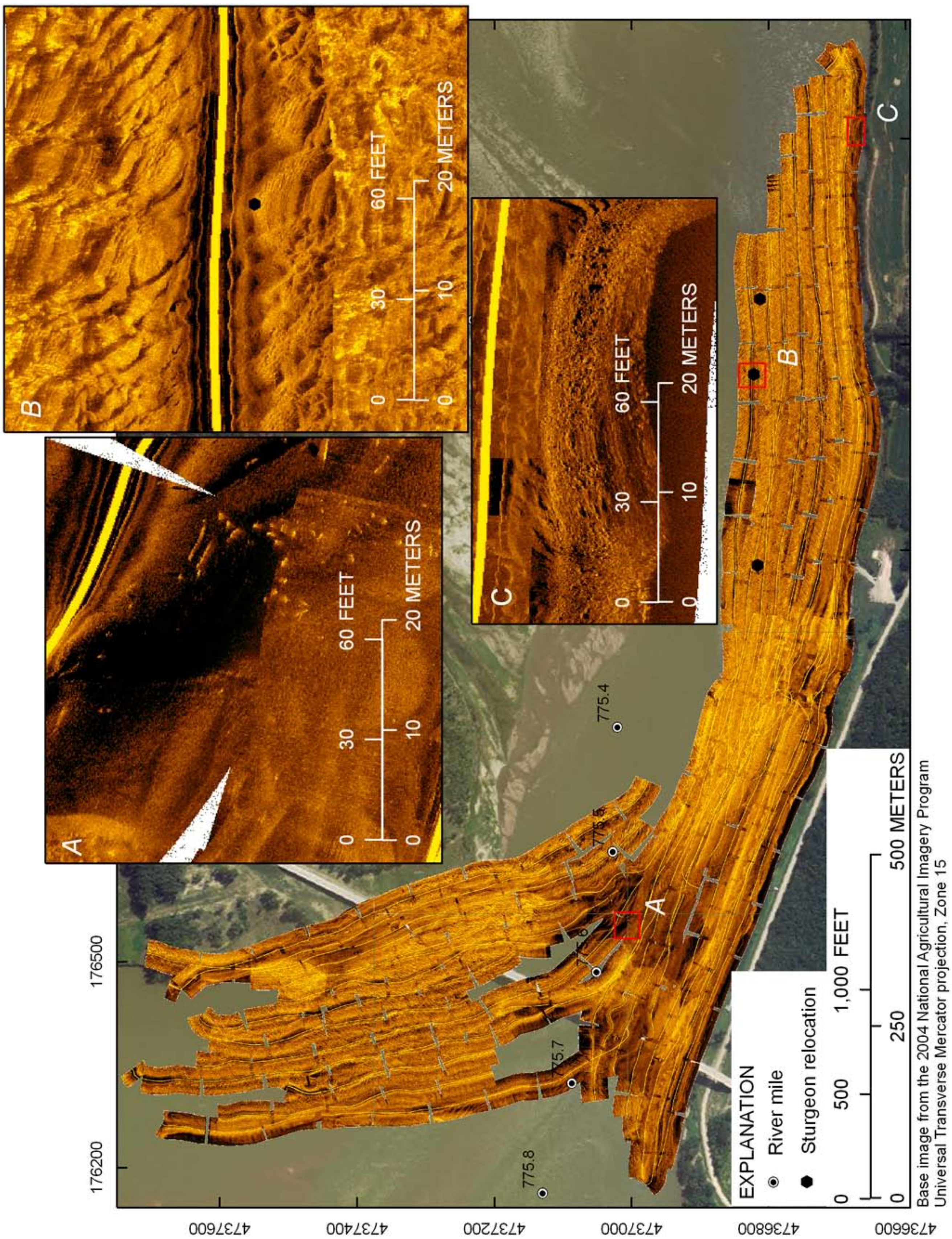


Figure D7. Side-scan sonar imagery for Mulberry Bend, Gavins segment. Insets show examples of (*A*) mud and fish (bright objects), (*B*) dunes, and (*C*) gravel-cobble substrate.

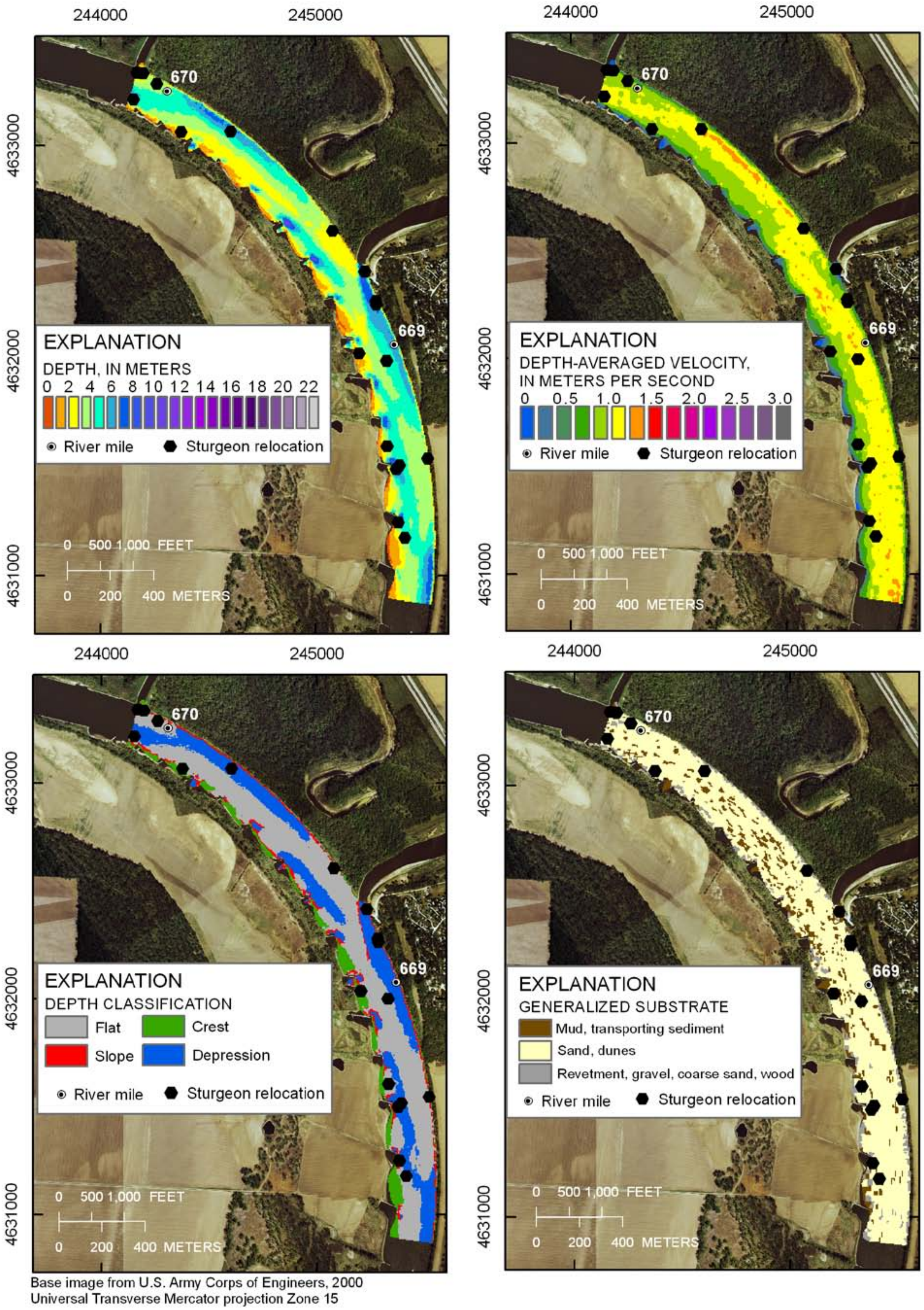


Figure D8. Maps of depth, velocity, terrain classification, and substrate for a reach at the mouth of the Little Sioux in the Big Sioux segment, mapped on June 1, 2006, at a discharge of approximately 26,400 ft^3/s.

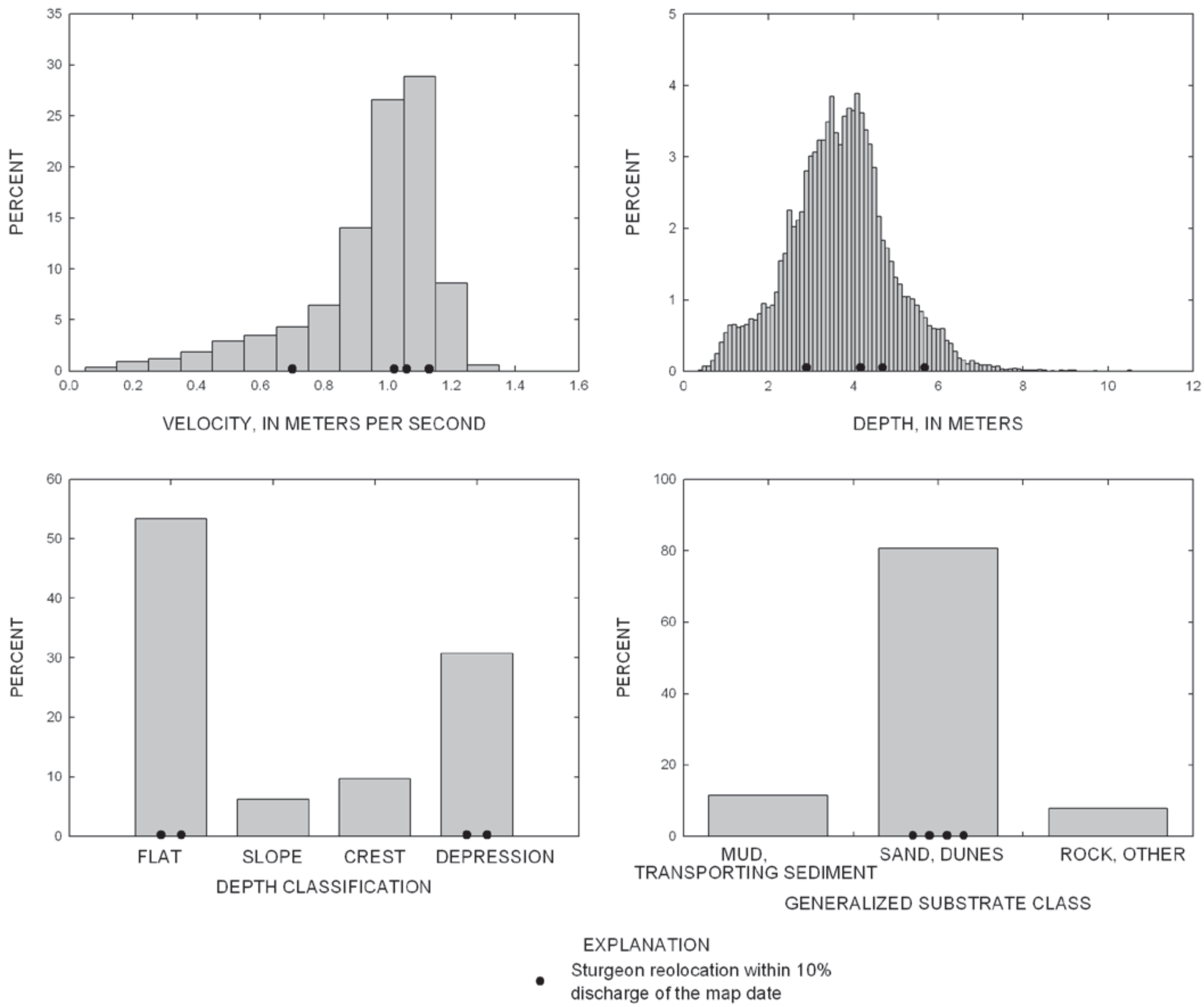


Figure D9. Histograms of depth and velocity, and percent distribution of terrain (depth) classification and substrate, for the reach at the mouth of the Little Sioux River (fig. D8). Points indicate the values at the sturgeon positions that were found within 10 percent of the discharge on the map date.

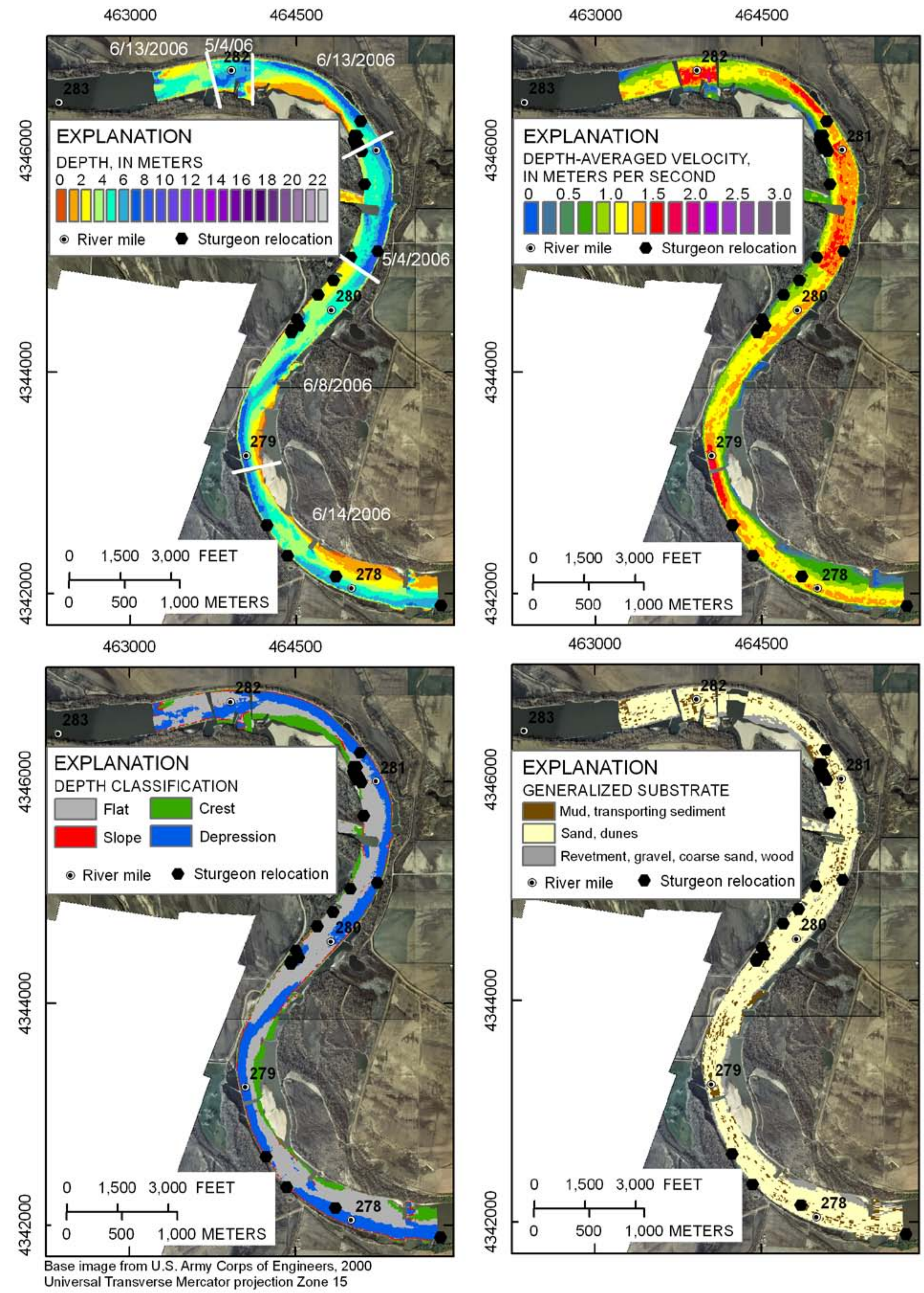


Figure D10. Maps of depth, velocity, terrain classification, and substrate for several reaches at Cranberry Bend, Kansas segment; reaches were mapped at different discharges, ranging from 36,600 ft^3/s to 65,100 ft^3/s.

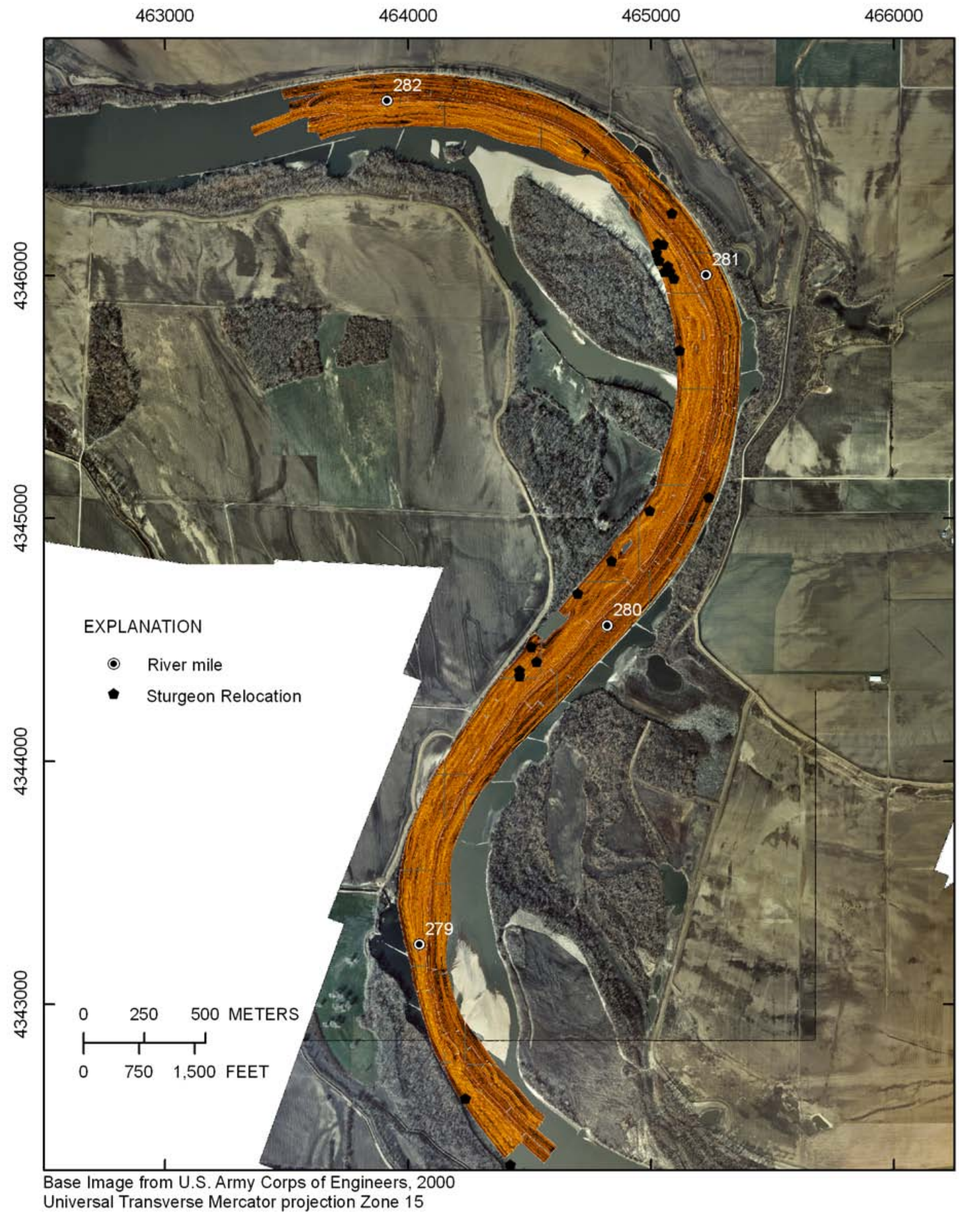


Figure D11. Side-scan sonar imagery for Cranberry Bend, Kansas segment.

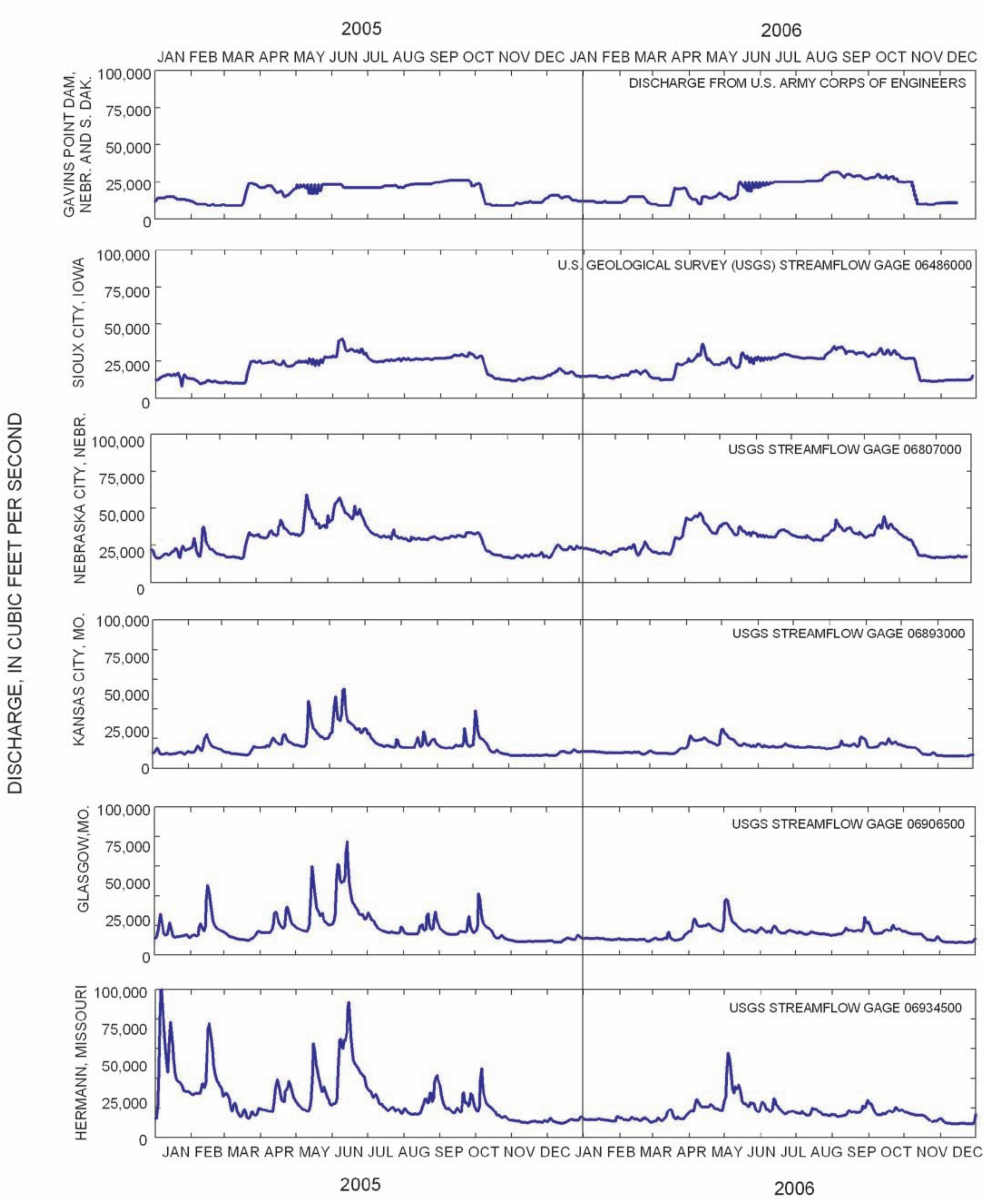


Figure D12. Hydrographs for six locations on the main stem of the Lower Missouri River, 2005–06.

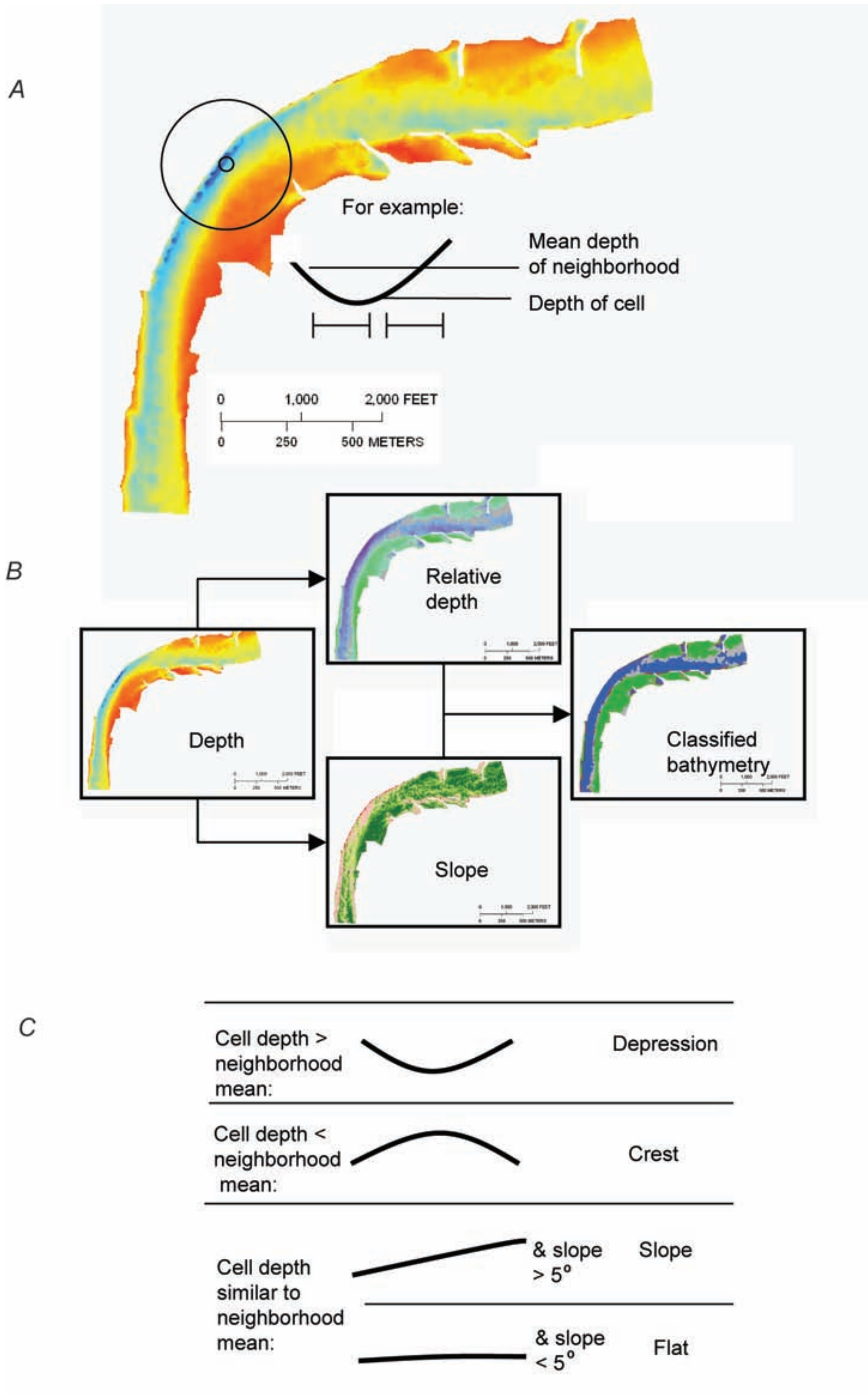


Figure D13. Schematic of the terrain-classification approach. (*A*) For each grid cell, relative depth is computed by determining the difference between the depth at the cell and the mean depth in an annulus surrounding the cell, generating a map of relative depth. (*B*) Relative depth and slope, both computed from the depth grid, are used for the classification. (*C*) The grid values are used to differentiate four terrain classes: depression, crest, slope, and flat.

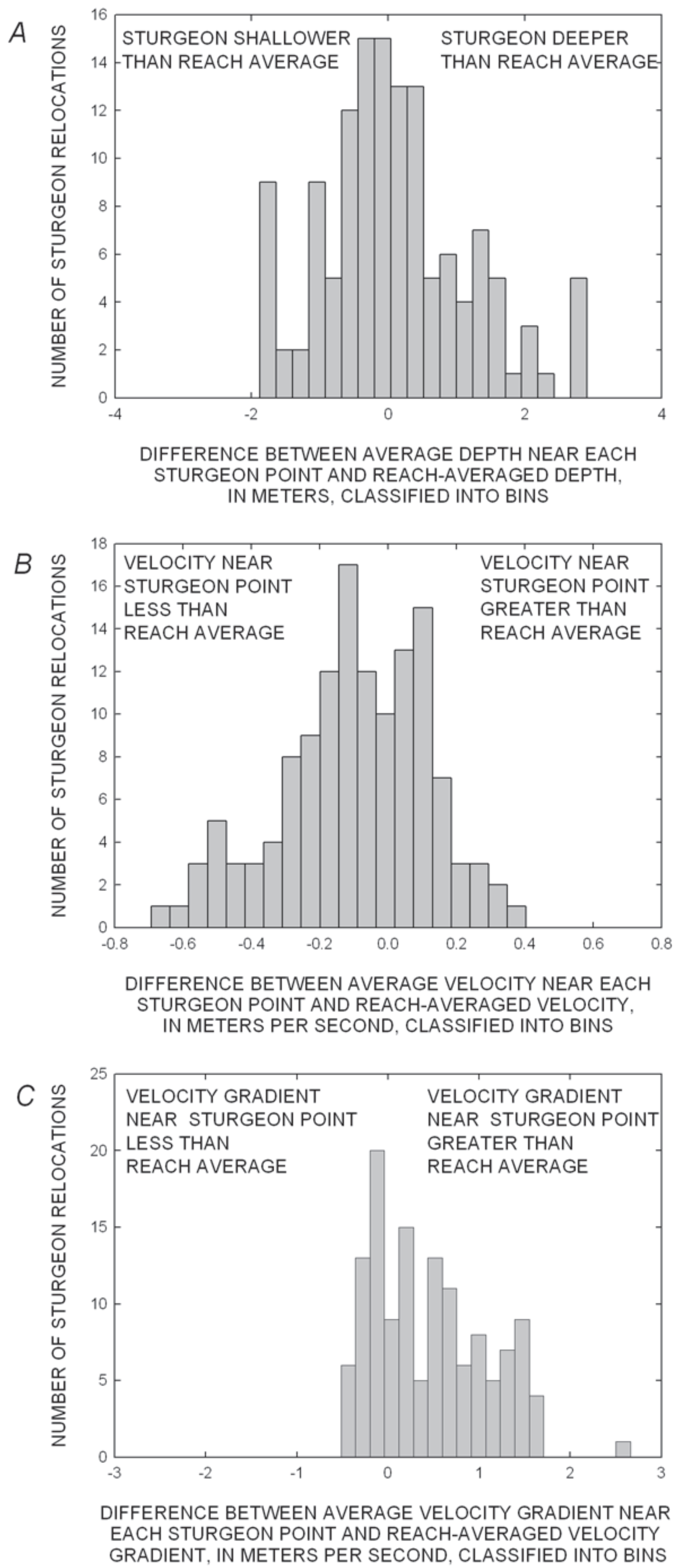


Figure D14. Histograms showing comparison of conditions near sturgeon points with reach averages for 2006. Mean grid values were computed within 25 m of each sturgeon relocation point and compared with reach-averaged values for the respective reach. Data are for 132 sturgeon that were relocated at discharges within 10 percent of the discharge on the hydroacoustic map date. Results are shown for (*A*) depth, (*B*) velocity, (*C*) velocity gradient, computed as percent change in velocity within a 9-cell patch from a 5-m grid.

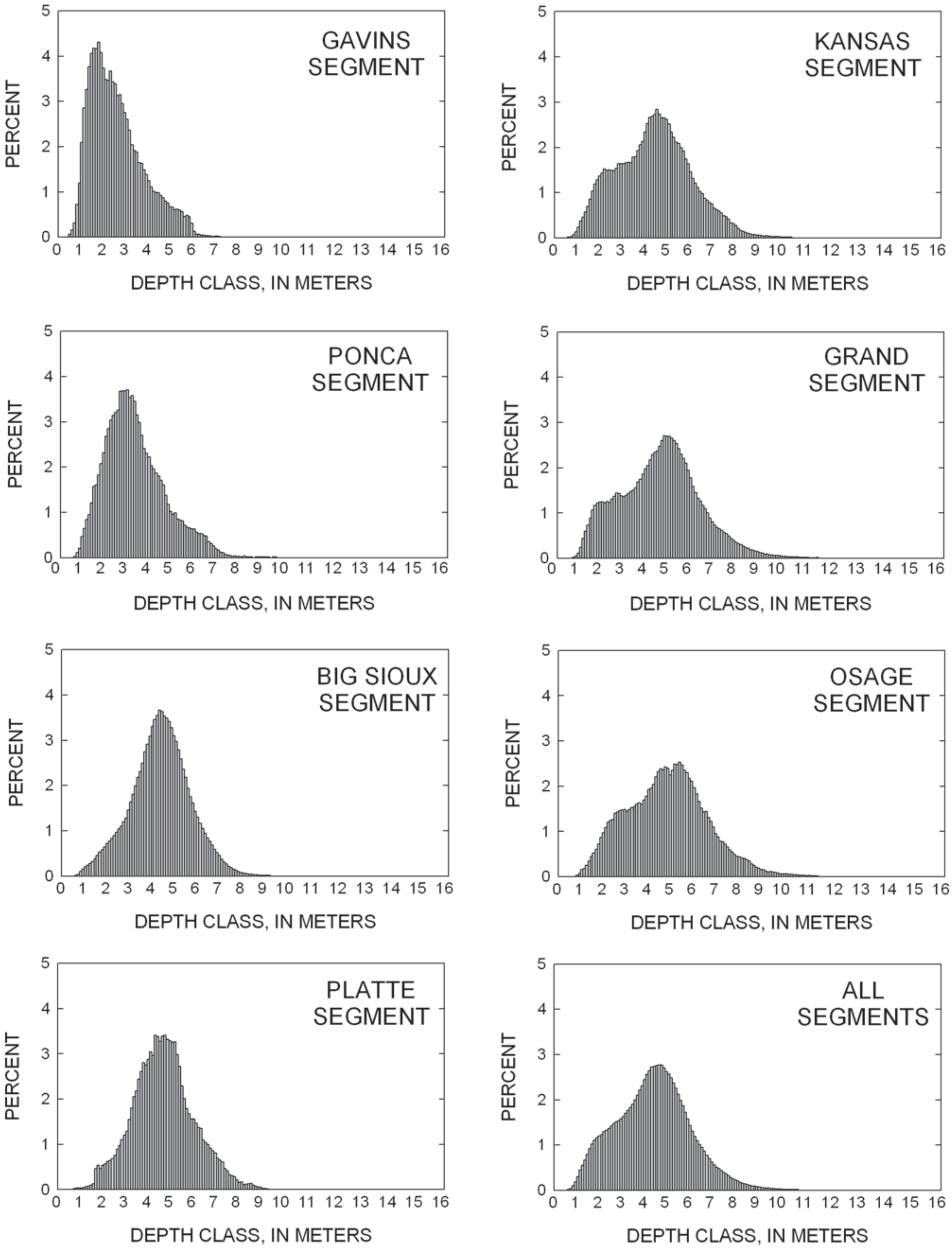


Figure D15. Histograms of depth for the segments of the Lower Missouri River, compiled from reaches mapped for habitat use. (In addition to the reaches listed in table D1, some reaches less than 1 km in length were included in this compilation.)

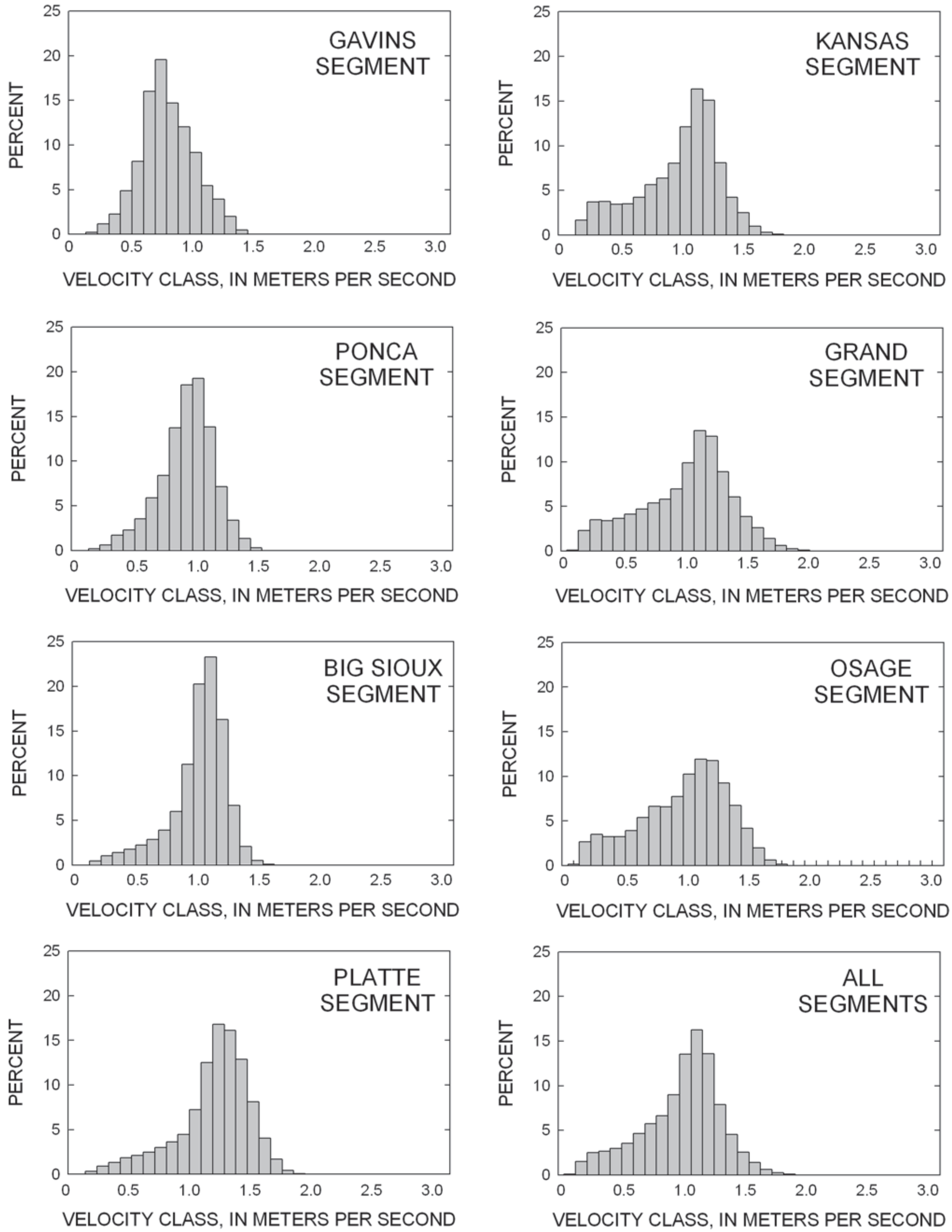


Figure D16. Histograms of velocity for the segments of the Lower Missouri River, compiled from reaches mapped for habitat use. (In addition to the reaches listed in table D1, some reaches less than 1 km in length were included in this compilation.)

Figure D17. Example of a modeling/monitoring reach, Missouri River near Yankton, S. Dak. Black lines indicate survey transects and centerline for collecting elevation data. Red lines are randomly selected monitoring transects for evaluating geomorphic change and sediment transport (Component 3).

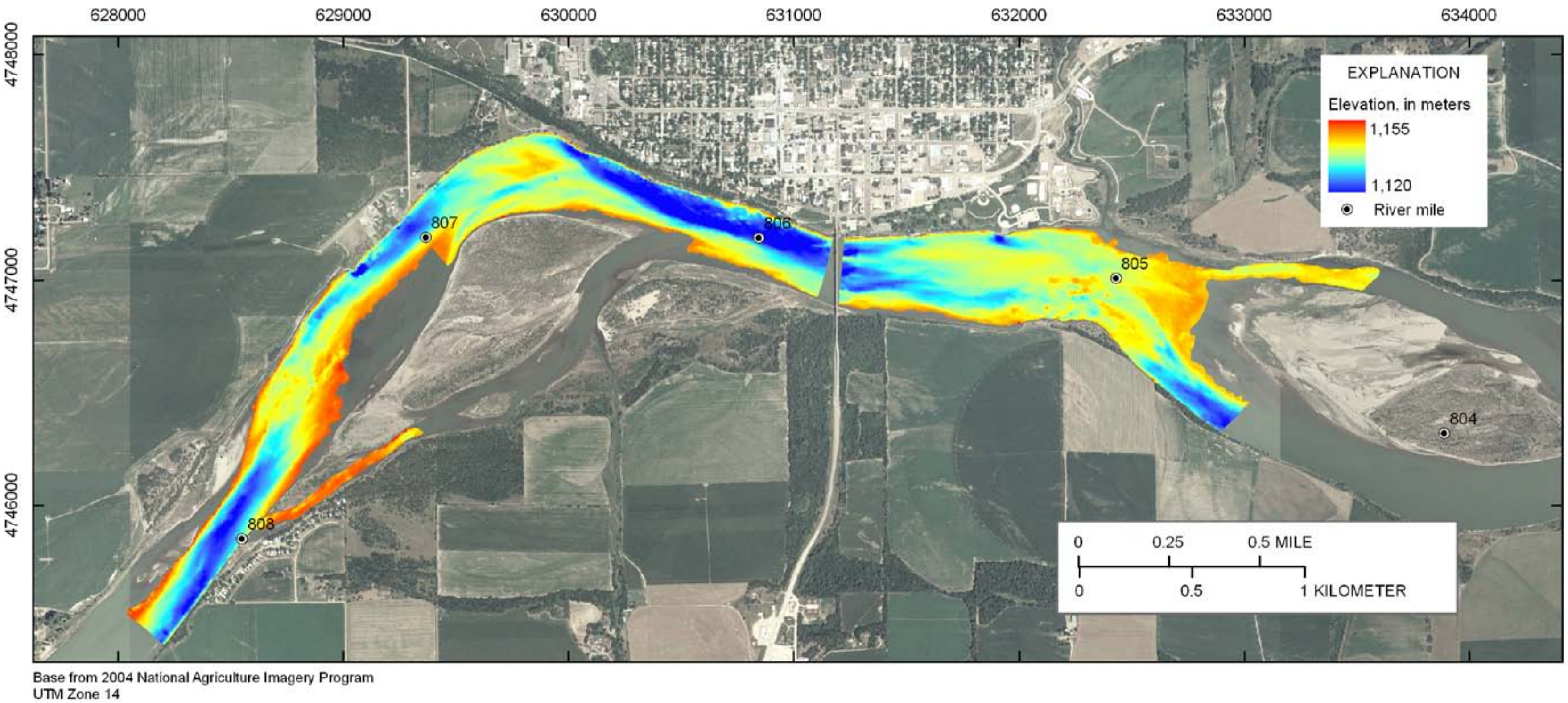


Figure D18. Bed-elevation grid at Yankton modeling/monitoring reach was produced from a bathymetric survey, made by using hydroacoustic depth sounders. Transects spanning from left descending bank to right descending bank were spaced 20 m apart and gridded to a 5-m mesh.

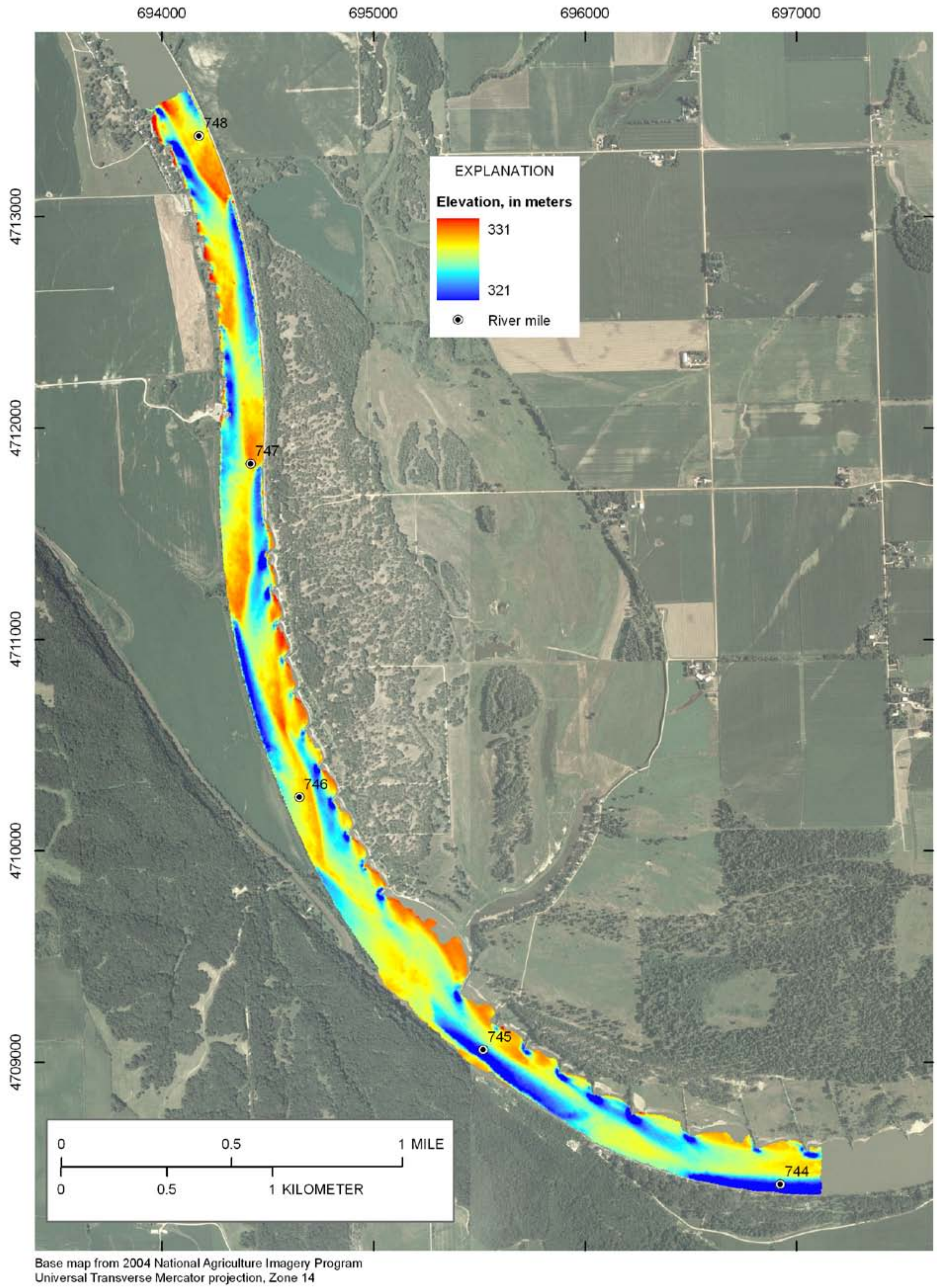
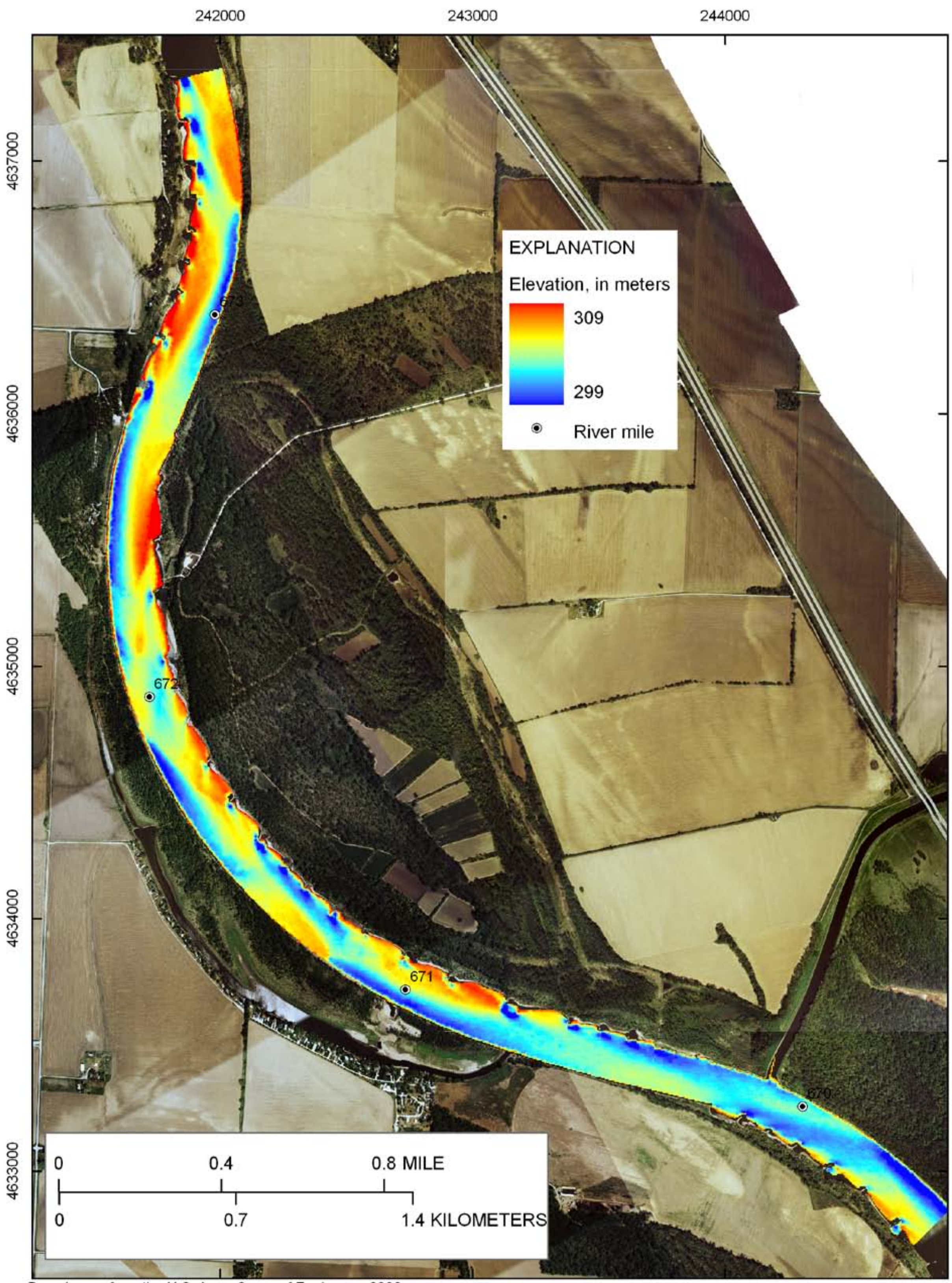


Figure D19. Bed-elevation grid at Kensler's Bend modeling/monitoring reach was produced from a bathymetric survey made by using hydroacoustic depth sounders. Transects spanning from left descending bank to right descending bank were spaced 20 m apart and gridded to a 5-m mesh.



