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

Assessment of Lower Missouri River Physical Aquatic Habitat and Its Use by Adult Sturgeon (Genus *Scaphirhynchus*), 2005–07

Scientific Investigations Report 2009–5121

U.S. Department of the Interior
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Cover. Top: Research vessel Slim Funk mapping physical aquatic habitat on the Lower Missouri River near Ponca, Nebraska. Bottom left: Shovelnose sturgeon (*Scaphirhynchus platorynchus*; on left) and pallid sturgeon (*Scaphirhynchus albus*; on right) from the Lower Missouri River. Bottom right: Sturgeon telemetry tracking boat on the Lower Missouri River.

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Conversion Factors

Inch/Pound to SI

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

SI to Inch/Pound

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	10.76	square foot (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	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)
meter per day (m/d)	3.281	foot per day (ft/d)

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

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

Assessment of Lower Missouri River Physical Aquatic Habitat and Its Use by Adult Sturgeon (Genus *Scaphirhynchus*), 2005–07

By Joanna M. Reuter, Robert B. Jacobson, Caroline M. Elliott, and Aaron J. DeLonay

Abstract

This report presents an exploratory analysis of habitat availability and use by adult *Scaphirhynchus* sturgeon on the Lower Missouri River from Gavins Point Dam, South Dakota, to the junction with the Mississippi River. The analysis is based on two main data sources collected from 2005 to 2007: (1) a compilation of 153 reach-scale habitat maps (mean reach length, 2.4 kilometers) derived from boat-collected hydroacoustic data and (2) a sturgeon location dataset from which 378 sturgeon telemetry locations are associated with the maps (within 7 days of the mapping and within 10 percent of the discharge). The report focuses on: (1) longitudinal patterns of geomorphic and hydraulic characteristics revealed by the collection of reach maps; (2) assessment of environmental characteristics at sturgeon locations in the context of the mapped reaches; and (3) consideration of spatial distribution of habitat conditions that sturgeon appear to select.

Longitudinal patterns of geomorphology, hydraulics, and associated habitats relate strongly to the engineered state of the river. Reaches within each of the following river sections tended to share similar geomorphic, hydrologic, and hydraulic characteristics: the Minimally Engineered section (Gavins Point Dam to Sioux City, Iowa), the Upstream Channelized section (Sioux City, Iowa, to the junction with the Kansas River), and the Downstream Channelized section (Kansas River to the junction with the Mississippi River).

Adult sturgeon occupy nearly the full range of available values for each continuous variable assessed: depth, depth slope, depth-averaged velocity, velocity gradient, and Froude number (a dimensionless number relating velocity to depth). However, in the context of habitat available in a reach, sturgeon tend to select some areas over others. Reproductive female shovelnose sturgeon (*Scaphirhynchus platorynchus*), in particular, were often found in parts of the reach with one or more of the following characteristics: high velocity gradient, high depth slope, low Froude number, and low (though not necessarily the lowest) depth-averaged velocity. Depths used by sturgeon varied considerably.

We explored spatial patterns representing the variable ranges that reproductive female shovelnose sturgeon most strongly and consistently selected by mapping areas within reaches meeting the following criteria: greater than the 80th percentile of depth slope, greater than the 80th percentile of velocity gradient, and less than the 20th percentile of Froude number. Our data exploration indicates that areas meeting these criteria have some predictive value regarding sturgeon habitat selection. Of all sturgeon locations that fall on maps from the same year (sample size = 2,013), about 63 percent fall within about 35 percent of the area where at least one variable meets the above criteria and 18 percent of locations fall within 4 percent of the area where all three variables meet the above criteria. The spatial patterns of these mapped areas show distinct differences among the sections of the Lower Missouri River. For example, the areas of predicted selection exhibit a relatively complex mosaic with multiple interconnected pathways in reaches of the Minimally Engineered section. In contrast, areas of predicted selection are concentrated along the channel margins in reaches of the Upstream Channelized section. Because the patterns described in this report represent habitat use in the context of the available habitat in a highly altered river system, selection may not necessarily indicate preferred habitats or habitats sufficient for reproduction and survival of sturgeon species.

Introduction

This report presents an analysis of fluvial habitat and habitat selection by *Scaphirhynchus* sturgeon on the Lower Missouri River downstream from Gavins Point Dam, South Dakota (fig. 1). The physical character of the Lower Missouri River has changed substantially relative to the historic condition because of human alteration, including impoundment and channelization (National Research Council, 2002; Galat and others, 2005b). In association with river alteration, a decline has occurred in native species and commercial fish catches (Hesse, 1987; Pflieger and Grace, 1987; Hesse and others,

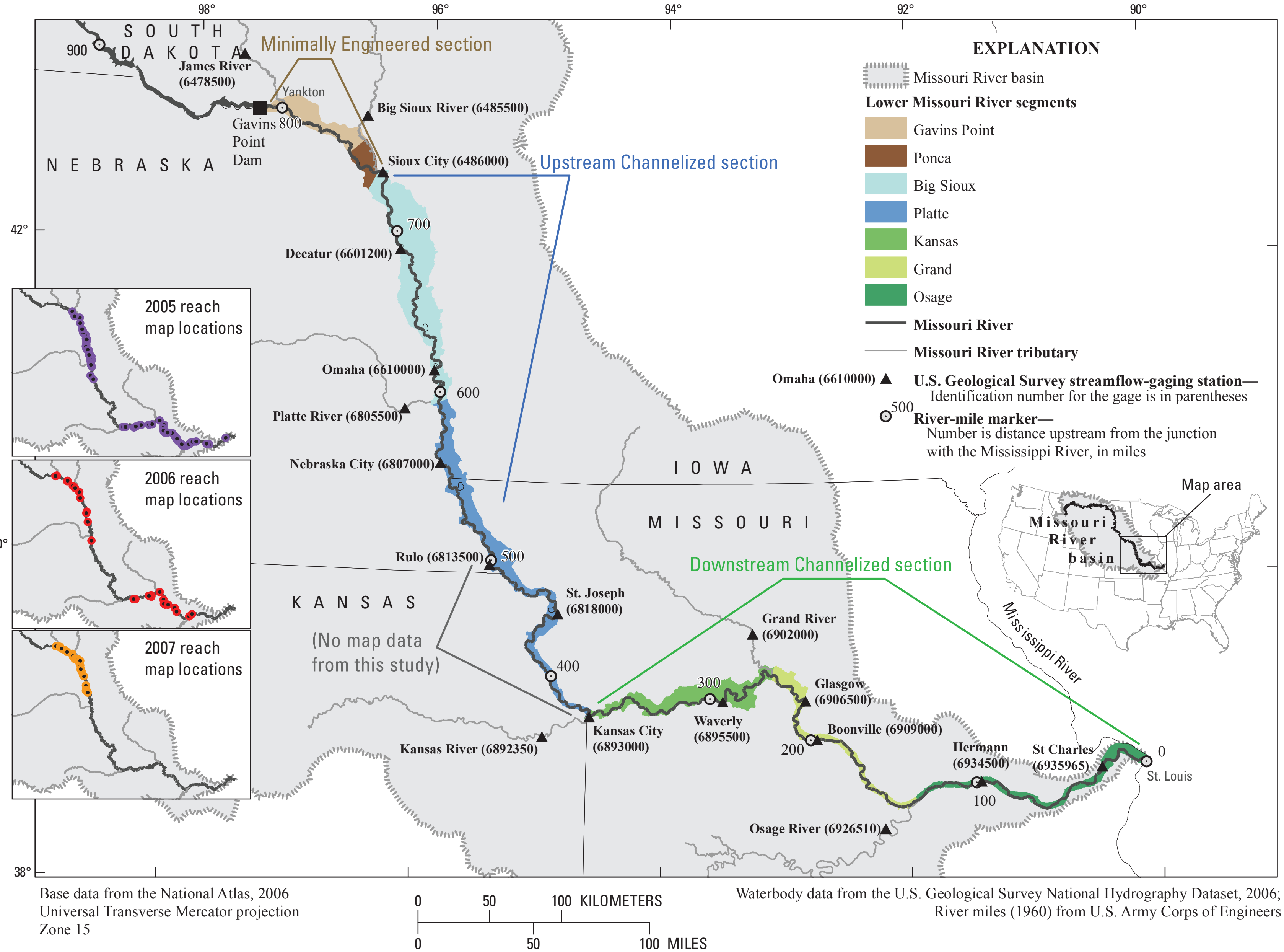

Figure 1. The Lower Missouri River, including insets showing the location of reach maps for each study year, 2005 through 2007. The Lower Missouri River is defined as the unimpounded length of the Missouri River extending from Gavins Point Dam to the junction with the Mississippi River.

1989; Hesse and Sheets, 1993; U.S. Fish and Wildlife Service, 2000; Galat and others, 2005a).

Two of the declining species are native riverine sturgeon. The pallid sturgeon (*Scaphirhynchus albus*) is considered rare to extremely rare in the Missouri River and was listed as endangered in 1990 under the Federal Endangered Species Act (Dryer and Sandvol, 1993). The shovelnose sturgeon (*Scaphirhynchus platorynchus*), a more common, but closely related species, also inhabits the Missouri River and has been used as a comparative model for studying the pallid sturgeon (DeLonay and others, 2007b). Although shovelnose sturgeon are not endangered on the Missouri River, populations have similarly declined and the species has been excluded or extirpated from significant portions of its historic range (June, 1977; Moos, 1978; Keenlyne, 1997; Quist and others, 2002). The pallid sturgeon differs from the shovelnose sturgeon in that the pallid grows larger, matures later, lives longer, is more tolerant of turbidity, becomes piscivorous as an adult, and is primarily found only in the mainstem river and the downstream portions of larger tributaries (Keenlyne, 1997).

In 2000, and again in 2003, the U.S. Fish and Wildlife Service, in consultation with the U.S. Army Corps of Engineers, concluded that the operation and maintenance of the Missouri River mainstem and reservoir system jeopardized the continued existence of the pallid sturgeon (U.S. Fish and Wildlife Service, 2000, 2003). Included among the reasonable and prudent management actions detailed in the resultant Biological Opinion are significant efforts at flow modifications, habitat creation, and research and monitoring to enhance spawning, reproductive success, and survival of sturgeon. The U.S. Geological Survey (USGS) is engaged in the Comprehensive Sturgeon Research Program (CSRP), a multiyear, multi-agency program of research to understand *Scaphirhynchus* sturgeon life history, especially as related to reproduction and proposed management actions, in the Lower Missouri River (Korschgen, 2007). This report presents results from the habitat-use component of the broader sturgeon research project. The focus of the report is on understanding variability of physical habitat along the river, and on understanding which habitats among those available are selected by adult sturgeon—especially reproductive female shovelnose sturgeon—during the time of year that spawning occurs. The research is intended to contribute to a scientific basis for managing the highly altered Lower Missouri River to arrest the decline of native sturgeon species and to promote the recovery of the imperiled pallid sturgeon.