Base Image from the U.S. Army Corps of Engineers, 2000
Universal Transverse Mercator projection Zone 14

Figure D20. Bed-elevation grid at Little Sioux modeling/monitoring reach was produced from a bathymetric survey using hydroacoustic depth sounders. Transects spanning from left descending bank to right descending bank were spaced 20 m apart and gridded to a 5-m mesh.

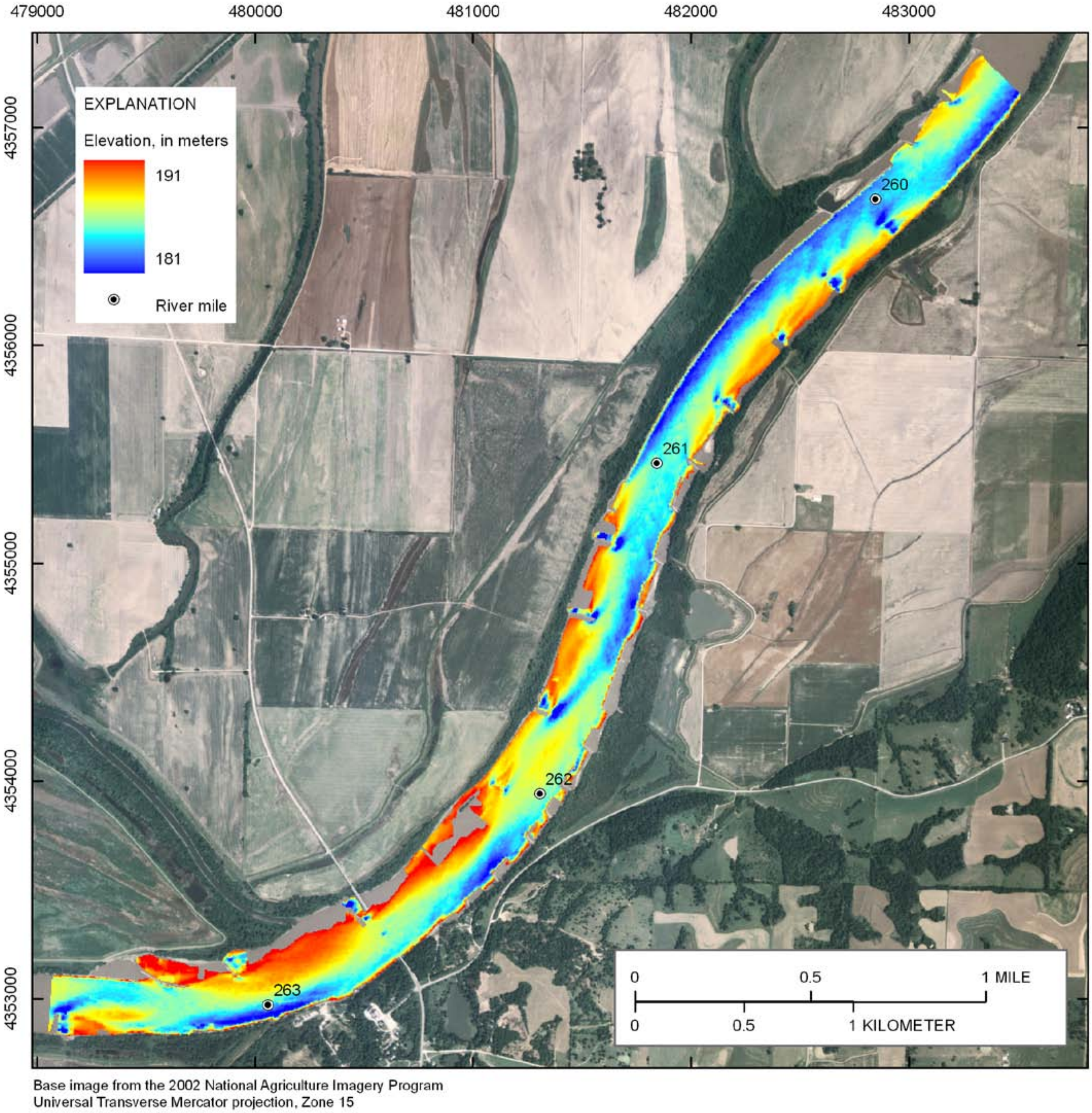


Figure D21. Bed-elevation grid at Miami modeling/monitoring reach was produced from a bathymetric survey, made by using hydroacoustic depth sounders. Transects spanning from left descending bank to right descending bank were spaced 20 m apart and gridded to a 5-m mesh.

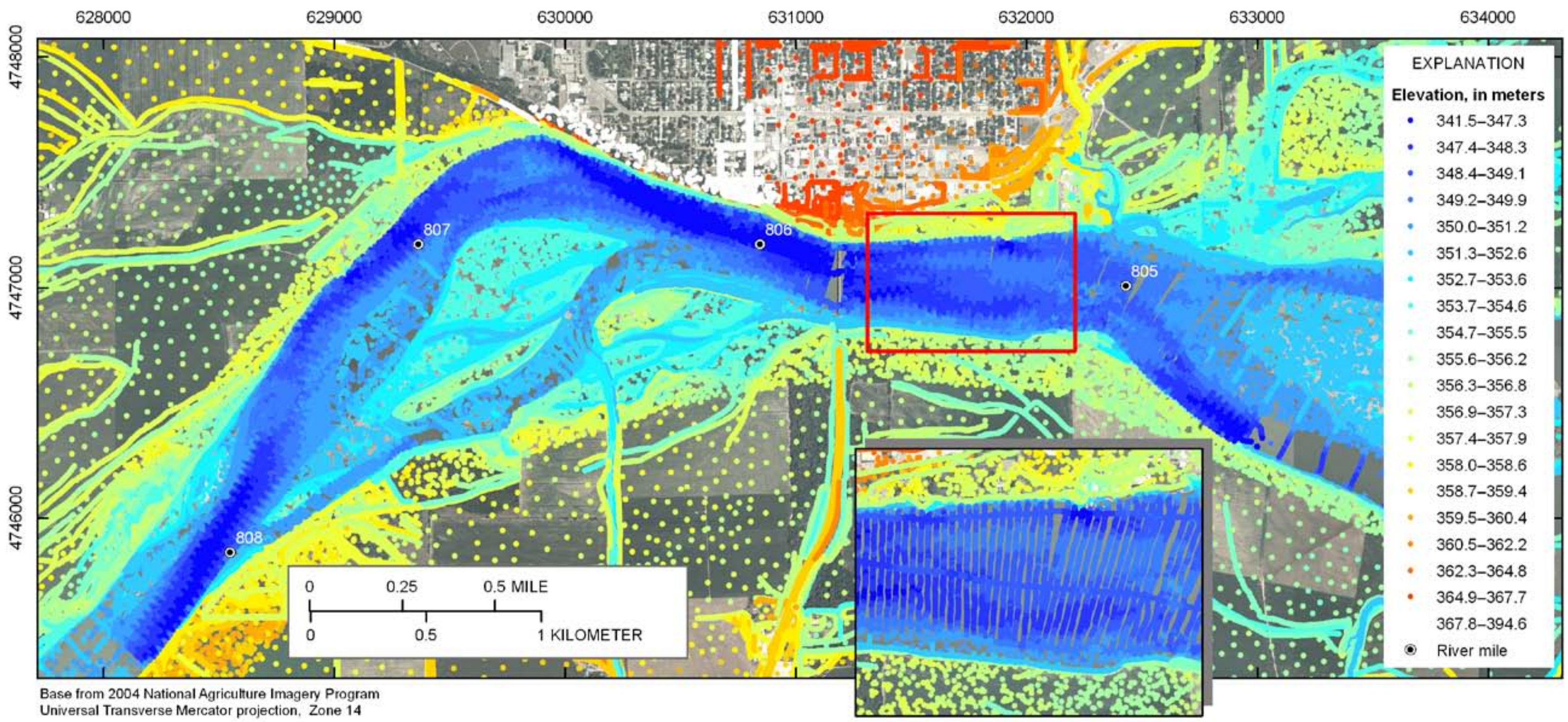


Figure D22. Multi-Dimensional Surface Water Modeling System model input at Yankton reach. The input data were created by using elevation data from the bathymetric and terrestrial surveys.

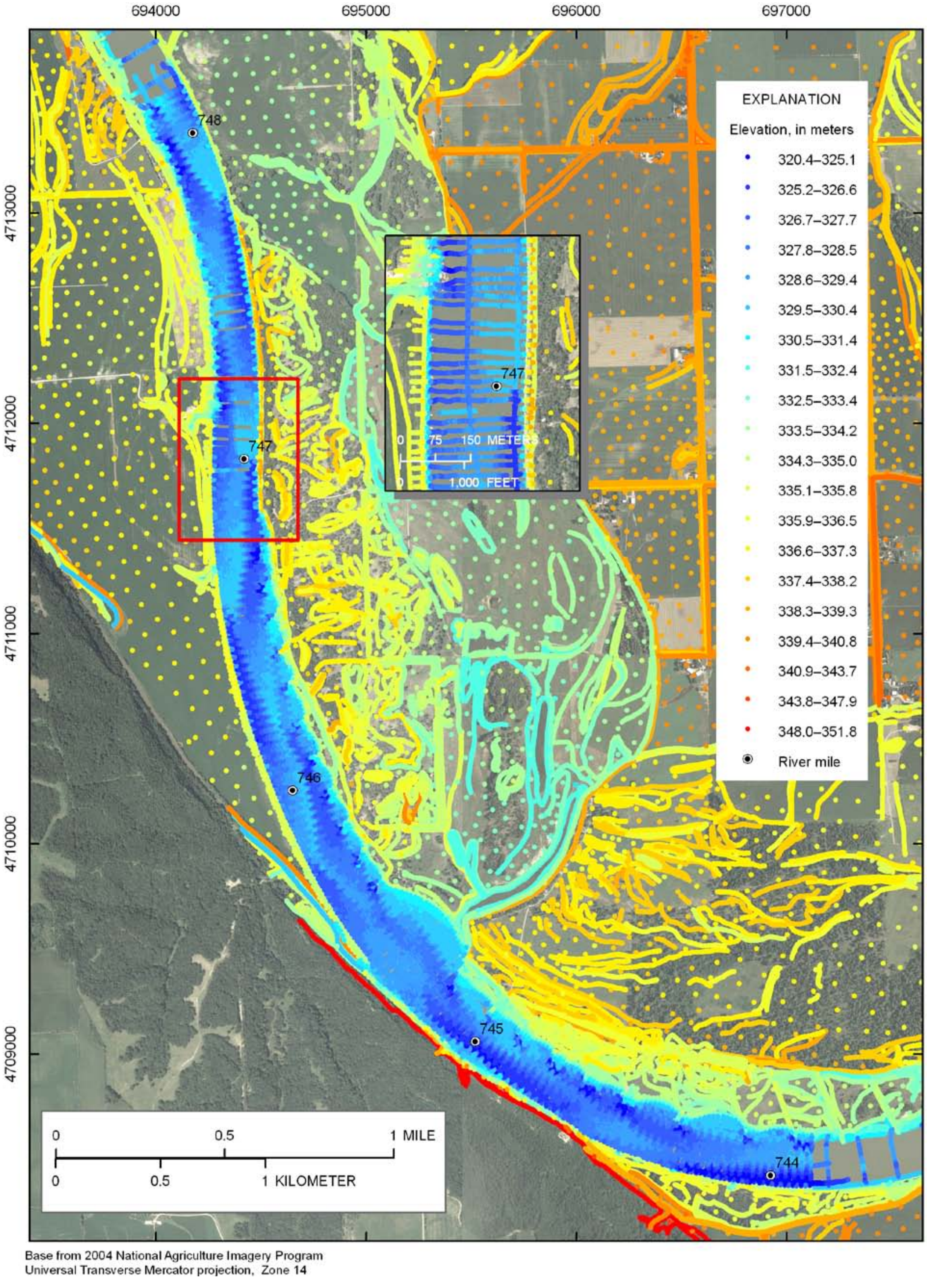
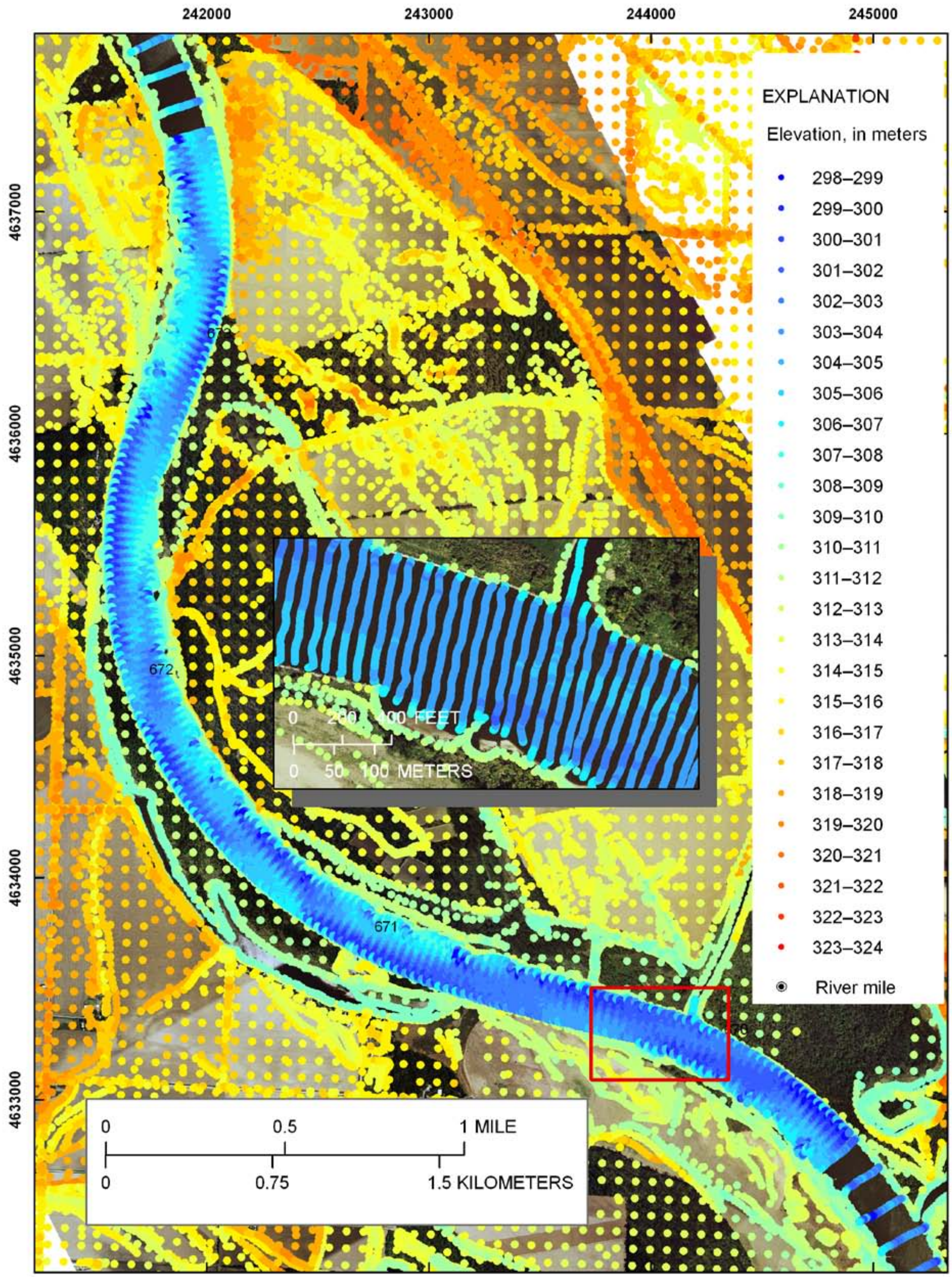


Figure D23. Multi-Dimensional Surface Water Modeling System model input at Kensler's Bend reach. The input data were created by using elevation data from the bathymetric and terrestrial surveys.



Base image from U.S. Army Corps of Engineers, 2000
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Figure D24. Multi-Dimensional Surface Water Modeling System model input at Little Sioux reach. The input data were created by using elevation data from the bathymetric and terrestrial surveys.

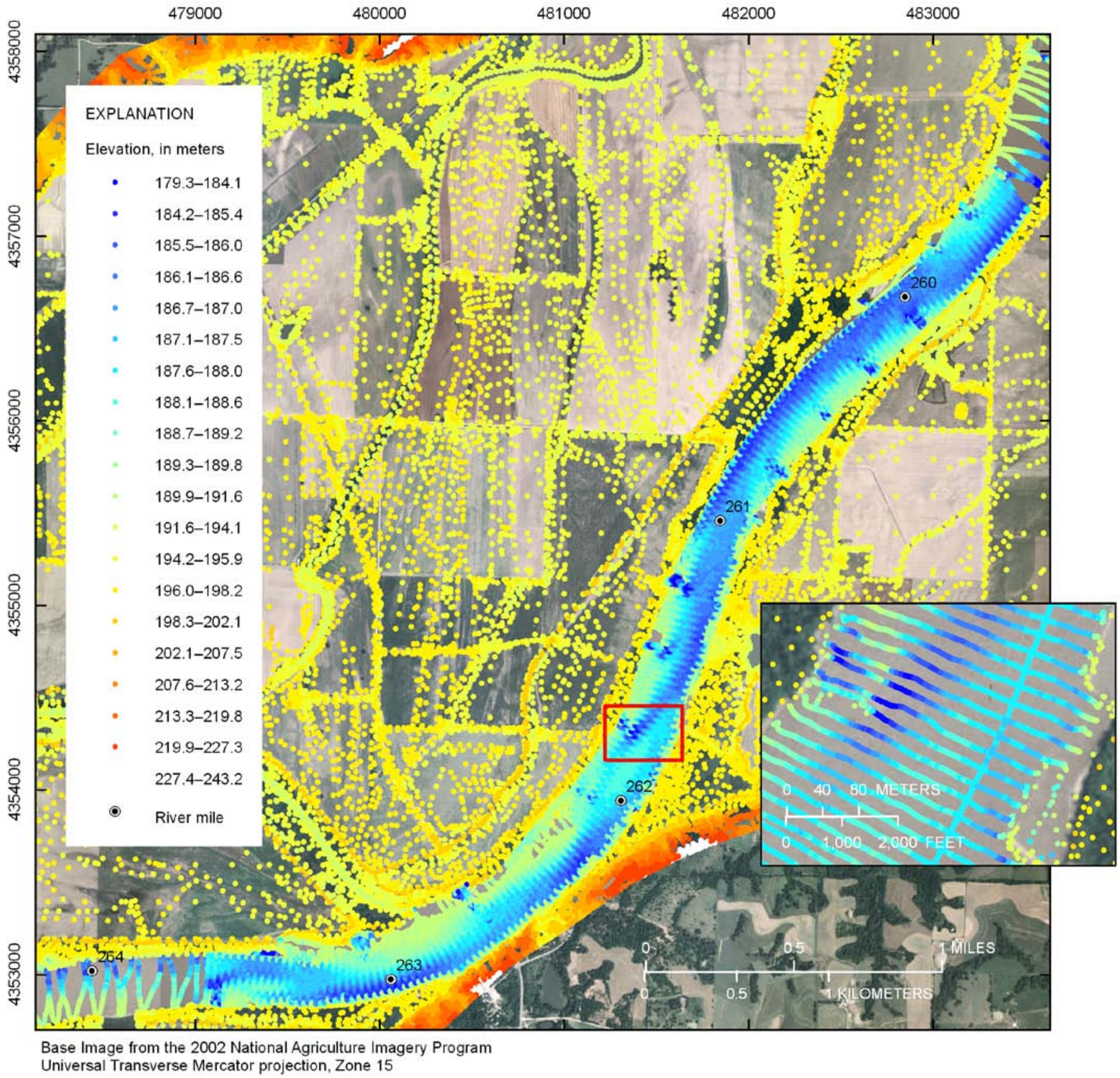


Figure D25. Multi-Dimensional Surface Water Modeling System model input at Miami reach. The input data were created by using elevation data from the bathymetric and terrestrial surveys.

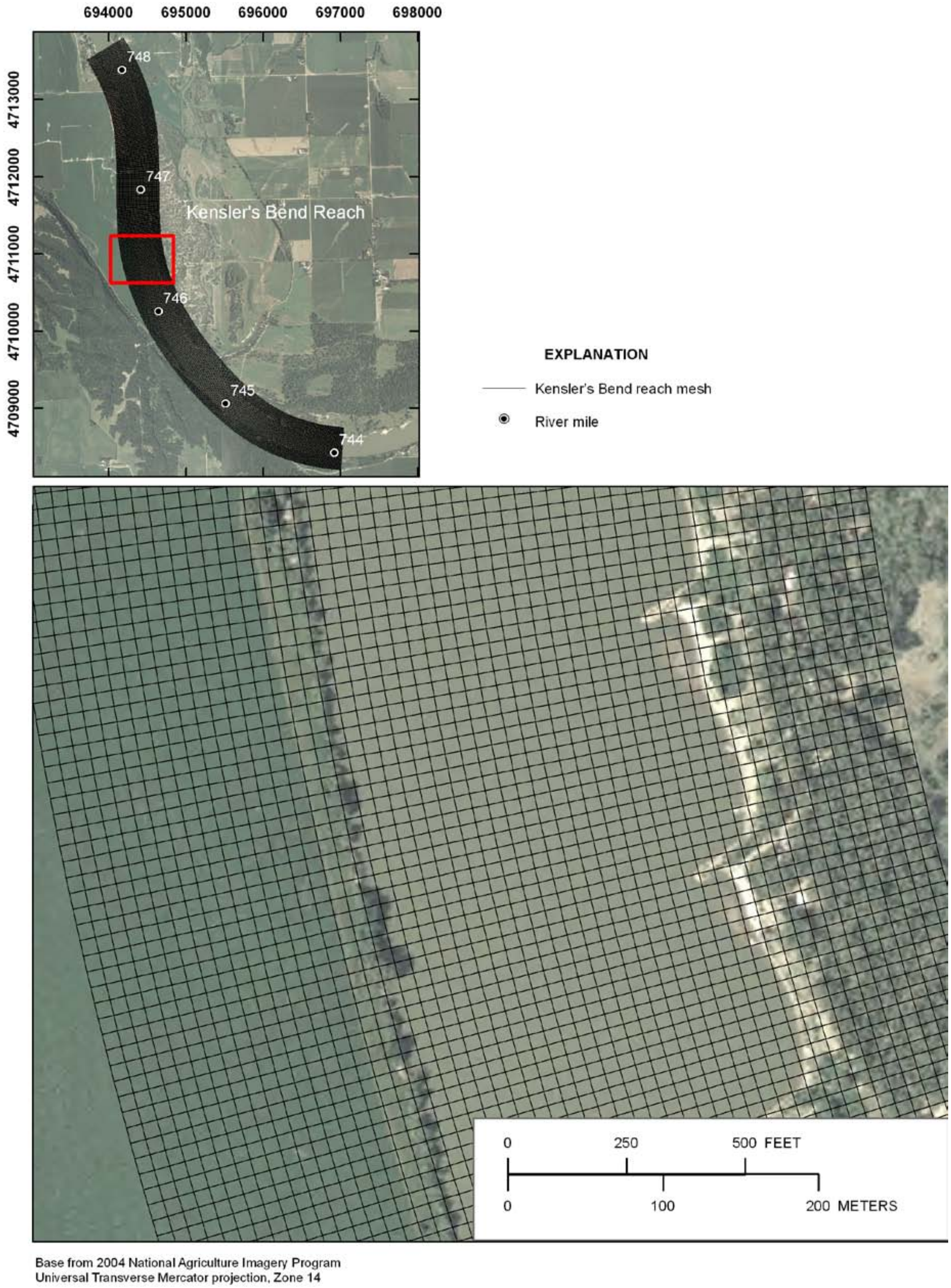


Figure D26. Multi-Dimensional Surface Water Modeling System mesh at Kensler's Bend. Mesh was created by using elevation data from the bathymetric and terrestrial surveys.

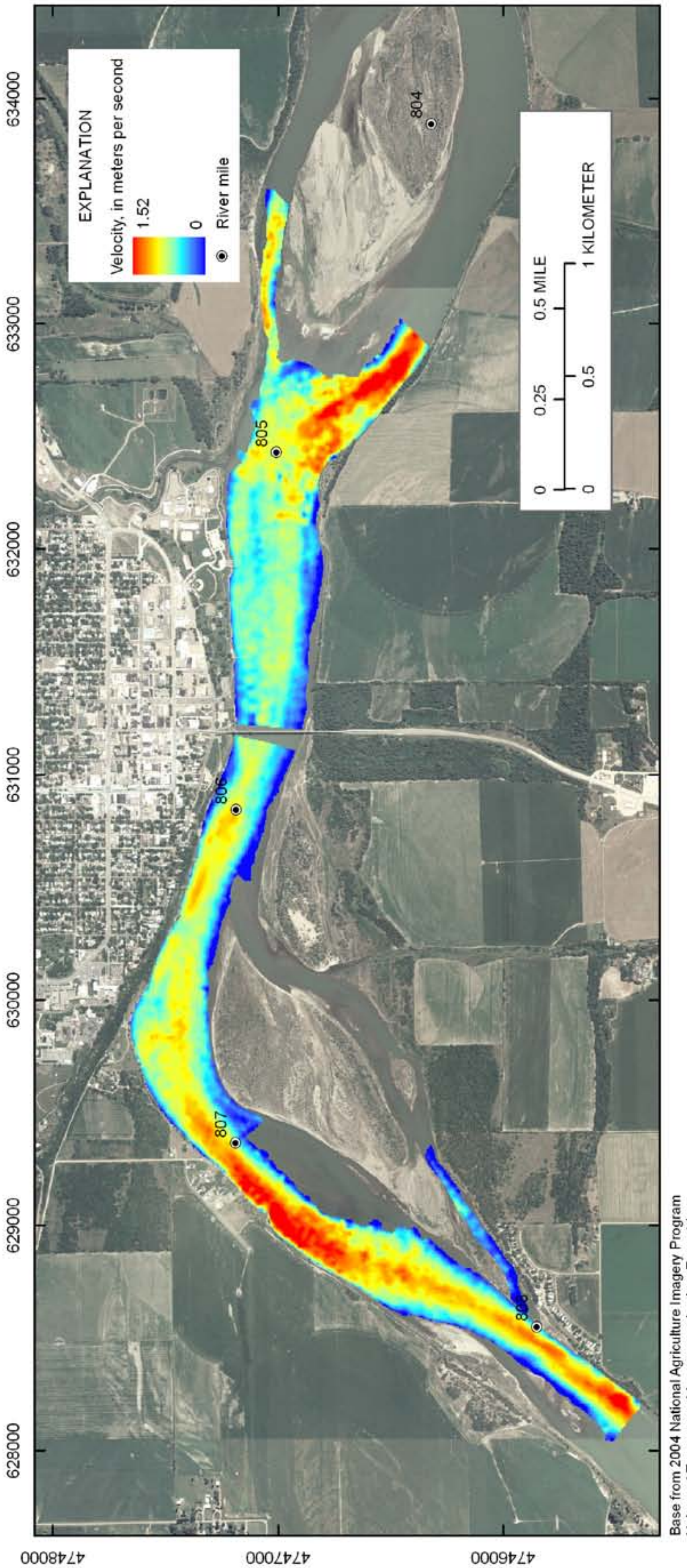


Figure D27. Depth-averaged velocity grid of the Yankton reach, which is used for comparison and calibration of the hydraulic model.

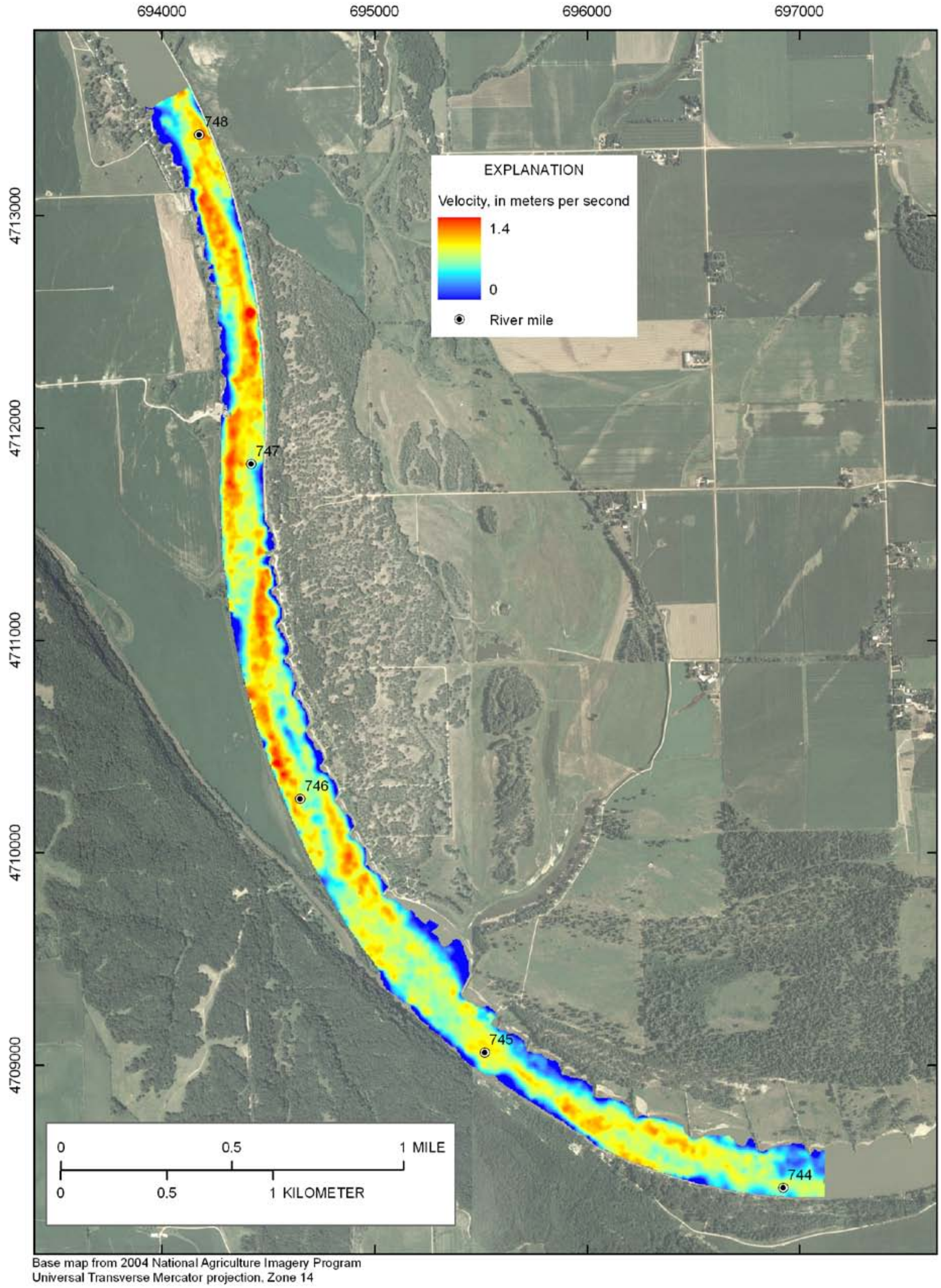


Figure D28. Depth-averaged velocity grid of the Kensler's Bend reach, which is used for comparison and calibration of the hydraulic model.

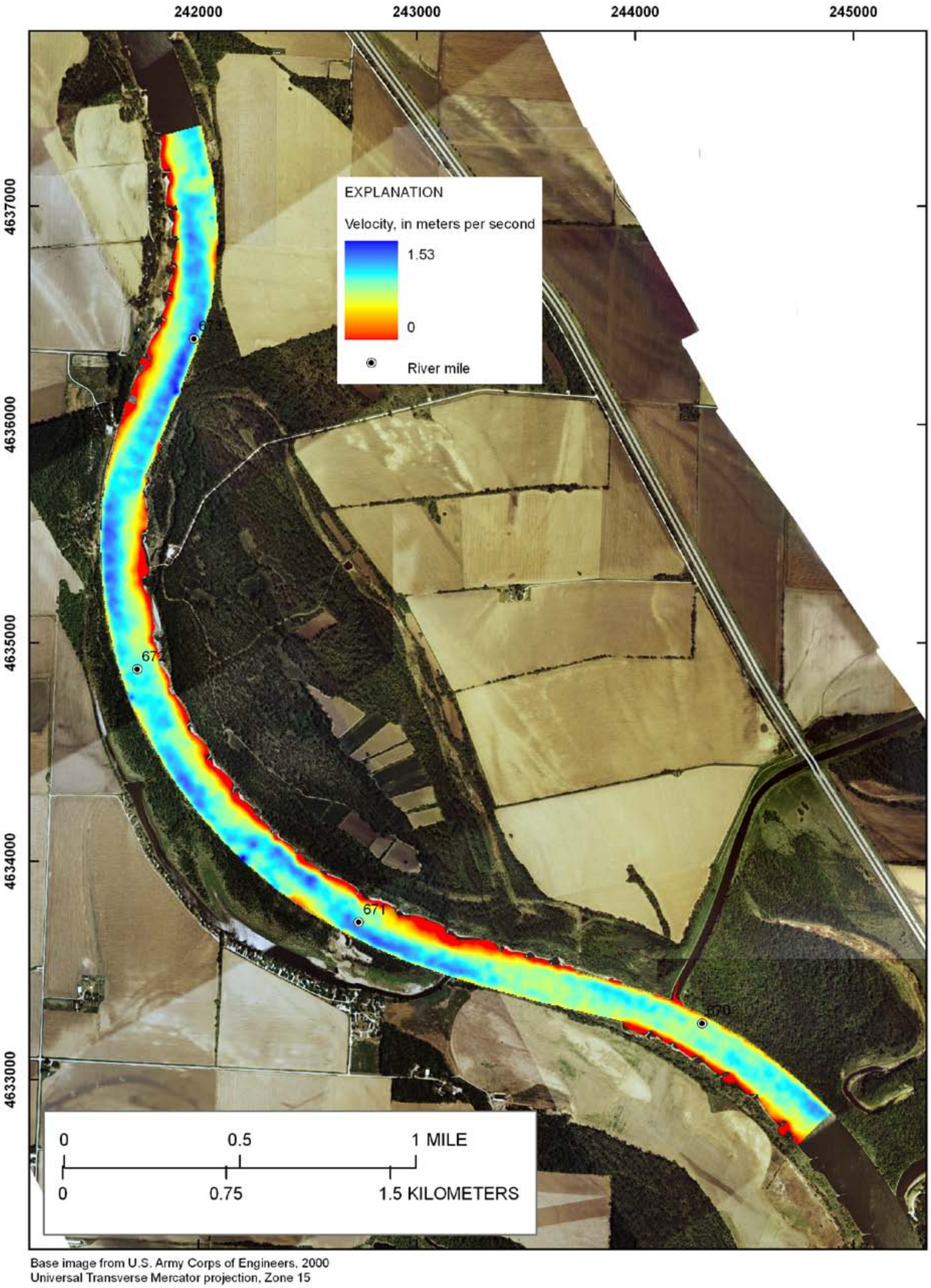


Figure D29. Depth-averaged velocity grid of the Little Sioux reach, which is used for comparison and calibration of the hydraulic model.

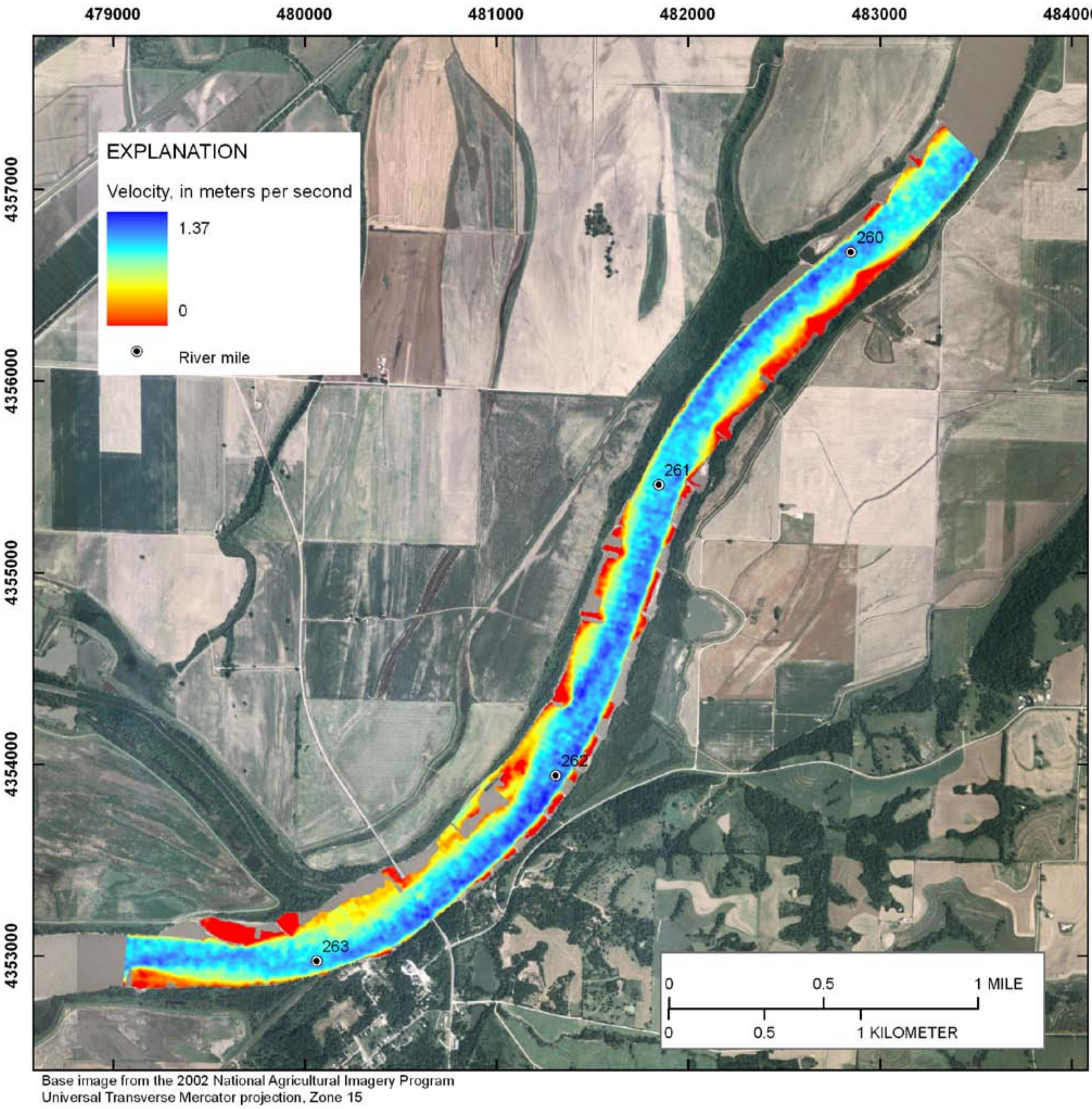


Figure D30. Depth-averaged velocity grid of the Miami reach, which is used for comparison and calibration of the hydraulic model.

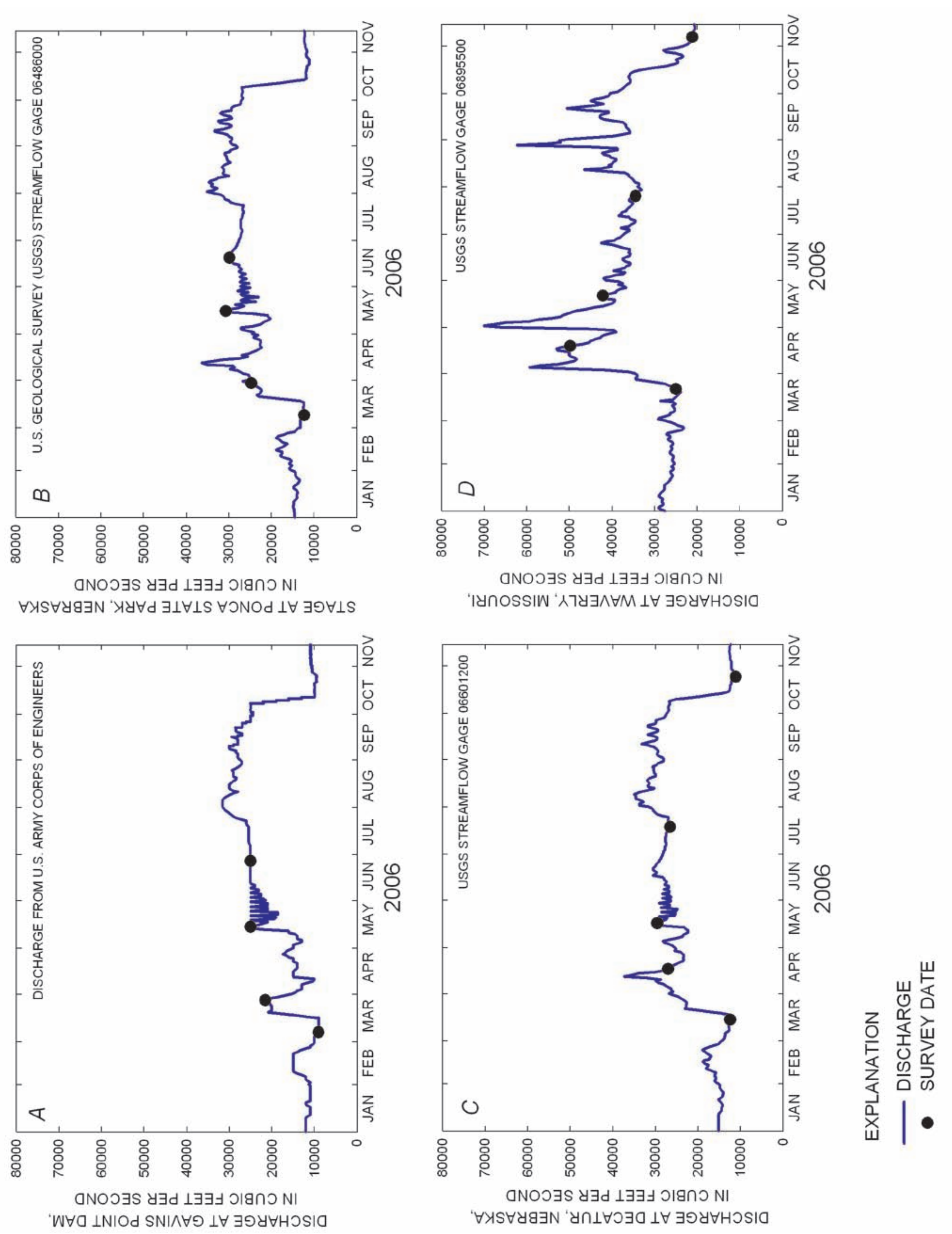


Figure D31. Hydrographs from stream gages at (*A*) Gavins Point Dam (U.S. Army Corps of Engineers); (*B*) Sioux City, Iowa (U.S. Geological Survey [USGS] 06486000); (*C*) Decatur, Nebr. (USGS 06601200); and (*D*) Waverly, Mo. (USGS 06895500). Survey dates are shown as black points.

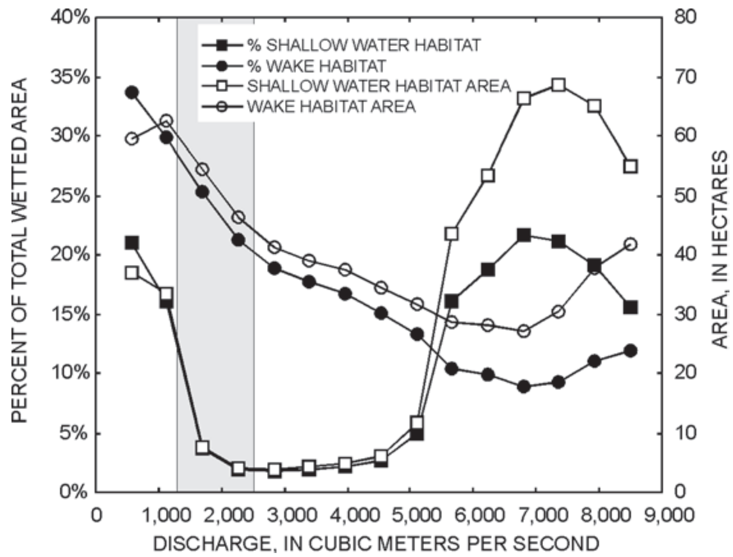
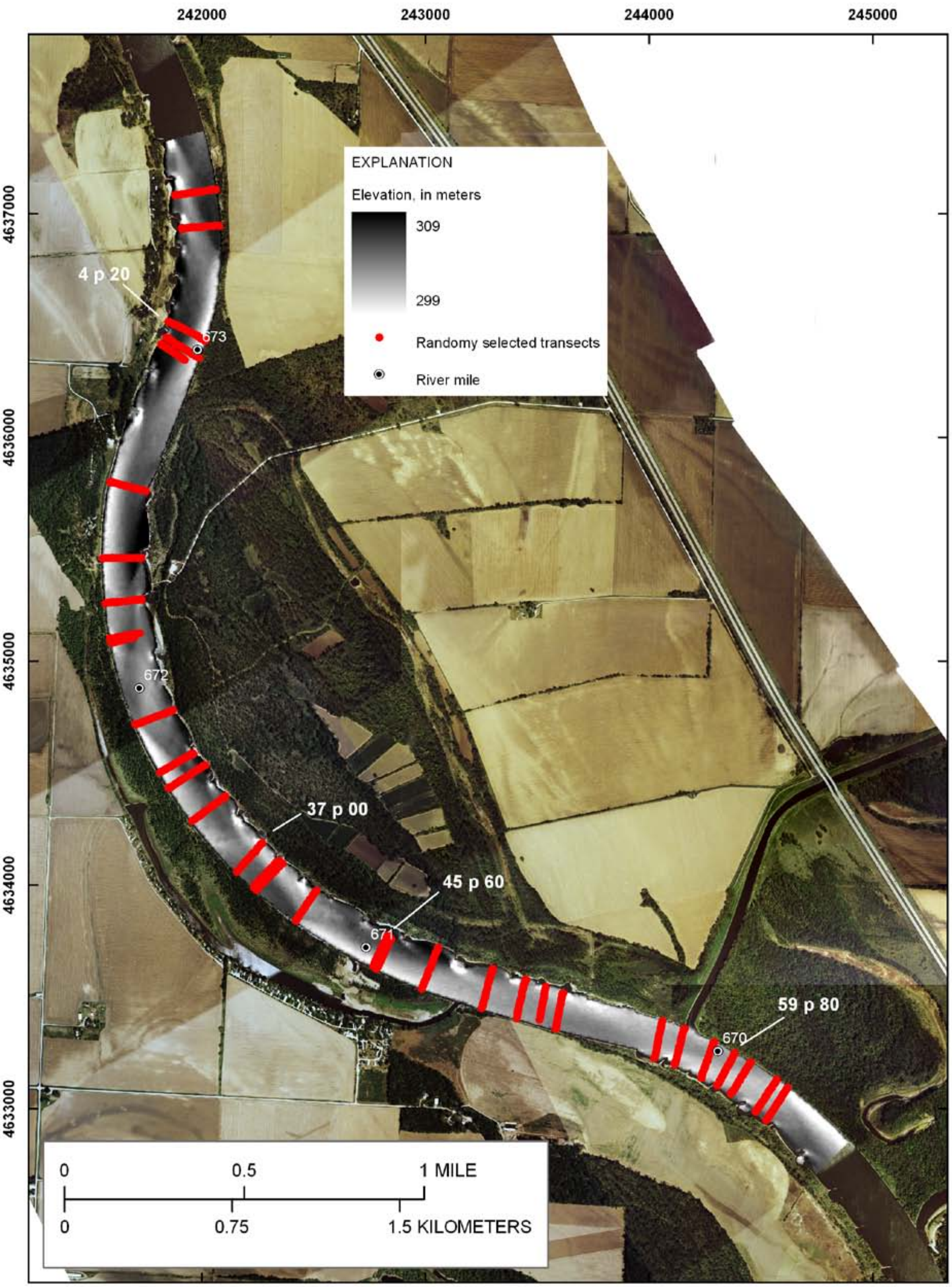


Figure D32. Example of discharge-habitat relations for two physical habitat classes simulated with a multidimensional hydrodynamic model on the Lower Missouri River near Boonville, Mo. (Johnson and others, 2006). The "wake" habitat is defined as regions of high spatial gradients of depth and velocity associated with flow separation.

Figure D33. Randomly selected transects at Yankton reach. The randomized sample was used to provide unbiased estimates of areas of the reach affected by flow and transport processes. Transects were surveyed four separate times throughout the year (2006) at various discharges. Transects with identification are for referencing in other figures.

Figure D34. Randomly selected transects at Kensler's Bend reach. The randomized sample was used to provide unbiased estimates of areas of the reach affected by flow and transport processes. Transects were surveyed four separate times throughout the year (2006) at various discharges. Transects with identification are for referencing in other figures.



Base image from U.S. Army Corps of Engineers, 2000
Universal Transverse Mercator projection, Zone 14

Figure D35. Randomly selected transects at Little Sioux reach. The randomized sample was used to provide unbiased estimates of areas of the reach affected by flow and transport processes. Transects were surveyed five separate times throughout the year (2006) at various discharges. Transects with identification are for referencing in other figures.

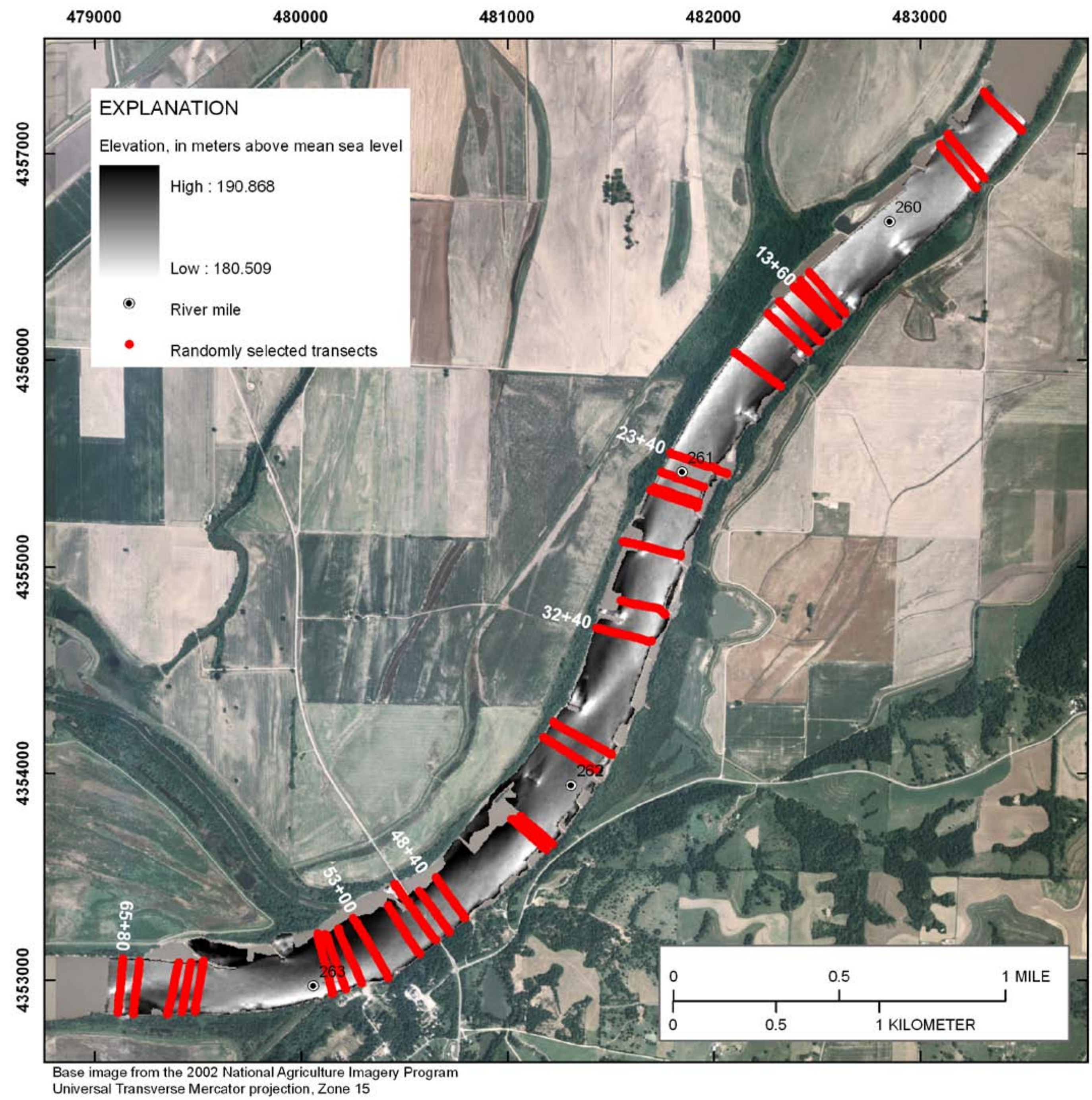


Figure D36. Randomly selected transects at Miami reach. The randomized sample was used to provide unbiased estimates of areas of the reach affected by flow and transport processes. Transects were surveyed four separate times throughout the year (2006) at various discharges. Transects with identification are for referencing in other figures.

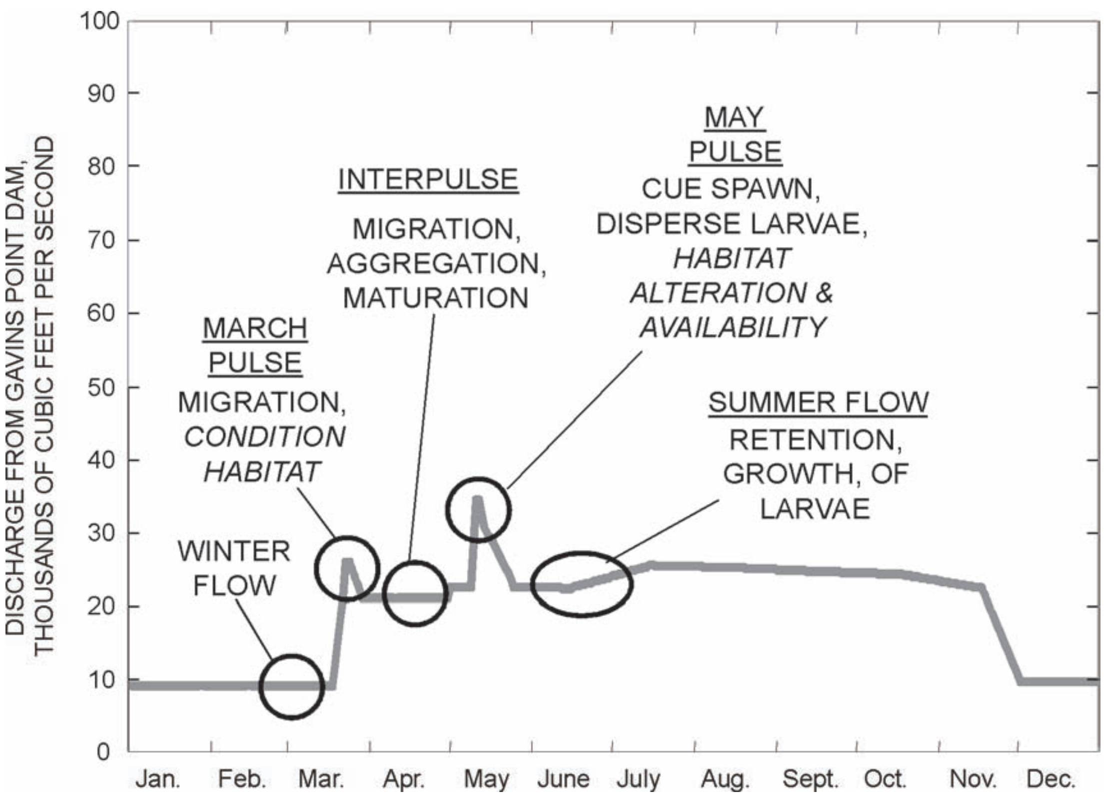


Figure D37. Planned release hydrograph for Gavins Point Dam, assuming median hydrologic conditions in the Missouri River basin, during fiscal years 2006 and 2007 if storage levels are adequate (U.S. Army Corps of Engineers, 2006). Text indicates the hypothesized functions of spring flow pulses as they may relate to reproduction of the pallid sturgeon.

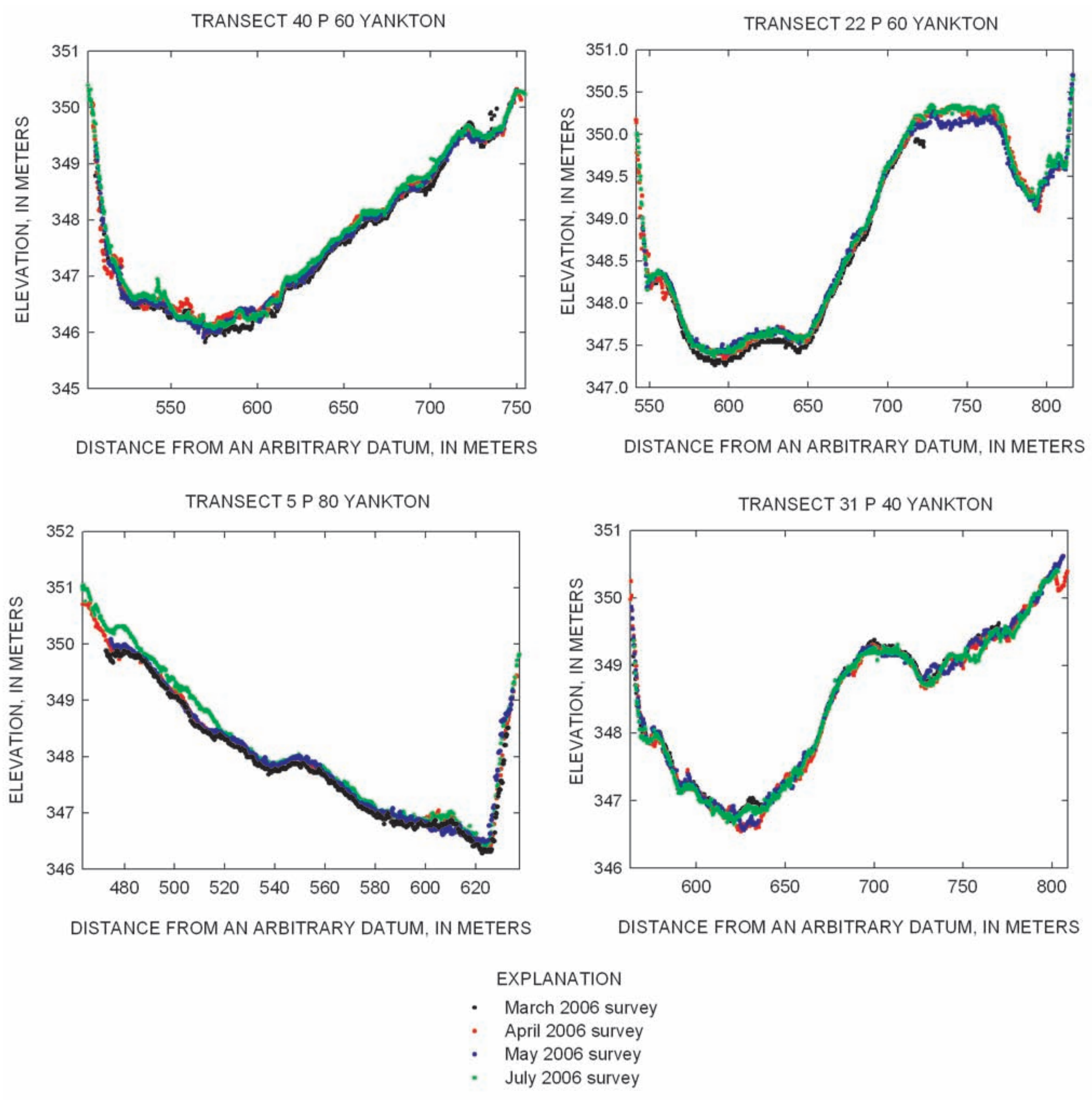


Figure D38. Examples of cross sections along four transects and four surveys at Yankton reach. Elevation of the river bed is in meters above the North American Datum of 1988. Data are displayed from left descending bank to right descending bank.

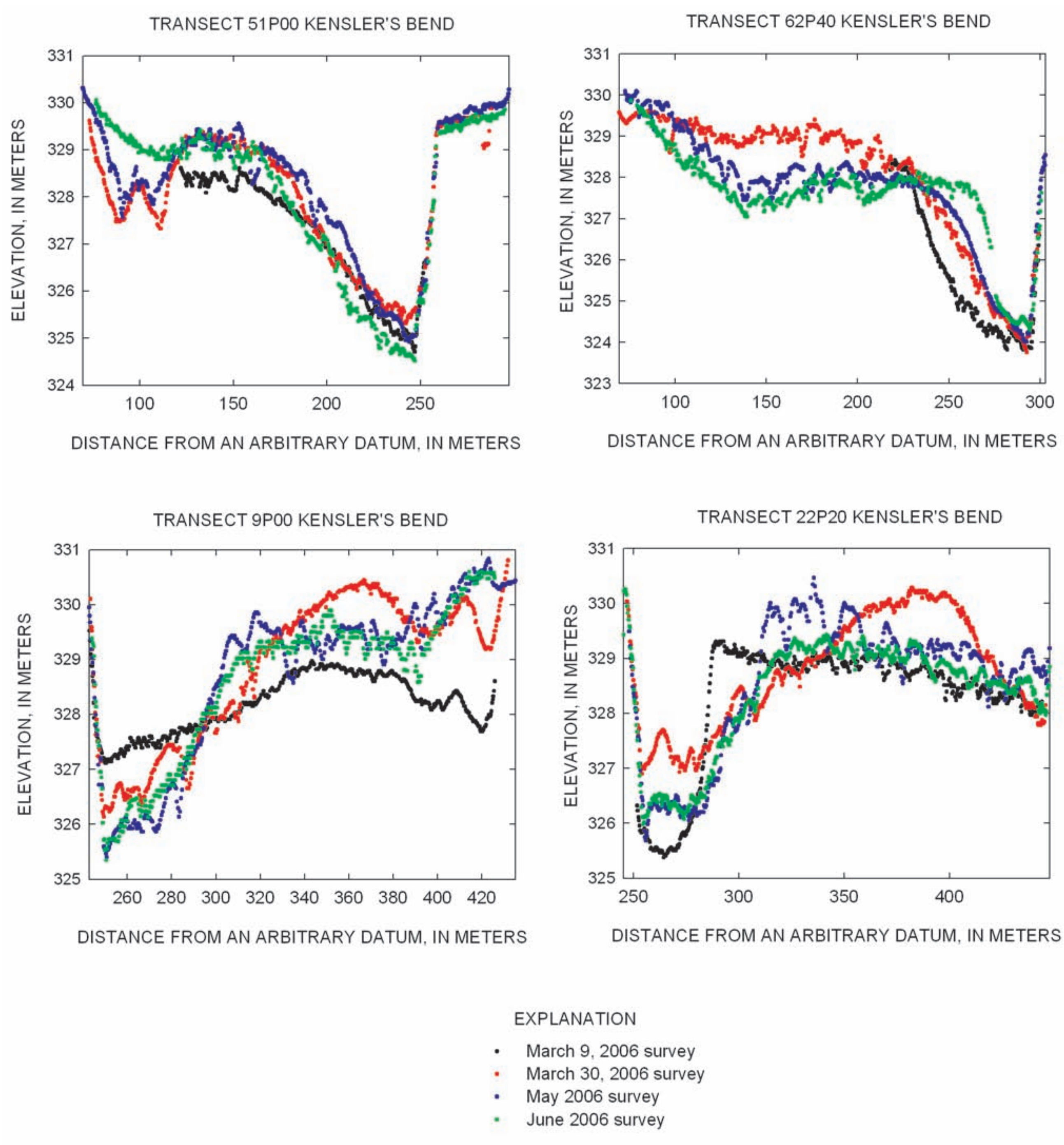


Figure D39. Examples of cross sections along four transects and four surveys, Kensler's Bend reach. Elevation of the river bed is in meters above the North American Datum of 1988. Data are displayed from left descending bank to right descending bank.

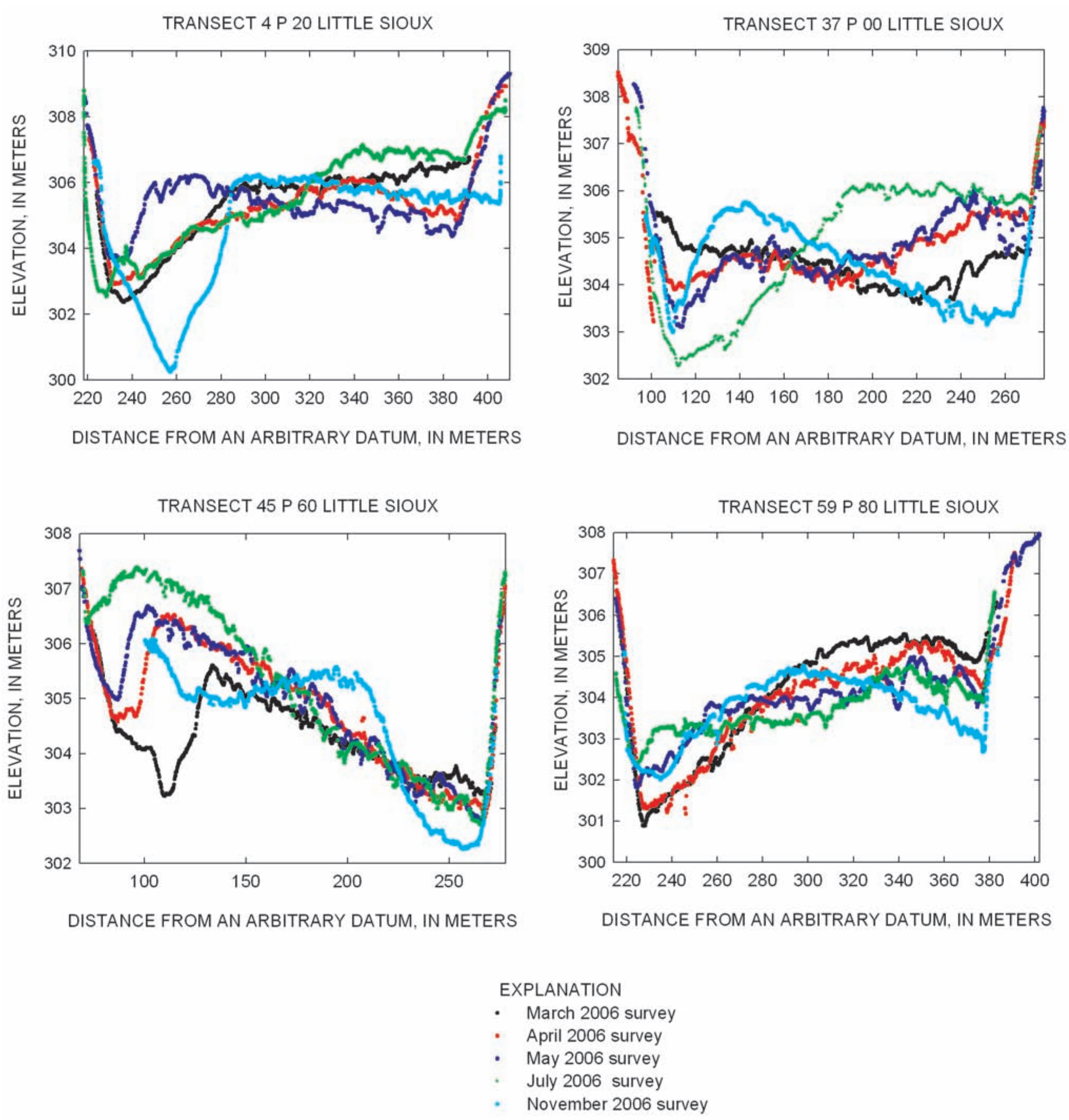


Figure D40. Examples of cross sections along four transects and four surveys, Little Sioux reach. Elevation of the river bed is in meters above the North American Datum of 1988. Data are displayed from left descending bank to right descending bank.

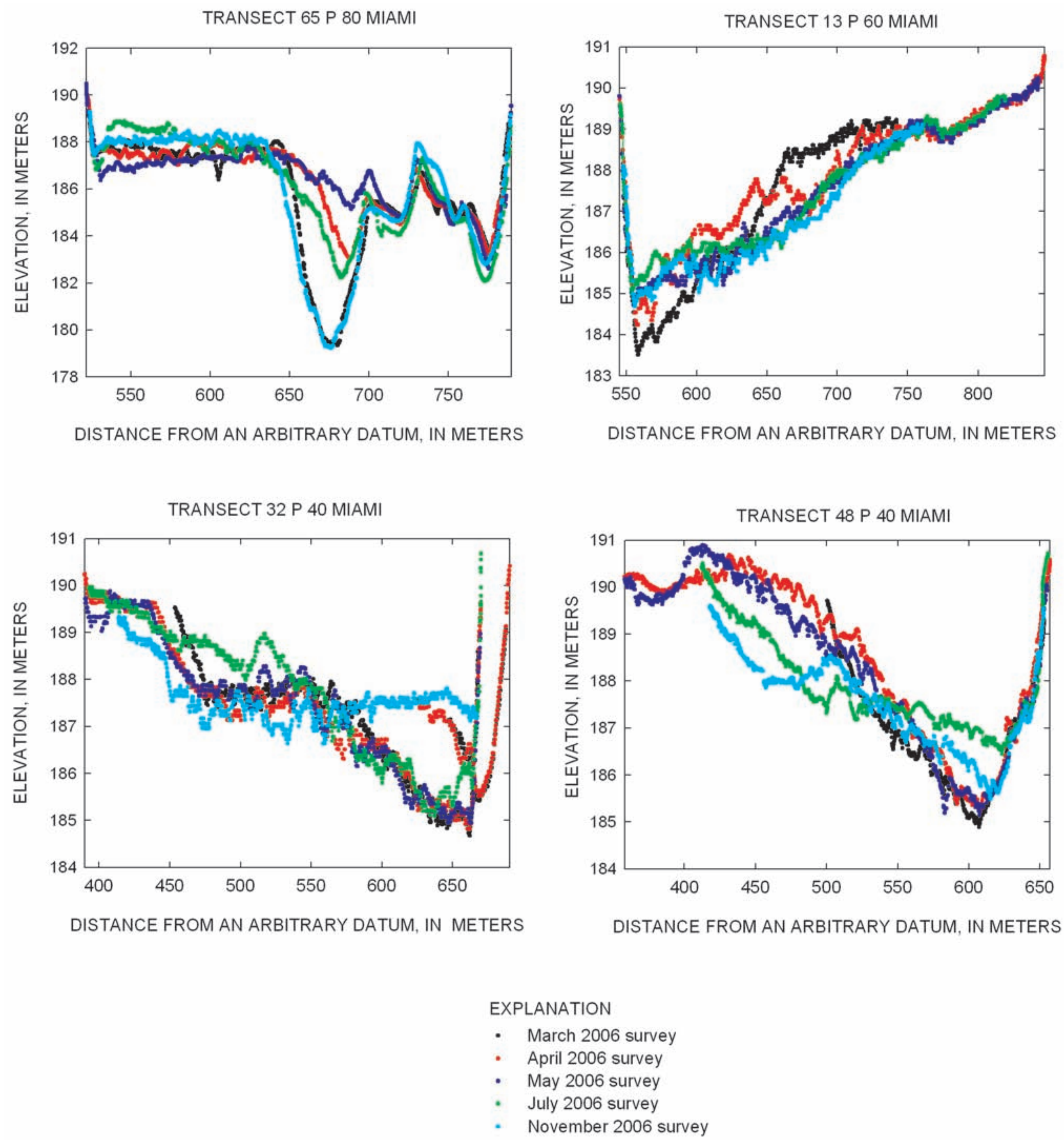


Figure D41. Examples of cross sections along four transects and four surveys, Miami reach. Elevation of the river bed is in meters above North American Datum of 1988. Data are displayed from left descending bank to right descending bank.

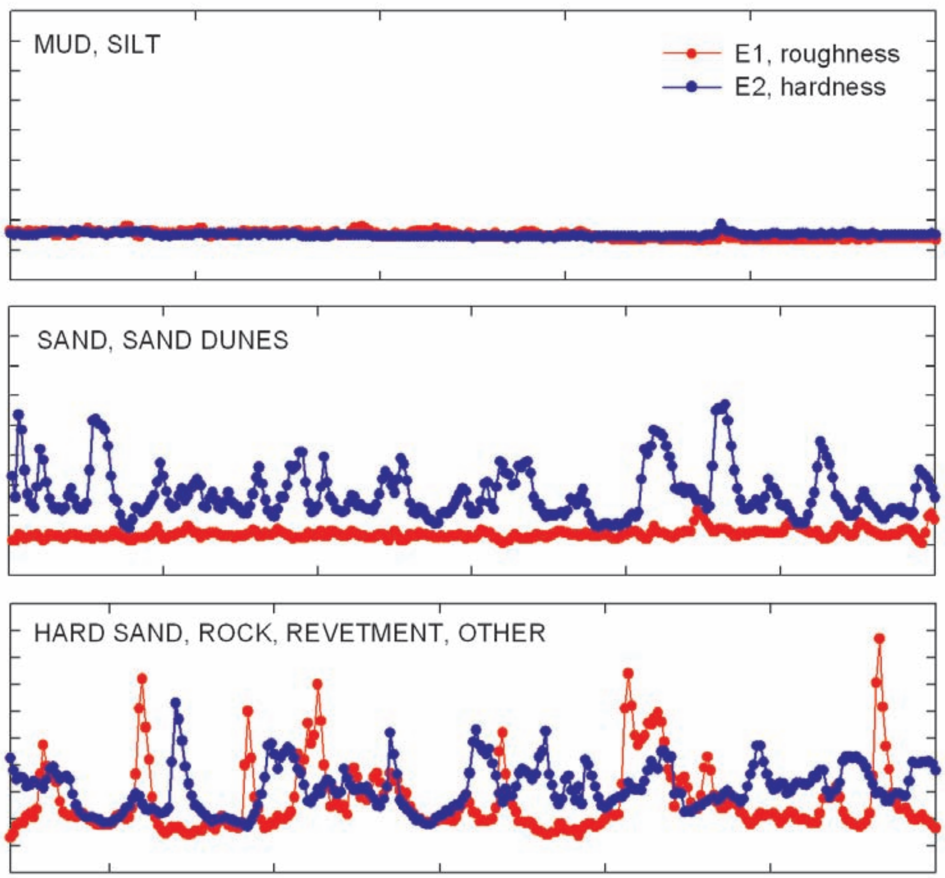


Figure D42. Conceptual interpretation of E1 and E2 values of substrate parameters along a cross section. Three distinct signatures of E1 and E2 values are illustrated based on repeat RoxAnn (Sonavision Ltd., Aberdeen Scotland) measurements, sediment sampling, and side-scan sonar interpretation. Mud (or silt) is characterized by low and stable E1 and E2 values. Sand is characterized by low and stable E1 values and byfluctuating moderate E2 values. The degree of fluctuation in E2 values is likely related to dune form and size. Rock, gravel, and coarse, hard sand tend to have very high E1 and/or E2 values.

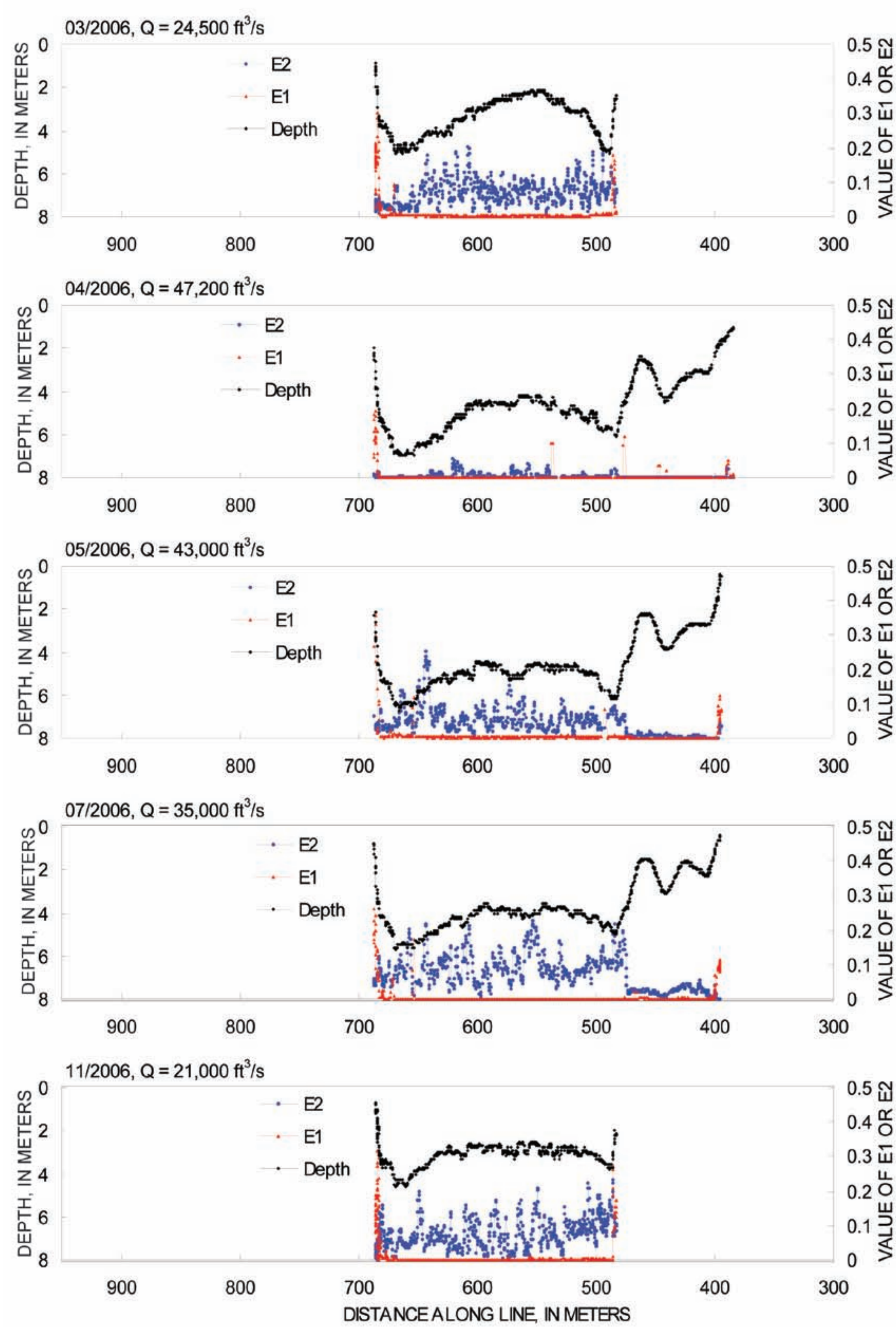


Figure D43. Depth, E1 (roughness), and E2 (hardness) at cross section 23 P 40 at the Miami reach. Cross sections are oriented downstream. E1 and E2 values on the left side of the cross section are both high, indicating a hard substrate, revetment. The right side of the cross sections have E1 and E2 values that are consistently low, indicating a fine (soft mud and silt) substrate. The middle of the channel illustrates E1 and E2 signatures typical of sand and dunes, with low E1 and E2 values of varying magnitude. Discharge is indicated by the variable Q.

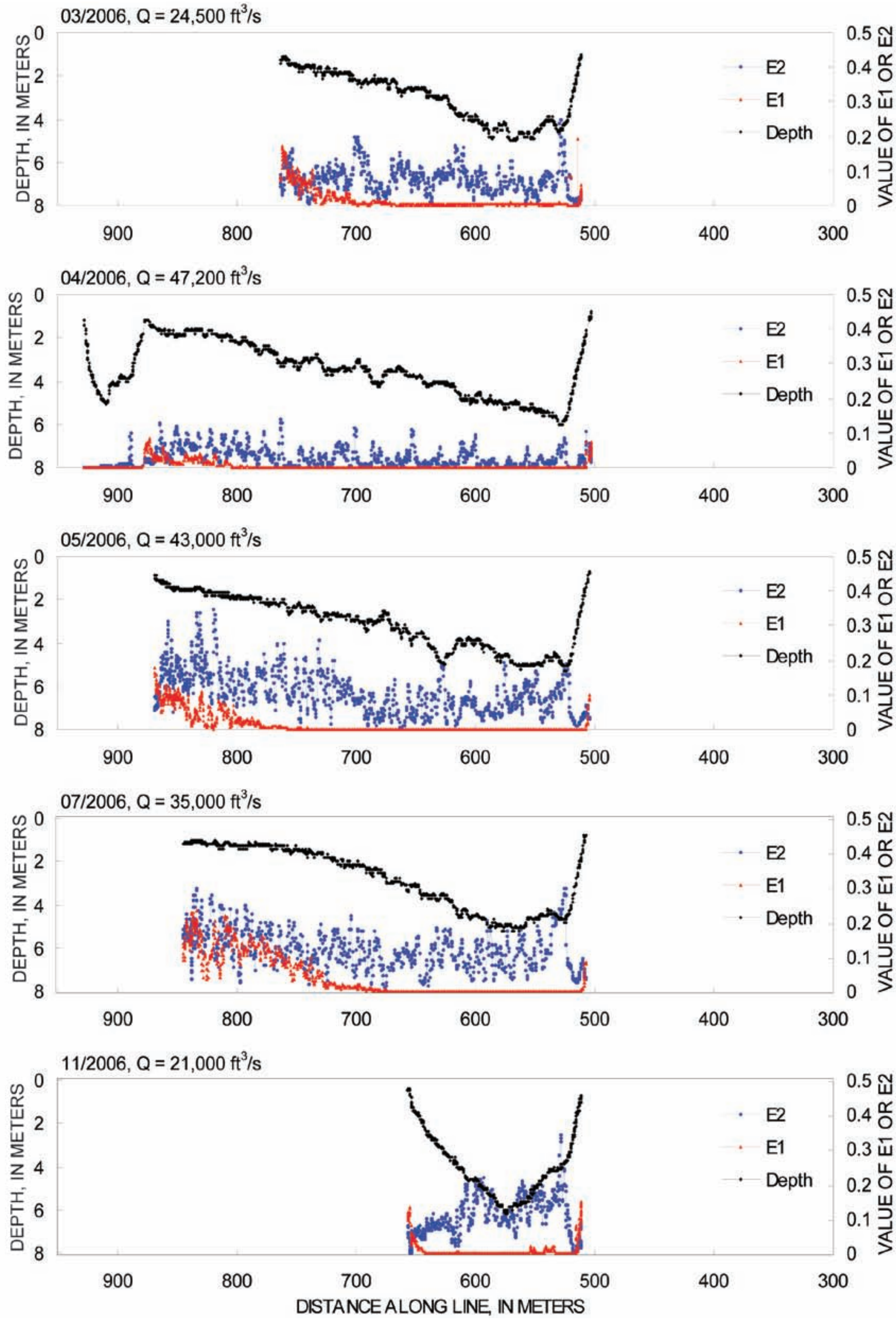


Figure D44. Depth, E1 (roughness) and E2 (hardness) at cross section 53 P 00 at the Miami reach. Cross sections are oriented downstream. Both E1 and E2 values on the left side of the cross section are relatively high, indicating a presence of gravel on the bed. The remainder of the bed illustrates E1 and E2 values typical of sand and sand dunes. Discharge is indicated by the variable Q.

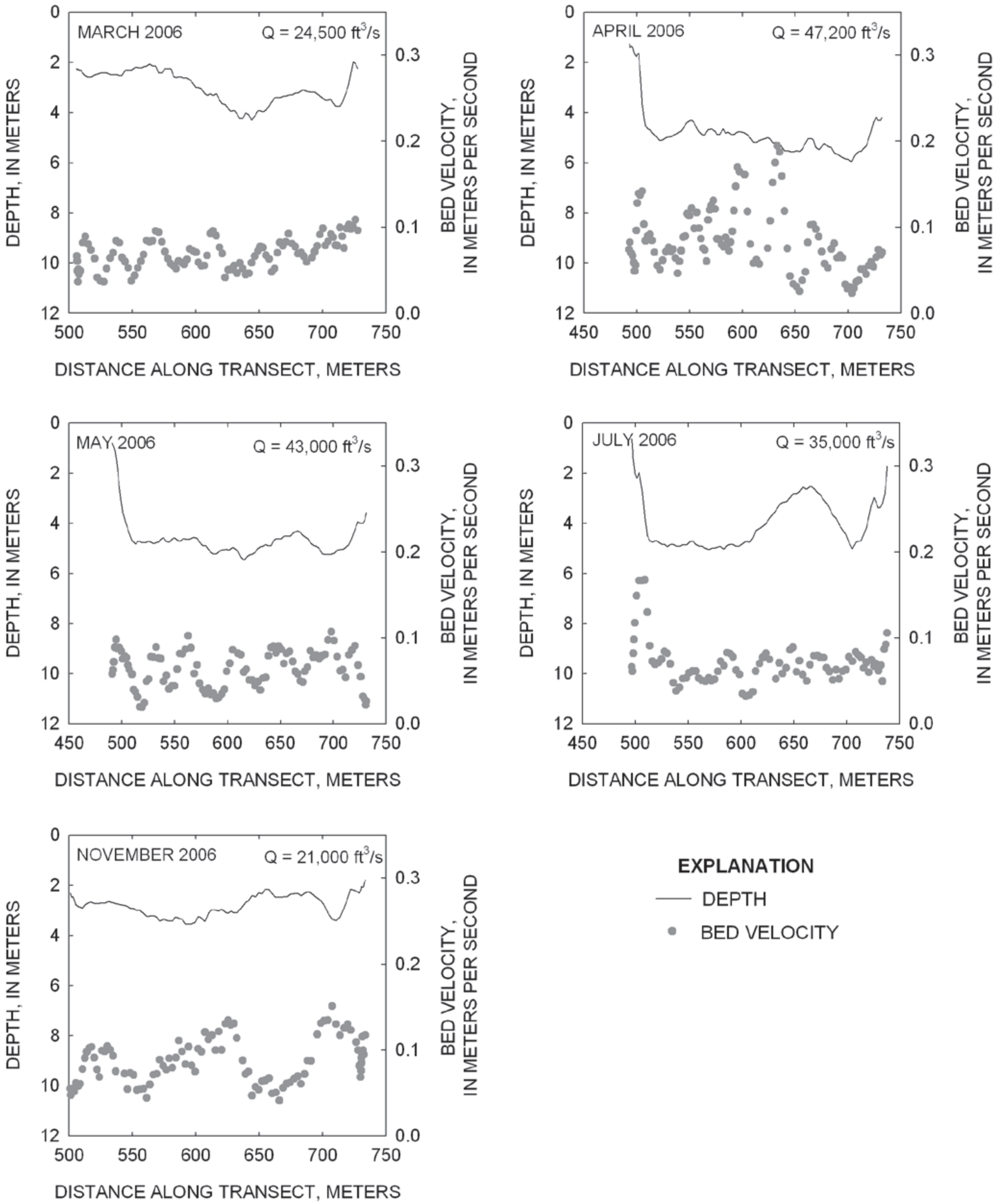


Figure D45. Bed velocity and depth at transect 62 P 60 from five separate surveys in the Miami reach. Transect is located downstream of a wing dike and is located on the right descending bank. Discharge is indicated by the variable Q.

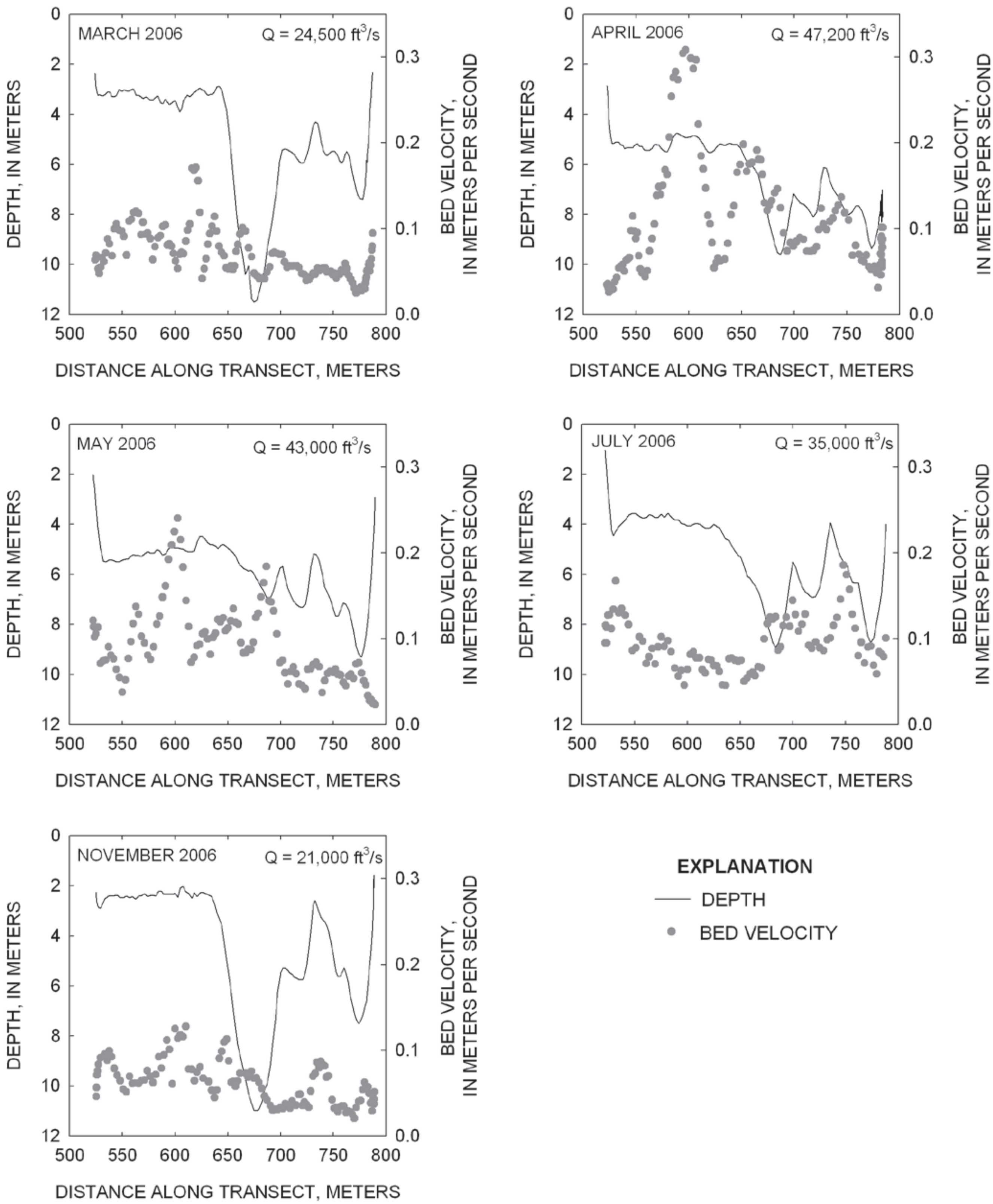


Figure D46. Bed velocity and depth at transect 65 P 80 from five separate surveys in the Miami reach. Transect is located downstream of a wing dike and is located on the right descending bank. Discharge is indicated by the variable Q.