The Lower Missouri River

The Lower Missouri River extends approximately 1,305 kilometers (811 miles) from Gavins Point Dam, South Dakota, to the junction with the Mississippi River at St. Louis, Missouri (fig. 1). Gavins Point Dam is the downstream-most impoundment of the Missouri River reservoir system, which consists of six mainstem reservoirs that are operated to satisfy multiple objectives, including hydropower generation, flood control, water supply, and navigation. Dam operation has resulted in a change in both flow regime and sediment regime. Inter- and intraseasonal flow variability have been substantially altered (Galat and Lipkin, 2000) and sediment loads have declined to approximately one-sixth of historic loads at Hermann, Missouri (Jacobson and others, 2009a). The mainstem Missouri River is unimpounded downstream from Gavins Point Dam, but it has been channelized to allow for commercial barge navigation downstream from Sioux City, Iowa (river mile 734). In addition, the river has been subjected to changes in water quality because of agricultural and industrial development in the basin (Sprague and others, 2006; Alexander and others, 2008; Echols and others, 2008). Among the stresses imposed on the river, the large magnitude of changes in flow regime and channel morphology have been assumed to be the most influential in species declines, largely through their influence on physical habitat availability (National Research Council, 2002; U.S. Fish and Wildlife Service, 2003). Furthermore, flow regime and channel morphology are among the factors that can be addressed most readily through management action (Jacobson and Galat, 2006).

This report uses the terms *reach*, *segment*, and *section* to define lengths of river at various spatial scales (Frissell and others, 1986). *Reaches* are lengths of river up to a few kilometers that include bend and crossover habitats; from a logistics standpoint, reaches could be mapped in a single day (Reuter and others, 2008). *Segments* are intermediate in scale and primarily are defined by tributary junctions (fig. 1). At the broadest scale, *sections* are lengths of river that show broadly similar morphologic and engineering characteristics (fig. 1).

Physical Setting

In the 1800s, the Missouri River had a dynamically migrating, multithread channel with numerous islands and side channels, high sediment loads, abundant woody debris, and floods that frequently inundated the flood plain (Chittenden, 1903; Jacobson and others, 2009a). During the 1900s, engineering efforts succeeded in channelizing and stabilizing the planform of most of the Lower Missouri River. Downstream from Sioux City, Iowa, navigation structures were used to focus flow to maintain a single-thread, self-dredging navigation channel. Channel engineering resulted in the loss of as much as 400 square kilometers of river-corridor habitats, an amount that is approximately two-thirds of the habitat that existed prior to the Missouri River Bank Stabilization and Navigation Project (Funk and Robinson, 1974; Hesse and Sheets, 1993; Ferrell, 1996; National Research Council, 2002; U.S. Army Corps of Engineers, 2004; Galat and others, 2005b). The Biological Opinion issued by the U.S. Fish and Wildlife Service in 2000, and amended in 2003, called for the restoration of 48 to 79 square kilometers of shallow-water aquatic habitat lost because of river engineering, on the basis that lack of this habitat class jeopardized survival of the endangered pallid sturgeon (U.S. Fish and Wildlife

Service, 2000, 2003). Shallow-water habitat, defined by the U.S. Fish and Wildlife Service as water 0 to 1.5 meters deep and 0 to 0.6 meters per second current velocity, was specified in particular because of its assumed importance for rearing of larval and juvenile pallid sturgeon and for other native fishes (U.S. Fish and Wildlife Service, 2003; U.S. Army Corps of Engineers, 2004). Projects to enhance habitat have included alteration of navigation structures (such as wing-dike notching) and construction of side-channel chutes (Jacobson and others, 2001, 2004).

The modern river varies substantially over its length because of contributions of tributaries, land-use patterns, and variation in channel engineering. The longitudinal variation is illustrated in a classification scheme that is based primarily on hydrologically defined segments bounded by junctions with major tributaries (fig. 1). Hydrologic variation among segments is evident in progressive downstream increase in intra-annual flow variability because of inputs from tributaries (fig. 2; Galat and Lipkin, 2000; Jacobson and Heuser, 2002; Pegg and others, 2003). Tributary junctions also have the potential to be locations of discrete changes in water quality because of land-use influences in the drainage basins; longitudinal variation in aquatic insect populations along the Lower Missouri River indicates that water-quality variations may be biologically significant (Poulton and others, 2003).

In addition to segment-scale hydrology, another factor that varies along the Lower Missouri River is channel engineering. Channel morphology is least disturbed relative to the historic (pre-engineered) condition in the non-navigation segment downstream from Gavins Point Dam, South Dakota, to Ponca State Park, Nebraska (Elliott and Jacobson, 2006). From Ponca State Park to Sioux City, Iowa, the river has been channelized and stabilized but is not used for commercial navigation so the construction is intermediate between the more natural channel upstream and the navigation channel that begins in Sioux City. From Sioux City, Iowa, to St. Louis, Missouri, the river has been channelized for commercial navigation and the banks have been stabilized to prevent erosion of the flood plain, resulting in narrowing and deepening of the channel, loss of habitat diversity, and changes to the relations between flow regime and habitat availability (Jacobson and Galat, 2006; Jacobson and others, 2009b).

Physiography of the Missouri River Valley also influences the river by determining valley width and geologic materials it interacts with in its banks. Just downstream from Gavins Point Dam, the river flows adjacent to glacial drift deposits that provide abundant coarse, hard substrate in those reaches (Laustrup and others, 2007). Between Yankton, South Dakota, and Sioux City, Iowa, the river flows for much of its length along bedrock bluffs that provide abundant bedrock and boulder substrate. At Sioux City, the river flows through a wide alluvial valley with little interaction with the valley wall until it enters the Ozark Plateaus Physiographic Province near Glasgow, Missouri. In this section of the river—mostly coincident with the hydrologically defined Grand and Osage segments—the valley narrows considerably and the river periodically encounters bedrock in its bed and banks (Laustrup and others, 2007).

Hydrologic Context

Prior to impoundment, the characteristic Missouri River hydrograph included two spring flood peaks (the first dominated by snow melt from the Great Plains and the second from the Rocky Mountains), followed by a low flow period later in the summer (fig. 2). Flow regulation has substantially affected the flow regime of the Lower Missouri River, resulting in reduced intra-annual flow variability, decreased spring pulses, and generally increased summer flows (Galat and Lipkin, 2000). The intensity of flow-regime alteration is most pronounced just downstream from Gavins Point Dam, and it diminishes in the downstream direction as tributaries enter the mainstem (fig. 2; Galat and Lipkin, 2000; Jacobson and Heuser, 2002; Pegg and others, 2003).

Natural flow regimes are considered important to ecosystem function; therefore, a common strategy for ecosystem recovery in impounded systems is to incorporate elements of the natural flow regime into managed flow releases (Poff and others, 1997; Galat and Lipkin, 2000). This is a strategy specified in the 2003 Amended Biological Opinion, which called for naturalization of the flow regime to provide spawning cues for the sturgeon, to connect the main channel periodically with low-lying flood plain, to build sandbars for nesting birds, and to improve the quality of sturgeon spawning habitats (U.S. Fish and Wildlife Service, 2003). During the study period, one pulsed release of about 9,000 cubic feet per second (260 cubic meters per second) was implemented from Gavins Point Dam in May 2006 (fig. 2) as an attempt to provide a sturgeon spawning cue (Jacobson and Galat, 2008).

River conditions varied over the course of this study because of the planned flow release as well as unplanned hydrologic conditions. Individual flow pulses during 2005 through 2007 were uniformly small in the upstream section, achieving no more than 15 percent flow exceedance at Sioux City. In all 3 years, flow pulses substantially larger than the 2006 release were evident downstream from the Platte River (fig. 2). For example, a flood pulse during May 2007 attained a 0.9 percent exceedance at the USGS streamflow-gaging station at Nebraska City, Nebraska and qualified as a 5- to 10-year recurrence interval flood at the Boonville, Missouri, gaging station (fig. 2).

Reproductive Ecology of *Scaphirhynchus* Sturgeon in the Missouri River

Sturgeon experts have identified sturgeon spawning requisites as a research priority (Quist and others, 2004; Wildhaber and others, 2007a; Bergman and others, 2008), in part because the precise spawning requirements for *Scaphirhynchus* sturgeon are largely unknown and because little to no recruitment is occurring among pallid sturgeon in the Missouri

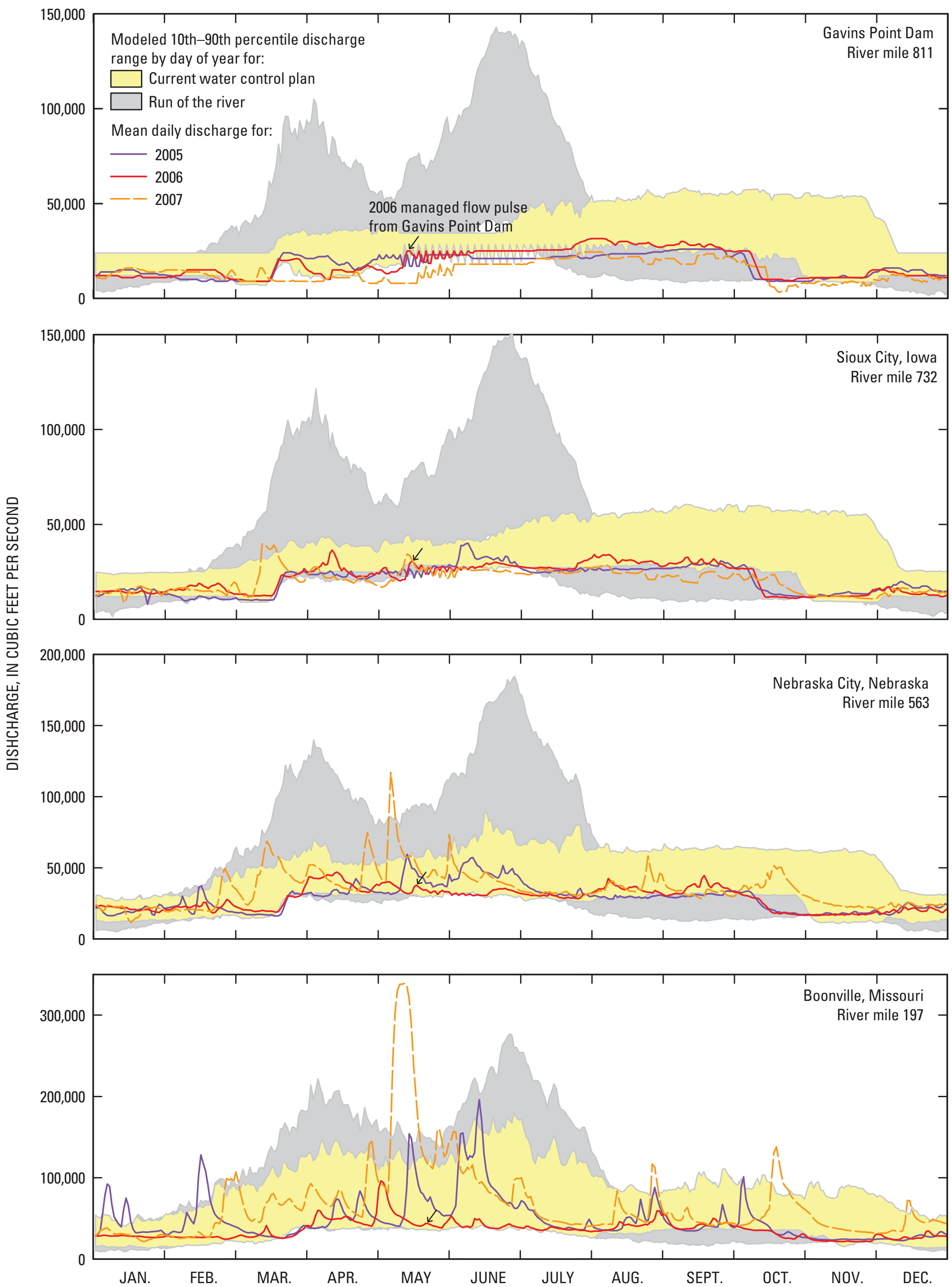

Figure 2. Hydrographs for 2005 through 2007. The shaded areas provide context for the range of flows expected under unmanaged conditions and under the current water control plan. “Run-of-the-river” conditions represent flows that would occur in the absence of dams (Jacobson and Heuser, 2002).