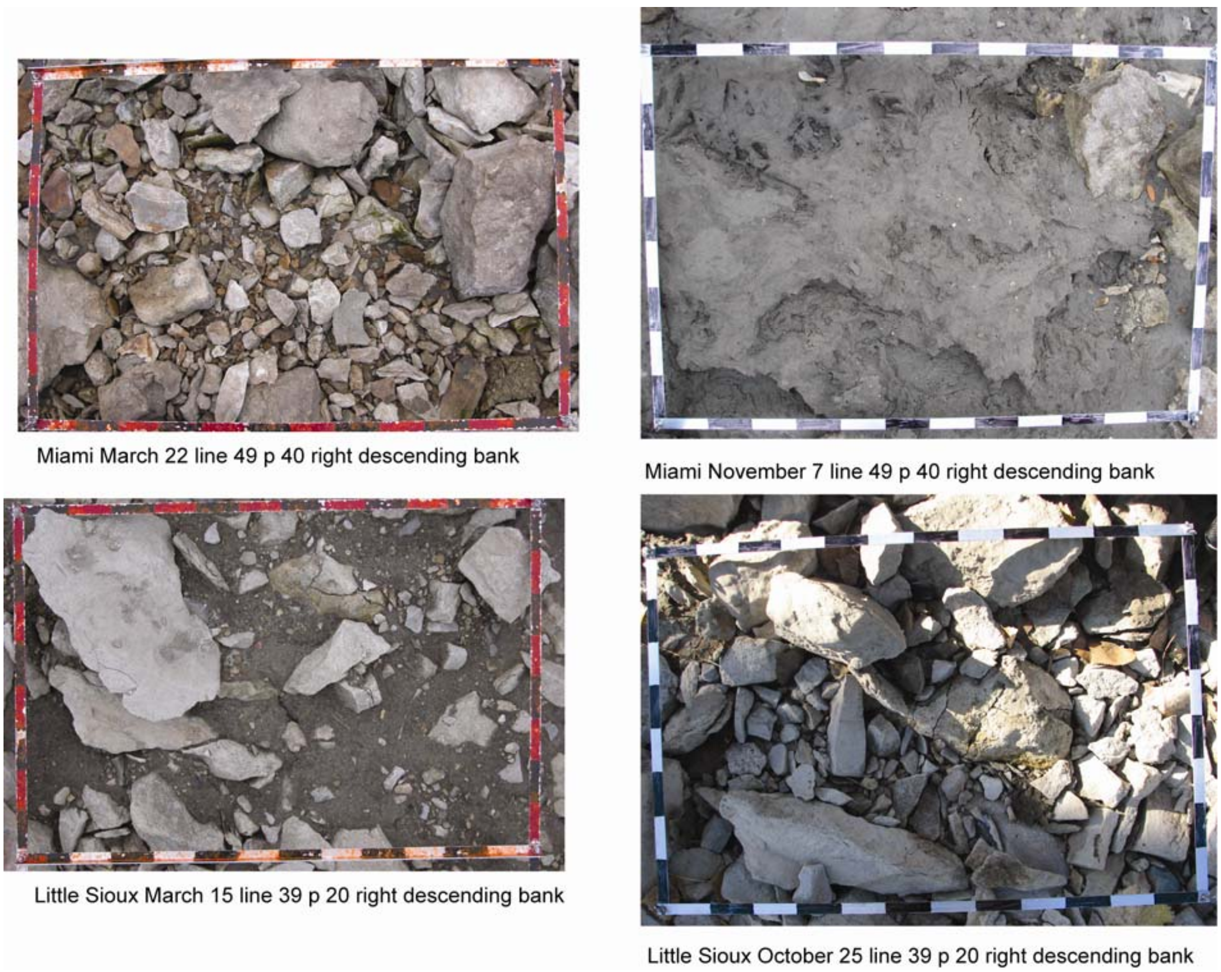


Figure D47. Substrate located within the zone exposed during non-navigation flows in the Miami and Little Sioux reaches. Photographs document the finding that 2006 flows were capable of altering substrate conditions in these reaches.

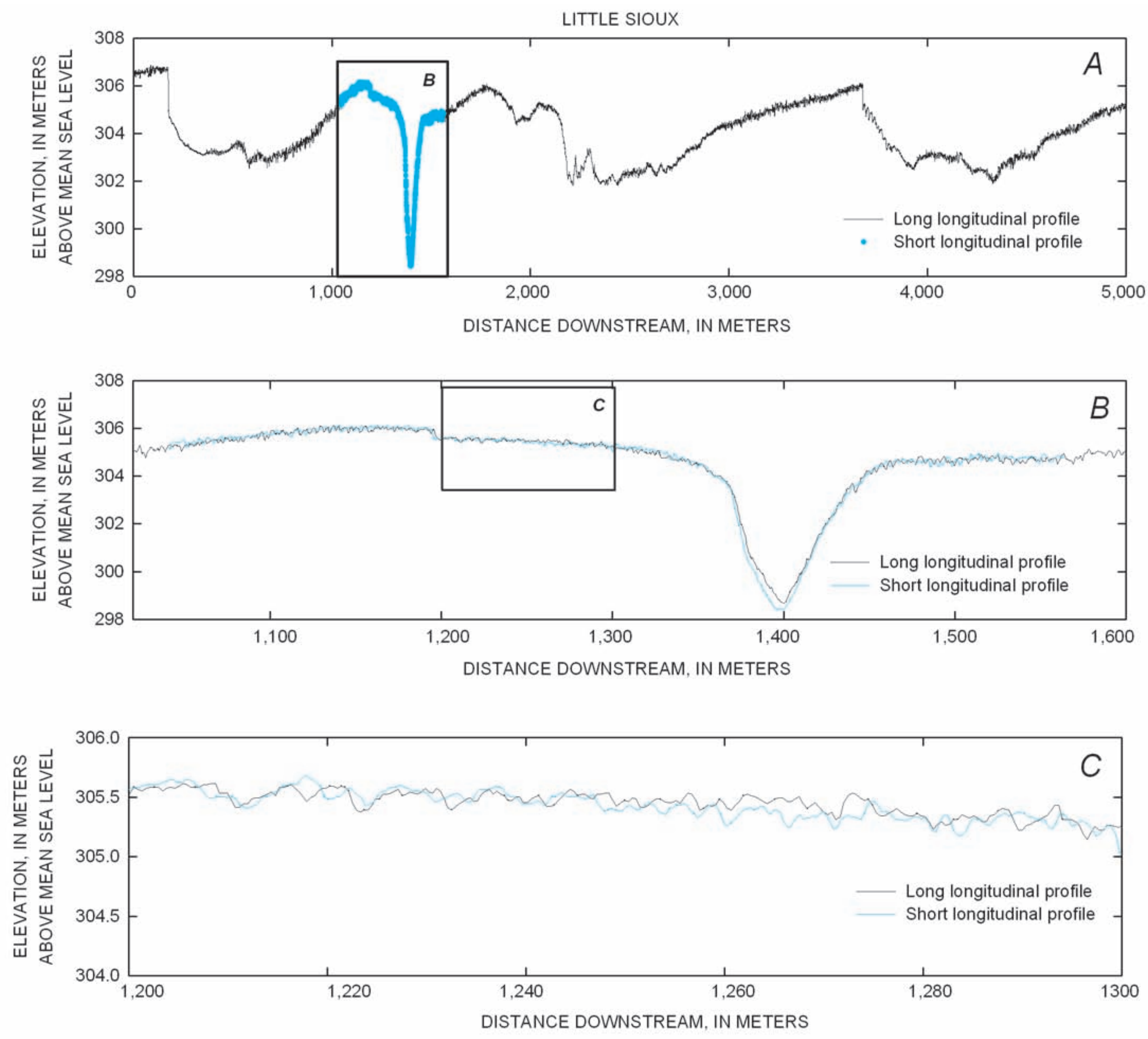


Figure D48. Sample of (*A*) one long and (*B*) one short profile showing bed elevations (*A*, *B*, and *C*) along the thalweg of the Little Sioux reach. In future studies, multiple profiles will be compared to provide a better understanding of bed morphology changes over time. Short profile was surveyed 2.5–3 hours after long profile.

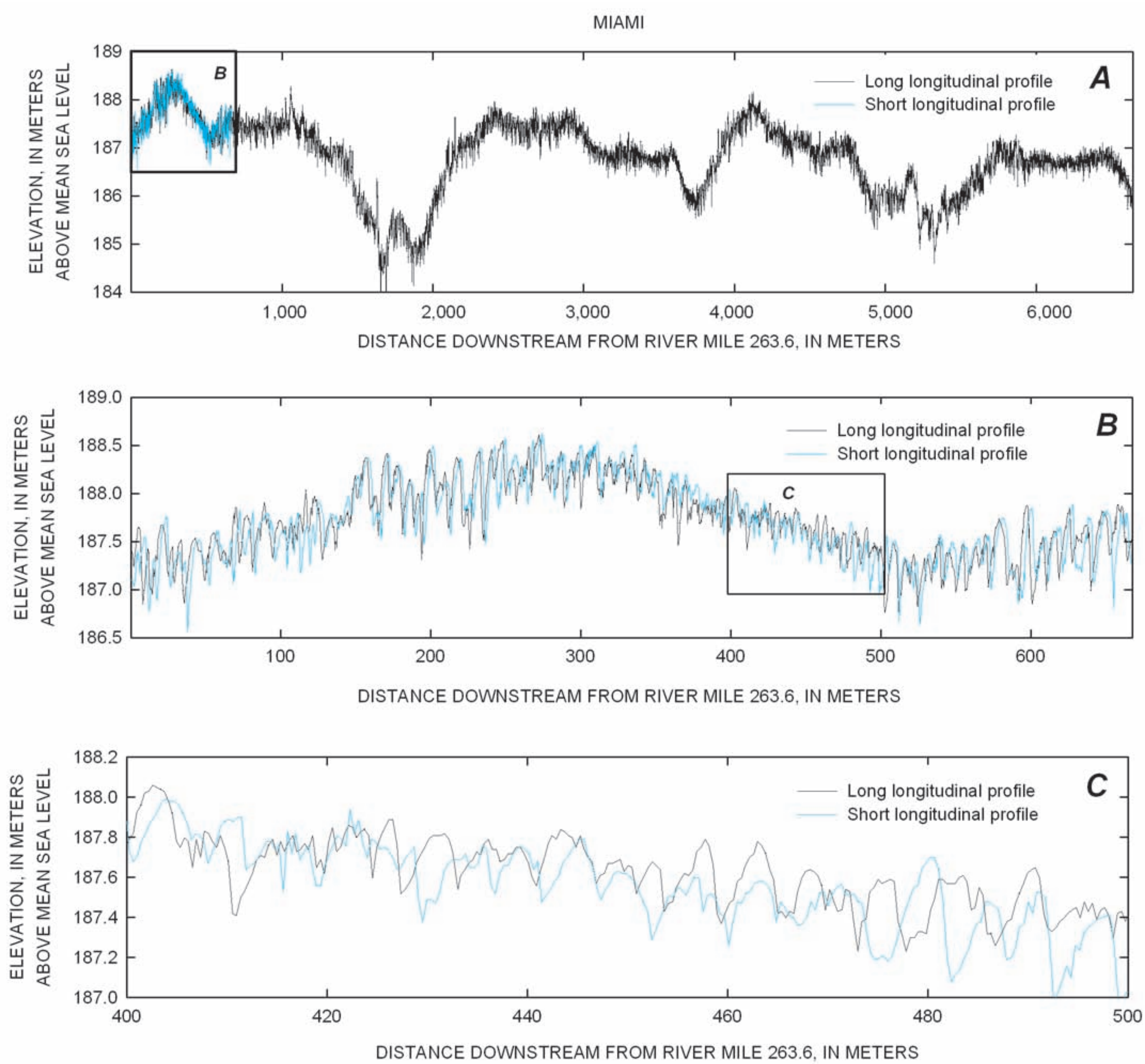


Figure D49. Sample of (*A*) one long and (*B*) one short profile showing bed elevations (*A*, *B*, and *C*) along the thalweg of the Miami reach. In future studues, multiple profiles will be compared to provide a better understanding of bed morphology changes over time. Short profile was surveyed 2.5–3 hours after long profile.

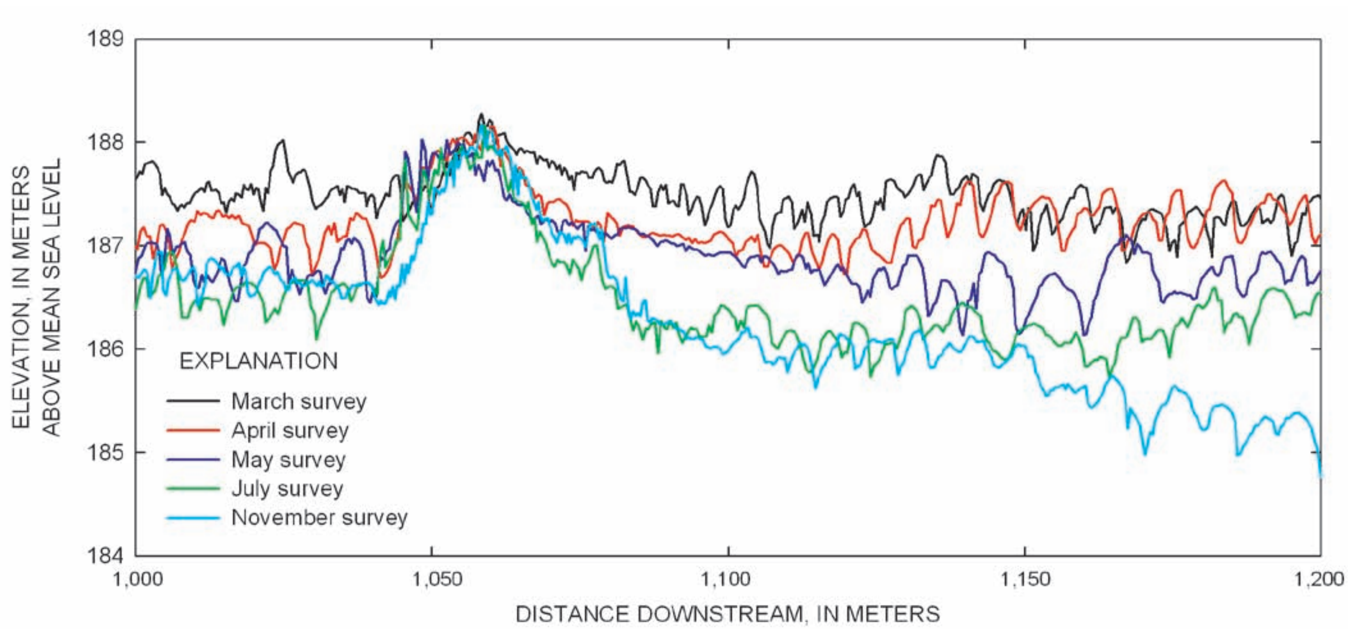


Figure D50. Long profiles surveyed in March, April, May, July, and November 2006 at the Miami reach.

Table D1. List of reaches greater than 1 km in length that were mapped for sturgeon habitat-use assessment in 2005 and 2006.

[km, kilometer; km^2, square kilometers]

For reaches greater than 1 km in length:		2005	2006	Total
Number of reaches				
	All reaches	88	28	116
	Randomized reaches	65	13	78
Number of reaches with				
	Depth	88	28	116
	Velocity	87	28	115
	Substrate	48	26	74
	Side-scan sonar	0	7	7
Number of reaches by segment				
	Gavins	1	4	5
	Ponca	2	2	4
	Big Sioux	42	5	47
	Platte	4	1	5
	Kansas	8	7	15
	Grand	23	7	30
	Osage	8	2	10
Length of river surveyed, in km				
	Overlapping areas counted only once	197.8	73.6	251.71
	Counting overlap each time mapped	231.1	74.4	305.5
Area of river surveyed, in km^2				
	Overlapping areas counted only once	51	19.3	64.81
	Counting overlap each time mapped	59.3	19.5	78.8
Number of sturgeon in mapped reaches (for all discharges)				
	Includes initial capture	407	215	622
	Relocations only	343	208	551

[1]Total values are net length or area mapped in both years. The total is less than the sum of 2005 and 2006 values because of areas that were mapped in both years.

Table D2. Summary of 2005 and 2006 reaches surveyed for sturgeon habitat-use assessment.

[RM, river mile, km^2, square kilometers; m/s, meters per second; ft^3/s, cubic feet per second; x, map completed; GP, Gavins Point Dam; --, not available; SUX, Sioux City; BS, Big Sioux; DE, Decatur; OM, Omaha; NC, Nebraska City; KC, Kansas City; WA, Waverly; GL, Glasgow; CH, Chariton; BO, Booneville; HE, Hermann; GA, Gasconade; STC, St Charles]

Segment	Center of reach RM	Map date	Area, km^2	Length, meters	Depth, meters	Velocity, m/s	Substrate	Side-scan sonar	Provisional discharge ft^3/s	Gages used[1]	Selection type	Acoustic ID of primary target sturgeon
Gavins	807.9	2006-07-11	0.66	2,966	x	x	x		25,500	GP	random	166
	805.6	2006-06-13	0.85	2,505	x	x	x	x	25,000	GP	nonrandom	--
	775.2	2006-05-30	0.54	2,314	x	x	x	x	21,000	GP	nonrandom	459
	774.1	2006-06-08	0.80	2,167	x	x			23,000	GP	nonrandom	461
	759.7	2005-06-15	0.58	1,384	x	x	x		27,500	SUX, BS	random	131
Ponca	751.7	2006-06-22	0.79	2,898	x	x	x		26,800	SUX, BS	nonrandom	460
	746.4	2005-06-10	0.58	2,570	x	x	x		32,400	SUX, BS	random	31400
	746.3	2005-07-11	0.30	1,332	x	x	x		22,800	SUX, BS	nonrandom	31400
	743.7	2006-07-12	0.69	3,005	x	x	x		26,200	SUX, BS	random	484
Big Sioux	732.4	2005-06-16	0.48	2,651	x	x	x		32,900	SUX	random	145
	725	2006-05-23	0.46	2,453	x	x	x		27,300	SUX	random	458
	716.9	2005-08-09	0.35	1,816	x	x	x		26,100	SUX	nonrandom	145
	709.2	2006-06-07	0.55	2,996	x	x	x		27,500	SUX	nonrandom	451
	701.1	2005-08-10	0.49	2,559	x	x			26,400	SUX	nonrandom	133
	697.8	2005-06-03	0.54	2,721	x	x	x		27,600	SUX	random	145
	693.5	2005-06-09	0.49	2,585	x	x	x		42,900	DE	random	29900
	693	2005-06-17	0.54	2,849	x	x	x		34,200	DE	random	29900
	692.7	2005-07-12	0.29	1,526	x	x	x		26,200	DE	nonrandom	126
	686.6	2005-05-18	0.41	2,164	x	x	x		23,900	DE	random	133
	683.9	2005-06-24	0.46	2,327	x	x	x		31,900	DE	random	143
	673.8	2005-05-10	0.58	3,016	x	x	x		26,400	DE	random	133
	672.4	2005-06-02	0.52	2,726	x	x	x		29,300	DE	random	139
	670.4	2005-08-11	0.52	2,759	x	x			28,000	DE	nonrandom	31400
	669.2	2006-06-01	0.59	3,013	x	x	x		26,400	DE	nonrandom	472
	668.9	2005-04-22	0.42	2,190	x	x	x		31,200	OM	nonrandom	--
	665.6	2006-06-06	0.59	3,021	x	x	x		29,500	OM	nonrandom	490
	663	2005-06-08	0.55	2,780	x	x	x		45,200	OM	random	124
	657.4	2005-05-19	0.41	2,077	x		x		31,600	OM	random	82
	654.7	2005-05-07	0.45	2,369	x	x	x		26,800	OM	random	139
	652	2005-05-25	0.45	2,357	x	x	x		29,900	OM	nonrandom	135
	651.8	2005-07-13	0.29	1,532	x	x	x		28,800	OM	nonrandom	135
	650.3	2005-06-23	0.53	2,746	x	x	x		34,300	OM	random	93
	647.6	2005-05-11	0.43	2,085	x	x	x		32,200	OM	random	137
	644.8	2005-06-14	0.58	2,799	x	x	x		36,900	OM	random	142
	641.5	2006-05-18	0.31	1,612	x	x	x		34,600	OM	random	477
	640.5	2005-05-05	0.60	3,120	x	x	x		27,700	OM	random	141
	638.9	2005-06-01	0.55	2,762	x	x	x		33,100	OM	random	86
	638.3	2005-04-20	0.57	3,065	x	x	x		27,900	OM	nonrandom	--
	627.8	2005-07-14	0.29	1,525	x	x	x		28,600	OM	nonrandom	30800
	627.6	2005-05-20	0.49	2,487	x	x	x		35,000	OM	nonrandom	83
	626.1	2005-09-01	0.46	2,349	x	x	x		27,800	OM	nonrandom	30800
	622.8	2005-06-22	0.61	2,862	x	x	x		33,800	OM	random	30900
	620.2	2005-05-12	0.56	2,952	x	x	x		34,000	OM	random	29600
	618.7	2005-06-21	0.54	2,765	x	x	x		34,600	OM	random	83
	616.3	2005-08-31	0.54	2,702	x	x	x		27,800	OM	nonrandom	86
	614.5	2005-04-30	0.50	2,799	x	x	x		25,200	OM	nonrandom	--
	611.6	2005-04-28	0.56	2,867	x	x	x		25,100	OM	nonrandom	--
	627.8	2005-07-14	0.29	1,525	x	x	x		28,600	OM	nonrandom	30800

Table D2. Summary of 2005 and 2006 reaches surveyed for sturgeon habitat-use assessment.—Continued

[RM, river mile, km^2, square kilometers; m/s, meters per second; ft^3/s, cubic feet per second; x, map completed; GP, Gavins Point Dam; --, not available; SUX, Sioux City; BS, Big Sioux; DE, Decatur; OM, Omaha; NC, Nebraska City; KC, Kansas City; WA, Waverly; GL, Glasgow; CH, Chariton; BO, Booneville; HE, Hermann; GA, Gasconade; STC, St Charles]

Segment	Center of reach RM	Map date	Area, km^2	Length, meters	Depth, meters	Velocity, m/s	Substrate	Side-scan sonar	Provisional discharge ft^3/s	Gages used[1]	Selection type	Acoustic ID of primary target sturgeon
	609.9	2005-05-06	0.50	2,537	x	x	x		26,800	OM	random	81
	609.7	2005-06-05	0.50	2,542	x	x	x		33,100	OM	random	122
	608.2	2005-04-29	0.55	3,151	x	x	x		25,100	OM	nonrandom	--
	606.8	2005-05-17	0.27	1,349	x	x	x		36,100	OM	random	30500
	606.4	2005-04-27	0.54	2,844	x	x	x		25,300	OM	nonrandom	--
	604.1	2005-06-04	0.48	2,521	x	x	x		32,900	OM	random	30600
	602.4	2005-05-09	0.57	3,005	x	x	x		28,500	OM	random	123
	601.2	2005-05-22	0.49	2,620	x	x	x		31,100	OM	random	148
Platte	593.7	2005-06-11	0.37	1,896	x	x	x		57,300	NC	random	123
	588.6	2005-05-23	0.49	2,385	x	x	x		39,400	NC	random	146
	583.8	2006-07-13	0.56	2,974	x	x	x		30,200	NC	random	526
	565.4	2005-05-24	0.53	2,488	x	x	x		39,600	NC	random	121
	554.2	2005-06-25	0.51	2,319	x	x	x		46,300	NC	random	30300
Kansas	362.8	2005-05-04	0.72	3,013	x	x			39,200	KC	random	75
	354.4	2005-05-25	0.76	3,004	x	x			52,900	KC	random	29700
	331.9	2006-06-20	0.74	2,709	x	x	x		35,600	KC	nonrandom	527
	330.1	2005-04-29	0.96	3,048	x	x			43,300	KC	random	96
	326.8	2006-05-24	0.86	2,989	x	x	x		38,600	KC	nonrandom	529
	325.2	2005-05-11	0.63	2,141	x	x			37,600	KC	random	74
	315.1	2005-04-27	0.83	3,032	x	x			45,000	KC	random	30100
	311.6	2005-05-05	0.81	3,019	x	x			39,200	WA	random	95
	291.8	2005-05-26	1.00	3,026	x	x			53,000	WA	random	30700
	289.4	2006-07-06	0.86	3,026	x	x	x		36,200	WA	random	443
	281.5	2006-06-13	0.28	1,331	x	x	x	x	36,700	WA	nonrandom	--
	280.4	2006-05-04	0.54	2,002	x	x	x	x	65,100	WA	random	437
	279.7	2006-06-08	0.52	2,171	x	x	x	x	38,200	WA	nonrandom	437
	278.2	2006-06-14	0.56	2,242	x	x	x	x	37,400	WA	nonrandom	--
Kansas	275.8	2005-06-10	0.40	1,514	x	x			84,400	WA	random	105
Grand	247.6	2006-06-02	0.76	2,567	x	x	x		45,700	GL, CH	random	447
	247.5	2005-05-12	1.01	2,921	x	x			44,400	GL, CH	random	107
	230.6	2005-05-06	0.81	3,017	x	x			42,700	GL	random	29500
	219.2	2005-04-15	0.93	3,049	x	x			69,500	GL	random	176
	218.9	2006-05-19	0.78	3,021	x	x			39,700	GL	random	420
	217.6	2005-06-27	0.94	3,025	x	x			68,900	GL	random	31300
	208.7	2005-07-05	0.86	2,697	x	x			59,300	GL	random	102
	206.1	2006-06-07	0.73	3,004	x	x	x	x	38,000	GL	nonrandom	411
	203.3	2005-04-28	0.88	3,043	x	x			53,300	GL	random	30000
	202.3	2006-06-06	0.80	2,886	x	x	x		40,100	BO	nonrandom	440
	201.3	2005-04-07	0.93	3,236	x	x	x		38,700	BO	random	71
	197.4	2005-05-18	1.09	3,067	x	x			106,000	BO	random	30400
	197	2005-07-13	0.47	1,538	x	x			43,000	BO	nonrandom	31200
	196.1	2006-07-07	0.94	3,002	x	x	x		38,000	BO	random	411
	186.8	2005-05-27	0.91	3,032	x	x			59,500	BO	random	114
	178	2005-04-12	0.76	2,772	x	x			48,500	BO	random	118
	177.4	2006-05-10	0.83	2,851	x	x	x		54,000	BO	nonrandom	522
	173.5	2005-06-01	0.99	2,948	x	x			53,600	BO	random	109
	173.3	2005-04-22	0.94	2,946	x	x			53,800	BO	random	118
	168	2005-07-01	1.13	3,036	x	x			65,400	BO	random	176

Table D2. Summary of 2005 and 2006 reaches surveyed for sturgeon habitat-use assessment.—Continued

[RM, river mile, km^2, square kilometers; m/s, meters per second; ft^3/s, cubic feet per second; x, map completed; GP, Gavins Point Dam; --, not available; SUX, Sioux City; BS, Big Sioux; DE, Decatur; OM, Omaha; NC, Nebraska City; KC, Kansas City; WA, Waverly; GL, Glasgow; CH, Chariton; BO, Booneville; HE, Hermann; GA, Gasconade; STC, St Charles]

Segment	Center of reach RM	Map date	Area, km^2	Length, meters	Depth, meters	Velocity, m/s	Substrate	Side-scan sonar	Provisional discharge ft^3/s	Gages used[1]	Selection type	Acoustic ID of primary target sturgeon
Osage	166.9	2005-05-19	0.97	2,422	x	x			90,900	BO	random	92
	165.5	2006-06-21	0.82	2,983	x	x	x		37,600	BO	random	410
	160.6	2005-05-10	0.86	3,033	x	x			40,500	BO	random	92
	146.5	2005-06-03	0.98	2,849	x	x			59,600	BO	random	109
	146.5	2005-08-10	0.90	2,929	x	x			35,000	BO	nonrandom	109
	142.7	2005-05-23	0.98	2,814	x	x			71,000	BO	random	113
	142.1	2005-08-09	0.69	2,394	x	x			35,100	BO	nonrandom	113
	140.9	2005-06-02	0.89	2,750	x	x			54,000	BO	random	178
	136.3	2005-04-14	0.96	2,795	x	x	x		73,900	BO	random	102
	130.7	2005-04-19	0.86	2,495	x	x			50,000	BO	random	164
	128.5	2005-05-31	0.96	2,780	x	x			53,600	HE,GA	random	164
	127.6	2006-05-09	1.06	2,705	x	x	x		69,700	HE,GA	random	412
	127.2	2005-04-26	0.98	2,377	x	x			86,500	HE,GA	random	170
	120.6	2005-04-05	0.34	1,084	x	x			43,500	HE,GA	nonrandom	--
	119.6	2006-06-30	1.00	3,006	x	x	x		41,700	HE,GA	random	522
	118.4	2005-05-03	1.07	3,041	x	x			52,700	HE,GA	random	23
	118.2	2005-07-06	1.09	2,833	x	x			66,800	HE,GA	random	23
	109.3	2005-08-31	1.23	2,992	x	x			90,600	HE,GA	nonrandom	164
	75.9	2005-07-07	0.97	2,796	x	x			70,600	HE	random	179
	27.3	2005-07-08	1.15	3,011	x	x			71,800	STC	random	30000

[1]Gavins Point Dam discharge is from the U.S. Army Corps of Engineers; all other streamflow discharges are from the U.S. Geological Survey.

Table D3. Habitat classification hierarchy used in this study.

[X, maps exist at appropriate level of hierarchy]

Habitat hierarchy	Variable	Sturgeon found in reaches within narrow range of discharge (10%) on mapped date and in appropriate time period	Sturgeon found in reaches that were mapped within wider range of discharge and in appropriate time period	All sturgeon relocations
Microhabitat	Depth	X		
	Velocity	X		
	Substrate	X		
	Velocity gradient	X	X	
Mesohabitat	Proximity to mapped control structures	X	X	X
	Classified topographic location: depression, crest, flat, slope	X	X	
Macrohabitat	Inner bend, outer bend, crossover	X	X	X
Hydrologic/physiographic	River segment	X	X	X

Table D4. Habitat-availability sites with survey date and discharge indicated.

[ft^3/s, cubic feet second; NEWSC, U.S. Geological Survey Nebraska Water Science Center; IAWSC, U.S. Geological Survey Iowa Water Science Center; CERC, U.S. Geological Survey Columbia Environmental Research Center; RV, research vessel]

Site	Survey date	Survey crew/ vessel	Discharge (average ft^3/s)
Yankton	3/7/2006	NEWSC	9,000
	3/28/2006	NEWSC, IAWSC	18,800
	5/15/2006	NEWSC, IAWSC	23,500
	6/26/2006	NEWSC, IAWSC	25,000
Kensler's Bend	3/9/2006	NEWSC	12,300
	3/30/2006	IAWSC	23,800
	5/16/2006	NEWSC, IAWSC	29,300
	6/20/2006	NEWSC, IAWSC	28,500
Little Sioux	3/14/2006	CERC, RV Slim Funk	12,600
	4/17/2006	CERC, RV Slim Funk	27,000
	5/16/2006	CERC, RV Slim Funk	40,200
	7/18/2006	CERC, RV Slim Funk	26,400
	10/24/2006	CERC, RV Slim Funk	11,600
Miami	3/23/2006	CERC, RV Lucien Brush	24,500
	4/19/2006	CERC, RV Lucien Brush	47,200
	5/22/2006	CERC, RV Lucien Brush	43,000
	7/25/2006	CERC, RV Lucien Brush	35,000
	11/6/2006	CERC, RV Lucien Brush	21,000

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Director
U.S. Geological Survey
Columbia Environmental Research Center
4200 New Haven Road
Columbia, MO 65201
(573) 875–5399
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Site-Specific Assessment of Spawning Behavior and Habitat Use

By Darin G. Simpkins[1] and Steven R. LaBay[2]

Chapter E of

Factors Affecting the Reproduction, Recruitment, Habitat, and Population Dynamics of Pallid Sturgeon and Shovelnose Sturgeon in the Missouri River

Edited by Carl E. Korschgen

[1] U.S. Geological Survey, Columbia Environmental Research Center.
[2] South Dakota Game, Fish, and Parks, Yankton Field Office.

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Site-Specific Assessment of Spawning Behavior and Habitat Use

By Darin G. Simpkins[1] and Steven R. LaBay[2]

Abstract

The Missouri River biological opinion developed by the U.S. Fish and Wildlife Service (U.S. Fish and Wildlife Service, 2000, 2003) formally identified that river engineering and flow management practices on the Missouri River have impacted reproductive success, growth, and recruitment of pallid sturgeon (*Scaphirhynchus albus*) in the Missouri River below Gavins Point Dam. In response, the U.S. Army Corps of Engineers (USACE) partnered with state and federal agencies to identify causes for poor reproduction and recruitment by funding research and monitoring projects that addressed questions about environmental conditions required by pallid sturgeon and shovelnose sturgeon (*S. platorynchus*) to complete their life cycles and flow management practices that enhance environmental conditions for spawning and recruitment of sturgeon in the Missouri River. This chapter describes results from activities supported by USACE in 2006 to (1) determine if and when gravid pallid sturgeon or shovelnose sturgeon were found near coarse substrate habitats, (2) assess if sturgeon aggregate in the vicinity of coarse substrate habitats during modified hydrologic events, (3) evaluate if coarse substrate habitats are used for spawning by sturgeon, and (4) assess the spatial and temporal distribution of drifting larval sturgeon and other larval fishes in relationship to coarse substrate habitats and tributaries below Gavins Point Dam. This research was conducted in the Missouri National Recreational River reach of the Missouri River below Gavins Point Dam and jointly implemented by the U.S. Geological Survey Columbia Environmental Research Center and South Dakota Game, Fish, and Parks.

Flows released from Gavins Point Dam were not exactly as prescribed in the 2006 USACE annual operating plan (U.S. Army Corps of Engineers, 2006), but flow periods were prescribed based on patterns in flow releases and water temperature. Winter period was characterized by relatively stable flows of 9,000–10,000 ft^3/s when water temperatures were less than 5.5 degrees Celsius (°C). The March pulse period began March 17, 2006, when flows increased to 21,000 ft^3/s and continued until the interpulse period began on April 1when flows decreased to 15,400 ft^3/s. The May pulse period began on May 13 when flow increased to 25,000 ft^3/s and was characterized by fluctuations in mean daily flow as high as 6,500 ft^3/s. Daily mean water temperatures were 14–23°C during the May pulse period. The summer period began on June 15 after mean flows stabilized at 25,000 ft^3/s over 3 consecutive days.

Sturgeon were captured by using drifting trammel nets at targeted and randomly selected sites from March through August to identify if and when pallid sturgeon and shovelnose sturgeon occur and aggregate near coarse substrate deposits. Gravid shovelnose sturgeon were assessed for reproductive condition to determine readiness to spawn. Pallid sturgeon and shovelnose sturgeon were collected near coarse substrate deposits. Capture rates of shovelnose sturgeon indicated the possibility of a winter aggregation near one coarse substrate deposit upstream from the Highway 81 bridge in Yankton, S. Dak., but interactions between fish behavior and high and variable flows affected capture efficiencies and our ability to identify aggregations during other periods. Nevertheless, capture rates of gravid shovelnose sturgeon were high during the May pulse and summer period upstream from the Highway 81 bridge despite any effect of flow. Assessments of reproductive condition suggested that most of these fish were ready to spawn if appropriate stimuli were available for fish to release eggs (chap. C).

Egg mats were used to determine if coarse substrate deposits were used for spawning by sturgeon. Sturgeon eggs were not collected despite the deployment of 132 mats over coarse substrate deposits from May through mid-July. However, opaque eggs were collected on mats on four separate occasions. Eggs from one occasion were successfully hatched in the hatchery and tentatively identified as Catostomidae. Collections of adhesive eggs on mats demonstrate the usefulness of the technique to determine spawning sites and characterize spawning habitats for lithophillic fishes in the Missouri River. Future attempts to use egg mats should be closely coupled with telemetry activities (chap. B).

Larval fishes were sampled two times per week from early May to early August at seven sites from Gavins Point Dam to Ponca State Park in Nebraska. As of December 5, 2006, 65 percent of the samples had been processed. A total of 10,392 larvae representing 10 families were sampled across

[1] U.S. Geological Survey, Columbia Environmental Research Center.

[2] South Dakota Game, Fish, and Parks, Yankton Field Office.

sites. Freshwater drum (Sciaenidae *Aplodinotus grunniens*) was the most dominant taxon and composed 85.6 percent of the larvae sampled. Other relatively abundant taxa included gizzard shad (*Dorosoma cepedianum)* 6.5 percent), suckers (Catostomidae) 3.9 percent, temperate basses (Moronidae) 1.8 percent, and minnows and carps (Cyprinidae) 0.8 percent). Larval sturgeon (Acipenseridae *Scaphirhynchus* spp.) and paddlefish (Polyodontidae *Polyodon spathula*) composed 0.3 percent and 0.2 percent of the larval fishes sampled, respectively. Small larval sturgeon (7–10 mm in total length) were collected upstream from the James River in August but were collected upstream and downstream of the Vermillion River and downstream from the boat ramp at Ponca State Park in late May and June. On the basis of the sizes of larval sturgeon collected, water temperatures, incubation times, movement data and recaptures of gravid shovelnose sturgeon used in telemetry studies (chap. B), and reproductive assessments of gravid female sturgeon captured in the Missouri National Recreational River reach (this chapter), we estimate that many shovelnose sturgeon spawned between May 28 and June 22 at water temperatures of 19–23°C. The collection of small sturgeon larvae in August upstream from the James River however, supports suggestions that shovelnose sturgeon in the Missouri River have a protracted spawning period: spawning occurred during the May pulse and summer flow periods.

Introduction

The U.S. Fish and Wildlife Service (USFWS) listed pallid sturgeon (*Scaphirhynchus albus*) as endangered in 1990 and identified in a biological opinion to the U.S. Army Corps of Engineers (USACE) that river engineering and flow management practices on the Missouri River have impacted reproductive success, growth, and recruitment of pallid sturgeon and other large river fishes (U.S. Fish and Wildlife Service 2000, 2003). Following the guidance provided by the USFWS that was outlined in the opinion as reasonable and prudent alternatives, the USACE partnered with State and Federal agencies to identify causes for poor reproduction and recruitment by funding research and monitoring projects that addressed questions about environmental conditions required by pallid sturgeon to complete their life cycle. Funded efforts included (1) scopes of work from the U.S. Geological Survey (USGS) to determine the ecological requirements for successful pallid sturgeon and shovelnose sturgeon (*S. platorynchus*) reproduction and recruitment in the Missouri River, referred to as the Comprehensive Sturgeon Research Project (CSRP), and (2) a cooperative, multiagency proposal for long-term evaluation of Sturgeon Response to Flow Modifications (SRFM) on the Lower Missouri River (Fleming and others, 2006). In 2006, these projects were conceived, developed, and proposed to be integrated. The CSRP concentrated on the biology of pallid sturgeon and shovelnose sturgeon, overall unknowns about sturgeon life histories, and methods development and evaluation for research and monitoring programs on sturgeon and other fishes throughout the Missouri River. The SRFM project focused on how a specific management action (flow manipulation) affected spawning habitat, behavior, and success of sturgeon in the Lower Missouri River. Thus, SRFM was inherently a subcomponent of the broad purpose and goals outlined within CSRP.

The SRFM study design was based on hypotheses that related specific life-history events of sturgeon to a hydrograph that exhibited two discrete pulses during the spring that coincided with historical patterns of snowmelt and precipitation across the Rocky Mountains and Great Plains (fig. E1). The USACE annual operating plan (AOP) in 2006 indicated that winter flow from Gavins Point Dam would increase from 9,000 ft^3/s to 26,000 ft^3/s over a period of 5 days for the first pulse in mid- March (U.S. Army Corps of Engineers, 2006). After two days, flow would be gradually reduced over 5 days and maintained at 21,000 ft^3/s during the interpulse period. When water temperatures reached 16°C, flow would again increase over 2 days and be maintained at 34,000 ft^3/s for an additional 2 days. Subsequently, flow would be cut by 30 percent over the next 2 days and then decline at a constant rate to navigation service over the next 8 days. Analyses of physical changes (redistribution of sediments and habitat creation) and biological responses (timing of migration, aggregation, spawning, hatching, and dispersal) in relationships to patterns in flow were dependent on the occurrence of discrete flow events outlined in the AOP and SRFM proposal.

The purpose of this chapter is to provide a report of activities from tasks funded in 2006 by USACE that were described as “site-specific assessments” of spawning behavior and habitat use of sturgeon under both CSRP (task 4) and SRFM (task 1bii). The research approach outlined under these two tasks was complementary to ongoing telemetry activities funded by USACE under CSRP and SRFM to describe spawning movements and habitat use of pallid sturgeon and shovelnose sturgeon in the Missouri River (chap. B), but our approach used a multimetric design to document spawning behavior, occurrence, and habitat use of sturgeon (and opportunistically other fish species) under various environmental conditions (flow and temperature) in the Missouri River below Gavins Point Dam. Our approach was patterned from research and monitoring activities in the Missouri River below Fort Peck Dam (referred to as the Fort Peck Flow Modification Biological Data Collection Plan or simply the Fort Peck Data Collection Plan) that was jointly implemented by Montana Fish Wildlife and Parks and U.S. Geological Survey and funded by USACE (Braaten and Fuller, 2002; 2005). Efforts described in this chapter were funded by the USACE and jointly implemented by the USGS Columbia Environmental Research Center (CERC) and South Dakota Game, Fish, and Parks.

Our efforts were based on an a priori hypothesis that was developed from other sturgeon species in other river systems. Spawning habitat for pallid sturgeon and shovelnose sturgeon has not been described but is thought to have similar physical characteristics used by various sturgeon species for spawning (Quist and others, 2004). Sturgeon generally spawn over coarse gravel, cobble, or boulder substrates where water velocities are swift (Parsley and Beckham, 1994; Auer, 1996; Marchant and Shutters, 1996; Kynard, 1997; Fox and others, 2000; Bruch and Binkowski, 2002). Such spawning habitats have been characterized below or in close proximity to impoundments or other structures that modify hydrologic characteristics (bridges) or serve as migration barriers (Auer, 1996; Bruch and Binkowski, 2002; Peterson and others, 2002; Cooke and Leach, 2004; Duncan and others, 2004). In 2005, USGS personnel conducted visual and side-scan sonar surveys in the Lower Missouri River and identified several large and relatively discrete patches of coarse substrates below Gavins Point Dam (figs. E2 and E3). Consequently, our hypothesis was that sturgeon in the Missouri River would aggregate and spawn in habitats with coarse substrates near Gavins Point Dam. Our objectives were to (1) determine if and when gravid pallid sturgeon or shovelnose sturgeon were found near coarse substrate habitats (CSRP), (2) assess if sturgeon aggregate in the vicinity of coarse substrate habitats during modified hydrologic events (SRFM), (3) evaluate if coarse substrate habitats are used for spawning by sturgeon (CSRP), and (4) assess the spatial and temporal distribution of drifting larval sturgeon and other larval fishes in relationship to coarse substrate habitats and tributaries (CSRP) below Gavins Point Dam.

Study Area

The Missouri River study area in 2006 was in the Missouri National Recreational River reach that extends from Ponca State Park in Nebraska near river mile (RM) 753 to Gavins Point Dam at RM 811 (fig. E2). The river through this reach is relatively shallow and has shifting sandbars as well as islands and snags (Berry and Young, 2004). River width averages approximately 600 m and varies from 200 m to 1.6 km; depth can be as much as 6 m in pools, but much of the river is shallow (less than 1 m) deep. Annual discharge after the dam was closed averaged 29,556 ft^3/s at Sioux City, Iowa. A variety of aquatic macrohabitats occur, including main channel and border, secondary channels, backwaters, pools downstream from sandbars, and tributary confluences. The flood plain is relatively level, except for a few areas having steep, tree-covered bluffs. Riverbanks vary from flat, sandy beaches to areas with 5-m vertical faces where active erosion occurs. Tributaries of the Missouri River within the reach include the James River (mean annual discharge = 759 ft^3/s) and the Vermillion River (mean annual discharge = 374 ft^3/s).

Operation of Gavins Point Dam has caused changes in the aquatic habitat (Schmulbach and others, 1981; Galat and Lipkin, 2000). Turbidity and temperature have decreased: the timing, duration, and extent of spring flows have diminished: channel incision has increased: channel macrohabitats have been dewatered: and substrate size on the river bottom has increased from scouring (Holly and Karin, 1986). Habitat change and fish stocking caused shifts in the kinds and numbers of plankton, macroinvertebrates, and fishes after the dam was closed (Morris and others 1968; Walburg and others, 1971; Hesse and Sheets, 1993; Committee on Missouri River Ecosystem Science, 2002). Nevertheless, the Missouri National Recreational River reach below Gavins Point Dam contains a species-rich fish fauna that includes pallid sturgeon and shovelnose sturgeon (Berry and Young, 2004).

Methods

Hydrologic Conditions and Temperature

Flow data were obtained from USACE operation reports for Gavins Point Dam (*http://www.nwd-mr.usace.army.mil/rcc/,* accessed March–September 2006). The actual 2006 hydrograph was compared to the anticipated hydrograph described in the 2006 USACE AOP for Gavins Point Dam to determine if specific flow periods inferred from the AOP in the SRFM proposal could be characterized on the basis of patterns in flow and water temperature. Water temperature data was obtained from a USGS stream gage station (stream gage 06467500) at Yankton, S. Dak. (*http://waterdata.usgs.gov/sd/nwis/*, accessed March–September 2006, chap. F).