River (U.S. Fish and Wildlife Service, 2000). In contrast, some successful recruitment is occurring among shovelnose sturgeon (Moos, 1978; Keenlyne, 1997). During 2005 through 2007, CSRP research efforts focused on following the movements of reproductive female shovelnose sturgeon to provide insight on various aspects of reproductive ecology. Subsequent efforts have shifted the focus to comparative assessments of pallid sturgeon.

The time to reach reproductive maturity is estimated to be approximately 7 years for female shovelnose sturgeon (Keenlyne, 1997) and nearly a decade or more for female pallid sturgeon (Keenlyne and Jenkins, 1993). Female shovelnose sturgeon may spawn as often as once every 2 to 3 years, while pallid sturgeon females are thought to spawn only once every 3 to 10 years (Mayden and Kuhajda, 1997). Female sturgeon with black eggs in the spring are in condition to spawn that spring or summer (Wildhaber and others, 2007b).

All sturgeon species spawn in freshwater with most migrating upstream from marine or estuarine environments to deposit their eggs in the upper reaches of larger rivers. The timing and length of spawning migrations varies among sturgeon species and may range over hundreds to thousands of kilometers from adult feeding or wintering areas (Auer, 1996). For some sturgeon species, a phase of the upstream migration may occur during fall prior to the final spawning run (Bemis and Kynard, 1997).

Scaphirhynchus sturgeon live exclusively in the large freshwater rivers of mid-continental North America and do not thrive in reservoirs or move downstream into estuarine environments (Wilson and McKinley, 2004). In preparation for spawning, reproductive *Scaphirhynchus* sturgeon migrate upstream on the order of tens to hundreds of kilometers, as documented by telemetry studies on the Missouri River (DeLonay and others, 2007b). Spawning of *Scaphirhynchus* species is hypothesized to occur near the apex, or most upstream point, of a female's migratory path, although the specific location and success of spawning by telemetered sturgeon remains to be validated through egg or larvae collection. Missouri River sturgeon tend to reach their migratory apex locations during late spring and early summer, as determined from telemetry data (Aaron J. DeLonay, unpub. data, 2008). Historically, large flow pulses were typical during the period of sturgeon migration on the Missouri River, leading to the hypothesis that sturgeon may require a flow pulse to act as a spawning cue (U.S. Fish and Wildlife Service, 2003; Jacobson and Galat, 2008). High river discharge and the increasing daylight of spring are associated with the period of spawning for many sturgeon species (Cech and Doroshov, 2004).

Specific spawning locations and the relative suitability of spawning conditions for these sturgeon species in the Lower Missouri River are not known conclusively. Hard, coarse substrate is assumed to be suitable spawning substrate based on spawning requirements of other sturgeon species (Bemis and Kynard, 1997), and recent studies on the Lower Missouri River have mapped the distributions of such substrate (Laustrup and others, 2007). In 2008, three reproductive female pallid sturgeon were tracked to inferred spawning patches on the outsides of river bends covered with riprap revetment (Aaron J. DeLonay, unpub. data, 2008). Subsequent recapture verified that eggs had been released; however, the specific site of egg deposition was not confirmed through egg or larvae collection.

Sturgeon migratory behavior varies by sex and reproductive condition as well as among individuals. Habitat use may also depend on these factors. Telemetry studies have documented that reproductive male sturgeon have less systematic upstream migrations and nonreproductive female sturgeon typically do not migrate upstream (Aaron J. DeLonay, unpub. data, 2008). Furthermore, a substantial amount of variation exists in the observed rate and distance of the upstream migration among reproductive individuals. Not all black-egged female sturgeon spawn successfully or completely; some resorb their eggs because of factors that are not fully understood (DeLonay and others, 2007a; Papoulias and others, 2007).

A variety of questions exist regarding whether habitat for migration or spawning is limiting for reproduction of the pallid sturgeon. Key questions include: (1) Has alteration of the Missouri River decreased the availability of low-velocity pathways for migratory sturgeon, resulting in increased rates of energy expenditure and decreased spawning success? (2) Has alteration of the Missouri River decreased or modified quantity or quality of spawning habitat patches? (3) Has the altered distribution and availability of habitats changed the timing and duration of migration or altered the location and timing of spawning? (4) Has habitat had a role in reducing reproductive isolation between species and increasing the apparent rate of hybridization in sturgeon? (5) Are engineered habitat features used by sturgeon for migration and spawning, and how does habitat quality compare to pre-engineered habitats?

Habitat Definitions and Assessments

Fish habitat is 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). Habitat for a particular species consists of all the characteristics of all the places that the fish may occupy during its life history. For Missouri River sturgeon that migrate long distances during their lives (DeLonay and others, 2007b), habitat assessments may, therefore, need to consider a wide range of conditions at a wide range of locations. A more restricted definition of physical habitat is the 3-dimensional structure of physical and chemical characteristics in which a riverine organism lives; time variation in these characteristics (frequency, duration, sequence, rate of change) adds a critical fourth dimension that must be assessed (Gordon and others, 1992). Of a wide range of physical and chemical characteristics, depth, current velocity, and substrate are the three main characteristics of physical habitat that are usually evaluated. Other factors like water temperature and turbidity can be important habitat components and often covary with the physical components. Physical components of habitat can be managed directly by changes in flow regime or channel morphology (Jacobson and Galat, 2006).

A central challenge in fish habitat assessment is to relate habitats *used* by a fish to all *available* habitats in order to evaluate whether the fish select specific habitats over others. Habitat selection is a measure of relative choice of habitat from the range that is readily available to the fish; habitat preference is a measure of relative choice if all possible habitats are available (Hall and others, 1997). In the case of field studies in a river like the Lower Missouri, selection indicates choice among available habitat patches, none of which may be preferred or sufficient for a particular life stage.

Availability is conditioned by water discharge, as physical characteristics like depth and velocity are highly dependent on discharge. Therefore, use and availability should be considered simultaneously or at equivalent discharges in order to assess selection.

Existing literature on *Scaphirhynchus* sturgeon provides information regarding sturgeon habitat use, but most studies have not addressed reach-scale habitat availability or selection. *Scaphirhynchus* sturgeon are primarily benthic, but the literature supports the idea that adult pallid sturgeon do not select strongly for river depth. For example, pallid sturgeon in the Mississippi River used a wide range of depths, 1.8 to 19.1 meters (Hurley, 1999) and pallid sturgeon in the Upper Missouri and Yellowstone Rivers were captured at 0.6 to 14.5 meters depth (Bramblett and White, 2001). Depth selection of other fishes is often thought to relate the cover that depth provides for predator avoidance rather than a hydraulic effect on the fish (Rabeni and Jacobson, 1999), and this effect would be expected to vary with turbidity. However, adult pallid sturgeon have few predators and selected habitats may be related more to the availability or habitat selection of prey species.

Pallid sturgeon selection for velocity may be stronger than for depth. Adult pallid sturgeon have been found at a fairly narrow range of velocities: 0 to 1.37 meters per second in the Upper Missouri and Yellowstone Rivers (Bramblett and White, 2001) and 0.17 to 0.97 meters per second in the Platte River (Snook and others, 2002).

Purpose and Scope

This report presents an exploratory analysis of habitat maps of Lower Missouri River reaches (Reuter and others, 2008) and associated sturgeon relocations (DeLonay and others, 2007b; Aaron J. DeLonay, unpub. data, 2008) with the objective of providing information about habitats selected by adult *Scaphirhynchus* sturgeon, especially reproductive female shovelnose sturgeon, during the spring and summer. The mapped reaches provide a basis for characterization of aspects of the geomorphology of the Lower Missouri River, including broad patterns of longitudinal variability of the river from Gavins Point Dam to the junction with the Mississippi River. In the context of the geomorphic setting, the sturgeon locations associated with mapped reaches reveal trends of habitat selection. Presentation of results includes an extensive set of tables intended to make data publically available; however, we discuss only the highlights of this large dataset. Data collection was not targeted at specific, a priori hypotheses; thus, we do not use statistical hypothesis testing in this report. Instead, the exploratory approach used was intended to investigate trends and to generate working hypotheses.

Acknowledgments

Funding for this project was provided by the U.S. Army Corps of Engineers, Missouri River Recovery—Integrated Science Program and the USGS. This work is part of the Comprehensive Sturgeon Research Program (CSRP), a large, interdisciplinary, multiyear, multi-agency research project to which many individuals have contributed. The following individuals assisted with hydroacoustic mapping: Harold Johnson, III (USGS), Matt Smith (Arctic Slope Regional Corporation, ASRC), Chad Vishy (ASRC), Mark Laustrup (USGS), and David Gaeuman (National Research Council Post-Doctoral Fellow). Sturgeon telemetry crews tagged and tracked sturgeon. Crews were supervised by Aaron DeLonay (USGS) and led by Sabrina Davenport (ASRC) and David Combs (ASRC). Core crew members included: Brian Carollo (ASRC), Jermyn Porter (ASRC), Caleb Troutt (ASRC), Daniel Schertz (ASRC), and Kyle Singer (ASRC). Tracking crews with the Nebraska Game and Parks Commission provided some of the telemetry locations in 2007. Kim Chojnacki, Emily Tracy-Smith, Sandy Clark-Kolaks, and Emily Kunz (USGS) provided support through management and quality control of the sturgeon telemetry data. Diana Papoulias, Mandy Annis, and Janice Bryan (USGS) provided data concerning the sex and reproductive condition of telemetered sturgeon. Many additional individuals have provided indirect support; the chapters of the volume edited by Korschgen (2007) contain acknowledgments for numerous other individuals involved with the CSRP. Color schemes for some maps were inspired by Color Brewer, *http://colorbrewer.org*. Lewis Coggins and Edward Little (USGS) reviewed this report.

Data Sources

This section provides basic background information on the two source datasets that were the focus of analysis for this report. The two data sources are: (1) a sturgeon telemetry dataset with thousands of recorded sturgeon positions in the 2005 through 2007 time period (DeLonay and others, 2007b; Aaron J. DeLonay, unpub. data, 2008) and (2) a set of reach-scale maps that are associated with a subset of the sturgeon telemetry locations (Reuter and others, 2008). Maps depict depth, depth-averaged velocity, and substrate, as well as habitat characteristics derived from these variables. Thus, for a set of known sturgeon locations, maps provide data for environmental characteristics at the sturgeon coordinate locations, assuming the that discharge and bed configuration did not vary substantially between sturgeon location and mapping. In addition, the maps provide the context of habitat availability in the reach surrounding the sturgeon. Here we provide an overview of these datasets; additional information has been documented in other published reports (Korschgen, 2007; Reuter and others, 2008).