Presence and Aggregation of Sturgeon near Coarse Substrate Habitats (Objectives 1 & 2)

From early March through late August, 2006 trammel nets were used to sample sturgeon near three coarse substrate habitat patches previously identified as potential spawning locations in 2005 surveys below Gavins Point Dam (figs. E2 and E3). Trammel nets were 125 ft (38.1 m) long multifilament nets with an 8-ft (2.4-m) inner wall of 2.5-in (6.4 cm) bar mesh and a 6-ft (1.8-m) outer wall of 12-in (30.5-cm) bar mesh. Nets were actively fished by drifting them perpendicular to the current for a target distance of 984 ft (300 m), the target distance, but frequently was less because of the net becoming tangled in large substrates and woody debris. Sample sites included a patch immediately downstream from the dam (bend 1), near the highway 81 bridge (bend 3), and 5 mil (8 km) downstream from Gavins Point Dam (bend 4; fig. E2; table E1). Fish were also sampled from two randomly selected bends from each of two river segments every week. The upper segment was between RM 802 and RM 811 (bends 1–6) and the lower river segment was between RM 790 and RM 801 (bends 7–12; table E1). Bends were numbered on the basis of aerial photographs taken in 2005.

Sampling followed protocols outlined in Drobish (2004). Trammel nets were drifted two times per week near each coarse substrate patch with at least a 3-day interval between samples. Samples consisted of four net drifts per site for each visit. Attempts were made to drift at least one net in each of three macrohabitats within the bend, including inside and outside bends and channel crossovers as described in Drobish (2004) and Sappington and others (1998; fig. E4), with the purpose of identifying where sturgeon could be effectively sampled with drifting trammel nets within the bend and of maximizing capture rates. Consequently, the fourth net was deployed in the habitat where sturgeon had been previously collected to maximize sturgeon captures within the bend. Sturgeon were weighed, measured, and individually marked by using alphanumeric T-bar anchor tags.

Sturgeon exhibiting any one of the following characteristics were evaluated for the presence of black eggs: relative weight body condition index (W_r) greater than 86 (Quist and others, 1998), dark belly markings, and/or protruded bellies. Analyses (analysis of variance and Tukeys multiple comparisons tests; Zar 1996) on existing USGS data of 343 shovelnose sturgeon sampled from May 2001 to June 2002 (data from Wildhaber and others, 2005) revealed that mean W_r of gravid shovelnose sturgeon (stage 5; table E2) significantly differed ($P < 0.05$; JMP 4.0.4, SAS Institute Inc., 2001) from males and younger stages of females (stages less than 5; table E2). Although the ranges of W_r values overlapped among reproductive stages and sexes, 56 percent of stage 5 female shovelnose sturgeon collected in 2001–2002 had W_r values greater than 86. Thus, W_r was used with other characteristics (dark belly markings and protruded bellies) of fish collected in 2006 to minimize the necessity for surgical evaluation of reproductive state and provided cost-effective, conservative estimates of gravid shovelnose sturgeon capture rates.

Egg and blood samples were collected from gravid shovelnose sturgeon in the field following CERC standard operating procedures (SOP P.624; SOP P.626: chap. C), and reproductive readiness was assessed in the laboratory by using blood chemistry, egg polarization index measurement, and physiology (germinal vesicle breakdown during progesterone assays) as described under separate tasks of CSRP (task 2) and SRFM (task 1ci) (chap. C). Assessments of reproductive condition of males were not conducted.

Capture data were sent to the Missouri Department of Conservation for electronic entry to the USACE Missouri River monitoring database (Drobish, 2004). The total number of gravid shovelnose sturgeon and female shovelnose sturgeon captured was compared between targeted bends with coarse substrate and randomly selected bends by using chi-square analysis (Zar, 1996). Catch-per-unit effort (CPUE) was calculated as the number of sturgeon collected per 100 m that the net drifted. Total shovelnose sturgeon and gravid shovelnose sturgeon CPUE were compared to CPUE estimates derived from randomly selected sites over time in association with changes in flow and water temperature.

Use of Coarse Substrate Habitats for Spawning (Objective 3)

We designed devices to collect eggs deposited over coarse substrates where sturgeon were suspected to spawn in the Missouri River below Gavins Point Dam (fig. E2, E3, and E4). Egg mats were designed according to Marchant and Shutters (1996) with general modifications described in Duncan and others (2004). Mats consisted of a commercial spawning mat material (Spawntex, Blocksom & Co., Michigan City, Ind.) that was placed within a folded piece of wire mesh. Straight reinforcement bar was attached to the structures to provide added stability and weight. Egg mats measured 24 square inches (61 cm^2) and weighed 15–17 lb (7–8 kg). One or two 5- lb (2 kg) concrete weights were attached as anchors when needed to secure egg mat placement. Buoys were attached to each mat with rope that was used for egg mat retrieval.

Egg mats were placed in a grid pattern over coarse substrate patches identified in 2005 below Gavins Point Dam that were suspected spawning sites based on studies of other sturgeon species in other river systems and on behavioral data from telemetry activities described in CSRP (task 1) and SRFM (tasks 1ai and 1bi) (chap. B). Sample sites included patches where gravid shovelnose sturgeon were sampled for objectives 1 and 2 (figs. E2 and E3; table E1): (1) patch immediately downstream from the dam (bend 1), (2) a patch near the Highway 81 bridge (bend 3), and (3) a patch 5 mi (8 km) downstream from Gavins Point Dam (bend 4). The size of the grid depended on the size of the substrate deposit, but egg mats were spaced approximately 26 ft (8 m) apart throughout each submerged deposit where water velocities were relatively swift in comparison to the surrounding area and depths were greater than 3 ft (1 m) at the time of deployment.

Mats were deployed in early May 2006 and checked for the presence of eggs every 48–72 hours through mid-July. Eggs that were collected on mats were counted. The spatial arrangement and concentration of eggs on mats were recorded. Egg samples were collected and preserved in 70 percent ethanol and 10 percent buffered formalin for later identification made by using genetics or egg morphology. Another sample of eggs was delivered to the USFWS Gavins Point National Fish Hatchery in Yankton, S. Dak., in attempt to hatch eggs and identify specimens based on larval fish morphology.

Habitat characteristics were assessed at sites where eggs were collected. Depth was determined by using sonar (Garmin GPSMAP® model 178–I). Mean column and bottom water velocity was measured by using a Flow Mate 2000 (Hach/Marsh-McBirney, Inc., Frederick, Maryland) that was attached to a 75-lb (34-kg) Columbus-style sounding weight and deployed by using a davit. Mean column velocity was estimated by averaging current velocity measured at 0.2 and 0.8 times depth where depths were greater than 4 ft (1.2 m) and at 0.6 times depth otherwise. Turbidity was measured with a model 2100P turbidimeter (Hach Company, Loveland, Colo.). Water temperature data were obtained from a USGS gaging station (gage 06467500) at Yankton, S. Dak.

Spatial and Temporal Distribution of Larval Sturgeon and Other Larval Fishes (Objective 4)

Larval sturgeon and other larval fishes were sampled two times per week from early May through August 2006 at seven sites (fig. E2; table E3). Two of the sites were located downstream from coarse substrate patches where sturgeon were suspected to spawn in the Missouri River below Gavins Point Dam. One site was downstream from Gavins Point Dam (bend 2) and another site was downstream from Riverside Park in Yankton, S. Dak. (bend 4), approximately 5-miles (8 km) downstream from Gavins Point Dam. Other sites that were sampled in the Missouri River were above and below confluences with the James River and the Vermillion River. Another site was downstream from the boat ramp at Ponca State Park. Larval fish at all sites were sampled with a 0.5-m-diameter icthyoplankton net (750-µm mesh) attached to a 75-lb (34-kg) Columbus-style sounding weight and fitted with a model 2030R velocity meter (General Oceanics Inc, Miami, Fla.) (fig. E6).

Larval fish sampling followed general protocols used in the Missouri River below Fort Peck Dam as described by Braaten and Fuller (2002); however, swift current velocities limited our ability to deploy two nets simultaneously at one location. Consequently, a single net was attached to a 75-lb (34-kg) Columbus-style sounding weight that was deployed by using a davit. The boat was anchored during net deployment ("passive" sampling). Duplicate samples were collected at both midwater (M) and bottom (B) areas of the water column at both inside bend (ISB) and outside bend (OSB) locations of the river channel (macrohabitats) for each site (two samples x two depths x two macrohabitats = eight samples per visit at each site; table E3). Net position in the water column was monitored by using a Lowrance® X-15 sonar unit (Lowrance®, Tulsa, Okla. Sampling duration for nets was approximately 10 minutes but was dependent on accumulation of drifting debris. One sample collected from each area in the water column and location in the river channel was preserved in 10 percent buffered formalin containing phloxine-B dye, whereas the corresponding duplicate sample was preserved in 70 percent ethanol. Samples were stored in Whirl-paks® (M-Tech Diagnostics ltd., Chesire, England) until field sampling activities were completed.

Larval fish were extracted from samples and placed in vials containing either 10 percent buffered formalin or 70 percent ethanol, depending on initial preservation method. Larvae were identified by using Auer (1982) to at least family, but sometimes to genus and species, on the basis of morphological characteristics and were counted (fig. E7). Damaged individuals that could not be identified were classified as unknown. Identifications of sturgeon and paddlefish (*Polyodon spathula*) larvae were verified by Darrel Snyder at Colorado State University (Snyder, 1980, 2002).

Results and Discussion

Hydrologic Conditions and Temperature

The AOP described a hydrograph that exhibited two distinct flow pulses that were planned to be released in 2006 from Gavins Point Dam when water temperature criteria were met (16°C for May pulse) if sufficient water was available for release from Lewis and Clark Lake (U.S. Army Corps of Engineers, 2006). The SRFM proposal presented hypotheses about life-history events of pallid sturgeon and shovelnose sturgeon that may be related to specific flow periods that were inferred from the hydrograph in the AOP (fig. E1). Actual flows released from Gavins Point Dam in 2006 did not occur exactly as described in the 2006 AOP. The March pulse was cancelled because of insufficient water storage in Lewis and Clark Lake, because flows were generally lower than described in the AOP, and because the May pulse was substantially smaller in magnitude and did not exhibit the 30 percent decrease in flow after peaking as described in the AOP (fig. E8). Nevertheless, flow periods inferred from the AOP in the SRFM proposal were modified for the actual 2006 hydrograph to assess relationships between flow and capture rates of sturgeon. For this analysis, the winter flow period was characterized by daily mean flows of 9,000–10,000 ft^3/s that occurred when water temperatures were less than 5.5°C (fig. E8). The March pulse period began on March 17 when flow was increasing to 21,000 ft^3/s and the period continued until the interpulse period began on April 1 when flow decreased to 15,400 ft^3/s. Flows during the interpulse period varied from 10,000 to 16,100 ft^3/s as daily mean water temperatures increased from 5.5°C–15°C. The May pulse period began on May 13when flows were increased to 25,000 ft^3/s over a period of 2 days and was characterized by fluctuations in daily mean flow as high as 6,500 ft^3/s. Daily mean water temperatures were 14°C–23°C during the May pulse period. The summer period began on June 15 after mean flows stabilized at 25,000 ft^3/s over three consecutive days. Daily mean water temperatures were 19°C–27°C during the summer period.

Presence and Aggregation of Sturgeon near Coarse Substrate Habitats (Objectives 1 & 2)

A total of 997 trammel net drifts over a total of 78 mi (126 km) collected 1 lake sturgeon (*Acipenser fulvesce*ns), 3 pallid sturgeon, and 709 shovelnose sturgeon, including 73 gravid shovelnose sturgeon from March 6 to August 30, 2006 (table E1). The lake sturgeon and one pallid sturgeon were captured at RM 803 (bend 5) and the other two pallid sturgeon were captured at RM 808 (bend 3; fig. E2). Our captures of pallid sturgeon coincided with the location of a radio-tagged pallid sturgeon by USGS personnel at RM 808 in March (chap. B).

Fifty-four percent of the net drifts were targeted at hard substrate patches and collected 62 percent of the shovelnose sturgeon and 47 percent of the gravid shovelnose sturgeon. Significantly more shovelnose sturgeon were captured near hard substrate patches than at random locations ($X^2 = 22.68$; $P < 0.001$). Most of the shovelnose sturgeon were captured at bends 3 and 4 (table E1). The total number of gravid shovelnose sturgeon collected did not differ between targeted and randomly selected sites, but random sites that were sampled included hard-substrate patches that were targeted for sturgeon. Twelve out of 39 gravid sturgeon were collected from bends 1, 3, and 4 which were randomly selected. Removal of these random bends and associated fish data from the analysis did not result in a statistical difference in the total number of gravid shovelnose sturgeon collected between targeted and randomly selected sites. Nevertheless, most of the gravid shovelnose sturgeon were captured at bends 3 and 4 (table E1). Forty-three percent of gravid shovelnose sturgeon assessed for reproductive readiness at bends 1, 3, and 4 and 31 percent of gravid shovelnose sturgeon assessed for reproductive readiness at other sites had polarization index (PI) values of less than 0.10 and germinal vesicle breakdown during progesterone assays (chap. C).

Catch rates (CPUE) of shovelnose sturgeon and gravid shovelnose sturgeon varied spatially and temporally (figs. E9 and E10; table E1). Few shovelnose sturgeon were collected immediately below Gavins Point Dam (bend 1; fig. E9). Trammel nets were difficult to drift at many sites within this bend because of swift velocities, large substrates (cobble and boulders), debris, and the intermittent presence of recreational anglers. Nevertheless, gravid shovelnose sturgeon were sampled at this bend in late April and early May. Mean number per net and CPUE of shovelnose sturgeon from March through August was highest near coarse substrate patches above (bend 3) and below (bend 4) the Highway 81 bridge and at bend 8 (table E1). Daily mean CPUE of shovelnose sturgeon were highest during early to mid March at bend 3 and 4 (fig E9). After mid-March, shovelnose sturgeon were consistently captured at low rates at bend 3 throughout the study, but daily mean CPUE of shovelnose sturgeon at bend 4 was higher in April and early May than in the following months. Relatively high daily mean CPUE of shovelnose sturgeon collected with the trammel nets generally corresponded to collections of gravid shovelnose sturgeon. The highest mean daily CPUE of gravid shovelnose sturgeon among all sites was at bend 4 in early March (fig. E9).

Daily mean CPUE of shovelnose sturgeon at randomly selected bends varied among segments and over time (fig. E10). Bends selected from the upper segment (bends 1–6) generally had higher catches of sturgeon than did bends from the lower segment (bends 7–12). Relative catches of shovelnose sturgeon at random bends were not as high as targeted bends in March, but CPUE of shovelnose sturgeon in random bends was relatively high in April and May. Trends in daily CPUE of gravid shovelnose sturgeon were similar for randomly selected bends in upper and lower segments, but catches were relatively high in early June for upper segment bends and in mid-May for in lower segment bends.

Randomly selected sites where high CPUE of gravid female sturgeon occurred was at bend 8 (RM 799) on April 23, bend 6 (RM 802) on April 30, and bend 3 (RM 808) on June 6, but, the high CPUE estimate at bend 8 was based on the collection of only one gravid shovelnose sturgeon over a relatively short drift distance (39 ft or 12 m) in comparison to the mean drift distance for all samples (table E1). Nets deployed at bend 6 on April 30 captured three gravid shovelnose sturgeon, whereas nets at bend 3 on June 6 captured eight gravid shovelnose sturgeon. Only one of the fish collected at bend 6 had a PI value of less than 0.10 and germinal vesicle breakdown during progesterone assays, but all of the gravid shovelnose sturgeon captured at bend 3 had PI values less than 0.10 and germinal vesicle breakdown during progesterone assays (chap. C). Furthermore, 19 out of 22 (86 percent) gravid shovelnose sturgeon assessed for reproductive readiness between June 1and June 22from bend 3 had PI values less than 0.10 and 16 out of 22 (73 percent) had germinal vesicle breakdown during progesterone assays. Thus, assessments of reproductive condition that were based on egg morphology (polarization index (PI) measurement) and physiological assays (germinal vesicle breakdown during progesterone assays) suggested that some gravid shovelnose sturgeon collected in late May from bend 6 (RM 802) and most of the fish collected in early to mid-June from bend 3 (RM 808) below Gavins Point Dam were ready to spawn if appropriate stimuli were available for fish to release eggs (D. Papoulias, USGS, oral commun.; chap. C).

Mean CPUE of shovelnose sturgeon varied across flow periods (table E4). Highest mean CPUE occurred during the winter flow period at targeted bends 3 and 4. Mean CPUE was also relatively high at targeted bends during the interpulse period compared to the pulse and summer periods but did not differ from randomly sampled bends from upper or lower segments during the interpulse period. Catch rates of gravid shovelnose sturgeon did not differ among flow periods or between targeted and random bends (table E5).

Patterns in mean CPUE among flow periods and sample locations suggest the possibility of winter aggregations of shovelnose sturgeon at two of the three targeted sites where coarse substrates occur (bends 3 and 4). In comparison to other periods and random sites, mean CPUE was also relatively high at bend 4 during the interpulse period, suggesting the possibility of an aggregation at this site during this period; however, it was expected that recaptures of sturgeon would be frequent during specific periods if aggregations occurred. Thirty individual shovelnose sturgeon were tagged and then recaptured during sampling under SRFM in 2006. Recapture of shovelnose sturgeon at a sample site occurred infrequently, but 14 shovelnose sturgeon at bend 3, 10 shovelnose sturgeon at bend 4, and 1 shovelnose sturgeon at bend 9 were recaptured in the same bend where they were tagged. Most of the recaptures occurred during the interpulse period at bend 4 and during summer period at bend 3 (table E6). One gravid shovelnose sturgeon was tagged on March 8 at bend 4 and recaptured at bend 3 on April 10.

An issue in using CPUE and recapture frequencies to assess the possible aggregation of sturgeon among flow periods includes interactive effects of flow on capture efficiencies and changes in flow on sturgeon behavior. High and variable flows were associated with reduced capture rates of shovelnose sturgeon during this study. Highest CPUE occurred when flows from Gavins Point Dam were less than 20,000 ft^3/s (fig. E11) and did not change over a period of 3 days (fig. E12). The effect of flow was evident in mean daily CPUE of sturgeon captured at bend 3 and bend 4 (fig. E13). On the basis of pooled data (data from random and targeted collections), it seems that highest CPUE occurred when flows were relatively low and stable. Nevertheless, CPUE of shovelnose sturgeon and gravid shovelnose sturgeon was high in early and mid-June at bend 3 and remained relatively stable from April to June at bend 4 despite any effect of flow on capture efficiencies (fig. E14). Since reproductive assessments suggested that the majority of gravid shovelnose sturgeon from bend 3 was ready to spawn in June if appropriate stimuli were available for fish to release eggs, high daily mean CPUE of shovelnose sturgeon and gravid shovelnose sturgeon in June may suggest aggregation behavior of fish in similar reproductive condition. However, it is unknown if fish were aggregating to spawn at bend 3. Gravid shovelnose sturgeon were not recaptured at bend 3, and assessments of reproductive condition of males were not conducted. It is possible that shovelnose sturgeon in similar reproductive condition formed an aggregation during the migration to suitable spawning habitats and that our sampling at bend 3 identified this group of fish.

Use of Coarse Substrate Habitats for Spawning (Objective 3)

We constructed 152 egg mats and then transported them from Columbia, Mo. to the USGS Field Research Station in Yankton, S. Dak. Beginning on May 3, 2006, 30 egg mats were deployed on coarse substrates immediately below Gavins Point Dam (bend 1), 21 egg mats were deployed on coarse substrates beneath or upstream of the Highway 81 bridge (bend 3), and 73 egg mats were deployed downstream of the Highway 81 bridge (bend 4; fig. E2). On May 11, four egg mats were deployed over coarse substrates in an outside bend that abuts a bluff immediately downstream from Ponca State Park at RM 753. Four additional egg mats were deployed at RM 775 (bend 17) immediately downstream from the Highway 19 bridge near Vermillion, S. Dak. on June 4 after USGS tracking crews located a radio-tagged gravid shovelnose sturgeon several times near a coarse substrate deposit that was previously identified in 2005 surveys. Egg mats were checked two times every week from May 3 until July 13 for the presence of eggs. Black eggs that resembled those of sturgeon or paddlefish were not collected at any site, but opaque eggs were collected on egg mats in May on four separate occasions (fig. E15). Eggs were collected below the dam, downstream from Highway 81 bridge, and at Ponca State Park. Samples of eggs were removed from the mat and preserved in either 70 percent ethanol and 10 percent buffered formalin. Another sample of eggs and an egg mat were transported to the USFWS Gavins Point National Fish Hatchery in Yankton, S. Dak. Attempts were made to hatch sampled eggs by using jars as well as by hatching eggs directly on the egg mat in a raceway by using water supplied from a well. Attempts to hatch eggs were conducted in an area of the hatchery that was not used for sturgeon culture but that was used for culture of other nonendangered fish species from various rivers, lakes, and ponds in the area. Two groups of eggs were successfully hatched from the jars. One group of eggs collected on May 12 was immediately preserved after hatching in formalin for identification using morphological characteristics of larval fish. The preliminary identification of fish from this sample was Catostomidae. The latter group of eggs that hatched was collected from mats on May 19, hatched approximately a week later, and was moved into an aluminum tank that was supplied with unfiltered water from Lewis and Clark Lake. Increased growth rates associated with relatively warm water from the lake aided in efficiently identifying fish that were spawned on the egg mat on the basis of juvenile characteristics instead of larval fish morphology; however, the use of unfiltered water from the lake resulted in contamination of our samples with various other fishes. Fish represented in the contaminated tanks included individuals from the families Centrarchidae, Cyprinidae, Clupeidae, Percidae, and Sciaenidae.

Depth, mean column velocity, bottom velocity, water temperature, and turbidity were measured at locations of each mat containing eggs. The presumed Catostomidae spawned on May 12 immediately below the dam when daily mean water temperatures were 14.5°C and turbidity was 14 nephelometric turbidity units (NTUs). The substrate where mats were placed immediately below the dam consisted of large cobbles and boulders. Fish spawned at depths of 3.5–5.5 m, mean column velocities of 0.8–1.4 m/s, and bottom velocities of 0.2–0.7 m/s (fig. E16). The highest proportion of mats with eggs had bottom velocities of 0.5 m/s and depths of 5 m. Velocity measurements near the river bed at spawning sites below Gavins Point Dam were similar to those reported for catostomids in other rivers (Curry and Spacie, 1994).

Collections of adhesive eggs on mats demonstrate the usefulness of the technique to determine sites and characterize habitat of spawning locations for lithophillic fishes in the Missouri River. Despite the fact that the technique had been used to sample sturgeon eggs in other rivers (Marchant and Shutters, 1996; Duncan and others, 2004), sturgeon and paddlefish eggs were not collected on egg mats deployed below Gavins Point Dam in 2006. Since female sturgeon in reproductive condition were collected near coarse substrate patches that were sampled during this study, sturgeon eggs were expected to be collected on mats. Sturgeon may not have spawned on coarse substrate deposits below Gavins Point Dam in 2006, or egg mats may not have been deployed exactly on spawning sites or during the times when spawning occurred. A few gravid shovelnose sturgeon collected during this study in August had eggs that appeared to be resorbing (M. Annis, USGS, oral commun., 2007). Modification of the egg mat deployment technique based on behavior of telemetered fish, fish reproductive condition, proximity of sturgeon to coarse substrates, and water temperatures when spawning is suspected to occur may aid in collecting sturgeon eggs. Any future attempts to use egg mats to identify spawning locations and habitats of sturgeon in the Missouri River should be closely coupled with telemetry techniques.

Spatial and Temporal Distribution of Larval Sturgeon and Other Larval Fishes (Objective 4)

Larval fish were sampled on 20–25 individual sampling events, depending on the sampling site, between May 8 and August 10, 2006. The larval fish sampling regime resulted in a total of 1,350 larval fish samples. The number of total samples collected varied among sites because of weather conditions and associated safety concerns, difficulties with equipment, and personnel schedules (table E3). Mean volume of water sampled per sample was 86.8 m^3 at the site downstream from Gavins Point Dam (bend 2; total = 16,671 m^3), 42.6 m^3 at the site downstream from Riverside Park (bend 4; total = 8,649 m^3), 91.2 m^3 at the site upstream from the James River confluence with the Missouri River (bend 7; total = 18,323 m^3), 82.7 m^3 at the site downstream from the James River confluence with the Missouri River (bend 11; total = 13,560 m^3), 66.5 m^3 at the site upstream from the Vermillion River confluence with the Missouri River (bend 17; total = 13,290 m^3), 88.8 m^3 at the site downstream from the Vermillion River confluence with the Missouri River (bend 20; total = 15,541 m^3), and 70.1 m^3 downstream from the boat ramp at Ponca State Park (bend 30; total = 14,932 m^3).

As of December 5, 2006, 65 percent of the samples had been processed in the laboratory (table E3). All of the samples preserved in formalin were processed, but only 29 percent of the samples preserved in ethanol were processed. Consequently, results are presented only for samples that have been processed, and results will change when sorting and identification of larval fish in the remaining samples are completed. To date, a total of 10,392 larvae representing 10 families were sampled across sites during 2006 (table E6). Freshwater drum (Sciaenidae *Aplodinotus grunniens*) was the numerically dominant taxon and composed 85.6 percent of the larvae sampled. Other relatively abundant taxa sampled included gizzard shad (Clupeidae *Dorosoma cepedianum*, 6.5 percent), suckers (Catostomidae, 3.9 percent), temperate basses (Moronidae, 1.8 percent) and minnows and carps (Cyprinidae, 0.8 percent). Larval sturgeon (Acipenseridae *Scaphirhynchus* spp,) and paddlefish (Polyodontidae *Polyodon spathula*) composed 0.3 percent and 0.02 percent of the larval fishes sampled, respectively.

Larval Fishes

Composition of the larval fishes sampled in 2006 varied among taxa and sites (table E7). Larval fishes from nine families were collected upstream from the Vermillion River confluence with the Missouri River and at Ponca State Park. Seven families were collected downstream from Riverside Park, both upstream and downstream from the James River confluence with the Missouri River, and downstream from the Vermillion River confluence with the Missouri River. Six families of larval fishes were sampled downstream from Gavins Point Dam. Representatives of Catostomidae, Centrarchidae (sunfishes and basses), Clupeidae, Cyprinidae, Sciaenidae, and Moronidae were sampled at all seven sites. Larval sturgeon (Acipenseridae) and fish from the darter, perch, walleye and sauger family (Percidae) were collected at four sites, whereas bullhead catfish (Ictaluridae) and paddlefish (Polyodontidae) larvae were only collected at one site.

The larval fish community at the site downstream from Gavins Point Dam was dominated by freshwater drum (Sciaenidae; fig. E17). Mean densities of Sciaenidae increased from late May to early June to a maximum of 764.84 larvae/100 m^3 and then substantially declined in mid-June and were relatively low (less than 5.00 larvae/100 m^3) in July and August. Mean densities of Clupeidae and Moronidae peaked in early June (5.63 and 7.49 larvae/100 m^3, respectively), but mean density of Clupeidae exhibited two more peaks, in late June (8.64 larvae/100 m^3) and in early July (4.24 larvae/100 m^3). Catostomidae exhibited a peak in mean density on June 1(1.39 larvae/100 m^3) but were also collected on June 8, June 22, and June 26 in relatively low densities (mean = 0.48–0.78 larvae/100 m^3). Cyprinidae) exhibited three peaks in mean densities that were relatively low compared to other families. The first peak was on June 5 (1.51 larvae/100 m^3), the second peak was on July 14 (1.07 larvae/100 m^3), and the third peak was on July 24 (1.77 larvae/100 m^3). Centrarchidae were collected on three dates (July 21, July 28, and August 2) at relatively low densities (mean = 0.07–0.40 larvae/100 m^3). The highest mean density of Centrarchidae occurred in August. No Percidae, Ictaluridae, Acipenseridae, or Polyodontidae were collected.

Larval fishes collected downstream from Riverside Park in Yankton, S. Dak. were dominated by Sciaenidae (fig. E18). Mean densities of Sciaenidae increased from late May to early June to a maximum of 483.34 larvae/100 m^3, declined to 2.19 larvae/100 m^3 in mid June, increased to 152.19 larvae/100 m^3 in late June, and declined thereafter; however, Sciaenidae continued to be collected in low to moderate densities in July (mean = 0–10.49 larvae/100 m^3) and August (mean = 0.27–1.13 larvae/100 m^3). Clupeidae was the second most dominant family of larval fishes collected downstream from Riverside Park and exhibited three peaks in mean density. Peaks occurred on June 8 (14.66 larvae/100 m^3), June 22 (24.89 larvae/100 m^3), and July 6 (5.81 larvae/100 m^3). Mean densities of Catostomidae and Moronidae were high in early June, but Catostomidae were collected over a longer period (May 15 to July 14) than Moronidae (May 28 to June 28). Cyprinidae were collected in early June and late July, whereas Centrarchidae were collected in late July. Percidae were collected in relatively low densities on May 18 (0.21 larvae/100 m^3) and May 24 (0.95 larvae/100 m^3). No Ictaluridae, Acipenseridae, or Polyodontidae were collected.

Similar to the dam and Riverside Park sites, the larval fish assemblage sampled upstream from the James River was dominated by freshwater drum (Sciaenidae; fig. E19). Mean densities of drum were highest on June 5 (353.98 larvae/100 m^3) and June 22 (90.93 larvae/100 m^3). Gizzard shad (Clupeidae) was the second most dominant family, with mean densities peaking on June 1 (6.09 larvae/100 m^3), June 8 (13.21 larvae/100 m^3), and June 22 (5.18 larvae/100 m^3). Catostomidae larvae were collected from mid May to late June, but mean density peaked on June 1(4.13 larvae/100 m^3) with densities of Cyprinidae (2.34 larvae/100 m^3) and Moronidae (1.89 larvae/100 m^3). Centrarchidae were collected on 1 day in late July (0.52 larvae/100 m^3) and on 1 day in early August (0.14 larvae/100 m^3). One sturgeon (Acipenseridae) was collected on August 8, but no Percidae, Ictaluridae, or Polyodontidae were collected (table E8).

Downstream from the James River, freshwater drum (Sciaenidae) again dominated the larval fish community (fig. E20), but at lower densities than at upstream sites. Mean densities were highest in early June (maximum = 76.34 larvae/100 m^3) and peaked again in late June (28.40 larvae/100 m^3) and late July (5.02 larvae/100 m^3). Gizzard shad (Clupeidae) was again the second most dominant taxon and had similar peaks in mean density as observed at the site upstream from the James River; however, gizzard shad were not collected downstream of the James River until June 8 (mean density = 12.75 larvae/100 m^3). Catostomidae larvae were collected from late May to mid-July, but mean density peaked on June 1 (10.78 larvae/100 m^3). Cyprinidae and Moronidae were collected from early June through early August, and mean densities were highest in early June. Centrarchidae larvae were collected on June 8 (0.53 Centrarchidae larvae/100 m^3), whereas Percidae were only collected on May 8 (0.27 Percidae larvae/100 m^3). No Ictaluridae, Acipenseridae, or Polyodontidae were collected.

The larval fish assemblage upstream from the Vermillion River consisted primarily of freshwater drum, but mean densities were not as high as upstream sites (fig. E21). Mean density of Sciaenidae peaked on June 4 at 150.82 larvae/100 m^3. Catostomidae was the second most dominant family and demonstrated four peaks in mean density in May and June. Clupeidae were captured early June through late July but demonstrated a bimodal peak in mean density in early (5.46 larvae/100 m^3) and late (13.77 larvae/100 m^3) June. Moronidae larvae were collected in late May through June and mean densities were highest on June 4 (3.76 larvae/100 m^3) and June 11 (3.96 larvae/100 m^3). Cyprinidae were captured on 4 days in June and densities were highest on June 4 (1.60 larvae/100 m^3). Centrarchidae were collected 2 days in July at low densities (mean densities of less than 0.25 larvae/100 m^3), whereas Percidae were collected on 2 days in May (mean densities = 0.29–0.96 larvae/100 m^3). Ictaluridae were collected on July 25 (0.21 larvae/100 m^3). No Polyodontidae were collected, but sturgeon (Acipenseridae) were collected late May through June (table E9).

Downstream from the Vermillion River, the larval fish community was largely Sciaenidae (fig. E22). Mean densities of freshwater drum were highest on June 4(214.16 larvae/100 m^3). Catostomidae and Clupeidae were also common larval fishes collected, with maximum densities of Catostomidae in late May (10.23 larvae/100 m^3) and of gizzard shad in late June (5.11 larvae/100 m^3). Cyprinidae and Moronidae were collected from early June through early August, and mean densities were highest for both Cyprinidae (1.73 larvae/100 m^3) and Moronidae (8.99 larvae/100 m^3) in early June. Centrarchidae were collected 1 day each in May, June, and July at low densities (mean densities less than 0.35 larvae/100 m^3). No Percidae, Ictaluridae, or Polyodontidae were collected, but sturgeon (Acipenseridae) were collected in June (table E10).

Similar to all of the other sites, larval fishes collected downstream from the boat ramp at Ponca State Park were dominated by freshwater drum (Sciaenidae; fig. E23). Mean densities of Sciaenidae were highest on June 4(467.79 larvae/100 m^3). Catostomidae was the second most dominant family and was collected from May through July. Mean densities of Catostomidae were highest on June 4 (9.86 larvae/100 m^3). Gizzard shad (Clupeidae) were collected in June and July and had maximum mean densities on June 11 (5.34 larvae/100 m^3). Mean densities of Cyprinidae were highest on June 4 (3.49 larvae/100 m^3), but were collected at low densities (mean densities less than 0.65) on seven days from May through August. Moronidae were collected from late May through June and mean densities were highest on June 14 (2.46 larvae/100 m^3). Percidae were collected only on May 21 (mean density = 0.62 larvae/100 m^3). No Ictaluridae were collected, but paddlefish (Polyodontidae) were collected on 2 days in mid- to late May (mean densities = 0.27–0.44 larvae/100 m^3), and sturgeon (Acipenseridae) were collected in late May and June (table E11).

Larval Sturgeon

The periodicity and densities of larval sturgeon sampled during 2006 varied among sampling sites and dates. Larval sturgeon were only collected upstream from the James River confluence, upstream and downstream of the Vermillion River confluence, and at Ponca State Park. Only one larval sturgeon was captured upstream from the James River in August (table E8). Upstream from the Vermillion River confluence, a total of 13 larval sturgeon were collected on three dates between May 31 and June 21 (table E9; fig. E7). Mean density of larval sturgeon was highest on May 31 (4.35 larvae/100 m^3) but less than 1.5 larvae/100 m^3 on the other days. Twelve larval sturgeon were collected in the Missouri River downstream from the Vermillion River confluence in 5 days in June (table E10). Mean density of larval sturgeon was highest on June 21 (mean

= 1.01 larvae/100 m^3) but less than 0.90 larvae/100 m^3 on the other dates. In the Missouri River downstream of the boat ramp at Ponca State Park, four larval sturgeon were collected over 3 days (table E11). Mean density of larval sturgeon was highest on June 18 (mean = 0.98 larvae/100 m^3) but was less than 0.50 larvae/100 m^3 on the other days.

Pallid sturgeon and shovelnose sturgeon hatch at approximately 8–9 mm in total length (Snyder, 2002). Based on length ranges of larvae collected at each site (table E8, 6–9, 6–10, and 6–11), larval sturgeon collected were probably less than 1 day post hatch. Incubation times for *Scaphirhynchus* spp. eggs depend on water temperature but approximately range from 74 hours (~3 days) at 24°C to 100 hours (4 days) at 20°C after fertilization (K.M. Kappenman and M.A. Webb, U.S. Fish and Wildlife Service, written commun., 2007). Daily mean water temperatures at Gavins Point Dam in May and June, when most of the sturgeon larvae were collected were 19–23°C. On the basis of daily water temperatures and our larvae collections, we estimate that many shovelnose sturgeon spawned in the Missouri National Recreational River reach below Gavins Point Dam between May 28 and June 22, 2006. Data from telemetry efforts on movements of gravid shovelnose sturgeon and reproductive assessments of gravid shovelnose sturgeon sampled in 2006 support these findings (chap. B). Twelve radio-tagged fish were located at their furthest upstream locations in the Missouri National Recreational River reach below Gavins Point Dam. Eight of the twelve fish were recaptured between May 31 and October 11 and were determined to have spawned. One gravid shovelnose sturgeon was located at RM 798 (upstream from the James River) on June 2. Five gravid shovelnose sturgeon were located within 19 mi upstream from bend 17 (the site upstream from the Vermillion River) from May 10 to June 19, including one fish that was located immediately upstream from the site where larval fishes were sampled (RM 775). Two gravid shovelnose sturgeon were located 3–5 mi upstream from RM 769 (site downstream from the Vermillion River) from May 9 to June 9 and one of these fish was recaptured at RM 774 on May 31 and determined to have spawned. The Ponca State Park site where larval sturgeon were collected was within 3–16 mi downstream from the most upstream location of four radio-tagged shovelnose sturgeon between May 11 and June 2. Reproductive assessments of gravid shovelnose sturgeon sampled in the Missouri National Recreational River reach in late May and June suggested that the majority of fish were ready to spawn if appropriate stimuli were available for fish to release eggs (see above; see also chap. B).

Even though most spawning by sturgeon appeared to occur in late May and June, spawning also occurred later in the summer. Small sturgeon larvae (8 mm total length) were collected upstream from the James River in August when water temperatures were 25°C–26°C. These findings support earlier suggestions that shovelnose sturgeon in the Missouri River below Gavins Point Dam have a protracted spawning period (D. Papoulias, U.S. Geological Survey, oral commun., 2006). Spawning occurred during both the May pulse and summer flow periods.

Summary

Pallid sturgeon (*Scaphirhynchus albus*) and shovelnose sturgeon (*S. platorynchus*) were collected near coarse substrate deposits. Capture rates of shovelnose sturgeon indicated the possibility of a winter aggregation near one coarse substrate deposit upstream from the Highway 81 bridge in Yankton, S. Dak., but interactions between fish behavior and high and variable flows affected capture efficiencies and our ability to identify aggregations during other periods. Nevertheless, capture rates of gravid shovelnose sturgeon were high during the May pulse and summer period upstream from the Highway 81 bridge despite any effect of flow. Assessments of reproductive condition suggested that most of these fish were ready to spawn if appropriate stimuli were available for fish to release eggs (chap. C).

Sturgeon eggs were not collected despite deployment of 132 mats over coarse substrate deposits from May through mid-July; but, opaque eggs were collected on mats on four separate occasions. Eggs from one occasion were successfully hatched in the hatchery and tentatively identified as Catostomidae. Collections of adhesive eggs on mats demonstrate the usefulness of the technique to determine spawning sites and characterize spawning habitats for lithophillic fishes in the Missouri River. Future attempts to use egg mats should be closely coupled with telemetry activities (chap. B).

As of December 5, 2006, a total of 10,392 larvae representing 10 families were collected. Freshwater drum (Sciaenidae *Aplodinotus grunniens*) was the most dominant taxon and composed 85.6 percent of the larvae sampled. Other relatively abundant taxa included gizzard shad (Clupeidae *Dorosoma cepedianum*; 6.5 percent), Catostomidae (suckers; 3.9 percent), Moronidae (temperate basses; 1.8 percent), and Cyprinidae (minnows and carps; 0.8 percent). Larval sturgeon (Acipenseridae *Scaphirhynchus* spp.) and paddlefish (Polyodontidae *Polyodon spathula*) composed 0.3 and 0.2 percent of the larval fishes sampled, respectively. Small larval sturgeon (7–10 mm in total length) were collected upstream from the James River in August but were collected upstream and downstream of the Vermillion River and downstream from the boat ramp at Ponca State Park in late May and June. On the basis of the sizes of larval sturgeon collected, water temperatures, incubation times, movement data and recaptures of gravid shovelnose sturgeon used in telemetry studies (chap. B), and reproductive assessments of gravid female sturgeon captured in the Missouri National Recreational River reach of the Missouri River (chap. C and this chapter), we estimate that many shovelnose sturgeon spawned between May 28 and June 22 at water temperatures of 19°C–23°C. The collection of small sturgeon larvae in August upstream from the James River, however, supports suggestions that shovelnose sturgeon in the Missouri River have a protracted spawning period and spawned during the May pulse and summer flow periods.

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Figures and Tables

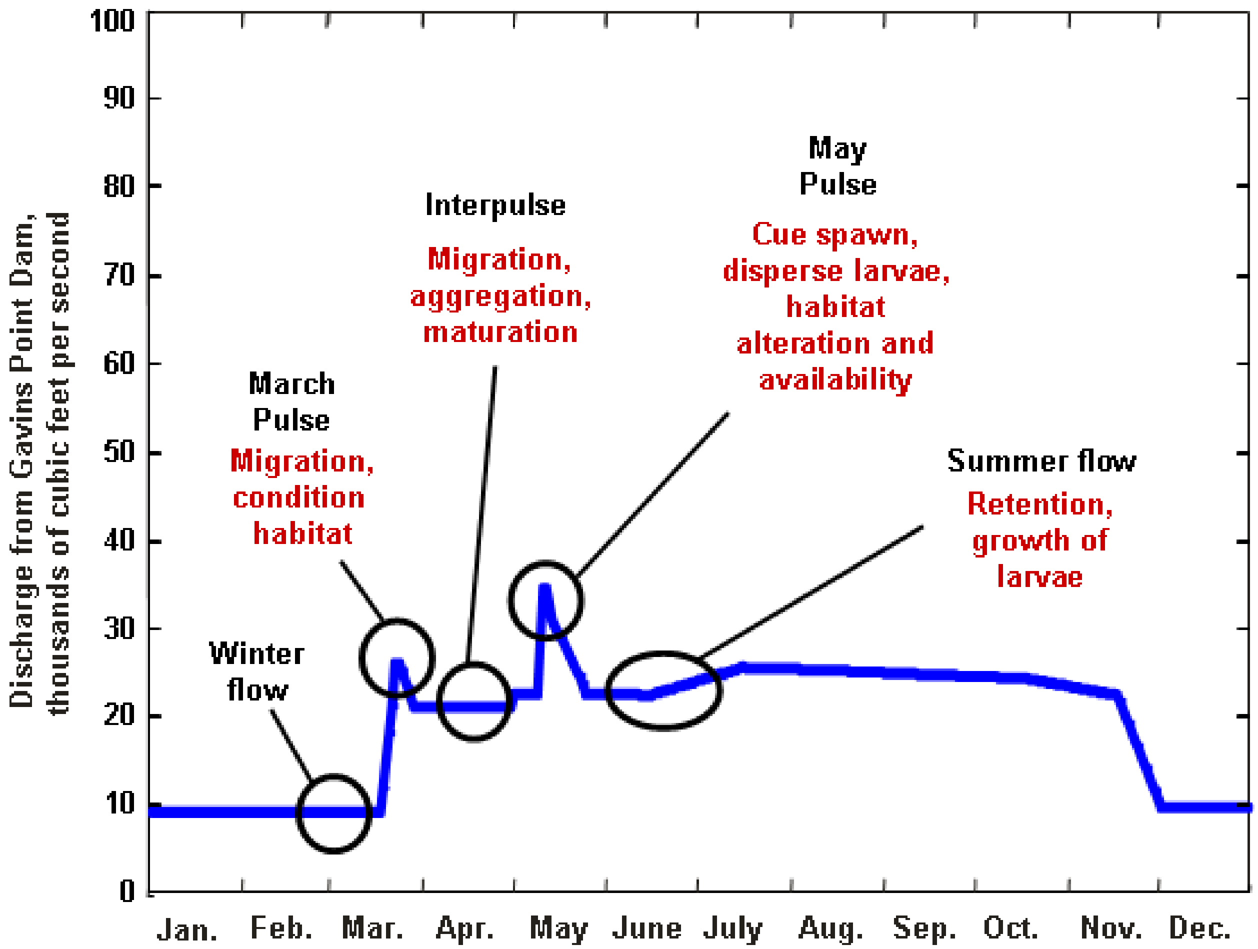

Figure E1. Hydrograph from the U.S. Army Corps of Engineers 2006 annual operating plan for the Missouri River below Gavins Point Dam. Hypotheses (highlighted in red) about the role of discrete flow periods (highlighted in black) on specific life-history events of pallid sturgeon and shovelnose sturgeon were described in the Sturgeon Response to Flow Modification (SRFM) proposal (Fleming and others, 2006).

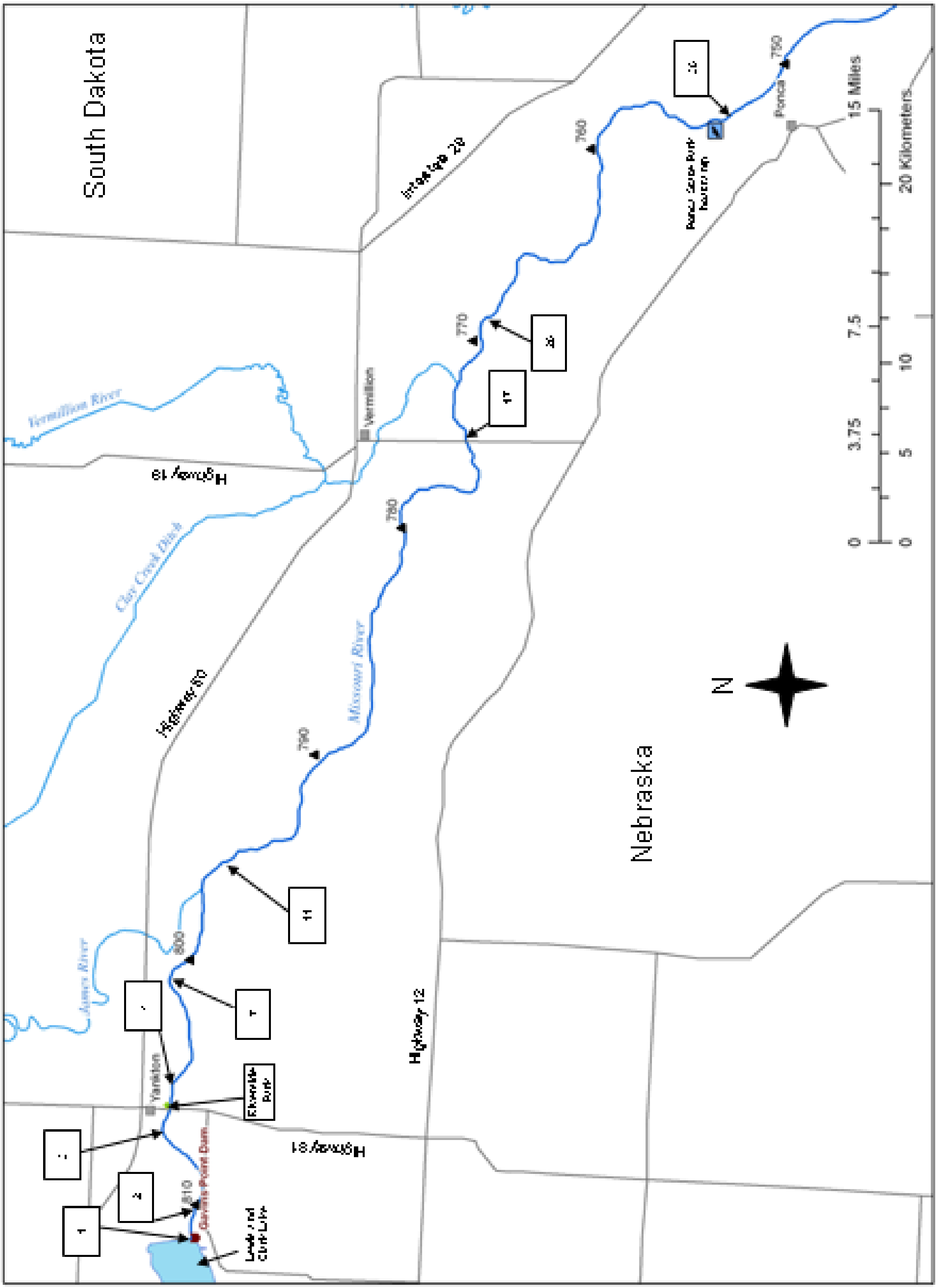

Figure E2. The Missouri National Recreational River system below Gavins Point Dam and approximate bend locations (numbered boxes) where hard substrates occurred (bends 1, 3, and 4) and sturgeon (bends 1–12), eggs (bends 1, 3, 4, 17, and 30), and larvae (bends 2, 4, 7, 11, 17, 20, 30) were sampled during 2006. River miles are denoted by black triangles.

Figure E3. Coarse substrate deposits at river mile 806 (bend 4) in early March 2006 at a discharge of 9,000 ft^3/s from Gavins Point Dam. Sturgeon were fished, egg mats were deployed, and larval fish were sampled on or near these deposits in 2006.

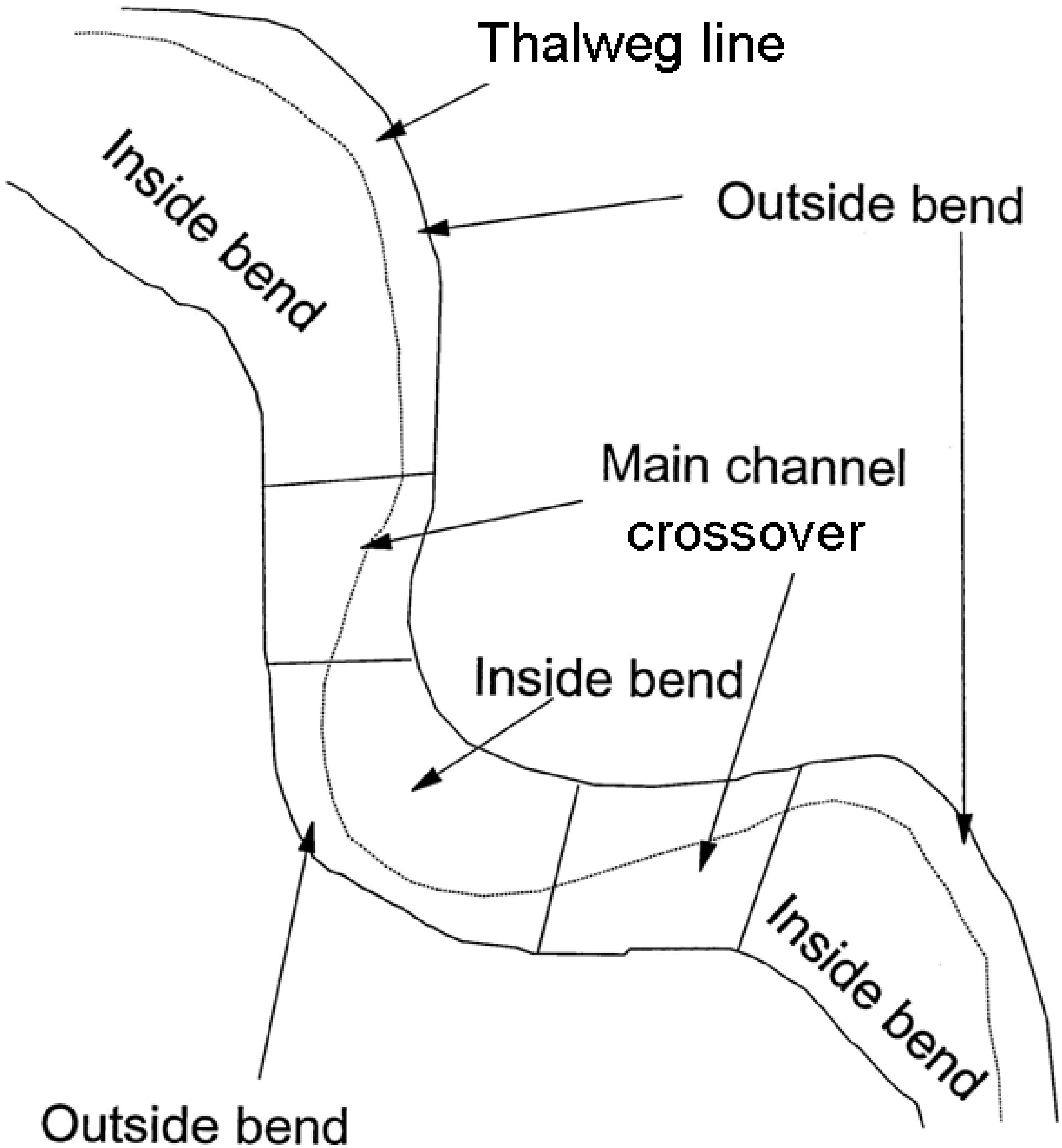

Figure E4. Hypothetical map of the Missouri River showing boundaries of continuous macrohabitats. Reprinted from Sappington and others (1998).

Figure E5. Mats used to sample eggs on coarse substrate deposits.

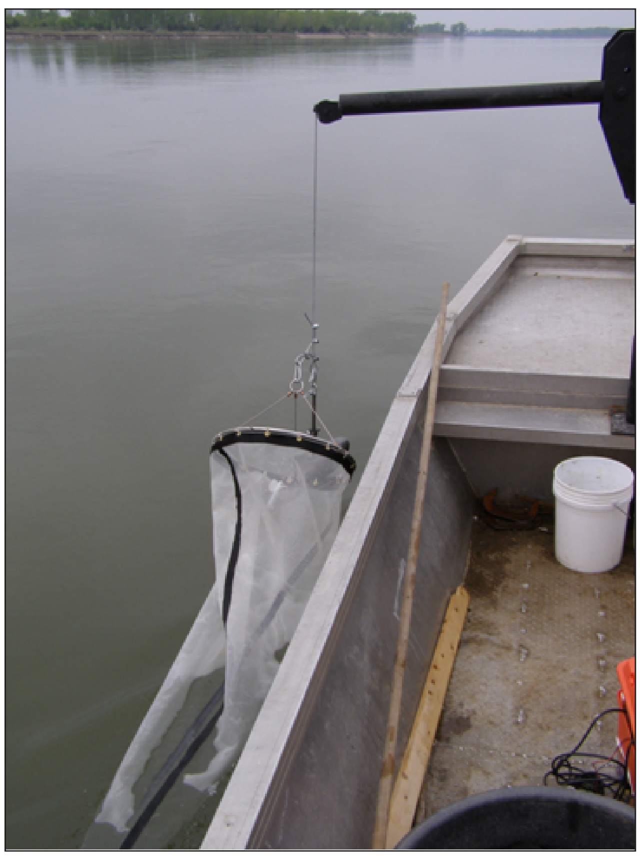

Figure E6. Lcthyoplankton net with 750-μm mesh attached to a 75-lb (34 kg) Columbus-style sounding weight used to sample drifting larval fishes.

Figure E7. A larval sturgeon (approximately 8-mm in total length) that was collected upstream from the Vermillion River bend 17 on May 3, 2006. The fish was identified based on morphological characteristics by Auer (1982) and verified by Darrel Snyder at Colorado State University (Snyder, 2002).

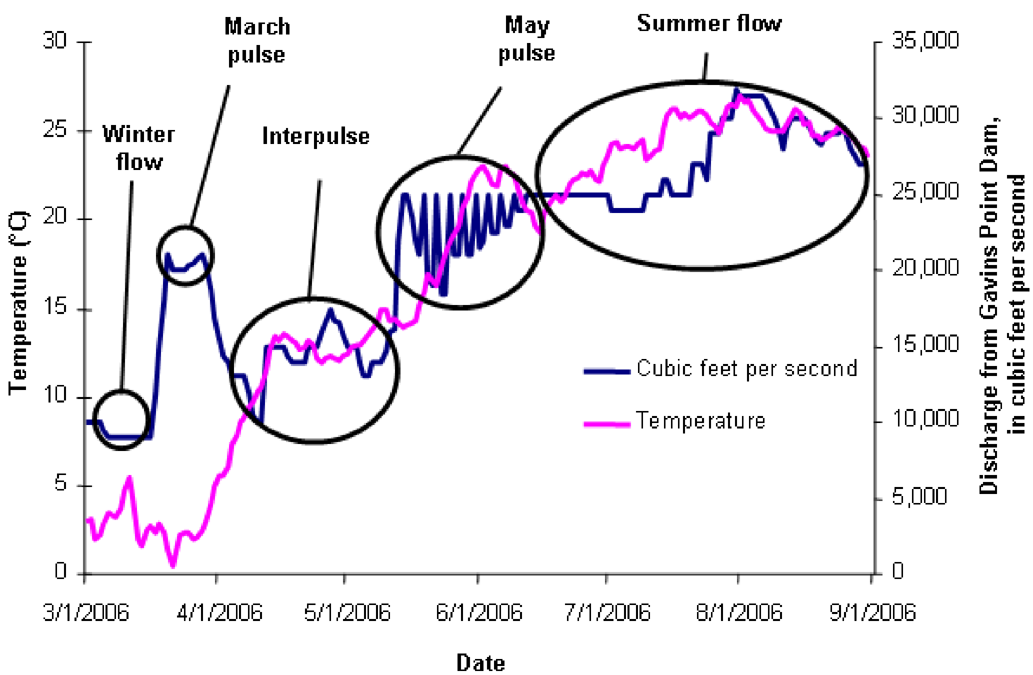

Figure E8. Actual flows and water temperatures at Gavins Point Dam in 2006. Flows were not exactly as described in the U.S. Army Corps of Engineers annual operating plan (AOP) in 2006 (see fig. E1), but flow periods described in the Sturgeon Response to Flow Modification (SRFM) proposal were modified for the actual 2006 hydrograph to assess relationships between flow and capture rates of sturgeon.

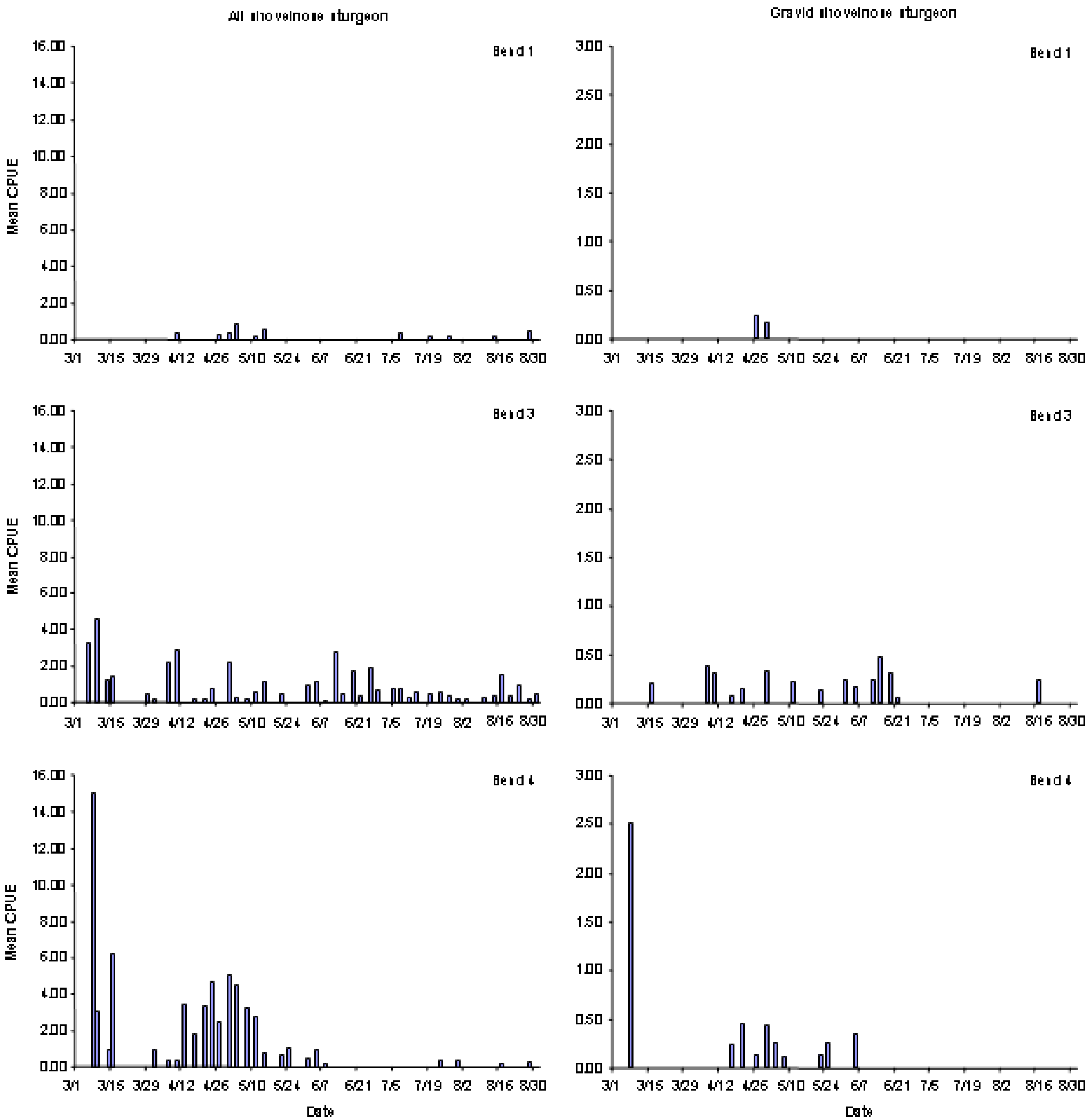

Figure E9. Mean catch-per-unit effort (CPUE) of shovelnose sturgeon and gravid shovelnose sturgeon at targeted bends in the Missouri National Recreational River reach below Gavins Point Dam that were sampled in 2006.

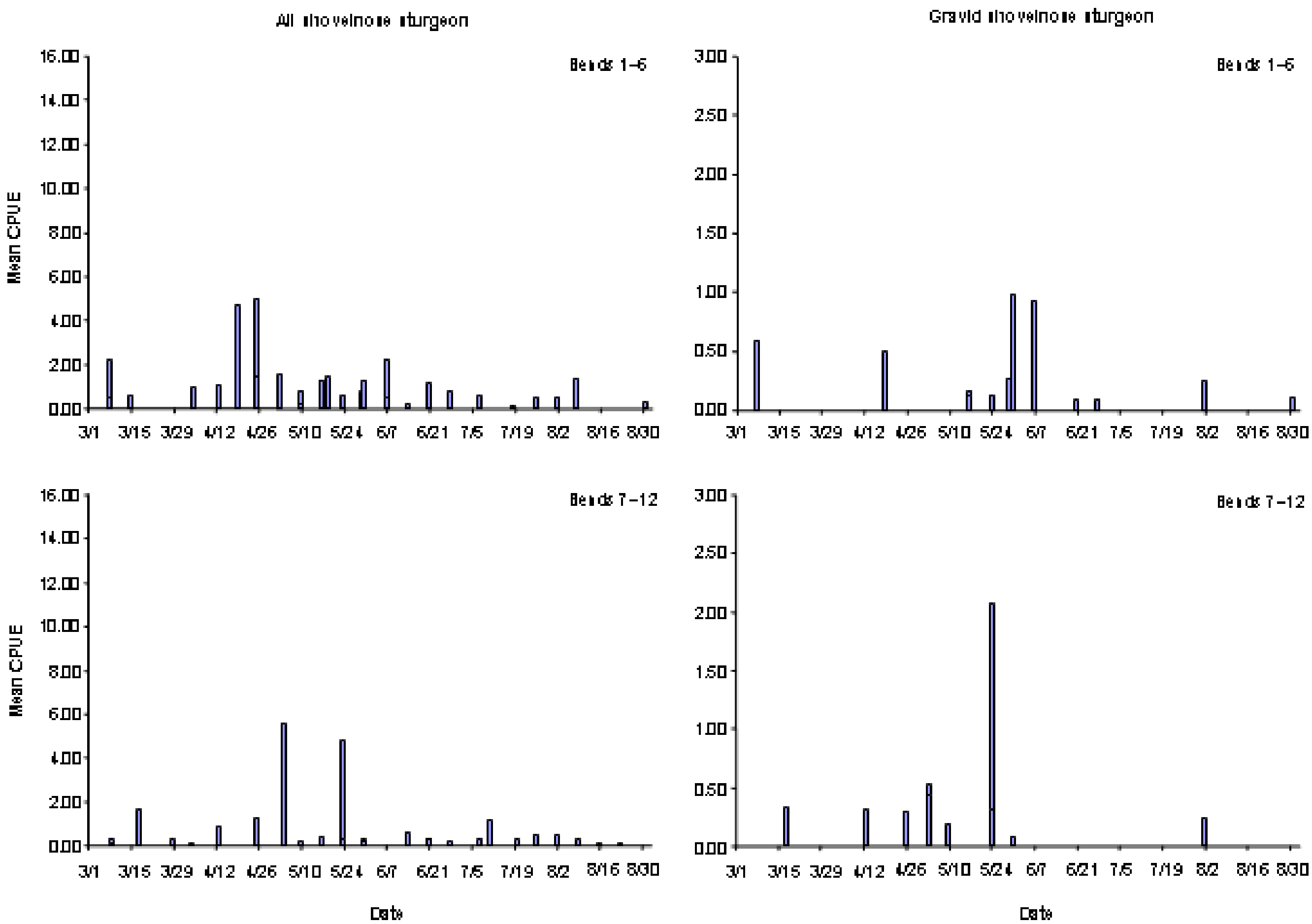

Figure E10. Mean catch-per-unit effort (CPUE) of shovelnose sturgeon and gravid shovelnose sturgeon at randomly selected bends from upper (bends 1–6) and lower (bends 7–12) river segments in the Missouri National Recreational River reach below Gavins Point Dam that were sampled in 2006.

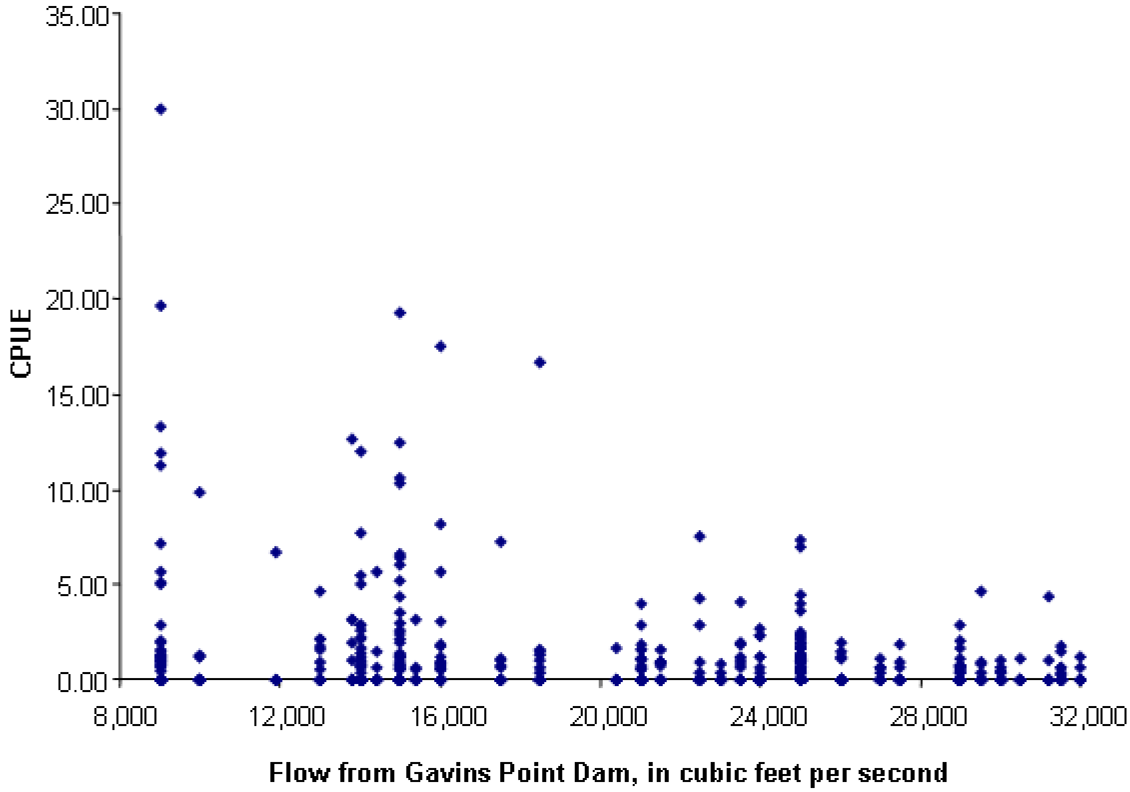

Figure E11. Effect of flow from Gavins Point Dam on catch-per-unit effort (CPUE) of shovelnose sturgeon collected in 2006.

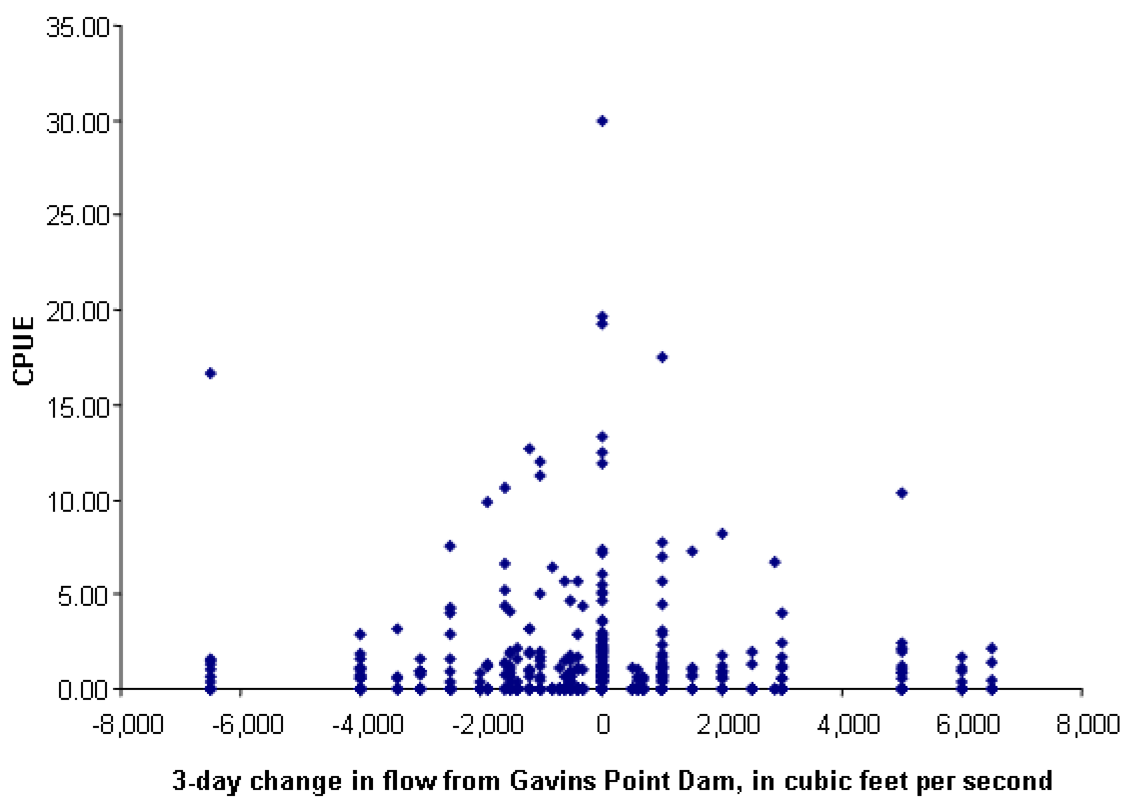

Figure E12. Effect of 3-day changes in flow on catch-per-unit effort (CPUE) of shovelnose sturgeon collected in 2006.

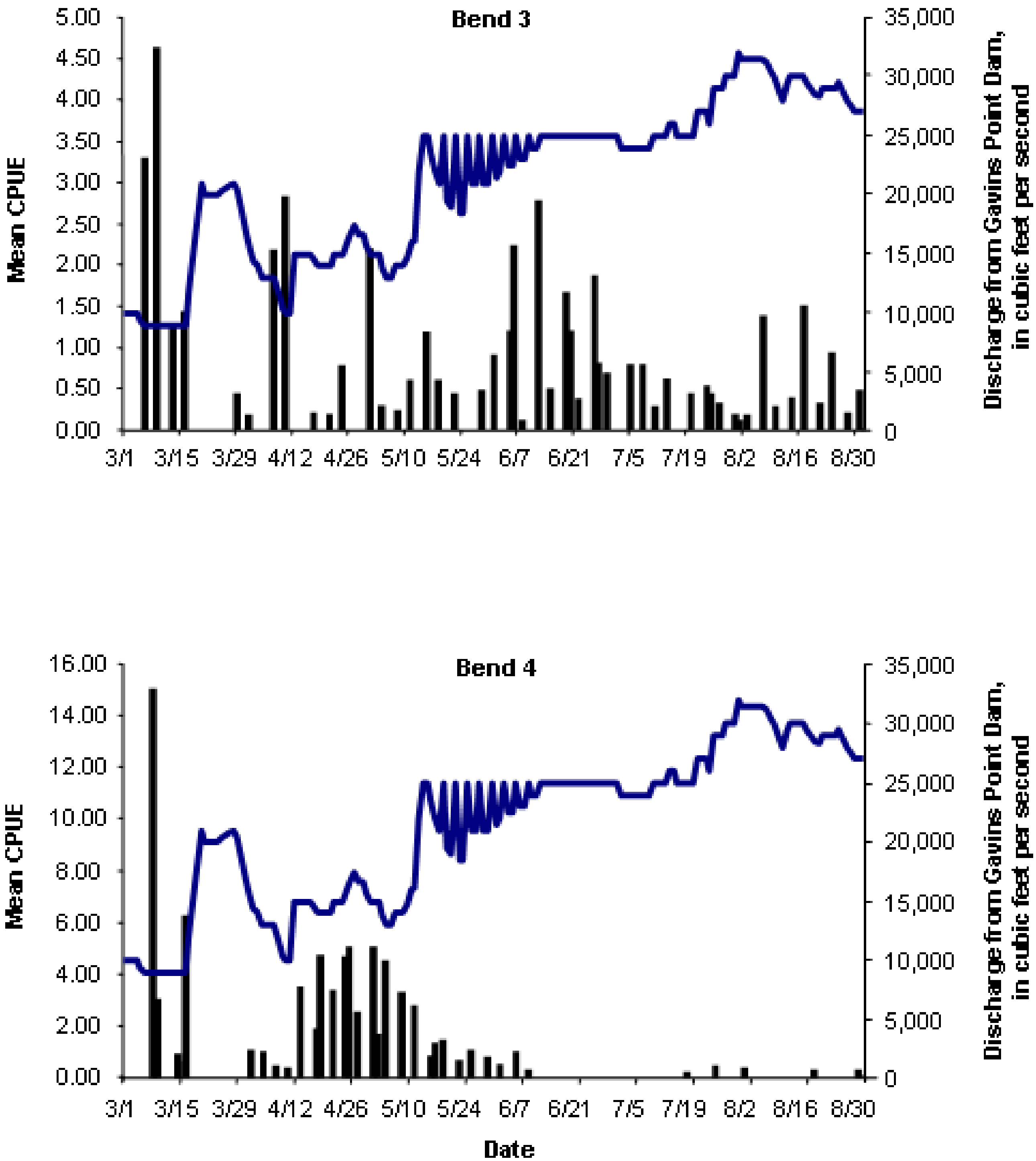

Figure E13. Trends in mean catch-per-unit effort (CPUE) of all shovelnose sturgeon collected at bend 3 (river mile 808) and bend 4 (river mile 806) in relationship to flow from Gavins Point Dam in 2006. The y-axis on the left for mean CPUE differs between the graphs.

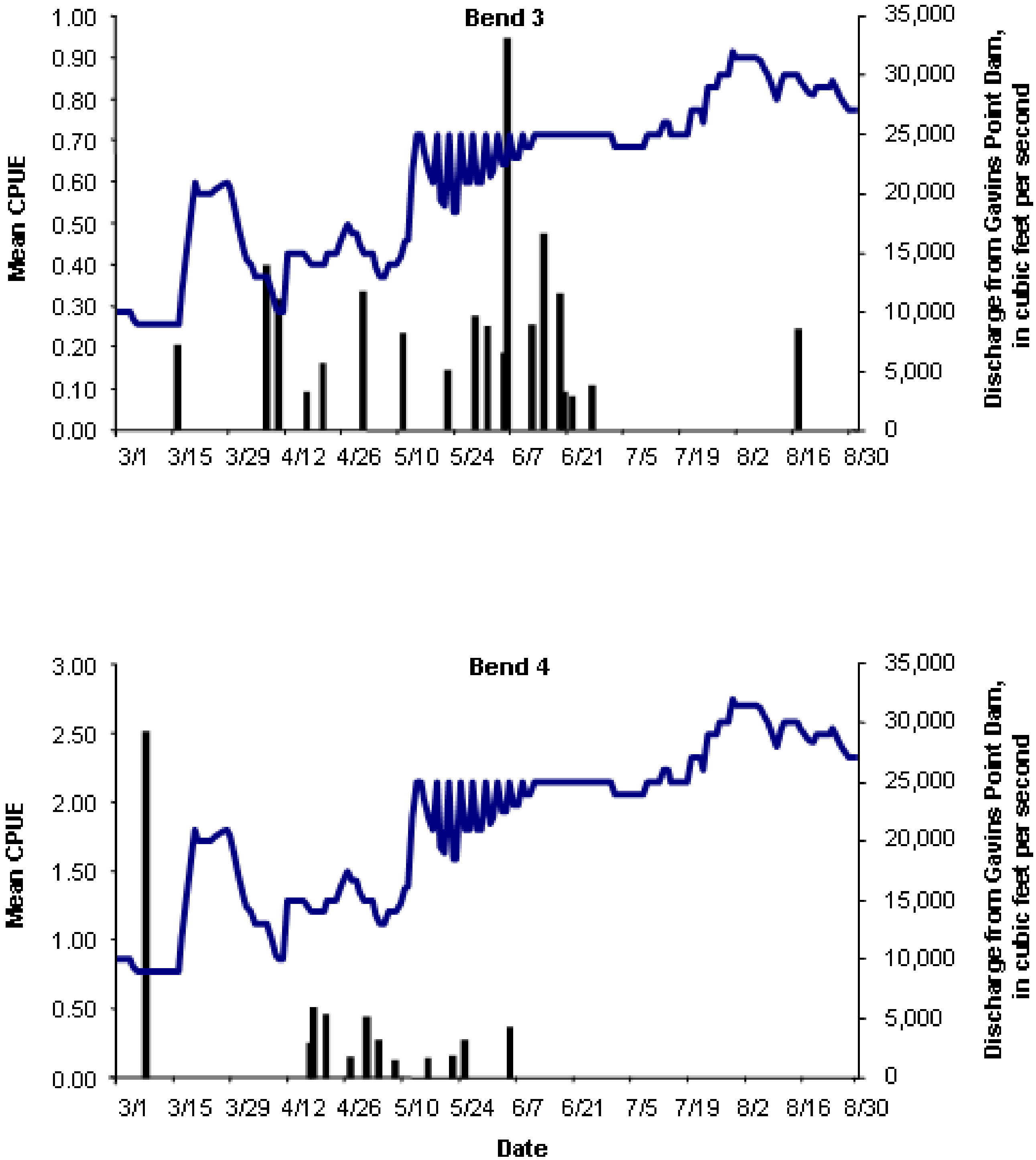

Figure E14. Trends in mean catch-per-unit effort (CPUE) of all gravid shovelnose sturgeon collected at bend 3 (river mile 808) and bend 4 (river mile 806) in relationship to flow from Gavins Point Dam in 2006. The y-axis on the left for mean CPUE differs between the graphs.

Figure E15. Picture of opaque eggs collected on mat.

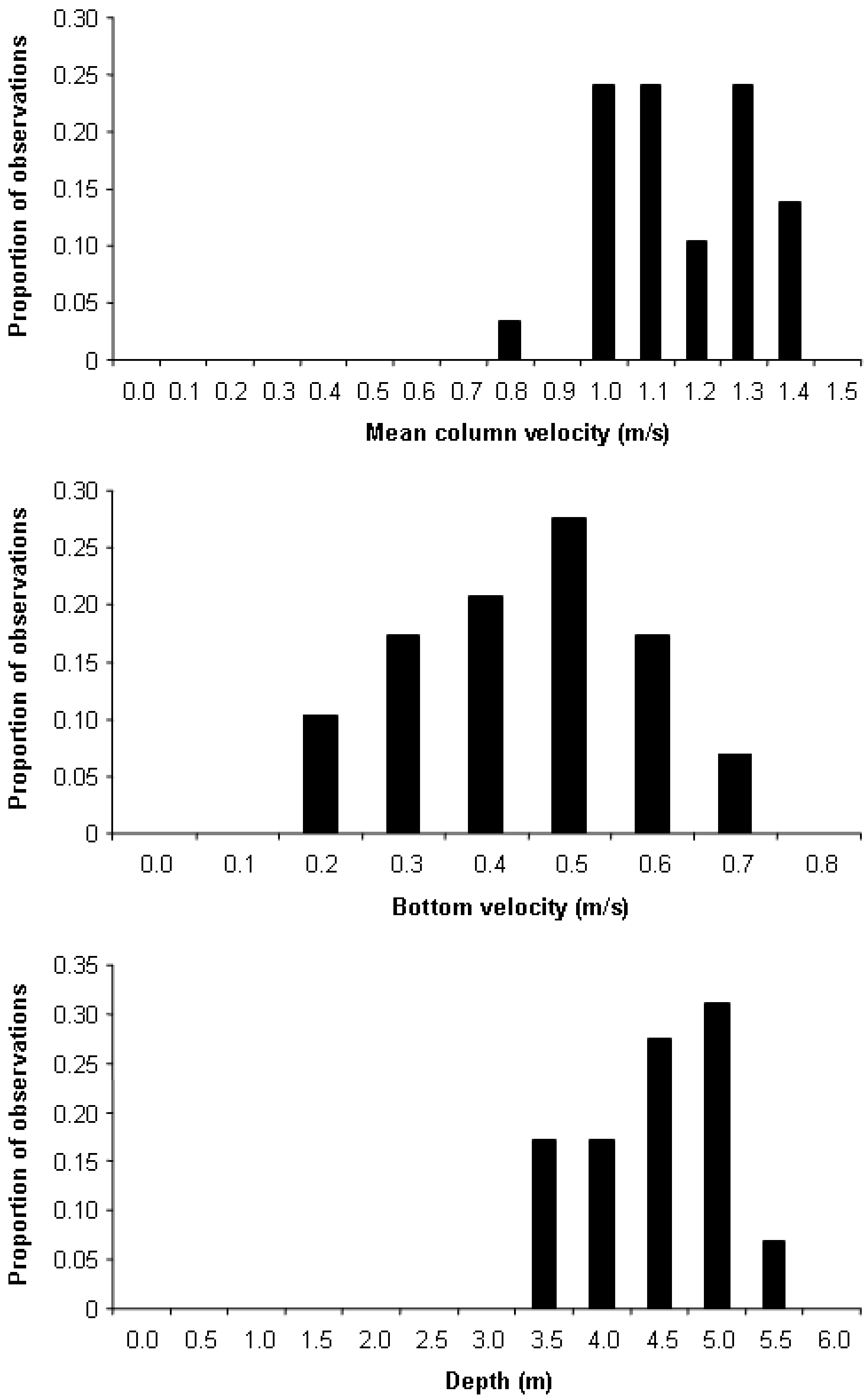

Figure E16. Mean column velocities (m/s), bottom velocities (m/s), and depths (m) for mats that were observed with opaque eggs.

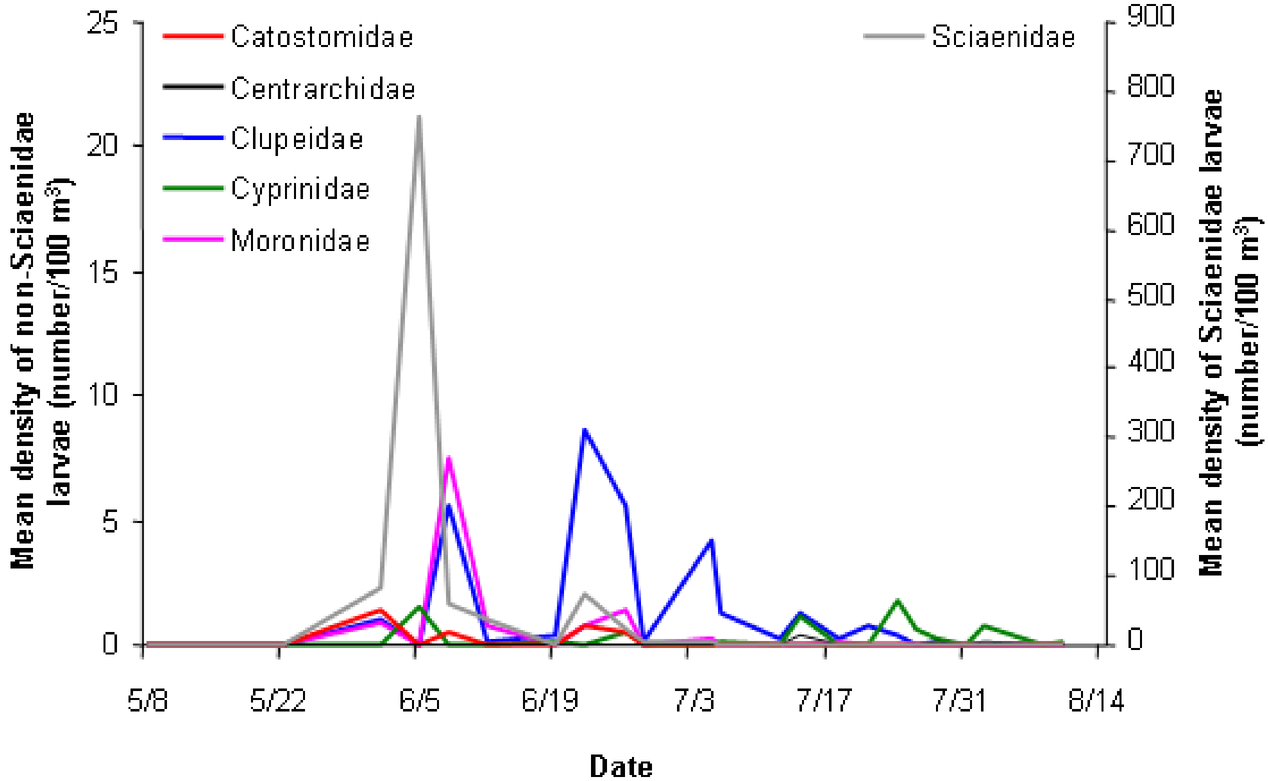

Figure E17. Mean density (number/100 m³) by date of larval fishes collected in the Missouri River downstream from the Gavins Point Dam (bend 2) in 2006.

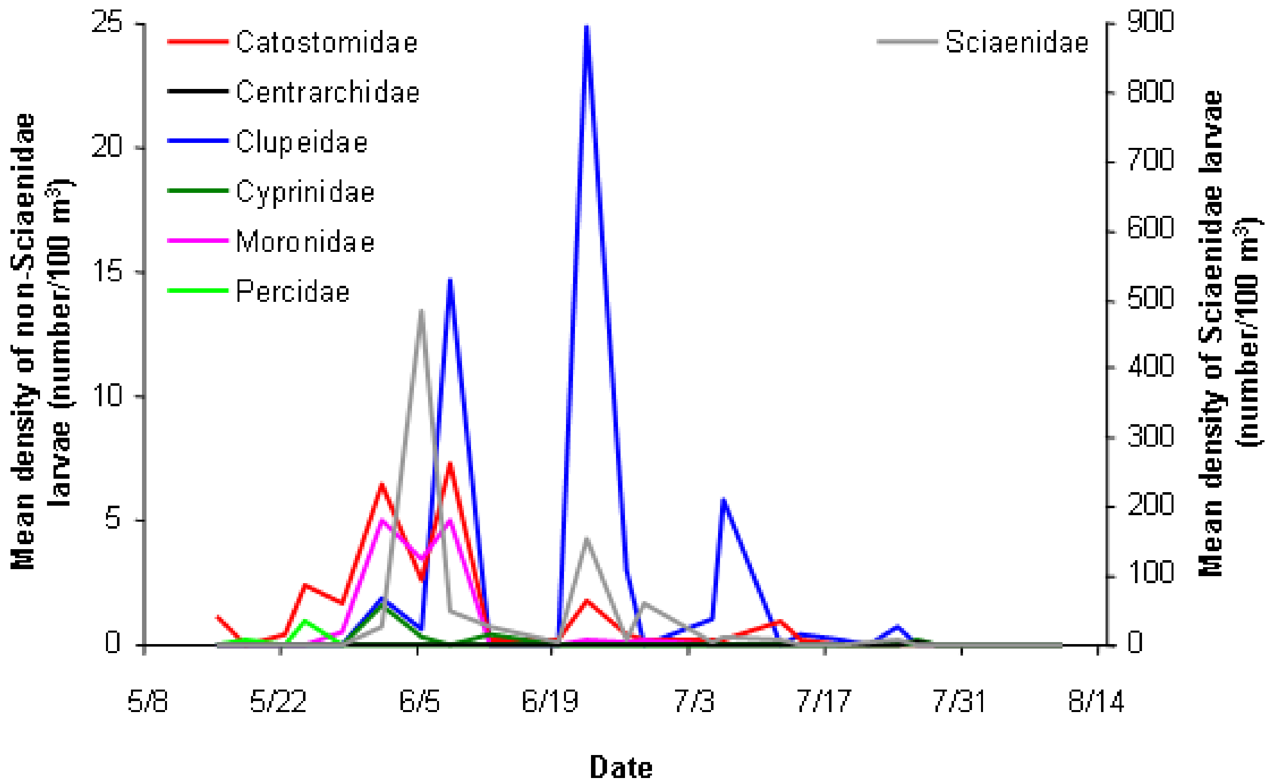

Figure E18. Mean density (number/100 m³) by date of larval fishes collected in the Missouri River downstream from Riverside Park in Yankton, S. Dak. (bend 4) in 2006.

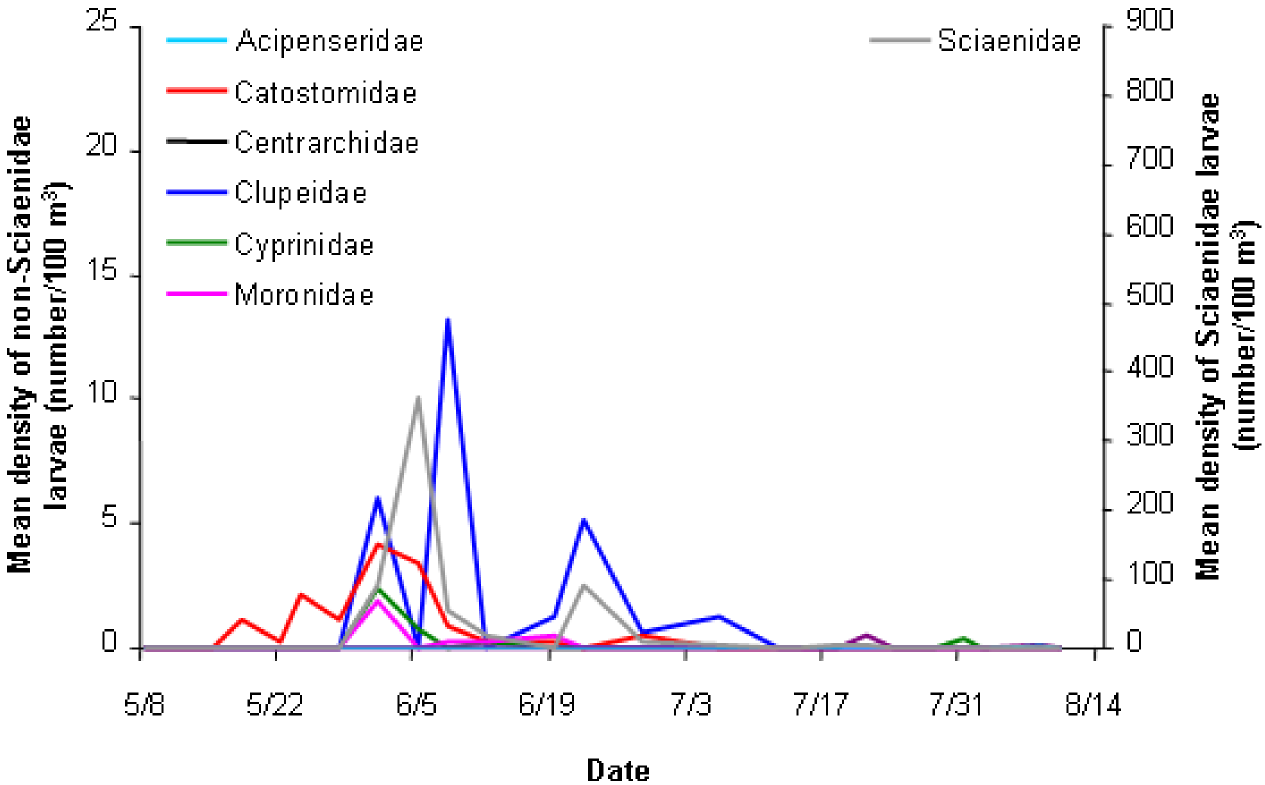

Figure E19. Mean density (number/100 m^3) by date of larval fishes collected in the Missouri River upstream from the James River (bend 7) in 2006.