Sturgeon Telemetry Data

The telemetry project involved capturing sturgeon from the Missouri River, implanting selected individuals with combined acoustic and radio transmitters, and tracking these telemetered sturgeon to obtain relocations of the sturgeon over time (DeLonay and others, 2007a; DeLonay and others, 2007b). We use the term “relocation” to refer to a point location where a sturgeon was found again through telemetry tracking, and *not* as a reference to an act of moving something from one place to another. Sturgeon were captured and implanted during the late winter and early spring of 2005, 2006, and 2007. In total, more than 400 sturgeon were tagged and implanted with transmitters during these 3 years. After release and a recovery period, telemetered sturgeon were tracked to determine their movement patterns. Crews tracked sturgeon by navigating through sections of river, using boats outfitted with acoustic and radio receivers to determine the locations of telemetered sturgeon. These relocation points, accurate to approximately 2 meters, were obtained using a differential global positioning system (DGPS) receiver and recorded in Universal Transverse Mercator (UTM) coordinates, Zone 15 North, using the World Geodetic System of 1984 (WGS 84) datum. The crews recorded more than 6,200 sturgeon relocation positions in 2005 through 2007. A subset of the telemetered sturgeon were recaptured to assess the spawning success of individuals.

Species, Sex, and Reproductive Condition of Telemetered Sturgeon

Sturgeon were selected for implantation based on size and field assessments of species, sex, and reproductive condition at the time of initial capture in the spring. Blood and egg samples were taken to confirm sex and reproductive condition in the lab (Papoulias and others, 2007; Wildhaber and others, 2007b). All implanted sturgeon were adults. Female sturgeon with black eggs at the time of initial capture were considered to be in reproductive condition, with a high probability of spawning that year. Female sturgeon that did not have black eggs at initial capture were unlikely to spawn that year (Moos, 1978); we refer to these sturgeon as nonreproductive. Male sturgeon also were assessed with regard to reproductive condition using the criteria in Wildhaber and others (2007b). In 2005 and 2006, all telemetered shovelnose sturgeon were reproductive females. In 2007, telemetered shovelnose sturgeon also included males and females in a range of reproductive stages, including sturgeon not expected to spawn in that year. A few pallid sturgeon were also included in each year from 2005 through 2007. Overall, the majority of sturgeon during this time period were reproductive female shovelnose sturgeon.

The reproductive designations used in this report are based on the condition at initial capture because this is the only reproductive assessment that is available for all sturgeon in the study. For a subset of telemetered sturgeon that were recaptured later in the year, assessments of spawning success based on field observations and laboratory assessments of gonad tissue also are available. However, we do not have sufficient data to consistently and confidently differentiate between locations that represent sturgeon in prespawn versus postspawn condition, nor do we have data regarding spawning success for all individuals. Therefore, in this report, we used the assessment of reproductive condition at initial capture to classify sturgeon reproductive condition for the entire season.

Spatial Distribution of Sturgeon Relocations

The regional distribution of sturgeon relocations is a byproduct of sample design and search effort (fig. 3). During 2005 and 2006, the CSRP sample design called for comparison between upstream and downstream locations in an attempt to isolate the effects of flow regulation on sturgeon reproduction. The upstream segments have highly regulated flow regimes and few spring flow pulses (fig. 2). The upstream segments also have the potential for manipulated pulsed-flow experiments like the one in 2006. The downstream segments have less-regulated flows and have a very high probability of experiencing natural spring flow pulses in every year. Downstream sturgeon initial capture/release locations were in the Missouri River between the Osage River and the Kansas River junctions, and the upstream sturgeon were captured/released between the junctions of the Platte River and the Vermillion River in South Dakota. During 2007, all initial capture/release locations were upstream from the Platte River.

On a reach scale, locations are minimally biased by search effort. The presence of the boat during tracking in the Missouri River had minimal impact on the activity and behavior of the sturgeon. Telemetered positions could be accurately located by placing the boat directly over the sturgeon (DeLonay and others, 2007b). Limitations do exist to the extent that sturgeon can only be relocated in areas deep enough to be navigable by the tracking boats. This is of primary concern in the segment downstream from Gavins Point Dam to Ponca State Park, where shallow water and multithread channels are prevalent. Additionally, some difficulties exist in locating telemetered sturgeon during very high water because of high acoustic noise associated with increased suspended sediment and bedload, as well as the proliferation of acoustic shadows where sturgeon can hide behind large bedforms or submerged engineered structures. On the whole, the

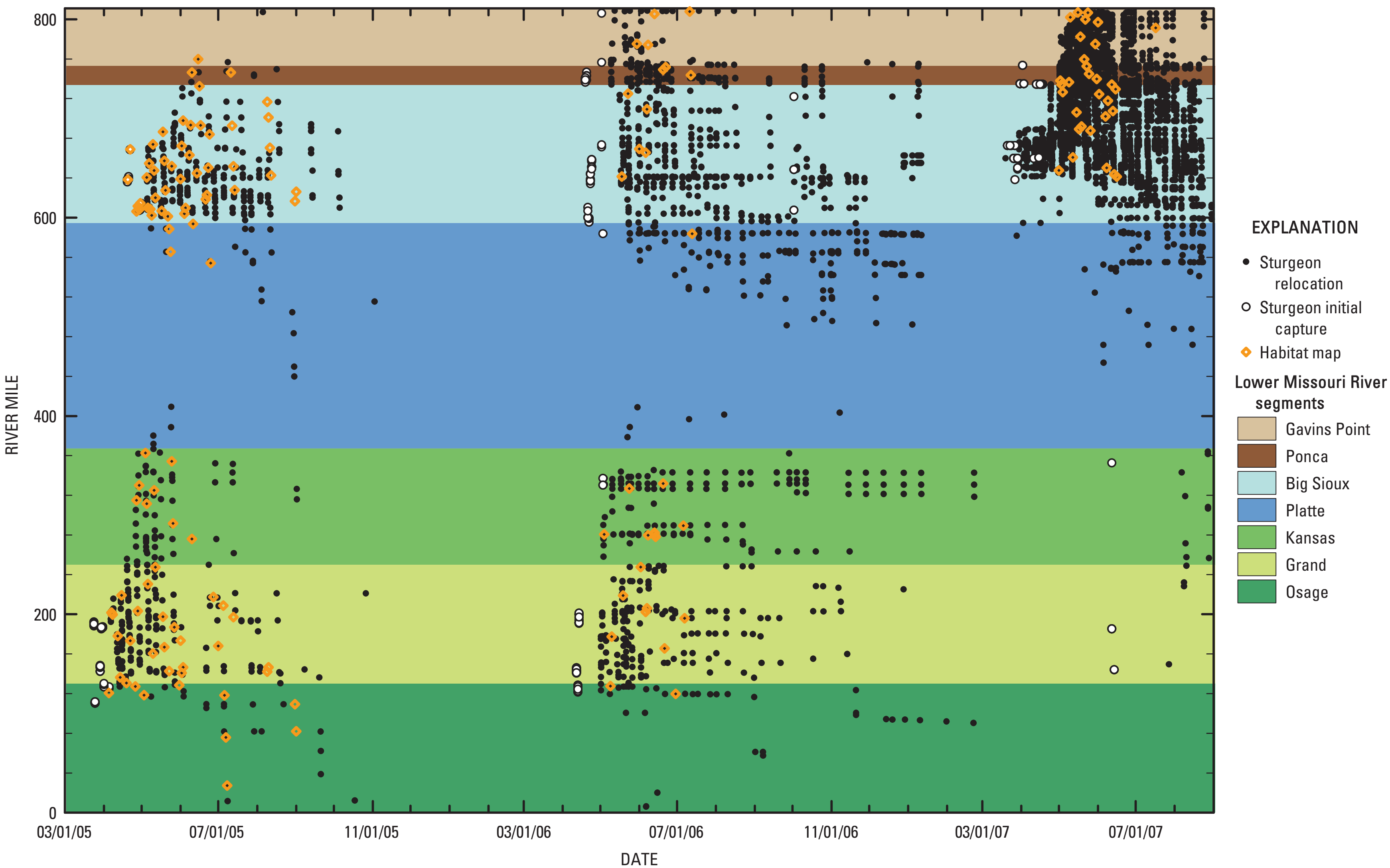

Figure 3. Plot of sturgeon telemetry and reach mapping activities, by date and river mile. In 2005 and 2006, telemetry and mapping efforts were divided between upstream and downstream parts of the Lower Missouri River. In 2007, effort was largely focused in the upstream part of the river. Relocations illustrate the broad patterns of search effort.

sturgeon relocations provide a relatively thorough sampling of where sturgeon are found within river reaches.

Maps of Hydraulic and Substrate Characteristics

Maps based on boat-collected hydroacoustic data depict hydraulic and substrate characteristics at sturgeon relocations and in surrounding reaches. These maps, along with a detailed description of methods used to derive them, were published in Reuter and others (2008). Maps were made at the reach scale (mean reach length, 2.4 kilometers) in order to include the immediate vicinity of a targeted sturgeon relocation as well as the full range of habitat available at the bend and crossover scale. Reaches typically were surveyed on the day following the relocation of a telemetered sturgeon and at a discharge within 10 percent of the discharge on the sturgeon relocation date in order to characterize as closely as possible the channel morphology and flow-field conditions at the time that the sturgeon was present.

Reach Map Information and Discharge Conditions

One-hundred fifty-three reaches were mapped during the months of April to September of 2005 through 2007, with the majority of data collection occurring in the months of May and June (coinciding with the period of sturgeon migration and spawning in the Lower Missouri River). Many maps were based on random selection of target *Scaphirhynchus* sturgeon (primarily shovelnose). Other maps were made based on nonrandom selection of target sturgeon for a variety of reasons; some of these nonrandom maps included suspected spawning locations, as inferred from information available at the time of mapping. Specific spawning locations were not verified during the time period in question. We consider all maps, random and nonrandom, in the exploratory analysis presented in this report. One-hundred twelve of the maps contain sturgeon relocations within an acceptable date and discharge range (see section on “Qualifying Sturgeon Relocations”).

Discharges at the time of mapping spanned a range of flow conditions in terms of flow exceedance and discharge (fig. 4). Flow exceedance values indicate how frequently flows of a given discharge are equaled or exceeded at a particular location based on a record of past discharge. We computed Missouri River flow exceedances from mainstem gages during the period of regulated flows from 1967 through 2008 (Galat and Lipkin, 2000). Most maps were made when discharges were moderate to low relative to annual data. No overbank flows were mapped during this study. The lowest flows at the time of mapping, in terms of both absolute discharge and flow exceedance, were between Gavins Point Dam and the first major tributary, the James River, during early May 2007 when the James, Vermillion, and Big Sioux Rivers were contributing

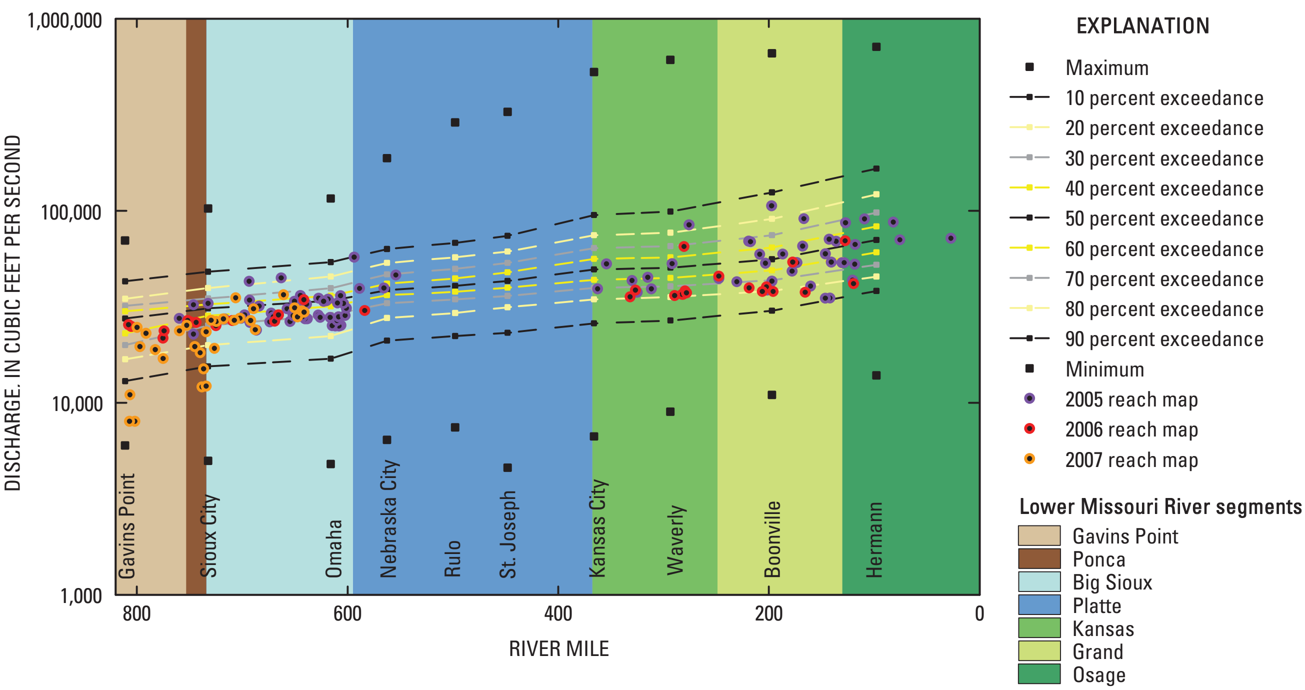

Figure 4. Plot of discharges on reach mapping dates in the context of flow exceedance data for the Lower Missouri River, based on daily discharge records. Flow exceedances were computed for Missouri River gages with records from 1967 to 2008. From upstream to downstream, the gages are: Gavins Point Dam (U.S. Army Corps of Engineers), Sioux City (USGS streamflow-gaging station ID 6486000), Omaha (USGS 6610000), Nebraska City (USGS 6807000), Rulo (USGS 6813500), St. Joseph (USGS 6818000), Kansas City (USGS 6893000), Waverly (USGS 6895500), Boonville (USGS 6909000), and Hermann (USGS 6934500).

substantial discharges to the Lower Missouri River; flow releases from the dam were very low during this period to compensate for flows from the tributaries.

The spatial distribution of maps along the length of the Lower Missouri River is a byproduct of a number of factors including the sampling design used in the telemetry studies, the movement of telemetered sturgeon, tracking search effort, and mapping effort. The distribution of telemetry relocations and reach maps at this broad scale does not indicate regional patterns of habitat selection. For example, the Platte segment is especially underrepresented in terms relocations and the number of maps, but this is primarily a result of the upstream-downstream structure of the study design, and not necessarily because of the relative use of that segment by sturgeon.

Descriptions of Specific Map Types

Primary maps were generated directly from boat-collected hydroacoustic data (Reuter and others, 2008), and derived maps were computed from the primary maps. The three types of primary maps are depth, depth-averaged velocity, and substrate. These maps are based on hydroacoustic data from a longitudinal profile and a set of cross-sections spaced 15 to 40 meters apart. Raw datasets were processed according to methods outlined in Reuter and others (2008) to yield interpolated maps with a grid cell size of 5 meters. Maps represent areas navigable by the survey boat, generally where depths are greater than 0.6 meter.

Maps derived from primary maps or combinations of primary maps provide additional ways of looking at physical habitat conditions. These alternate views of the data offer some specific advantages over the raw, primary variables, even though they are not independent of the primary variables. For example, depth slope is less dependent on discharge than depth itself. Because the primary and derived variables are not independent, we considered issues of covariance and colinearity by exploring bivariate relations among primary and derived variables; examples are presented in the results.

Table 1 summarizes the map types, and figure 5 shows an example of each map type for a reach. The following descriptions provide additional detail:

Depth.—Most maps of depth were based on echo-sounder data collected with high-resolution, single-beam Hydrotrac echo sounders (Odom Hydrographic Systems, Inc., Baton Rouge, Louisiana). Some depth maps were based on data from an acoustic Doppler current profiler.

Depth slope.—Depth slope is effectively the topographic slope of the bed, in degrees. It is computed as the maximum slope of the depth grid within a moving 3 by 3 cell matrix (with 5 meter grid cells) using the ArcGIS slope algorithm (Environmental Systems Research Institute, Redlands, California). Depth slope is nearly independent of discharge if the bed morphology is static.

Terrain classification.—We used a bathymetric terrain classification approach to visualize major channel features. This technique is based on the concepts of the Topographic Position Index and the Benthic Terrain Modeler (Weiss, 2001; Lundblad and others, 2006); it uses measures of relative depth and slope to classify the channel into crests (bars), depressions (thalweg and deep holes), slopes, and flat areas (fig. D13 in Jacobson and others, 2007). Relative depth is computed as the difference between the depth at each grid cell and the average depth within an area defined by an annulus (two concentric circles) surrounding the grid cell. We used the following parameters: horizontal radii for the annulus of 25 and 250 meters; the vertical threshold used to differentiate crests/depressions from flat/sloped areas as 0.5 meter; and the slope threshold that differentiates flat from sloped areas as 5 degrees.

Generalized substrate.—Maps of substrate are based on an interpretation of data from a RoxAnn instrument (Marine Microsystems and Sonavision, Ltd., Aberdeen, United Kingdom) in combination with spatial data regarding the location of engineered structures and bedrock (Reuter and others, 2008). These maps are general indicators of substrate characteristics. Two categories were derived from RoxAnn data alone; these categories are (1) sand (generally dunes) and (2) a

Table 1. Map types and sources.

Map type	Source	Primary or derived	Variable type	Units used in this report
Depth	Echo sounder or depth returns from acoustic Doppler current profiler (Reuter and others, 2008)	Primary	Continuous	Meters.
Depth slope	From depth map, based on 3 by 3 moving window of grid cells, using ArcGIS slope command	Derived	Continuous	Degrees.
Terrain classification	From depth, using methods in Jacobson and others (2007)	Derived	Discrete	--
Substrate	RoxAnn, supplemented by other map data (Reuter and others, 2008)	Primary	Discrete	--
Velocity, depth-averaged	Acoustic Doppler current profiler (Reuter and others, 2008)	Primary	Continuous	Meters per second.
Velocity gradient	From depth-averaged velocity map, using ArcGIS slope command	Derived	Continuous	Percent per meter.
Froude	From depth and depth-averaged velocity	Derived	Continuous	--
Shallow-water habitat	From depth and depth-averaged velocity, using Biological Opinion definition of shallow-water habitat, depth less than 1.5 meters, velocity less than 0.6 meters per second	Derived	Discrete	--

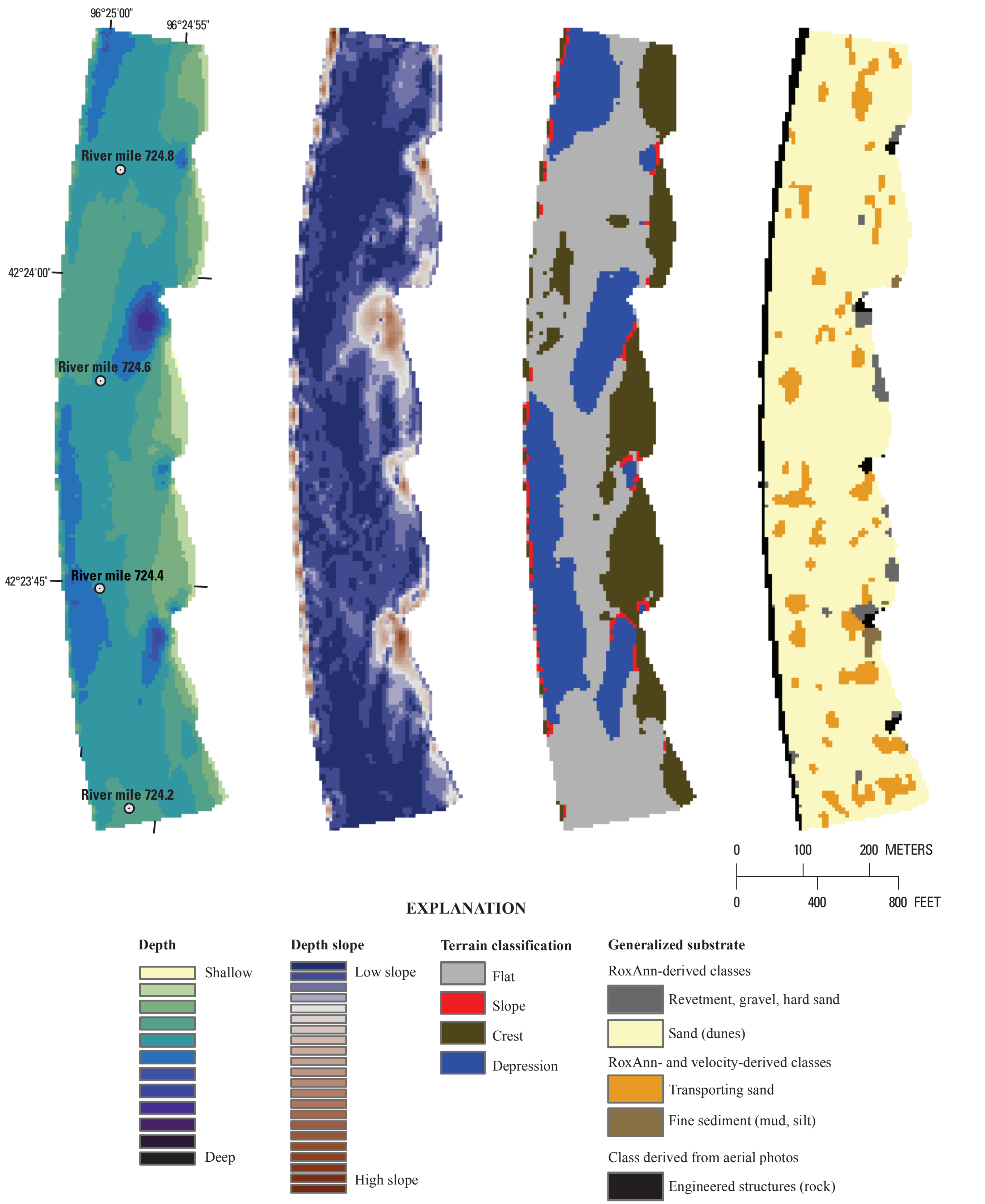

Figure 5. Maps of an example reach, with each type of primary and derived map illustrated: depth, depth slope (derived from depth), terrain classification (derived from depth), substrate, velocity, velocity gradient (derived from velocity), Froude number (derived from depth and velocity), and shallow-water habitat (derived from depth and velocity).