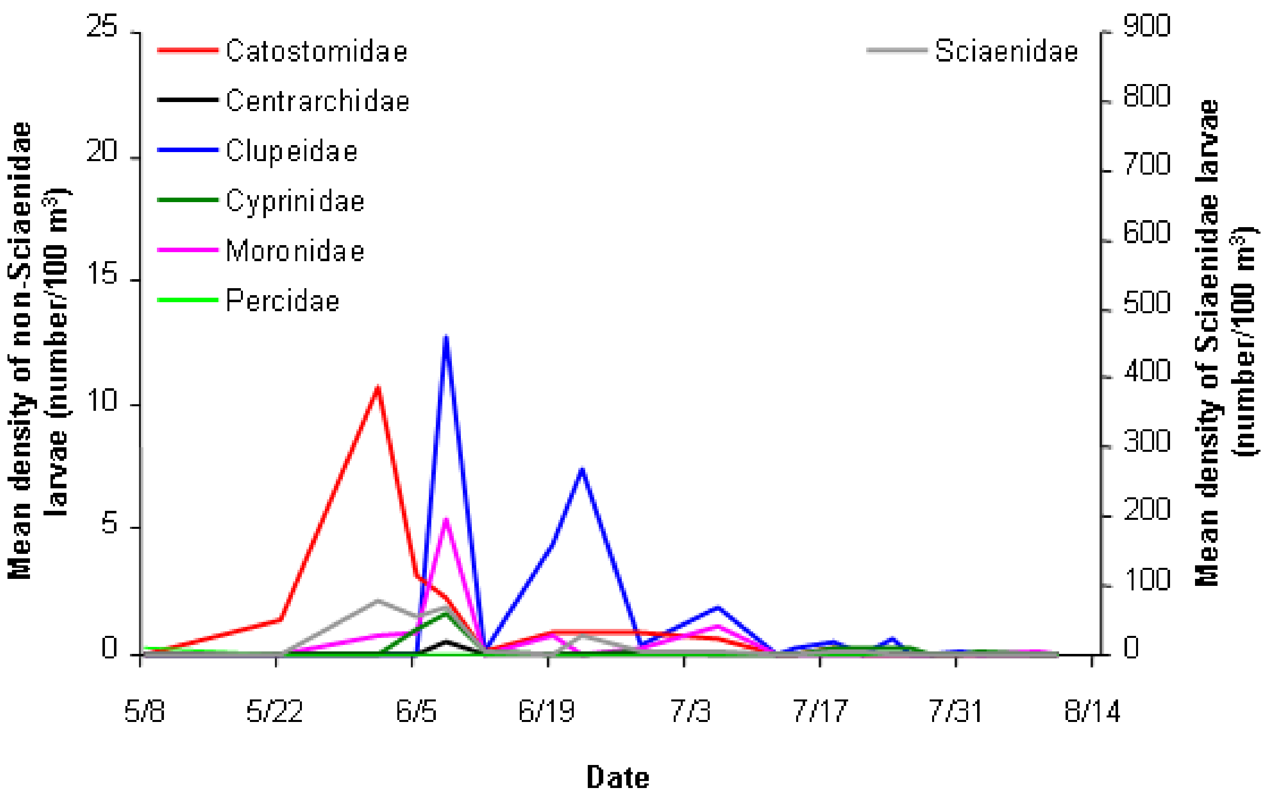

Figure E20. Mean density (number/100 m^3) by date of larval fishes collected in the Missouri River downstream from the James River (bend 11) in 2006.

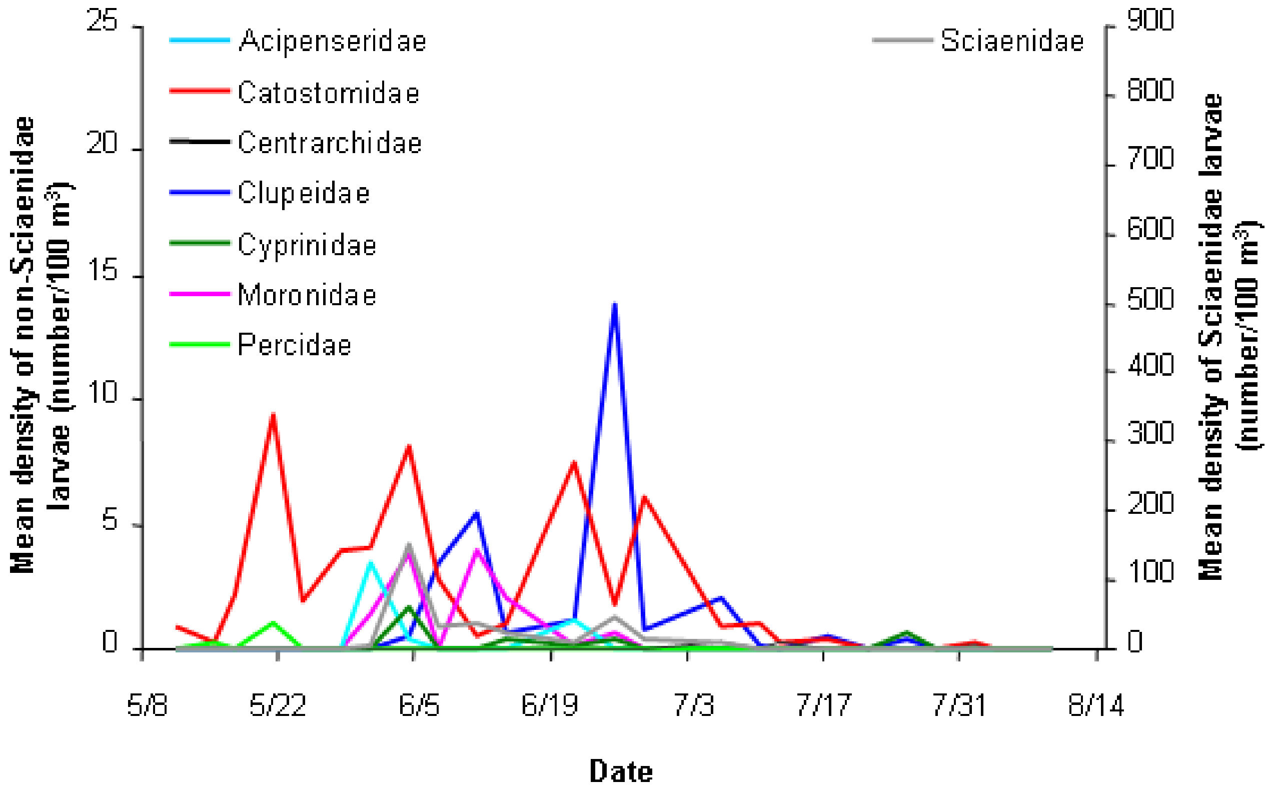

Figure E21. Mean density (number/100 m^3) by date of larval fishes collected in the Missouri River upstream from the Vermillion River (bend 17) in 2006.

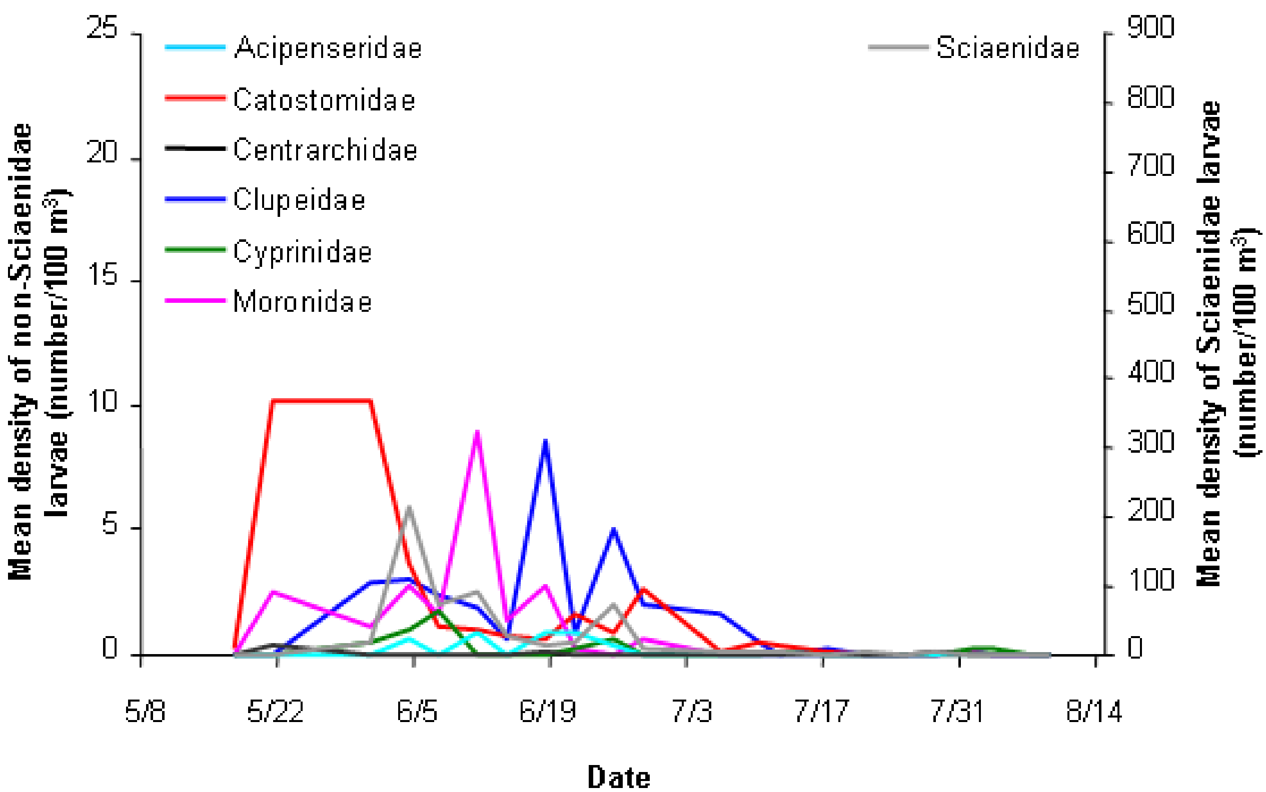

Figure E22. Mean density (number/100 m^3) by date of larval fishes collected in the Missouri River downstream from the Vermillion River (bend 20) in 2006.

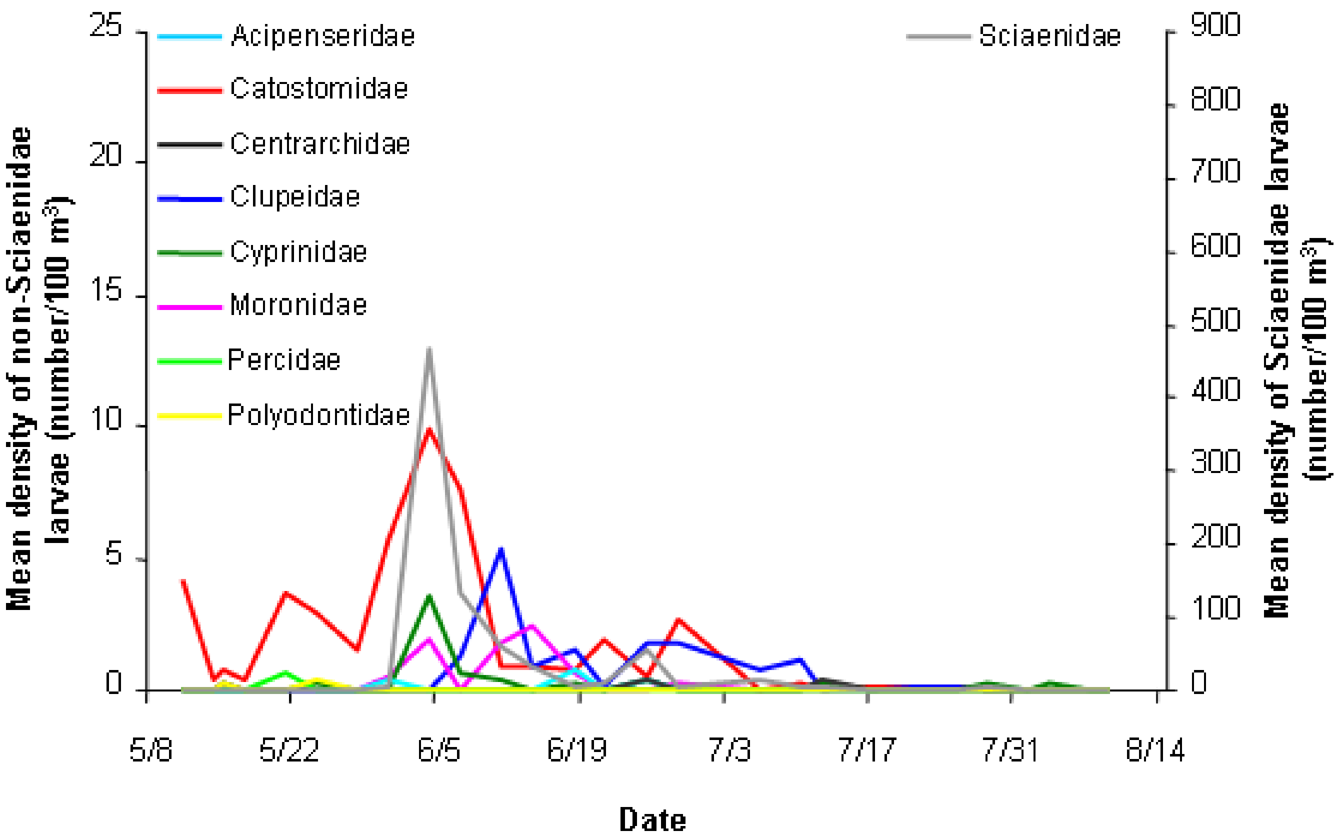

Figure E23. Mean density (number/100 m^3) by date of larval fishes collected in the Missouri River downstream from the boat ramp at Ponca State Park (bend 30) in 2006.

Table E1. River bends and associated river miles (RM) where trammel nets were drifted to sample shovelnose sturgeon (total) and gravid shovelnose sturgeon (gravid) in the Missouri National Recreational River reach below Gavins Point Dam.

[Bends 1, 3, and 4 were targeted sample locations where coarse substrates were present and egg mats were deployed. Random bends were selected every week from an upper segment (bends 1–6) and lower segment (bends 7–12). Mean drift distance, number of shovelnose sturgeon per net, and catch-per-unit effort (CPUE) with standard errors (SE) are presented]

			Mean drift distance (SE)		Number of shovelnose sturgeon		Mean number of shovelnose sturgeon captured per net (SE)		Mean CPUE (SE)	
Bend	RM	Number of nets	feet	meters	Total	Gravid	Total	Gravid	Total	Gravid
1	811	218	348 (11.8)	106 (3.6)	27	2	0.12 (0.03)	0.01 (0.01)	0.11 (0.03)	0.01 (0.01)
2	810	44	469 (38.7)	143 (11.8)	14	3	0.32 (0.11)	0.07 (0.05)	0.23 (0.08)	0.03 (0.02)
3	808	234	472 (18.4)	144 (5.6)	290	33	1.24 (0.18)	0.14 (0.04)	0.80 (0.12)	0.09 (0.02)
4	806	236	361 (11.2)	110 (3.4)	251	13	1.06 (0.16)	0.05 (0.02)	1.21 (0.22)	0.07 (0.03)
5	803	41	469 (39.4)	143 (12.0)	9	2	0.22 (0.15)	0.05 (0.03)	0.26 (0.16)	0.06 (0.04)
6	802	24	345 (30.2)	102 (9.2)	18	5	0.75 (0.28)	0.21 (0.10)	0.74 (0.27)	0.23 (0.13)
7	801	16	367 (40.4)	112 (12.3)	2	1	0.13 (0.09)	0.06 (0.06)	0.10 (0.07)	0.04 (0.04)
8	799	48	439 (36.7)	134 (11.2)	59	7	1.23 (0.60)	0.15 (0.08)	1.17 (0.52)	0.27 (0.18)
9	798	40	407 (39.0)	124 (11.9)	14	3	0.35 (0.15)	0.08 (0.04)	0.38 (0.20)	0.09 (0.05)
10	797	32	541 (56.8)	165 (17.3)	5	1	0.16 (0.10)	0.03 (0.03)	0.07 (0.04)	0.01 (0.01)
11	795	28	574 (46.6)	175 (14.2)	8	3	0.29 (0.15)	0.11 (0.08)	0.25 (0.14)	0.09 (0.07)
12	793	36	479 (40.7)	146 (12.4)	12	0	0.33 (0.11)	0.00 (0.00)	0.23 (0.08)	0.00 (0.00)
Total		997	413 (7.5)	126 (2.3)	709	73	0.71 (0.7)	0.07 (0.01)	0.63 (0.07)	0.07 (0.01)

Table E2. Reproductive stage of female and male shovelnose sturgeon collected from May 2001 through June 2002.

[number of samples (N), fork length (FL) range, mean relative weight (Wr) index values, with 95 percent (%) confidence intervals and range, and percent of fish with Wr greater than (>) 86. All data are from Wildhaber and others (2005)]

Reproductive stage	N	FL range (mm)	Mean Wr	95% CI Wr	Wr range	% of fish with Wr > 86
			Females			
1	12	317–668	75	72.0–77.9	68.5–83.5	0
2	47	443–732	78.6	75.8–81.3	51.8–98.4	13
3	30	552–725	82.1	78.4–85.9	67.4–114.8	20
4	21	547–730	83.9	80.6–87.2	69.5–99.8	33
5	43	542–760	90.9	87.5–94.4	73.5–118.5	56
6	3	588–710	81.7	50.6–112.8	68.2–92.9	33
			Males			
1	5	480–603	75.0	58.3–91.6	60.2–91.3	20
2	47	404–704	76.3	73.7–78.9	56.3–103.3	13
3	41	536–666	83.5	80.9–86.2	71.9–113.7	32
4	34	486–740	82.1	79.1–85.0	67.8–107.3	26
5	45	534–795	84.1	81.4–86.8	65.4–107.9	29
6	15	577–671	80.6	74.4–86.7	62.5–106.8	20

Table E3. Description of larval fish sampling sites for 2006 in the Missouri National Recreational River reach below Gavins Point Dam.

[Duplicate samples were collected in inside bend (ISB) and outside bend (OSB) macrohabitats at both bottom (B) and midwater (M) locations in the water column]

Larval fish sampling site	Bend	Approximate river mile (RM)	Macrohabitat	Replicates	Net location	Total number of samples collected	Samples processed	Samples remaining to be processed
Downstream from Gavins Point Dam	2	810	ISB/OSB	2	B/M	192	124	68
Downstream of Riverside Park	4	806	ISB/OSB	2	B/M	204	138	66
Upstream of James River	7	801	ISB/OSB	2	B/M	200	133	67
Downstream of James River	11	795	ISB/OSB	2	B/M	164	104	60
Upstream of Vermillion River	17	775	ISB/OSB	2	B/M	200	126	74
Downstream of Vermillion River	20	769	ISB/OSB	2	B/M	176	110	66
Downstream from Ponca State Park	30	753	ISB/OSB	2	B/M	213	138	75

Table E4. Mean catch-per-unit effort (CPUE; with standard errors in parentheses) of shovelnose sturgeon sampled with drifting trammel nets at targeted bends and randomly selected bends from upper (bends 1–6) and lower (bends 7–12) segments of the Missourri National Recreational River reach below Gavins Point Dam during five flow periods in 2006.

[Flow periods are described in fig. E8. --, no data]

Site	Flow period				
	Winter	March pulse	Interpulse	May pulse	Summer
Targeted Bends					
Bend 1	0.00 (0.00)	--	0.17 (0.09)	0.09 (0.06)	0.06 (0.03)
Bend 3	2.35 (0.87)	0.42 (0.42)	0.78 (0.27)	0.95 (0.33)	0.59 (0.12)
Bend 4	3.89 (1.97)	0.00 (0.00)	2.70 (0.49)	0.55 (0.16)	0.05 (0.03)
Total	2.66 (0.90)	0.19 (0.19)	1.25 (0.22)	0.52 (0.12)	0.24 (0.05)
Random Bends					
Upper segment	0.81 (0.38)	0.00 (0.00)	1.08 (0.40)	0.58 (0.15)	0.21 (0.06)
Lower segment	0.15 (0.11)	0.65 (0.55)	0.79 (0.41)	0.65 (0.42)	0.20 (0.06)
Total	0.52 (0.23)	0.39 (0.33)	0.95 (0.29)	0.61 (0.18)	0.20 (0.04)

Table E5. Mean catch-per-unit effort (CPUE; with standard errors in parentheses) of gravid shovelnose sturgeon sampled with drifting trammel nets at targeted bends and randomly selected bends from upper (bends 1–6) and lower (bends 7–12) segments of the Missouri National Recreational River reach below Gavins Point Dam during five flow periods in 2006.

[Flow periods are described in fig. E8. --, no data]

Site	Winter	Flow period			
		March pulse	Interpulse	May pulse	Summer
Targeted Bends					
Bend 1	0.00 (0.00)	--	0.04 (0.03)	0.00 (0.00)	0.00 (0.00)
Bend 3	0.04 (0.04)	0.00 (0.00)	0.12 (0.05)	0.12 (0.05)	0.05 (0.03)
Bend 4	0.28 (0.28)	0.00 (0.00)	0.13 (0.05)	0.11 (0.07)	0.00 (0.00)
Total	0.13 (0.11)	0.00 (0.00)	0.10 (0.03)	0.08 (0.03)	0.02 (0.01)
Random Bends					
Upper segment	0.15 (0.10)	0.00 (0.00)	0.04 (0.04)	0.15 (0.07)	0.02 (0.01)
Lower segment	0.00 (0.00)	0.11 (0.11)	0.16 (0.07)	0.25 (0.21)	0.01 (0.01)
Total	0.08 (0.06)	0.07 (0.07)	0.09 (0.04)	0.18 (0.09)	0.02 (0.01)

Table E6. Total number of sturgeon tagged and recaptured at the same bend at least once during five flow periods in 2006.

Site	Winter	March pulse	Interpulse	May pulse	Summer
Bend 3	1	0	2	1	10
Bend 4	1	0	6	3	0
Bend 9	0	0	0	0	1
Total	2	0	8	4	11

Table E7. Number (N) and frequency (%) of larval fishes collected at seven sites in the Missouri National Recreational River reach below Gavins Point Dam in 2006.

[The symbol "T" means less than 0.1%]

Taxon	Downstream from Gavins Point Dam (bend 2)		Downstream from Riverside Park (bend 4)		Upstream from James River (bend 7)		Downstream from James River (bend 11)		Upstream from Vermillion River (bend 17)		Downstream from Vermillion River (bend 20)		Downstream from Ponca State Park (bend 30)	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Catostomidae	11	0.42	56	3.93	23	1.79	43	5.82	122	11.20	60	3.50	93	6.20
Centrarchidae	4	0.15	1	T	3	0.23	1	0.14	3	0.28	3	0.17	4	0.27
Sciaenidae	2,427	92.11	1,210	84.91	1,179	91.54	543	73.48	822	75.48	1,447	84.32	1,305	87.00
Percidae	0	T	4	0.28	0	0.00	1	0.14	2	0.18	0	T	2	0.13
Clupeidae	124	4.71	126	8.84	66	5.12	104	14.07	91	8.36	119	6.93	49	3.27
Cyprinidae	23	0.87	7	0.49	7	0.54	13	1.76	10	0.92	13	0.76	13	0.87
Moronidae	38	1.44	27	1.89	6	0.47	24	3.25	26	2.39	52	3.03	19	1.27
Ictaluridae	0	0.00	0	0.00	0	0.00	0	0.00	1	T	0	T	0	T
Acipenseridae	0	0.00	0	0.00	1	T	0	0.00	13	1.19	12	0.70	4	0.27
Polyodontidae	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	T	2	0.13
Unidentified due to damage	7	0.27	7	0.49	3	0.23	9	1.22	5	0.46	12	0.70	8	0.53
Total larvae	2,635		1,425		1,288		739		1,089		1,716		1,500	

Table E8. Total number (N), mean density (number/100 m^3), median density, minimum density (min), maximum density (max), mean total length (mm), and total length range of larval sturgeon (*Scaphirhynchus* spp.), by date, collected in the Missouri River upstream from the James River (bend 7) in 2006.

Date	N	Density (number of larvae/100 m^3)				Total length (mm)	
		Mean	Median	Min	Max	Mean	Range
5/8/2006							
5/15/2006							
5/18/2006							
5/22/2006							
5/24/2006							
5/28/2006							
6/1/2006							
6/5/2006							
6/8/2006							
6/12/2006							
6/19/2006							
6/22/2006							
6/28/2006							
7/6/2006							
7/12/2006							
7/14/2006							
7/18/2006							
7/21/2006							
7/24/2006							
7/26/2006							
7/28/2006							
7/31/2006							
8/2/2006							
8/8/2006	1	0.14	0.00	0.00	0.99	8.02	8.02
8/10/2006							

Table E9. Total number (N), mean density (number/100 m³), median density, minimum density (min), maximum density (max), mean total length (mm), and total length range of larval sturgeon (Scaphirhynchus spp.), by date, collected in the Missouri River upstream from the Vermillion River (Bend 17) in 2006.

		Density (number of larvae/100 m³)				Total length (mm)	
Date	N	Mean	Median	Min	Max	Mean	Range
5/11/2006							
5/15/2006							
5/17/2006							
5/21/2006							
5/24/2006							
5/28/2006							
5/31/2006	5	4.35	0.00	0.00	17.40	8.52	7.22–9.58
6/4/2006	1	0.38	0.00	0.00	1.53	7.57	7.57
6/7/2006							
6/11/2006							
6/14/2006							
6/21/2006	7	1.35	1.04	0.00	4.36	9.25	7.97–11.30
6/25/2006							
6/28/2006							
7/6/2006							
7/10/2006							
7/12/2006							
7/17/2006							
7/21/2006							
7/25/2006							
7/28/2006							
8/1/2006							
8/3/2006							
8/7/2006							
8/9/2006							

Table E10. Total number (N), mean density (number/100 m^3), median density, minimum density (min), maximum density (max), mean total length (mm), and total length range of larval sturgeon (Scaphirhynchus spp.), by date, collected in the Missouri River downstream from the Vermillion River (Bend 20) in 2006.

Date	N	Density (number of larvae/100 m^3)				Total length (mm)	
		Mean	Median	Min	Max	Mean	Range
5/17/2006							
5/21/2006							
5/31/2006							
6/4/2006	1	0.57	0.00	0.00	2.27	8.22	8.22
6/7/2006							
6/11/2006	2	0.87	0.87	0.00	1.76	8.31	7.87–8.76
6/14/2006							
6/18/2006	3	0.85	0.44	0.00	2.51	8.30	7.66–9.43
6/21/2006	5	1.01	1.00	0.00	2.82	9.12	8.09–10.01
6/25/2006	1	0.39	0.00	0.00	1.58	9.35	9.35
6/28/2006							
7/6/2006							
7/10/2006							
7/12/2006							
7/17/2006							
7/21/2006							
7/25/2006							
7/28/2006							
8/1/2006							
8/3/2006							
8/7/2006							
8/9/2006							

Table E11. Total number (N), mean density (number/100 m^3), median density, minimum density (min), maximum density (max), mean total length (mm), and total length range of larval sturgeon (Scaphirhynchus spp.), by date, collected in the Missouri River downstream from the boat ramp at Ponca State Park (Bend 30) in 2006.

[NA means not available because of specimen being damaged]

		Density (number of larvae/100 m^3)				Total length (mm)	
Date	N	Mean	Median	Min	Max	Mean	Range
5/11/2006							
5/14/2006							
5/15/2006							
5/17/2006							
5/21/2006							
5/24/2006							
5/28/2006							
5/31/2006	1	0.48	0.00	0.00	1.92	7.87	7.87
6/4/2006							
6/7/2006							
6/11/2006							
6/14/2006							
6/18/2006	2	0.98	0.00	0.00	3.92	7.92	7.35–8.48
6/21/2006							
6/25/2006	1	0.35	0.00	0.00	1.41	NA	NA
6/28/2006							
7/6/2006							
7/10/2006							
7/12/2006							
7/17/2006							
7/21/2006							
7/25/2006							
7/28/2006							
8/1/2006							
8/3/2006							
8/7/2006							
8/9/2006							

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Rolla Publishing Service Center
1400 Independence Road
Rolla, MO 65401
For more information concerning this publication, contact:
Director
U.S. Geological Survey
Columbia Environmental Research Center
4200 New Haven Road
Columbia, MO 65201
(573) 875–5399
Or visit the Columbia Environmental Research Center website at:
http://www.cerc.usgs.gov

Water Quality and Hydrology

By Dale W. Blevins, Roy Bartholomay, Kathleen Neitzert, David Rus, Richard Wilson, Michael Andersen, Rich Kopish, and Roger Haschemeyer

Chapter F of

Factors Affecting the Reproduction, Recruitment, Habitat, and Population Dynamics of Pallid Sturgeon and Shovelnose Sturgeon in the Missouri River

Edited by Carl E. Korschgen

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Water Quality and Hydrology

By Dale W. Blevins, Roy Bartholomay, Kathleen Neitzert, David Rus, Richard Wilson, Michael Andersen, Rich Kopish, and Roger Haschemeyer

Introduction and Background

Increasing discharge and water temperatures have been identified as the most likely variables cuing the movement and spawning of sturgeon (S*caphrynchus*) in the Missouri River. Other water properties—such as velocity, stage, turbidity, dissolved oxygen, and pH—also are components of sturgeon habitat and are likely to have important roles in the movement, spawning, and survival of sturgeon. Therefore, flow and water-quality parameters are essential variables to be monitored during the study of sturgeon and river ecosystems. In 2006, 11 continuous real-time water-quality monitors and an acoustic Doppler velocity meter were installed on the Missouri River and operated for nearly 9 months. The effort in this first year of the study was focused on installing instruments at existing gaging stations with data collection platforms (DCPs) to collect continuous flow and water-quality data on a real-time basis and on transmitting the data by satellite to the U.S. Geological Survey's (USGS) National Water Information System (NWIS) for distribution on the Internet. Data corrections, compilations, and quality assurance were completed through September 30, 2006. This initial dataset provides some insight into the relations between water quality, flow, and flow sources. Interpretation of the data or attempts to correlate water-quality data with sturgeon or other biological data were not part of the 2006 study effort. Interpretative activities to characterize water quality and to investigate the relations between water quality, sturgeon, and ecosystem response are planned for 2007 through 2010.

Objectives

The water-quality and hydrology objectives of Spring Rise Flow Modification (SRFM) program on the Missouri River in 2006 were as follows:

1. Install and operate 11 real-time water-quality monitors at 11 gaging stations from Yankton, S. Dak. to Hermann, Mo.

2. Upgrade the stage-only gage at Ponca, Nebr. with a continuous real-time water-quality monitor and a velocity, discharge, and suspended-sediment measurement station using a "side-looking" acoustic Doppler velocity meter (ADVM).

3. Archive all water-quality and discharge data in appropriate computer databases and distribute the information on an unrestricted basis.

4. Provide descriptions of data collection methods and results. This chapter and the 2006 Water Resources Data Reports for Missouri, Iowa, Nebraska, and South Dakota (available in May 2007 at *http://water.usgs.gov*) will fulfill this objective.

Study Area and Methods

Real-time water-quality monitors were installed at 11 sites on the main stem of the Missouri River and near the mouths of the James and Vermillion Rivers in South Dakota (fig. F1). These sites were all collocated with USGS or U.S. Army Corps of Engineers (USACE) stage or discharge gaging stations. The gage at Ponca, Nebr. was upgraded from a stage-only station to a real-time water-quality, discharge, and suspended-sediment monitoring station with a side-looking ADVM.

All sites were equipped with YSI Model 6600 EDS (YSI Inc., Yellow Springs, Ohio) water-quality monitors and satellite telemetry to provide water-quality data in real time on the Internet. Four sites were installed on bridges that required the installation of dual polyvinyl chloride conduit pipes on bridge piers extending about 100 ft from the bridge deck to several feet below the water surface. The remaining sites were installed on riverbanks with underground conduits connecting the gage house to the monitors below the water surface. All monitors were protected by PVC pipe with holes drilled in the pipe to provide adequate water exchange between the river and the interior of the pipe. Installation was according to specifications provided by the manufacturer (YSI) and to USGS standards (Wagner and others, 2006).

Temperature, turbidity, dissolved oxygen, specific conductance, and pH were collected at 15-minute intervals at all 11 sites according to methods described in Wagner and others

(2006). Uniform data-collection methods and data comparability were ensured through use of standardized USGS methods and training of field technicians. Calibrations and instrument servicing were conducted at approximately 2-week intervals except when real-time monitoring of the data indicated that more frequent visits were needed. Near the end of the water year, several of the dissolved-oxygen membrane probes were replaced with new luminescent probes. These new nonmembrane probes may extend the time between servicing by as much as a week at some stations, reducing the cost of operation and maintenance. Data were automatically archived in the USGS NWIS database and are now accessible to the pubic through the NWIS Website (*http://waterdata.usgs.gov/nwis*). Data were processed in the USGS Automatic Data Processing System (ADAPS) and evaluated according to quality assurance criteria described in Wagner and others (2006). All field water-quality procedures and data-collection activities are technically reviewed every 3 years by USGS water-quality specialists from around the United States for adherence to standard procedures and uniformity among field offices.

At the Ponca gaging station (fig. F1, station 06479097), a multicomponent data-collection platform (DCP) was constructed in the spring of 2006. Previously, this stage-only gage was operated by the USACE. This site is located at the downstream end of the 59-mi reach of the Missouri National Recreational River that stretches from Gavins Point Dam to Ponca State Park in Nebraska. This 59-mi reach is the farthest downstream section of the Missouri River that is not channelized and it is thought to provide habitat for threatened and endangered species. Data collection activities at the Ponca gage included the following:

1. *Real-time water-quality monitoring* identical to efforts at the other 10 gages.

2. *Flow measurements* including stage, velocity, and discharge on a continuous and real-time basis. A Design Analysis H-522 DCP and high-speed Geosynchronous Orbit Environmental Satellite (GOES) Transmitter were installed. A SonTek 0.5MHz Long-Range Argonaut Side-Looking ADVM (fig. F2) was installed to collect stream flow characteristics. The DCP was programmed to log at 15-minute intervals and transmit every hour. Logged data include date, time, stage, signal to noise ratio (SNR), stream velocity in the downstream direction, velocity magnitude, and cell end. The DCP operated continuously and produced an accurate record of stage and velocity. The electronic data logged (EDL) was downloaded from the DCP on every site visit and archived for future reference.

   Calibration of the Ponca gage acoustic Doppler current profiler (ADCP) equipment included measurement of equipment draft, internal diagnostics test, and compass calibration. Velocity data were collected with either a 10- or 25-cm bin cell size and a blanking distance of 25 cm. Multiple bins arranged in a vertical column or “ensemble” were measured every 0.60–1.45 seconds (depending on the water mode selected). Boat speed was maintained at or near surface water velocity (roughly 2.0 knots). Data acquisition based on boat speed and differential Global Positioning System coverage occurred approximately every 1–5 ft. At a minimum, four passes or transects of the river channel were made collecting velocity data. These data were averaged together to obtain a final discharge.

   The cross-sectional ADCP measurements of the river channel at Ponca were performed to develop a stage-area rating of the site. Final ADCP discharge measurement values were used to calibrate the ADVM stage-area rating to develop an index-velocity rating for the site. The index-velocity rating is used to identify correlations between the velocities in subsections of river to the measured discharge. If successful, the ADVM is able to accurately measure velocity, stage, and therefore discharge (fig. F3). The ADVM may also be used to measure acoustic backscatter data that can be used to estimate suspended-sediment concentrations. The SonTek ADVM was mounted to a shuttle (fig. F4) on an 8-inch by 8-inch steel I-beam track system anchored to the ground. The I-beam measured 37 ft in length and was anchored to the slope of the river channel such that the lower portion of the shuttle remained below water level and the upper portion entered a 48-inch culvert set in a vertical position. The ADVM was initially programmed to collect data in a portion of the river measuring 6.56 ft by 6.56 ft and extending out 52.5 ft into the river channel from the instrument. On June 26, the cell end was extended to 150 ft and reprogrammed into the ADVM to allow the measurement of a greater percentage of the river flow. The ADVM was programmed to measure data once every 15 minutes and average the measurement over a 3-minute period. The ADVM has built-in memory that records a number of parameters for quality assurance. These data were downloaded on every site visit and archived for future reference.

   Standard discharge measurements were made from a boat using a Rio Grande 1200-KHz ADCP. The ADCP was deployed off the side or through the hull of a 20-ft Clark boat. Gage height and velocity profiles were logged into a ruggedized field computer running WinRiver software version 10.14 (fig. F5). Compass calibrations and an internal diagnostics test were performed before each measurement. Geospatial horizontal positioning of the ADCP was obtained using a Trimble Ag132 12-channel differentially corrected Global Positioning System (DGPS). The antenna for the DGPS was mounted directly over the bathymetric transducer. Channel geometry was collected using a survey grade echosounder and transducer. Equipment setup, calibration and data collection procedures complied with guidelines of the U.S. Army Corps of Engineers (2002). An Innerspace 456 single frequency (200-KHz) echosounder coupled with an 8° beam transducer was mounted directly in front of the ADCP. An Innerspace 443A velocity profiler was used to measure and record speed-of-sound profiles in the water column for calibration of the bathymetric echosounder.

3. *Suspended-sediment sampling* was conducted with a DH-95 suspended sediment sampler according to the guidelines outlined by Wilde and others (1999). The DH-95 is a depth-integrating suspended sampler that continuously collects a representative sample from a river while transiting a vertical at a constant rate (Davis and others, 2005). Suspended-sediment samples were collected from 10 vertical transits using the equal-width-increment (EWI) method. The EWI method requires the equal spacing of each vertical transit along with a constant transit rate of each vertical to yield a sample that is proportional to the total river flow (Edwards and Glysson, 1999). The DH-95 was suspended from a reel attached to a crane base mounted to a boat. The sample was collected along the same river transect as the ADCP measurement near the Ponca gage. River water from each vertical was composited in a churn, and a subsample was submitted for analysis.

Results and Discussion

Temperature, turbidity, dissolved-oxygen, specific conductance, pH, stage, and discharge data were collected at 15-minute intervals at all 11 sites from March through the end of September 2006. Less than 5 percent of all data was missed because of instrument malfunction, environmental conditions, or human error. All data collected in the most recent 31 days are available in real time on the USGS Water Resource Real-Time Web pages *(http://waterdata.usgs.gov/usa/nwis/rt);* however, in order to make access to real-time data easier for those interested in the Missouri River water quality, a special Web page, titled Missouri River Water Information Portal (MOR-WIP) was created to make quicker and easier access to the data (fig. F1; *http://ne.water.usgs.gov/missouririverwq/index.html).* This Web page shows the location of every real-time station on the main stem of the lower Missouri River as well as the locations of real-time stations near the mouths of major tributaries. All 11 continuous water-quality sites, discharge-only sites, and water-sampling sites are shown on the Web-page map. Clicking on a station will automatically bring up real-time data for that station.

The spring rise pulse from Gavins Point Dam on May 12–13, 2006, increased the stage at Yankton, S. Dak. and Ponca, Nebr. 2–3 ft (figs. F5 and F6), with smaller subsequent releases occurring every few days through the end of the month. From St. Joseph, Mo. downstream, the rise was attenuated to 1.5 ft or less. Consequently, water-quality responses were not expected to be large. Graphs of temperature (figs. F6 and F7) during the May release indicate a corresponding rise in water temperature of about 10 °C. An earlier rise with a colder temperature increase of similar magnitude occurred in late March and early April (fig. F6) at Yankton, S. Dak. Therefore, it may be difficult to distinguish whether river flow or temperature rise was more important to sturgeon migration. Monthly-mean water temperatures at main stem gages (table F1) generally increased with decreasing latitude. Water temperatures at the tributary gages on the James River at Scotland, S. Dak. and the Vermillion River at Vermillion, S. Dak. were higher than than those at the Yankton gage in March, April, and May, thus contributing to a quicker temperature increase downstream and providing a warmer refuge earlier in the spring. Maximum water temperatures were above 32°C for a few days during July downstream from Nebraska City, Nebr. Ecological effects of these high temperatures on pallid sturgeon (*scaphrynchus albus*) from the lower Missouri River and many other river species has not been documented. Diurnal fluctuations of about 1°C were commonly observed (fig. F7) at most gages.

Turbidity was generally the lowest of any gage in releases from Gavins Point Dam (as measured at Yankton). The ongoing releases of clear water from Gavins Point Dam from May 12 to June 15, 2006 caused little change in maximum or mean turbidity compared to previous and subsequent months at Yankton, S. Dak. (table F2). Monthly-mean turbidities at Ponca were similar to those at Yankton, but natural rises from downstream tributaries, including the James and Vermillion Rivers, caused large increases in turbidity (figs. F7, F8, and F9). This difference in turbidities between clear Gavins Point Dam releases and natural rises could be important if turbidity plays a role in the spawning, migration, or survival of juvenile river sturgeon. Frequently, small natural rises on the Missouri River caused equivalent or larger increases in turbidity as large rises (figs. F8 and F9). Specific conductance, turbidity, and other water quality parameters at Ponca, Nebr. varied more before the May rise and the initiation of navigation season than it varied after these flow increases, probably because reservoir water quality discharged from Gavins Point Dam is more stable than water quality from tributaries between Gavins Point and Ponca.

Dissolved-oxygen concentrations decreased to values less than the water-quality standard of 5 mg/L during several natural rises in the summer (fig. F7 and table F3) at several downstream gages, but, releases from Gavins Point Dam did not substantially decrease dissolved-oxygen concentrations, as the minimum concentration at the Yankton gaging station was 6.4 mg/L. Dissolved-oxygen concentrations as low as 3.8 mg/L were measured at St. Joseph, Mo. in August. Historically, dissolved-oxygen concentrations less than 2.0 mg/L have been recorded. The Vermillion and James Rivers also exhibited dissolved-oxygen sags with concentrations near 0 mg/L during one rise. The effects of low dissolved-oxygen concentrations on pallid sturgeon and other important species in the Missouri River are not well documented, but limitations may be possible given that low concentrations of dissolved oxygen persisted for several days. Diurnal fluctuations of 1–2 mg/L were common at most sites during the summer (fig F7).

Specific conductance is strongly related to the concentration of dissolved solids in the Missouri River. The specific conductance of the James and Vermillion Rivers is two to three times the conductance of the Missouri River at Yankton, S. Dak. (fig. F10 and table F4). Therefore, the large spring rises of these tributaries substantially increased the conductance and concentration of dissolved ions in the reach of the Missouri River between Yankton, S. Dak. and Ponca, Nebr, in April and May (table F4 and fig. F10), but low flows from these two tributaries in June through September did not substantially increase specific conductance in the Missouri River. Specific conductance at main stem sites below Ponca was relatively stable except when tributaries rose and caused short periods of dilution (fig. F11). Generally, but not always, monthly mean conductance values decreased slightly with distance downstream of Omaha as lower conductance tributaries dilute the Missouri River. Large changes in pH generally were not observed with changes in discharge. Monthly pH data are summarized in table F5.

At the Ponca gage, 26 standard ADCP discharge measurements were made by boat from March 30 through October 12, 2006 (table F6). Measured discharges ranged from 14,800 ft^3/s on October 12, 2006, to 31,800 ft^3/s on August 3, 2006. Special emphasis was placed on obtaining measurements that coincided with flow modifications or hydrologic events. Events of special interest include moderate to extreme changes in river stage particularly at the beginning and end of the navigation season and during pulse flows such as the spring rise. All discharge measurements comply with the guidelines described in “Quality-Assurance Plan for Discharge Measurements Using Acoustic Doppler Current Profilers” (Oberg and others, 2005).

At the Ponca gage, suspended-sediment samples were collected prior to, during, and after navigation season and during the spring rise flow modifications (table F7). A goal of the study was to determine the correlations between real-time water quality, acoustic backscatter (sound waves reflected off of sediment particles back to the instrument), and suspended sediment. If a water-quality parameter or acoustic backscatter can be established as a surrogate for suspended sediment, then suspended sediment can be estimated on a continuous and real-time basis and provide time-critical information to be used to evaluate the effectiveness of flow modifications upon suspended-sediment mobilization and transport.

Because 2006 was the first year of monitoring the effects of flow releases and restoration activities on the pallid sturgeon and its habitat—which include water quality, suspended sediment, and discharge—only instrumentation and data collection were undertaken in 2006. Continued data collection and substantial interpretation are planned in future years with substantial integration with existing information on the effects of water quality on sturgeon and large-river ecosystems and biological data collected by other participants in the SRFM program. These planned interpretative activities are as follows:

1. Identify and characterize the response of selected fish species and other biological response variables to continuous and surrogate water-quality parameters.

2. Evaluate the existing continuous water-quality network for efficiency.

3. Characterize the response of continuously monitored water-quality parameters to the flow pulses released from Gavins Point Dam and natural rises on the Missouri River.

4. Characterize the sources of sediment or turbidity during rises on the Missouri River.

5. Develop surrogate regression relations for suspended sediment, total organic carbon, total nitrogen, and other constituents with existing water-sample data at selected sites. Identify new analytes that could potentially have biological significance, and add them to compounds analyzed at existing sample sites. These contaminants would likely be highly toxic, bioaccumulative, or endocrine-disrupting compounds.

6. Characterize the amount of variation and central tendencies of temporal changes in continuous water-quality parameters observed in 2006.

Summary

All sites were equipped with YSI Model 6600 EDS water-quality monitors (YSI Inc., Yellow Springs, Ohio) and deployed with existing satellite transmitters to provide water-quality data in real time on the Internet. Temperature, turbidity, dissolved oxygen, specific conductance, and pH data were collected at 15-minute intervals at all 11 sites from early March through October 2006. A stage-only gage at Ponca, Nebr. was also upgraded to a multicomponent data collection platform that included measuring the flow parameters of stage, velocity, discharge, and acoustic backscatter with a side-scan acoustic Doppler velocity meter (ADVM). In future years, acoustic backscatter data from the ADVM will be correlated with turbidity and suspended-sediment concentrations in an effort to produce continuous estimates of suspended-sediment concentrations. Data were automatically archived in the U.S. Geological Survey National Water Information System (NWIS) database and are now accessible to the public through the NWIS Web site. All continuous water-quality and discharge data will be published on the World Wide Web in

the 2006 Water Resources Data Reports for Missouri, Iowa, Nebraska, and South Dakota (available at *http://water.usgs.gov/*).

Temperature rises of about 10°C were associated with the Gavins Point Dam release in May and were near the time of the planned release in late March and early April. Consequently, it may be difficult to separate the importance of flow and temperature on sturgeon behavior. Maximum temperatures greater than 30°C occurred for several days at the lower gages and may have caused problems for power stations and stress for some fish species. The May release from Gavins Point Dam did not cause increases in turbidity, but natural rises from downstream tributaries did. This difference in turbidities between clear Gavins Point Dam releases and natural rises could be important if turbidity plays a role in the spawning, migration, or survival of juvenile sturgeon. Dissolved-oxygen concentrations decreased to values of less than the water-quality standard of 5 mg/L during natural rises in the summer at several main stem sites. The Vermillion and James Rivers also exhibited dissolved-oxygen depletion with concentrations near 0 mg/L during one rise. The effects or limitations of low dissolved-oxygen concentrations on pallid sturgeon and other important species in the Missouri River are not well documented, but effects may exist given that low concentrations of dissolved oxygen persisted for several days.

This year was the first of monitoring the effects of flow releases and restoration activities on the pallid sturgeon and its habitat. Consequently, only instrumentation and data collection was initiated in 2006. Interpretation and integration of biological data are planned to begin in late 2007.