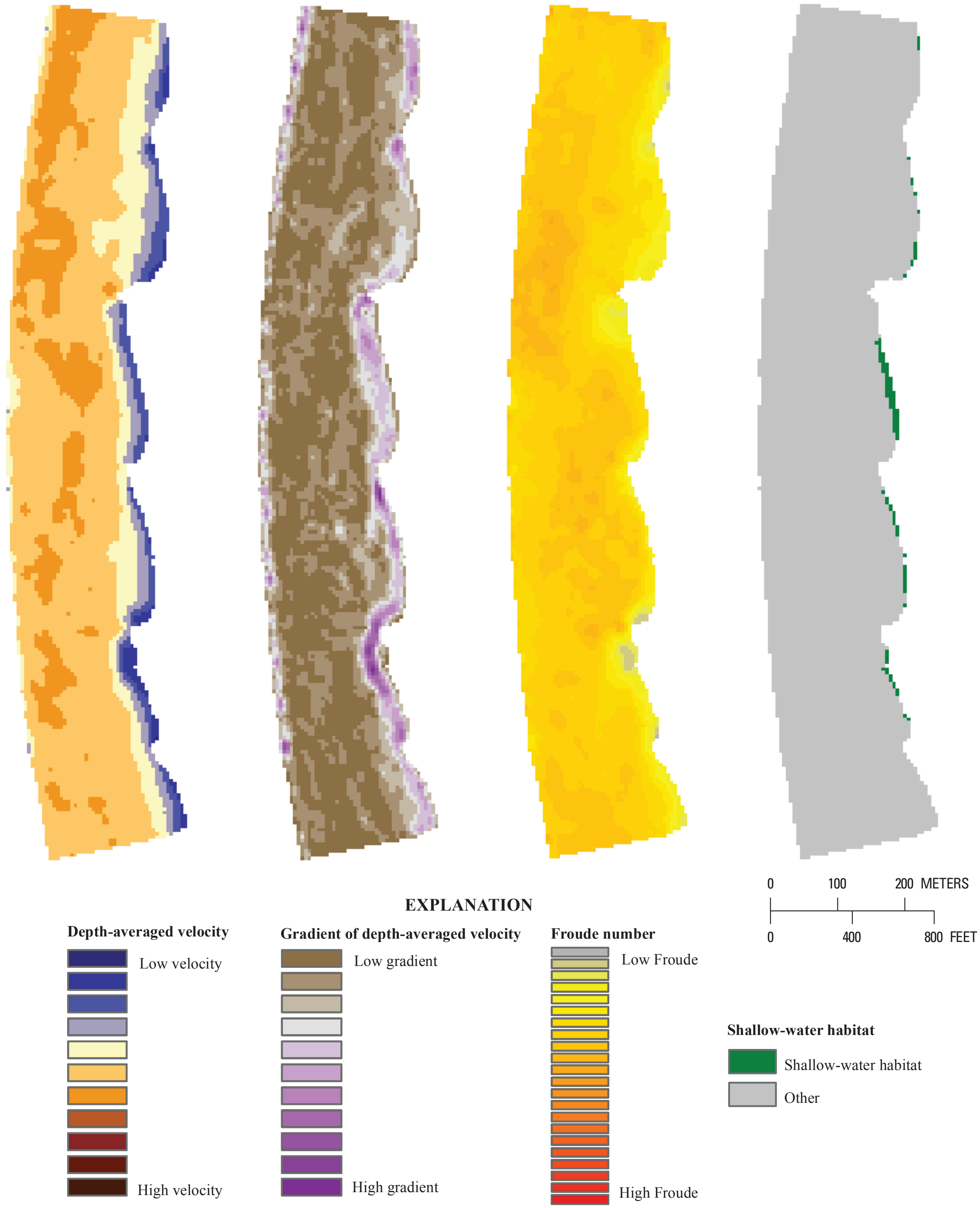

Figure 5. Maps of an example reach, with each type of primary and derived map illustrated: depth, depth slope (derived from depth), terrain classification (derived from depth), substrate, velocity, velocity gradient (derived from velocity), Froude number (derived from depth and velocity), and shallow-water habitat (derived from depth and velocity).—Continued

grouping that includes revetment, gravel, and hard sand. RoxAnn data, in combination with velocity data, were used for the differentiation of two categories: (1) transporting sand (where velocities were high) and (2) fine sediment, including mud and silt (where velocities were low). Two classes were derived from geospatial data: (1) engineered structures (generally rock) and (2) bedrock (a class with very little representation).

Depth-averaged velocity—Maps of depth-averaged water velocity were based on data from acoustic Doppler current profilers (Teledyne RD Instruments, Poway, California). Depth-averaged values were used for two reasons. Sturgeon are generally benthic fish, but the position in the water column is not known with certainty for the relocation points. Secondly, near-bottom velocity data tend to be noisy because of turbulence, so meaningful maps of near-bottom velocities cannot be readily generated from available datasets. Depth-averaged velocities provide the best available information about the overall hydraulic environment. Throughout this report, the term “velocity” refers to depth-averaged velocity.

Velocity gradient.—Velocity gradient represents the amount of spatial change in velocity, in percent per meter, computed using the ArcGIS slope algorithm. (Thus, the maximum slope is determined from a 3 by 3 cell matrix of 5 meter grid cells.) Various studies have concluded that fish respond to velocity-derived variables, including vorticity (Crowder and Diplas, 2000, 2006; Yang and others, 2007) and total hydraulic strain (Nestler and others, 2008). The velocity gradient variable that we used is based on a more simplistic approach, but the resulting maps show strong correlations with the vorticity and strain variables (Jacobson and others, 2009b).

Froude number.—Froude number is a dimensionless parameter derived from depth, velocity, and the gravitational constant. It is calculated as: Froude = velocity/√(gravitational constant * depth). Conceptually, Froude number represents how energetic the environment is; higher Froude number values correspond to higher energy environments (more kinetic energy relative to potential energy). Froude number commonly has been used in habitat characterization studies (for example, Yu and Peters, 1997; Reuter and others, 2003).

Shallow-water habitat.—The Missouri River Biological Opinion (U.S. Fish and Wildlife Service, 2000) defines shallow-water habitat as follows: depths are less than or equal to 1.5 meters and velocities are less than or equal to 0.6 meters per second. Shallow-water habitat maps are derived by reclassifying and combining depth and velocity maps to meet these criteria. The area of mapped shallow-water habitat is a minimum amount for each reach because maps include only parts of the reach navigable by the survey boat, generally where water depth exceeded 0.6 meters.

Analysis Approach

Analysis was based on an exploratory approach with three parts: (1) *Exploration of the reach map data alone.* We considered patterns and relations among physical variables, with an emphasis on longitudinal patterns along the Lower Missouri River. (2) *Exploration of characteristics at sturgeon relocations in the context of available conditions in the reach.* We investigated how the values of physical environmental variables at sturgeon relocations compare to the range of values in the surrounding reaches. The approach that we used considers only one variable at a time. (3) *Exploration of patterns of habitat use, as identified in the previous step, in a map context.* After identifying some relations between sturgeon relocations and the available environmental variables, we generated maps of selected habitat types. Each of these three parts is described in more detail in the following sections.

Descriptive Statistics of Reach Maps

The reach maps represent a sample of more than 20 percent of the length of the Lower Missouri River and are the most extensive set of maps available on the river with this level of detail. Descriptive statistics from these maps can be used to characterize longitudinal patterns of channel morphology and habitat complexity, although cataloging spatial variation in habitats was not the primary intended purpose of these maps. Instead, the maps were collected with the intention of assessing habitat availability for sturgeon at the reach scale. Thus, there are some caveats about how well these maps characterize habitat at the broadest scales. The maps represent a range of discharges determined by sturgeon relocations and, therefore, depict habitats over a range of flow exceedances. The maps also are distributed unevenly geographically; some locations were mapped more than once and some segments (especially the Platte segment) are poorly represented in the dataset. At the reach scale, the maps were constrained to include only areas that could be navigated by the survey boat. Nonetheless, robust patterns emerge from the descriptive statistics.

Reach geometry statistics.—The following summary statistics were used to characterize reach geometry: Reach wetted area was determined from the area of the polygon that encompassed all of the hydroacoustic data for the depth map. Reach length was determined from the length of an approximate center line passing through the reach. Reach mean width was computed as the area of the reach polygon divided by the reach length. The width is based only on mapped, wetted area; islands and emergent bars were ignored. Reach volume was computed as the sum of the depth grid cell values multiplied by the grid cell area (25 square meters). Reach mean wetted cross-sectional area was computed as the reach volume divided by the reach length. Note that some of the reach geometry statistics are biased estimates because they are based on the part of the reach that the boat could navigate and map (reach maps do not always represent 100 percent of wetted reach); Gavins Point segment reaches are particularly prone to err on the side of underestimating areas, widths, and volumes because of unmapped shallow areas. Unit length residence time was computed from the volume divided by the prevailing discharge divided by the reach length. Reach volumes (and thus residence times) are minimum estimates, especially in the Gavins Point segment. Prevailing discharge was estimated based on the nearest gages as described in Reuter and others (2008). Reach mean velocities were calculated as the mean of all grid cells in the depth-averaged velocity maps.

Histograms.—Univariate summaries included frequency data for each continuous variable (depth, depth slope, velocity, velocity gradient, and Froude number) for each reach. Reach histograms were pooled to generate composite histograms representing all of the mapped reaches in each segment. Histograms were normalized such that the area under the curve equals one.

Bivariate relations and correlation coefficients.—For each reach and for each pair of continuous variables, we considered bivariate relations by plotting scatter plots and computing linear correlation coefficients. A set of approximately 10,000 regularly spaced points were superimposed on each depth map, and values were extracted from the grid for each variable using bilinear interpolation from the surrounding grid cells to obtain an estimate of the value at each point. The bivariate plots and correlation coefficients were examined to assess degree of colinearity and to develop a better understanding of the relations of derived variables to primary variables.

Relations of Sturgeon Relocations to Habitat Variables

The analysis of sturgeon habitat selection is focused at the reach scale; that is, characteristics at sturgeon relocations are compared to the values available in the surrounding reach. This analysis uses all reach maps, random or nonrandom, and data from 3 years, 2005 through 2007.

Qualifying Sturgeon Relocations: 7 Day and 10 Percent Discharge Criteria

Most reach maps were made to target one particular sturgeon relocation. However, many maps have additional, nontargeted sturgeon relocations within their boundaries. If these opportunistic sturgeon relocations occurred near in time and at discharge conditions similar to those on the map date, then these sturgeon also were included in the analysis.

We took a conservative approach by restricting the analysis to relocations that had been documented within 7 days of the map date and within 10 percent of the discharge on the map date. We chose to limit the time frame to 7 days (either before or after the map date) because of recently developed understanding of rates and magnitude of geomorphic change in the Lower Missouri River by Elliott and others (2009). That study, based on channel-monitoring data from four reaches of the Missouri River during 2006 and 2007, demonstrated that substantial in-channel geomorphic change can occur on a month-to-month time scale; periods of shorter duration were not documented in the study. The discharge threshold of 10 percent was the same as that used to decide whether to map a targeted relocation. Discharge was estimated based on data from the nearest mainstem gage or a combination of mainstem and tributary gages, using methods described in Reuter and others (2008).

These criteria did eliminate some sturgeon relocations that were originally targeted for mapping. Ideal discharge ranges were not always met in the field, and the time lag between relocation and mapping was greater than 7 days in some cases. However, even with the loss of some targeted sturgeon from the analysis, the number of qualifying relocations ultimately increased relative to the group of directly targeted sturgeon relocations. The resulting dataset includes 112 maps with a total of 378 sturgeon relocations.

Uncertainty in determining a habitat value at a sturgeon relocation arises from a number of sources. Horizontal positions from differential GPS (DGPS) are accurate to less than 1 meter; both sturgeon relocations and hydroacoustic map data were collected with DGPS. Relocation position uncertainty also is related to how precisely the boat can be positioned over the sturgeon when the data point is logged; total horizontal uncertainty for positions is estimated to be approximately 2 meters, less than the scale of map grid cells (5 meters). Uncertainty in map data is largely related to data interpolation. Values are best constrained near the transects where data were collected, and uncertainty generally increases with distance from the nearest transect. Estimates from interpolation with ordinary kriging suggest that depth uncertainty is generally less than 1.5 meters and velocity uncertainty is generally less than 0.4 meters per second. However, even along a transect, features at a scale smaller than the 5 meter grid cells cannot be resolved (small- to moderate-size dunes, for example). Dynamically migrating sand dunes have the potential to alter benthic microhabitats and velocity distributions. Dune migration rates documented by Elliott and others (2009) ranged up to 3 meters per day, resulting in background variability of hydraulics and substrate characteristics at the dune scale. The uncertainty estimates from kriging do not incorporate potential changes resulting from differences in discharge between the time of relocation and the time of mapping. Discharge estimates also include uncertainty, both from the discharge estimation process at the gaging station and from the use of the gage data to estimate values at locations distant from gaging stations. Discharges are best constrained near USGS streamflow-gaging stations and at times when discharges are stable, because of the use of daily average discharge data. We used conservative date and discharge ranges to minimize data uncertainty. Furthermore, we took the approach of considering values at relocations relative to the context of the surrounding map. Use of this approach helps to minimize the uncertainty of values that tend to show a systematic change with discharge, such as depth.

Approaches for Assessment of Sturgeon Habitat Selection

The challenge for analyzing the sturgeon relocation and reach map data in the context of habitat selection lies in the fact that each sturgeon relocation should be considered in the context of habitat availability just in the surrounding reach, but most reach maps contain only one or a few relocation points—generally too few to be conclusive on their own. Thus, the results from individual reaches must be combined in a meaningful way. We took two complementary approaches to the assessment of habitat selection for continuous variables: an approach involving absolute variable values and an approach involving relative variable values. Assessment of habitat selection for categorical variables was similar to the absolute approach for continuous variables. All exploratory analyses were performed in a univariate context. The following sections describe each approach.

Continuous variables in terms of absolute variable values—For each continuous variable (depth, velocity, depth slope, velocity gradient, and Froude number), the absolute approach involved compiling: (1) composite histograms for groups of reach maps, and (2) composite histograms for values at sturgeon relocations from corresponding groups of maps. The histograms were normalized and plotted together. For a given histogram bin, the relative height of the histogram bar representing habitat availability compared to the height of the bar representing sturgeon relocations suggests whether the values represented by that bin were selected or avoided. For example, if the proportion of relocations exceeds the proportion of available habitat for a given bin, this suggests selection. Because multiple maps were pooled for these comparisons, a potential pitfall of this approach is that the sturgeon relocation values are compared to composite distributions from reach maps, and the distribution and range of values of the composite map histograms may differ somewhat from the distribution or range of values that each specific sturgeon could actually select—that is, the habitat values in the reach-scale vicinity of the sturgeon. To minimize this issue, we computed the histograms by geomorphically similar river sections. In spite of this limitation, we feel this approach is valuable because it is fairly intuitive, and because the results are in terms of absolute numeric values for the variables in question.

We took these results a step further by calculating Ivlev's selectivity coefficients to quantify the strength of selection for habitat values (Manly and others, 2002). Selectivity coefficients are calculated as:

$$E_i = \left(o_i - \pi_i\right) / \left(o_i + \pi_i\right)$$

where:

E_i is the selectivity coefficient for resource unit I (from -1 to +1),

o_i is the sampled proportion of used units, and

π_i is the sampled proportion of available units.

Values of the selectivity coefficient near zero indicate habitat is used in proportion to its availability. Positive coefficient values indicate habitat selection, whereas negative coefficient values indicate avoidance. Although these coefficients do not indicate a probability of sturgeon occurrence in the habitat unit, they document the strength of selection among a range of values. Bins with no relocations receive a -1 selectivity coefficient even if the amount of available habitat area is very small, so selectivity coefficients computed from such bins should be interpreted with caution.

Continuous variables in terms of relative variable values using a decile classification approach.—The relative approach used to explore sturgeon selection of habitat with respect to continuous variables (depth, velocity, depth slope, velocity gradient, and Froude number) in a univariate context involved computing the decile distribution for each map of the continuous variable type. This method divides the range of the variables such that each interval represents one-tenth of the mapped area (fig. 6). The value at each sturgeon relocation is considered in the context of the decile values for the respective reach to determine within which decile range the sturgeon relocation value falls. This is a measure of used habitat compared to available habitat in the reach. Using this approach, the value at a sturgeon relocation is compared to the range of values available locally. For groups of sturgeon relocations from collections of reach maps, the distribution of the sturgeon decile values can provide insight into whether sturgeon nonrandomly select habitats from among the range of values available to them. Because the decile zones are of equal area, this is a straightforward assessment of sturgeon habitat selection in the context of univariate data. If sturgeon are not responding to a given variable, either directly or indirectly, then we would expect similar numbers of relocations to be found in each decile range.

We have compiled the results by river section and by species, sex, and reproductive condition. In addition, for reproductive female shovelnose sturgeon, we have further compiled the data by year, by month of the year, and by discharge range. However, we have not assessed how relocations may have been influenced by antecedent hydrologic, hydraulic, or temperature conditions, nor have we accounted for sturgeon behavior at the time of relocation. These are possibilities for future analyses.

Categorical variables.—For each categorical variable (substrate, terrain classification, and shallow-water habitat), the available area of each category was summarized for each reach map. In addition, the category at the location of each qualifying sturgeon relocation was determined. Within geomorphically similar river sections, we computed the proportion of available habitat in each category, as well as the proportion of sturgeon found within each category. These values were used to compute Ivlev's selectivity coefficients. This approach compares the composite distribution of sturgeon relocations with the composite distribution of habitat values among many reaches. Within river sections, the broad similarity of the proportional availability of categorical values contributes to the validity of this approach.

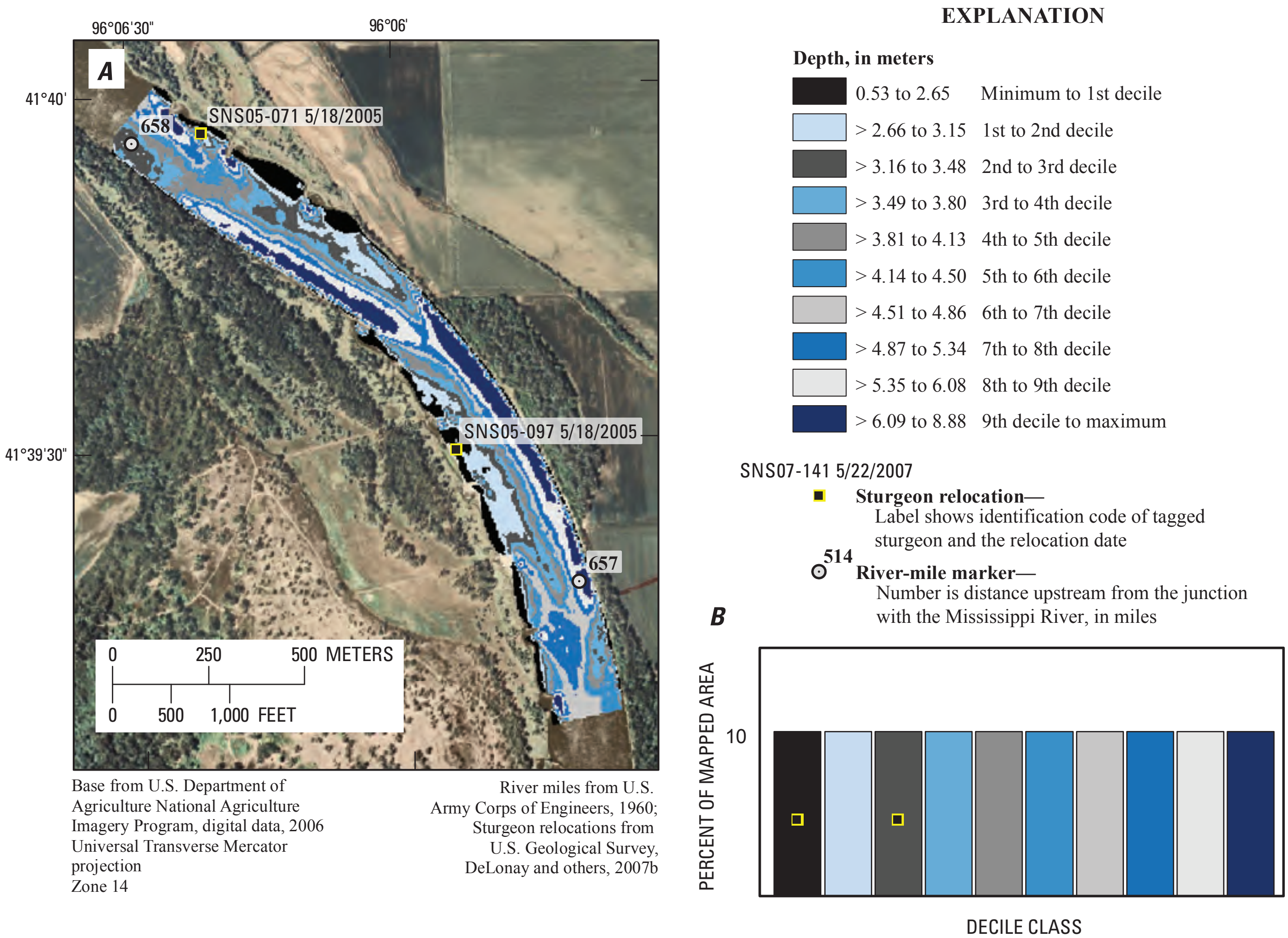

Figure 6. Illustration of the approach used to characterize sturgeon relocations by decile range of habitat used. *A*, Depth map color coded by decile ranges with two qualifying sturgeon relocation. *B*, Plot showing that each decile range represents an equal area. In this case, one sturgeon relocation fell in the first decile and one in the third.