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Figures and Tables

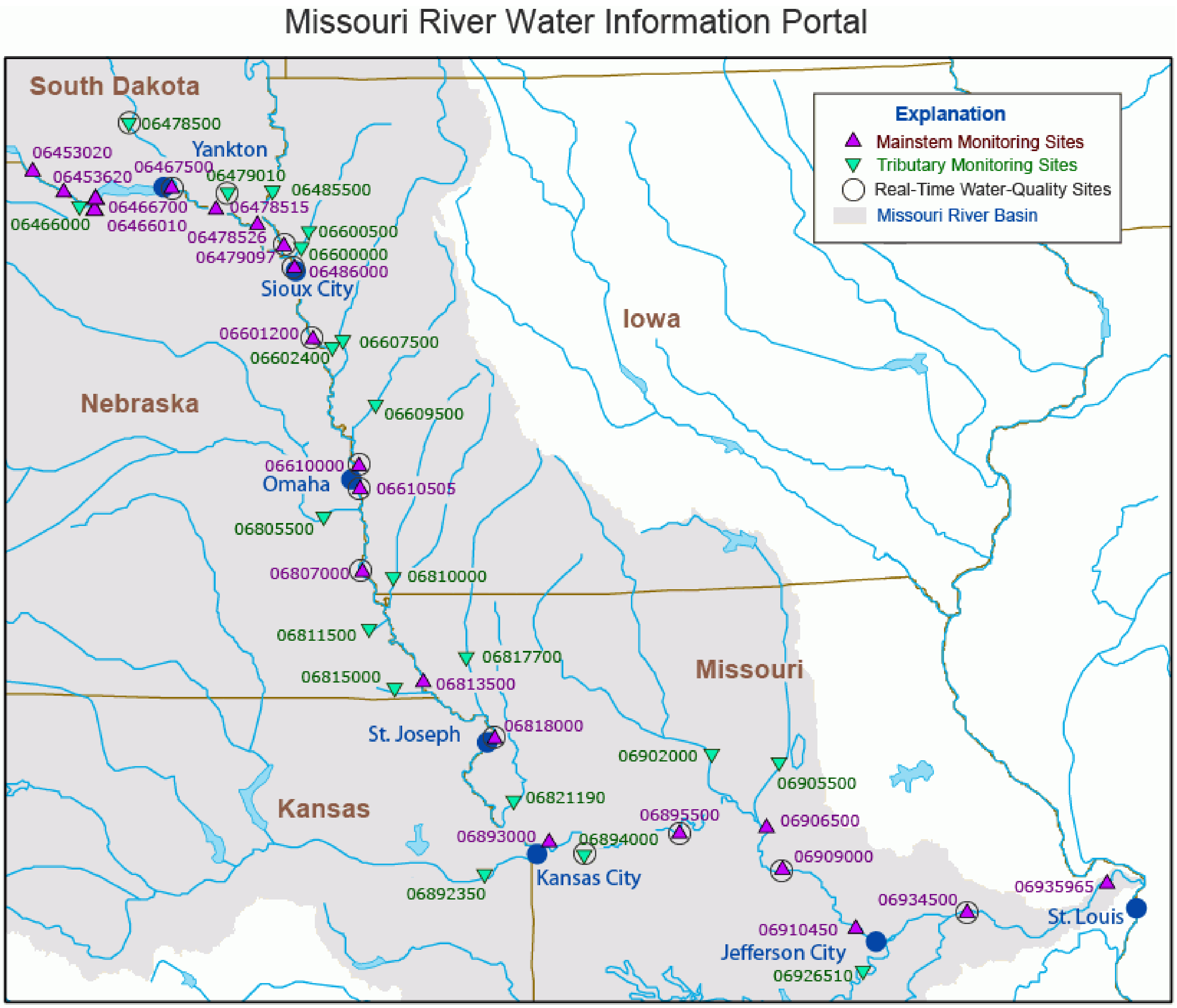

Figure F1. Missouri River Water Information Portal (MORWIP) webpage showing main stem and tributary monitoring sites in the Lower Missouri River Basin including the real-time continuous water-quality data-collection sites (*http://ne.water.usgs.gov/missouririverwq/index.html*).

Figure F2. SonTek acoustic Doppler velocity meter (Sontek/YSI incorporated, San Diego, Calif).

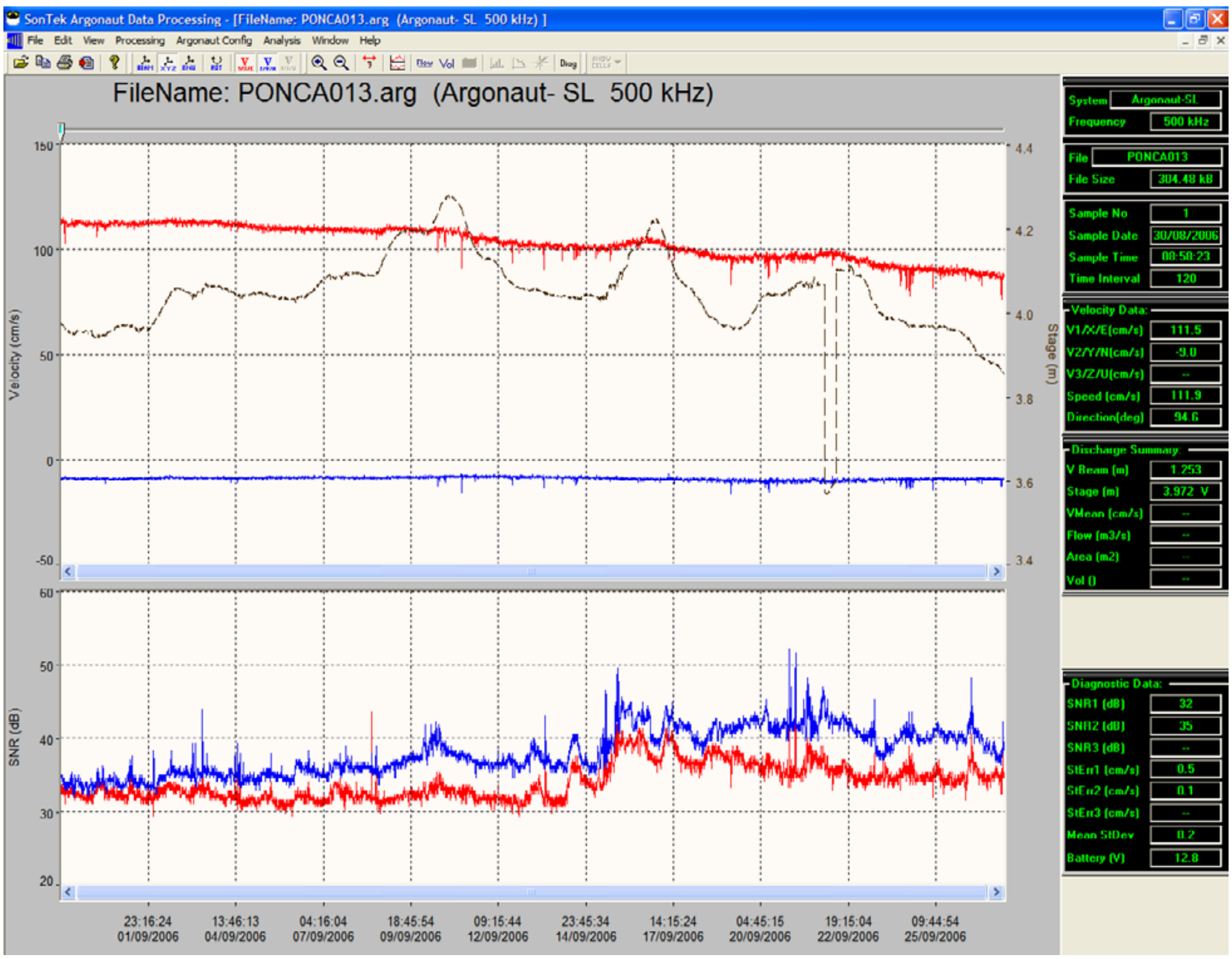

Figure F3. Output of the SonTek acoustic Doppler velocity meter (Sontek/YSI Incorporated, San Diego, Calif.).

Figure F4. SonTek shuttle at the gaging station near Ponca, Nebr.

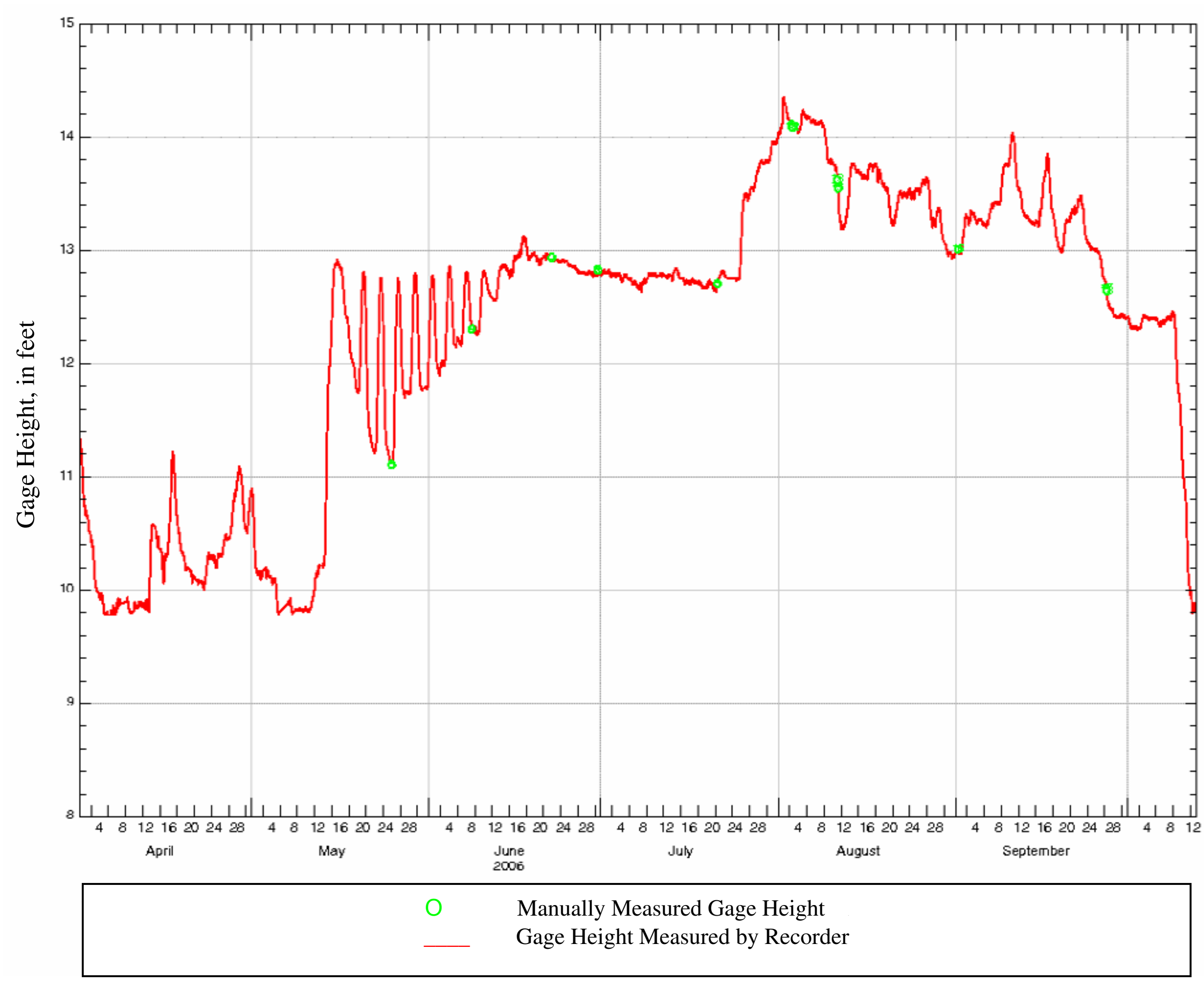

Figure F5. Gage height at Ponca, Nebr. showing the spring rise releases from Gavins Point Dam May 12–June 14, 2006.

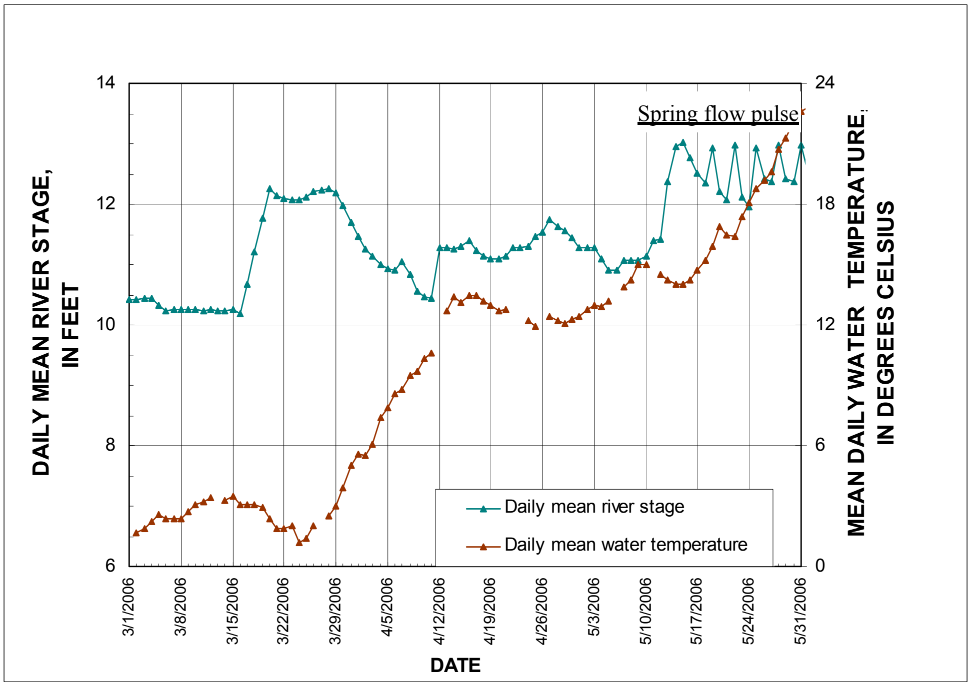

Figure F6. River stage and water temperature of the Missouri River at Yankton, S. Dak.

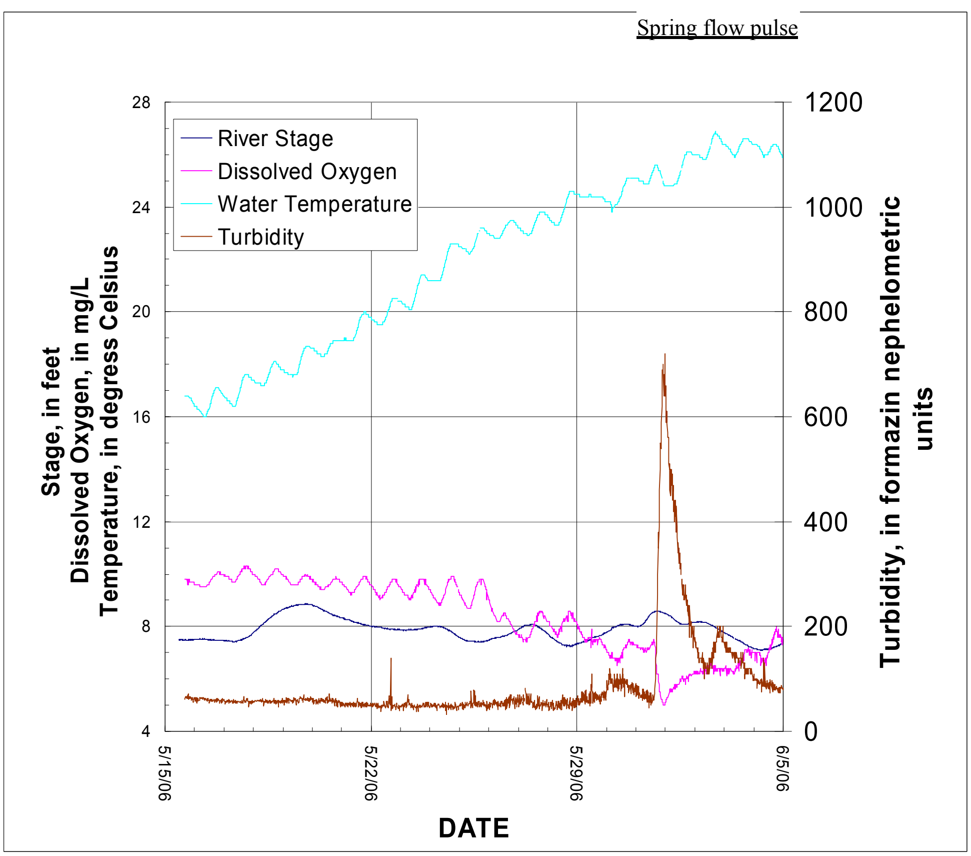

Figure F7. River stage, dissolved oxygen, water temperature, and turbidity with time during the spring flow pulse (released from Gavins Point Dam May 12 to June 15, 2006) at St. Joseph, Mo.

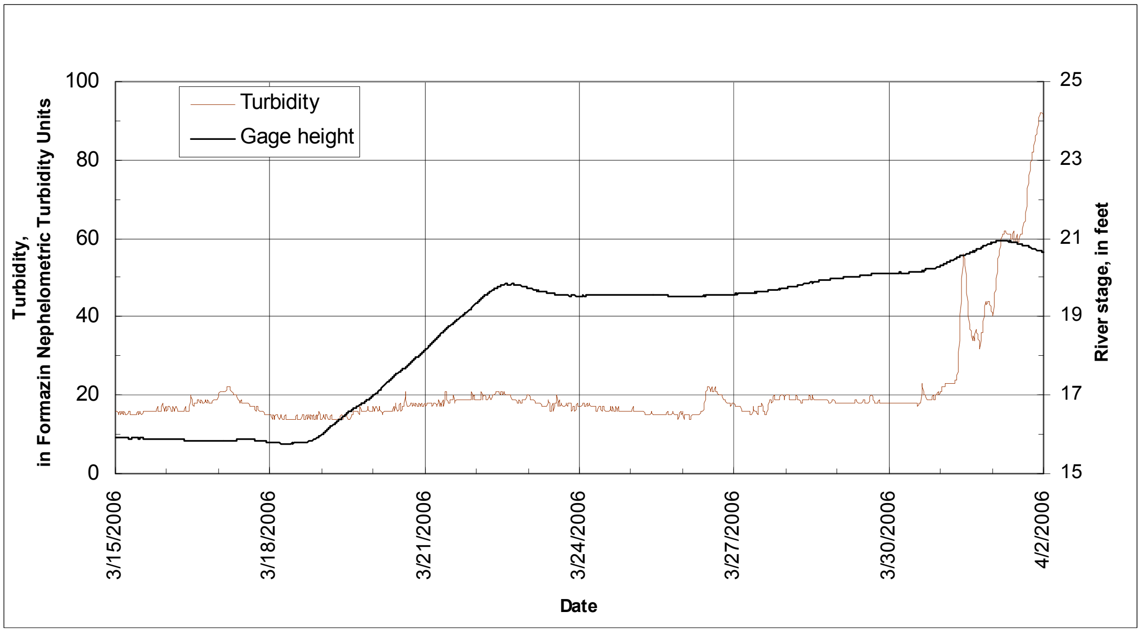

Figure F8. Turbidity and river stage at Decatur, Iowa, showing no increase in turbidity associated with a release from Gavins Point Dam.

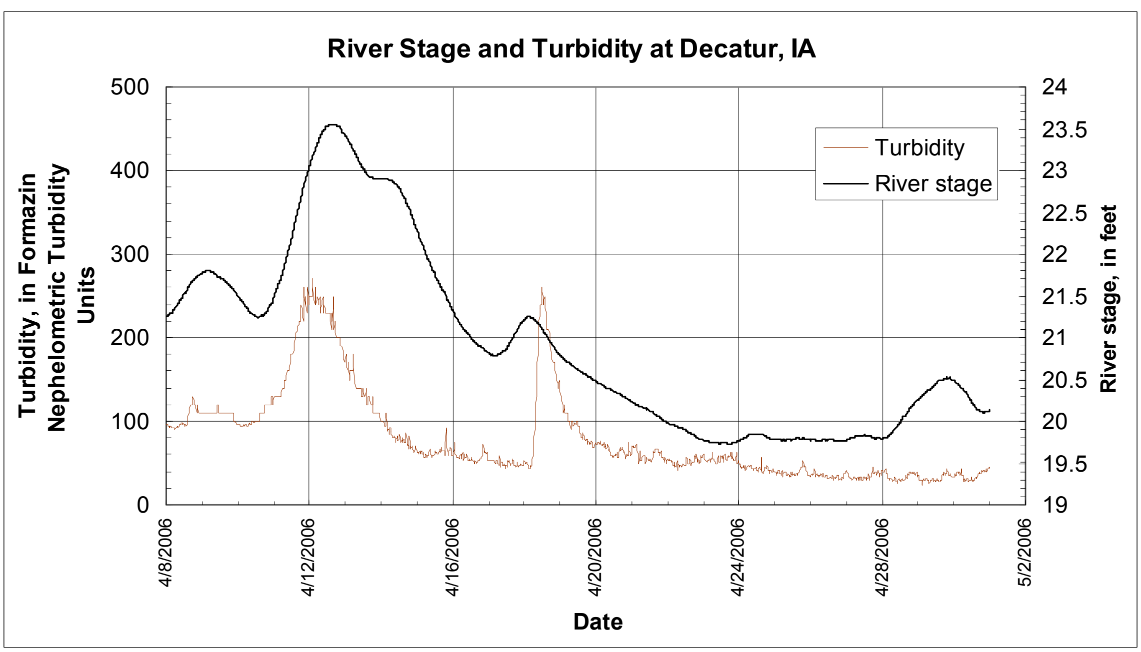

Figure F9. Turbidity and river stage at Decatur, Iowa, showing increases in turbidity associated with natural rises from tributaries downstream from Yankton, S. Dak.

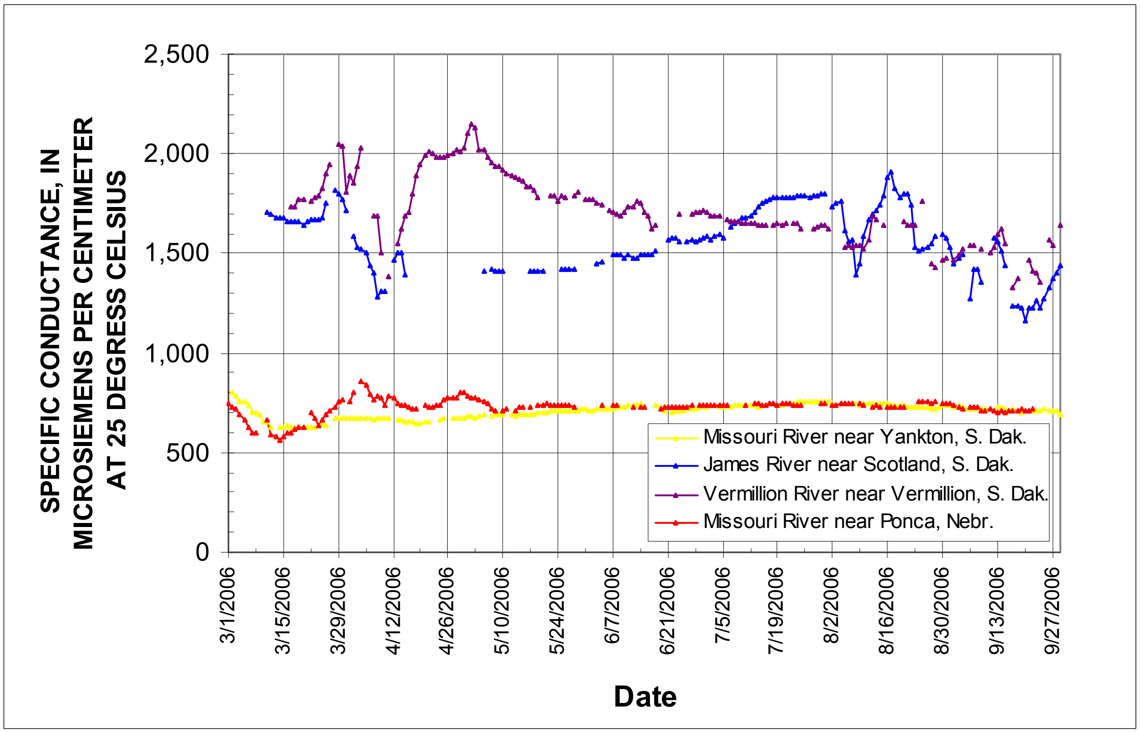

Figure F10. Specific conductance of the Missouri, James, and Vermillion Rivers in South Dakota.

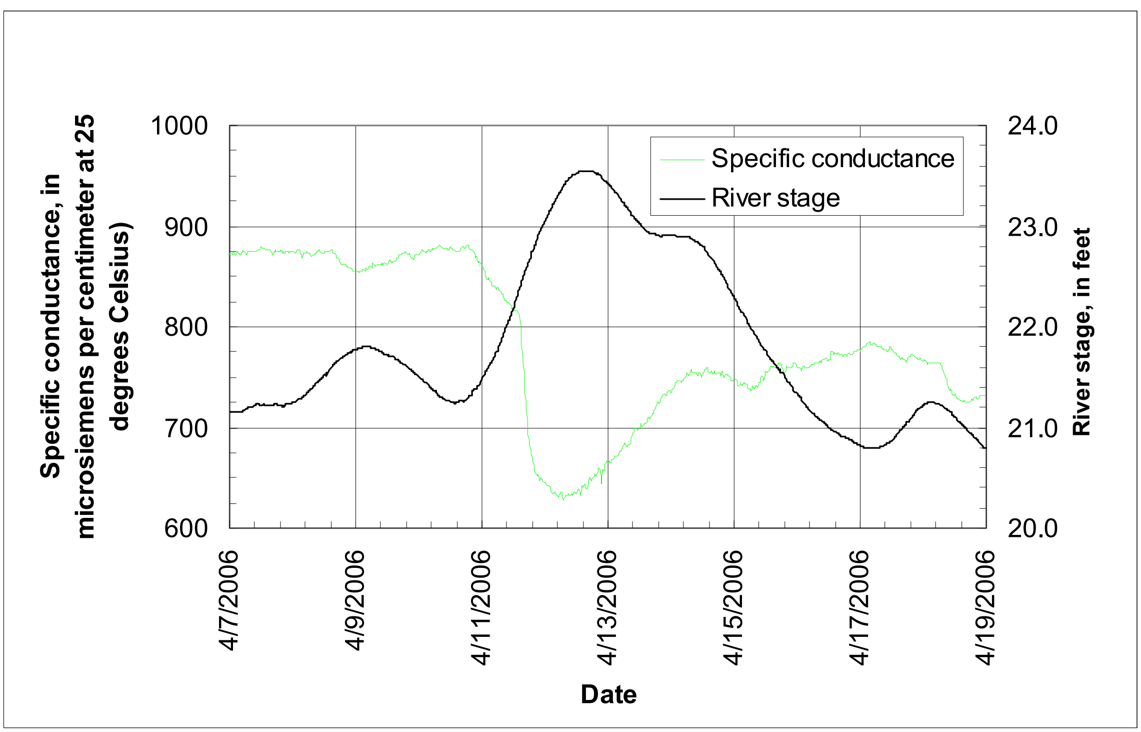

Figure F11. Specific conductance and river stage on the Missouri River near Decatur, Iowa, showing dilution from rises from tributaries below Ponca, Nebr.

Table F1. Monthly maximum (max), minimum (min), and mean water temperatures in the 2006 water year at 11 gaging stations on the Missouri, James, and Vermillion Rivers.

[See fig. F1 for locations; all values in degrees Celsius; --, missing data]

Nearest city	Station number	March			April			May			June		
		Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
Yankton, S. Dak.	06467500	5.7	0.9	2.6	14.5	5.0	11.0	23.5	12.1	16.0	24.1	18.5	21.8
Scotland, S. Dak.	06478500	[b]10.4	[b]1.0	[b]6.0	17.4	7.7	13.0	25.8	13.4	18.2	28.4	17.7	24.1
Vermillion, S. Dak.	06479010	--	0.0	--	18.1	6.9	12.5	26.4	12.1	16.9	[a]28.0	[a]14.8	[a]21.7
Ponca, Nebr.	06479097	[a]8.2	0.0	[a]3.6	17.4	4.9	12.2	24.3	11.5	16.9	25.5	18.5	23.0
Decatur, Nebr.	06601200	7.9	1.8	4.4	16.8	6.8	12.5	24.4	13.1	17.3	24.9	19.8	23.6
Council Bluffs, Iowa	06610505	8.1	3.5	5.6	17.0	8.1	13.2	25.3	13.5	17.7	25.8	21.8	24.5
Nebraska City, Nebr.	06807000	8.9	3.9	6.2	17.4	8.7	14.0	25.6	13.9	18.3	26.3	23.0	25.1
St. Joseph, Mo.	06818000	9.7	4.2	7.1	17.9	9.4	14.8	[a]25.6	[a]14.0	[a]19.0	[a]27.9	[a]24.1	[a]26
Waverly, Mo.	06895500	[a]11.3	[a]6.0	[a]8.5	19.1	10.8	16.0	25.9	15.8	19.5	28.3	25.3	26.6
Boonville, Mo.	06909000	11.5	5.9	8.6	20.0	10.9	16.4	26.3	16.0	19.4	27.8	23.6	26.3
Hermann, Mo.	06934500	12.3	6.6	8.9	[a]20.3	[a]11.8a	[a]16.5	[a]26.8	[a]16.0	[a]18.1	28.5	24.6	26.5

Nearest city	Station number	July			August			September		
		Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
Yankton, S. Dak.	06467500	27.8	22.8	25.1	27.7	23.2	25.2	23.2	14.4	18.8
Scotland, S. Dak.	06478500	31.6	24.3	27.9	30.3	21.4	26.0	[a]23.2	[a]12.8	[a]17.5
Vermillion, S. Dak.	06479010	32.9	18.1	24.9	31.2	17.1	23.8	[a]24.8	9.4	[a]16.1
Ponca, Nebr.	06479097	28.4	22.9	26.1	[a]28.3	[a]22.5	[a]25.6	23.4	14.0	18.6
Decatur, Nebr.	06601200	28.4	24.2	26.5	28.0	23.6	25.9	23.8	15.0	19.0
Council Bluffs, Iowa	06610505	29.4	25.1	27.4	28.9	24.2	26.6	24.4	15.7	19.7
Nebraska City, Nebr.	06807000	29.8	25.6	27.7	29.4	24.7	27.0	24.6	15.8	20.0
St. Joseph, Mo.	06818000	31.2	25.7	28.6	30.3	24.9	27.8	25.8	16.6	21.0
Waverly, Mo.	06895500	32.5	27.0	29.3	[a]30.9	[a]25.4	[a]28.5	25.8	17.5	22.2
Boonville, Mo.	06909000	32.0	26.6	29.0	[a]31.4	[a]25.5	[a]28.7	25.9	17.6	22.4
Hermann, Mo.	06934500	32.1	26.7	29.1	31.6	25.6	28.7	25.8	17.9	22.6

[a]Monthly statistic computed with 1–7 days of missing data.

[b]Monthly statistic computed with 8–10 days of missing data.

Table F2. Monthly maximum (max), minimum (min), and mean turbidity values in the 2006 water year at 11 gaging stations on the Missouri, James, and Vermillion Rivers.

[See fig. F1 for locations; all values in formazin nephelometric turbidity units; --, missing data]

Nearest city	Station number	March			April			May			June		
		Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
Yankton, S. Dak.	06467500	[b]41	[b]4	[b]10	60	4	14	36	8	15	[a]37	[a]6	[a]12
Scotland, S. Dak.	06478500	[b]58	[b]19	[b]27	200	43	117	130	71	94	120	37	70
Vermillion, S. Dak.	06479010	--	--	--	[a]490	[a]42	[a]147	[b]82	[b]24	[b]39	[a]240	[a]16	[a]61
Ponca, Nebr.	06479097	[b]38	[b]7	[b]16	[a]310	[a]8.1	[a]31	[a]51	[a]6.7	[a]15	26	5.6	13
Decatur, Nebr.	06601200	34.49	7.34	16	220	32	84	59	22	32	78	20	30
Council Bluffs, Iowa	06610505	67.72	19.01	27	240	43.49	120	91	37	57	78	28	39
Nebraska City, Nebr.	06807000	92	25	33	200	49	116	130	30	54	88	27	46
St. Joseph, Mo.	06818000	150	21	34	430	60	160	[a]720	[a]33	[a]95	[a]660	[a]28	[a]78
Waverly, Mo.	06895500	[a]490	[a]24	[a]47	370	49	160	480	44	120	350	42	89
Boonville, Mo.	06909000	700	15	85	340	69	160	660	33	150	930	34	110
Hermann, Mo.	06934500	[a]340	[a]15	[a]75	[a]280	[a]46	[a]130a	[a]520	[a]37	[a]140	[a]370	[a]21	[a]86

Nearest city	Station number	July			August			September		
		Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
Yankton, S. Dak.	06467500	[a]49	[a]6	[a]14	[a]88	[a]5	[a]11	44	3	12
Scotland, S. Dak.	06478500	88	[a]25	[a]37	[a]280	[a]25	[a]53	130	23	[a]46
Vermillion, S. Dak.	06479010	--	--	--	--	--	--	--	--	--
Ponca, Nebr.	06479097	[b]31	[b]6.9	[b]18	[a]33	[a]0.4	[a]8.8	32	3	9
Decatur, Nebr.	06601200	43	16.27	19	23	9.9	15	25	8.6	13
Council Bluffs, Iowa	06610505	37	21	27	51	21	27	62	14	26
Nebraska City, Nebr.	06807000	66	20	32	160	19	39	170	20	32
St. Joseph, Mo.	06818000	[a]130	[a]21	[a]45	340	12	63	[a]320	[a]30	[a]70
Waverly, Mo.	06895500	130	31	48	500	28	100	[a]380	[a]44	[a]94
Boonville, Mo.	06909000	620	26	49	[a]420	[a]23	[a]91	[a]320	[a]35	[a]100
Hermann, Mo.	06934500	200	18	38	280	16	65	280	25	82

[a]Monthly statistic computed with 1–7 days of missing data.

[b]Monthly statistic computed with 8–10 days of missing data.

Table F3. Monthly maximum (max), minimum (min), and mean dissolved-oxygen concentrations in the 2006 water year at 11 gaging stations on the Missouri, James and Vermillion Rivers.

[See fig. F1 for locations; all values in milligrams per liter; --, missing data]

Nearest city	Station number	March			April			May			June		
		Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
Yankton, S. Dak.	06467500	[b]18.1	[b]12.6	[b]13.9	13.9	9.8	11.7	12.8	9.2	11.0	[a]10.5	[a]7.0	[a]8.9
Scotland, S. Dak.	06478500	[b]14.0	[b]10.3	[b]12.7	[a]11.8	[a]6.9	[a]9.0	10.7	4.4	8.4	[b]11.2	[b]6.3	[b]8.2
Vermillion, S. Dak.	06479010	--	--	--	14.8	[a]7.2	[a]9.7	[a]17.6	[a]6.8	[a]11.2	[a]15.8	[b]6.4	[b]9.1
Ponca, Nebr.	06479097	--	--	--	[b]12.7	[b]9.3	[b]10.8	11.8	5.2	9.3	[b]10.8	[b]5.4	[b]8.0
Decatur, Nebr.	06601200	17.0	11.3	13.4	12.2	8.5	10.3	10.3	8.6	9.7	10.0	8.4	8.9
Council Bluffs, Iowa	06610505	14.4	11.5	13.1	11.1	7.9	9.5	10.3	8.8	9.5	9.8	7.7	8.7
Nebraska City, Nebr.	06807000	13.3	10.7	12.2	10.6	7.8	9.3	10.2	7.5	9.1	9.2	6.6	7.8
St. Joseph, Mo.	06818000	13.0	10.6	11.8	10.9	7.2	8.5	[a]10.3	[a]5.0	[a]8.7	[a]10.8	[a]5.1	[a]7.7
Waverly, Mo.	06895500	[a]12.9	[a]9.4	[a]11.4	11.4	7.0	8.5	9.5	6.2	8.2	8.9	4.9	6.5
Boonville, Mo.	06909000	13.6	9.2	11.7	11.5	7.7	8.6	10.1	5.8	8.4	8.7	4.4	6.6
Hermann, Mo.	06934500	[a]14.6	[a]9.9	[a]12.5	--	--	--	--	--	--	[a]9.1	[a]5.3	[a]6.8

Nearest city	Station number	July			August			September		
		Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
Yankton, S. Dak.	06467500	[a]8.4	[a]6.4	[a]7.2	[a]8.6	[a]6.6	[a]7.7	10.1	7.7	8.9
Scotland, S. Dak.	06478500	[b]17.4	[b]4.9	[b]9.0	[b]13.7	[b]0.3	[b]5.8	[b]11.8	[b]4.5	[b]8.2
Vermillion, S. Dak.	06479010	[a]12.0	[b]2.7	[b]7.7	11.7	[b]1.5	[b]6.6	[a]12.2	--	--
Ponca, Nebr.	06479097	[a]8.5	[a]5.6	[a]7.2	--	--	--	9.8	7.1	8.4
Decatur, Nebr.	06601200	8.1	7.3	7.7	8.6	6.9	7.7	9.4	8.3	8.9
Council Bluffs, Iowa	06610505	9.3	7.7	8.5	10.1	7.1	8.4	10.3	7.6	9.1
Nebraska City, Nebr.	06807000	8.4	7.0	7.7	10.0	6.1	7.8	9.9	7.1	8.5
St. Joseph, Mo.	06818000	--	--	--	[a]8.8	[a]3.8	[a]6.8	9.8	6.2	7.9
Waverly, Mo.	06895500	[a]8.8	[a]5.2	[a]6.9	9.2	4.0	6.5	10.0	5.5	8.0
Boonville, Mo.	06909000	[a]10.2	[a]5.9a	[a]7.8	[a]10.8	[a]4.4	[a]7.5	10.8	6.2	8.2
Hermann, Mo.	06934500	9.6	5.3	7.6	[a]9.5	--	--	[a]10.7	[a]5.4	[a]8.0

[a]Monthly statistic computed with 1–7 days of missing data.

[b]Monthly statistic computed with 8–10 days of missing data.

Table F4. Monthly maximum (max), minimum (min), and mean specific conductance values in the 2006 water year at 11 gaging stations on the Missouri, James and Vermillion Rivers.

[See fig. F1 for locations; all values in microsiemens per centimeter at 25 degress Celsius; --, missing data]

Nearest city	Station number	March			April			May			June		
		Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
Yankton, S. Dak.	06467500	812	618	669	683	627	666	725	674	698	748	692	723
Scotland, S. Dak.	06478500	[b]1,820	[b]1,630	[b]1,700	[b]1,690	[b]709	[b]1,300	--	--	--	[a]1,590	[a]1,440	[a]1,520
Vermillion, S. Dak.	06479010	--	--	--	2,120	1,170	1,840	2,190	1,730	1,880	[a]1,900	[a]1,140	[a]1,690
Ponca, Nebr.	06479097	[a]765	[a]587	[a]653	873	663	756	804	698	748	747	702	731
Decatur, Nebr.	06601200	825	690	750	876	641	775	860	752	792	759	686	726
Council Bluffs, Iowa	06610505	827	701	766	818	722	777	828	738	780	799	744	768
Nebraska City, Nebr.	06807000	756	648	709	790	651	730	780	689	743	793	716	754
St. Joseph, Mo.	06818000	797	655	741	796	621	727	[a]791	[a]630	[a]742	[a]772	[a]685	[a]741
Waverly, Mo.	06895500	[a]797	[a]657	[a]750	782	602	717	787	561	719	778	680	744
Boonville, Mo.	06909000	828	583	733	770	590	695	782	473	693	763	546	707
Hermann, Mo.	06934500	803	550	682	[a]763	[a]579	[a]665	[a]735	[a]433	[a]611	740	548	659

Nearest city	Station number	July			August			September		
		Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
Yankton, S. Dak.	06467500	772	647	742	[a]770	[a]517	[a]702	721	562	663
Scotland, S. Dak.	06478500	[a]764	[a]718	[a]742	765	710	740	737	624	717
Vermillion, S. Dak.	06479010	1,800	1,560	1,720	1,990	1,360	1,660	[a]1,590	[a]1,110	[a]1,370
Ponca, Nebr.	06479097	1,720	1,580	1,650	1,800	1,420	1,600	[a]1,670	1,190	[a]1,490
Decatur, Nebr.	06601200	749	727	740	[a]774	[a]727	[a]743	774	695	725
Council Bluffs, Iowa	06610505	753	706	734	764	719	742	757	672	721
Nebraska City, Nebr.	06807000	765	734	750	760	682	729	766	690	729
St. Joseph, Mo.	06818000	766	686	732	779	666	728	753	583	684
Waverly, Mo.	06895500	780	538	744	761	551	720	760	556	688
Boonville, Mo.	06909000	[a]771	[a]687	[a]747	[a]769	[a]517	[a]706	[a]747	[a]576	[a]687
Hermann, Mo.	06934500	744	620	703	741	566	687	710	539	651

[a]Monthly statistic computed with 1–7 days of missing data.

[b]Monthly statistic computed with 11–13 days of missing data.

Table F5. Monthly maximum (max), minimum (min), and mean pH values in the 2006 water year at 11 gaging stations on the Missouri, James and Vermillion Rivers.

[See fig. F1 for locations; all values in pH units; --, missing data]

Nearest city	Station number	March			April			May			June		
		Max	Min	Median	Max	Min	Median	Max	Min	Median	Max	Min	Median
Yankton, S. Dak.	06467500	8.8	8.2	8.5	8.8	8.4	8.6	8.7	8.6	8.7	8.6	8.1	8.4
Scotland, S. Dak.	06478500	[a]8.9	[a]8.5	[a]8.7	8.6	8.0	8.3	8.6	8.3	8.4	8.6	8.2	8.4
Vermillion, S. Dak.	06479010	--	--	--	8.4	7.9	8.1	8.3	7.6	8.0	[a]8.4	[a]7.8	[a]8.0
Ponca, Nebr.	06479097	[a]8.6	[a]7.8	[a]8.2	8.5	7.9	8.2	8.9	8.2	8.5	8.5	8.2	8.4
Decatur, Nebr.	06601200	8.5	8.2	8.3	8.5	8.0	8.3	8.6	8.4	8.5	8.4	8.2	8.3
Council Bluffs, Iowa	06610505	8.4	8.2	8.3	8.4	8.0	8.2	8.5	8.2	8.4	8.6	8.3	8.3
Nebraska City, Nebr.	06807000	8.4	8.2	8.3	8.4	7.9	8.1	8.4	8.2	8.3	8.5	8.2	8.3
St. Joseph, Mo.	06818000	8.5	8.4	8.4	8.5	8.0	8.2	[a]8.6	[a]8.0	[a]8.4	[a]8.8	[a]8.0	[a]8.4
Waverly, Mo.	06895500	[a]8.5	[a]8.1	[a]8.3	8.4	7.9	8.1	8.5	7.9	8.3	8.6	8.0	8.2
Boonville, Mo.	06909000	8.4	7.9	8.3	8.3	8.0	8.1	8.6	7.8	8.3	8.6	7.7	8.2
Hermann, Mo.	06934500	8.6	[a]8.1	[a]8.4	8.3	7.9	8.1	[a]8.4	[a]7.7	[a]8.1	[a]8.4	[a]7.8	[a]8.1

Nearest city	Station number	July			August			September		
		Max	Min	Median	Max	Min	Median	Max	Min	Median
Yankton, S. Dak.	06467500	8.4	8.1	8.2	8.4	8.2	8.3	8.6	8.4	8.5
Scotland, S. Dak.	06478500	8.7	8.2	8.5	8.7	7.8	8.3	8.8	8.0	8.4
Vermillion, S. Dak.	06479010	8.2	7.6	7.9	8.3	7.7	8.0	[a]8.3	[a]7.8	[a]8.1
Ponca, Nebr.	06479097	8.4	8.0	8.2	[a]8.8	[a]8.2	[a]8.5	8.6	8.3	8.4
Decatur, Nebr.	06601200	8.5	8.3	8.4	8.4	8.3	8.4	8.6	8.4	8.5
Council Bluffs, Iowa	06610505	8.5	8.2	8.3	8.4	8.0	8.2	8.5	8.3	8.4
Nebraska City, Nebr.	06807000	8.6	8.3	8.5	8.6	8.2	8.4	8.6	8.2	8.4
St. Joseph, Mo.	06818000	8.7	8.3	8.5	8.8	8.0	8.5	8.6	8.1	8.4
Waverly, Mo.	06895500	8.6	8.2	8.4	[a]8.6	[a]7.9	[a]8.2	8.7	8.0	8.3
Boonville, Mo.	06909000	8.7	8.0	8.5	[a]8.8	[a]7.8	[a]8.2	8.7	8.0	8.4
Hermann, Mo.	06934500	8.6	8.1	8.4	8.7	7.9	8.3	8.8	7.9	8.4

[a]Monthly statistic computed with 1–7 days of missing data.

Table F6. Discharge measurements at the gaging station near Ponca, Nebr.

[ft², square feet; ft³/s, cubic feet per second]

Date	Central Time	Measurement number	Width, in feet	Area, in ft²	Velocity, in feet per second	Gage height, in feet	Discharge, in ft³/s
3/30/2006	11:30	1	685	6,220	3.39	11.45	21,100
3/30/2006	13:30	2	664	6,120	3.44	11.43	21,100
5/25/2006	12:30	3	679	6,050	3.37	11.10	20,400
6/8/2006	11:15	4	681	8,080	3.28	12.93	26,500
6/8/2006	11:45	5	718	7,310	3.49	12.30	25,500
6/30/2006	11:30	6	715	7,640	3.36	12.82	25,700
6/30/2006	13:00	7	702	7,290	3.57	12.82	26,000
7/21/2006	9:00	8	687	7,590	3.38	12.70	25,600
8/3/2006	9:00	9	650	8,490	3.75	14.10	31,800
8/3/2006	10:10	10	649	8,510	3.71	14.08	31,500
8/3/2006	11:35	11	650	8,470	3.68	14.08	31,100
8/3/2006	13:10	12	650	8,460	3.69	14.08	31,200
8/11/2006	8:35	13	651	8,280	3.61	13.62	29,900
8/11/2006	9:10	14	650	8,280	3.55	13.56	29,400
8/11/2006	11:00	15	655	8,250	3.55	13.54	29,300
9/1/2006	11:00	16	692	7,960	3.52	13.01	28,000
9/27/2006	8:50	17	649	7,360	3.54	12.66	26,100
9/27/2006	10:00	18	647	7,359	3.52	12.64	25,910
10/10/2006	12:00	19	668	6,940	3.00	11.24	20,800
10/10/2006	13:40	20	674	6,830	2.96	11.18	20,200
10/11/2006	10:08	21	669	6,750	2.75	10.53	18,600
10/11/2006	11:25	22	666	6,410	2.83	10.42	18,100
10/11/2006	12:00	23	668	6,490	2.81	10.36	18,200
10/12/2006	10:40	24	662	5,810	2.67	9.55	15,500
10/12/2006	12:10	25	658	5,680	2.68	9.45	15,200
10/12/2006	13:05	26	655	5,480	2.70	9.38	14,800

Table F7. Suspended-sediment concentrations in samples collected from the Missouri River near Ponca, Nebr.

Date	Central Time	Suspended-sediment concentration, in milligrams per liter
3/17/2006	10:30	114
3/28/2006	15:15	251
4/26/2006	15:30	122
5/16/2006	10:30	231
6/8/2006	13:00	123
7/12/2006	11:30	56
9/1/2006	11:30	200
10/10/2006	13:00	67
10/11/2006	10:55	89

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For more information concerning this publication, contact:
Director
U.S. Geological Survey
Columbia Environmental Research Center
4200 New Haven Road
Columbia, MO 65201
(573) 875–5399
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