Inferred Patterns of Habitat Use in a Map Context

The decile analysis yielded results that indicate that habitat use by sturgeon is non-uniform in the Lower Missouri River. We explored the spatial distribution of the ranges of values that sturgeon tended to select for three variables (depth slope, velocity gradient, and Froude number) to address some basic questions: Where do these values occur? How do the different variables interact in a spatial context? How do the patterns differ by river section? In the approach that we took, we reclassified maps of each continuous variable such that a "1" represented the 2 most selected deciles, and a "0" represented the remainder of the deciles. After reclassifying each individual variable, we combined the maps by adding them together. In the resulting maps, each grid cell has a value from 0 to 3, representing the number of variables that fall within the range that sturgeon showed the greatest tendency to select. Finally, to assess whether these zones might represent a more general predictor of habitats that are selected by sturgeon, we considered where the general population of sturgeon relocations fell on the reclassified maps. All relocations falling on the maps were considered, as long as the relocations and the maps were from the same year.

The following reasons justify the decision to include all sturgeon relocations from the same year (rather than just those within 7 days and 10 percent discharge of the map): (1) For reaches that were mapped more than once, observations suggest that the spatial patterns of the mapped selection zones show some degree of persistence. For example, in some areas, selection zones tend to be associated with the edge of the channel, a pattern that appears relatively robust within the context of the observed amount of morphologic change. (2) Use of all relocations from the same year substantially increases the sample size of relocations associated with maps; notably, this means that many more relocations (sample size = 2,013) are being used to test the selection model relative to the number of relocations (sample size = 378) that were used to develop the selection model.

Geomorphic Characterization of the Lower Missouri River Based on Reach Maps

The reach maps provide insight into the geomorphic character and longitudinal variability of the Lower Missouri River. This section presents several summaries of reach characteristics. As a part of the data exploration, we address the question of how best to group similar parts of the river; are there natural groupings of data that suggest different parts of the river have distinct habitat structures? We approached this analysis with the working hypothesis that reaches within segments—defined primarily by major tributary junctions (fig. 1)—would share similarities (Frissell and others, 1986; Benda and others, 2004). Other factors that could influence longitudinal patterns of habitat quantity and quality include engineering structures, flow regime, and physiographic provinces. Qualitative patterns emerge from the reach summary data presented here.

In the first group of summary plots, reach geometry characteristics and other summary data are plotted against river mile (fig. 7). In these plots, each reach stands for itself, and no assumptions are made about how to group parts of the river with like characteristics. Plotted points represent all mapped discharges, regardless of flow exceedance. Several notable patterns can be discerned from figure 7. Discharge and wetted cross-sectional area show an overall increase in the downstream direction. However, other variables that commonly increase in a downstream direction under natural river conditions show more complex patterns on the Lower Missouri River; velocity and width are examples. For similar discharges, mean reach velocities are highest in the Big Sioux and Platte segments, where the widths are also the narrowest. Mean reach depth averages more than 4 meters throughout the navigable parts of the river, with generally shallower mean depths (less than 3 meters) upstream from Sioux City, Iowa.

A schematic summary of reach geometry data averaged by segment is presented in figure 8. Mean width, depth, and velocity were computed from the reaches located within each segment. In this plot, box length is scaled with mean segment width and box height is scaled with mean segment depth (with no vertical exaggeration); the arrows are scaled with mean velocity. This graphic illustrates that, on average, the Gavins Point and Ponca segments are wide, relatively shallow, and have relatively low velocities. The Big Sioux and Platte segments are narrow and deep, with relatively high velocities. The Kansas, Grand, and Osage segments have mean depths and velocities similar to each other, and mean segment widths progressively increase in a downstream direction.

Composite histograms provide another summary of data at the segment scale (fig. 9). The composite depth histograms for the Gavins Point and Ponca segments are both skewed to the right. The composite depth histograms for the Big Sioux and Platte segments are both relatively symmetrical. The Kansas, Grand, and Osage segment composite depth histograms are complex, with a subpopulation of relatively shallow depths associated with areas on channel margins and behind wing dikes. Similar to depth, three distinct sets of velocity histograms are apparent: The Gavins Point and Ponca composite velocity histograms are roughly symmetrical. The Big Sioux and Platte composite velocity histograms are skewed left. The Kansas, Grand, and Osage composite velocity histograms show a more complex, shape, heavily skewed left and containing secondary modes.

To simplify analysis, we grouped the seven Lower Missouri River segments into three major river sections on the basis of the similar groupings of habitat-variable distributions (fig. 9), mean widths (fig. 8), and mean velocities (fig. 8). From upstream to downstream, these are referred to as the Minimally Engineered, the Upstream Channelized, and the Downstream Channelized sections. Because of the gap in relocations and maps between the upper Platte segment and Kansas City, we cannot precisely determine the location or abruptness of the change from the Upstream Channelized to the Downstream Channelized section based on the map data. Generally, however, these river sections correspond to parts of the river that are engineered and managed in different ways. Typical reaches document habitat characteristics of the three river sections (figs. 10–12). For each of these example reaches, figures also show the bivariate relations of the continuous variables.

The bivariate relations among continuous variables (table 2, figs. 10–12) yield additional insight into the geomorphic and hydraulic structure of the mapped reaches. Variation exists among the correlation coefficients from reach to reach and section to section, but some generalizations can be made that apply to the entire Lower Missouri River. On a point by point basis, depth and velocity tend to be positively correlated; higher velocities tend to be associated with greater depths. Within reaches, the exceptions occur in association with deep scour holes that have low velocity; deep, slow scours are particularly prevalent in the Downstream Channelized section of river. The correlation of depth and velocity in the Lower Missouri River contrasts with depth-velocity relations in many smaller rivers and streams where the shallow riffle environments tend to have high velocities, and pools tend to have low velocities at moderate discharge (Rabeni and Jacobson, 1993). Depth slope and velocity gradient sometimes also exhibit a positive correlation. To the extent that depth and velocity covary, it is reasonable that their derivatives—depth slope and velocity gradient—would covary as well. A third variable pair that shows relatively strong positive correlations is velocity and Froude number. Froude number on the Missouri River tends to be relatively low, less than 0.3. Conditions that produce high Froude numbers (shallow depth and high velocity) tend not to occur on the Lower Missouri River. Under prevailing conditions, Froude number is strongly correlated with velocity but not with depth. Correlations between other variable pairs are weak or inconsistent (table 2). Recognition of the relations among physical variables may be useful in assessing responses of biota to the physical environment.

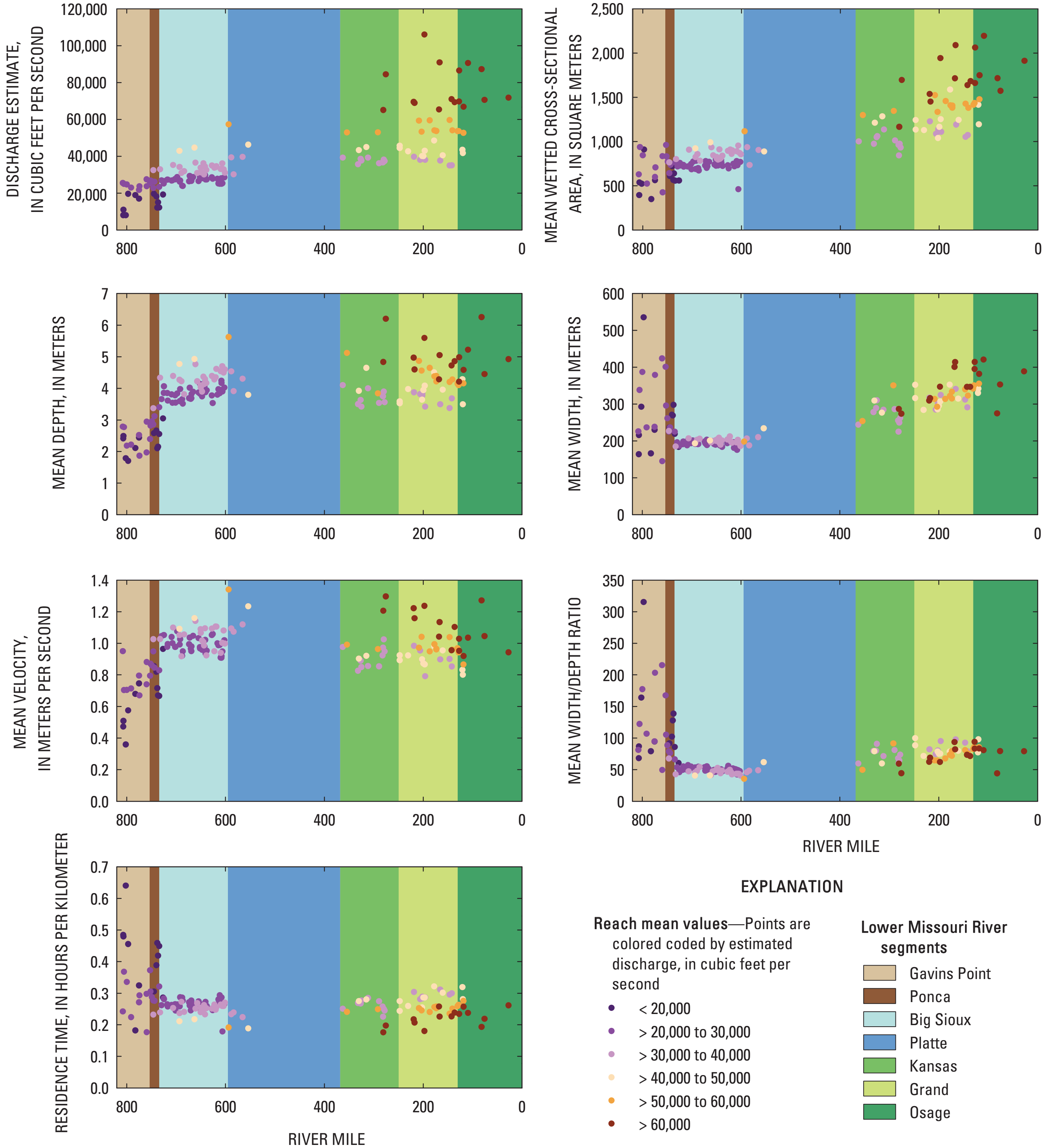

Figure 7. Plots of reach geometry and related statistics by river mile. Each point represents a reach. For reference, the segments are shaded in the background of the plot. Data values were omitted for the map on May 21, 2007, near river mile 759.6 because the map represents only a side channel.

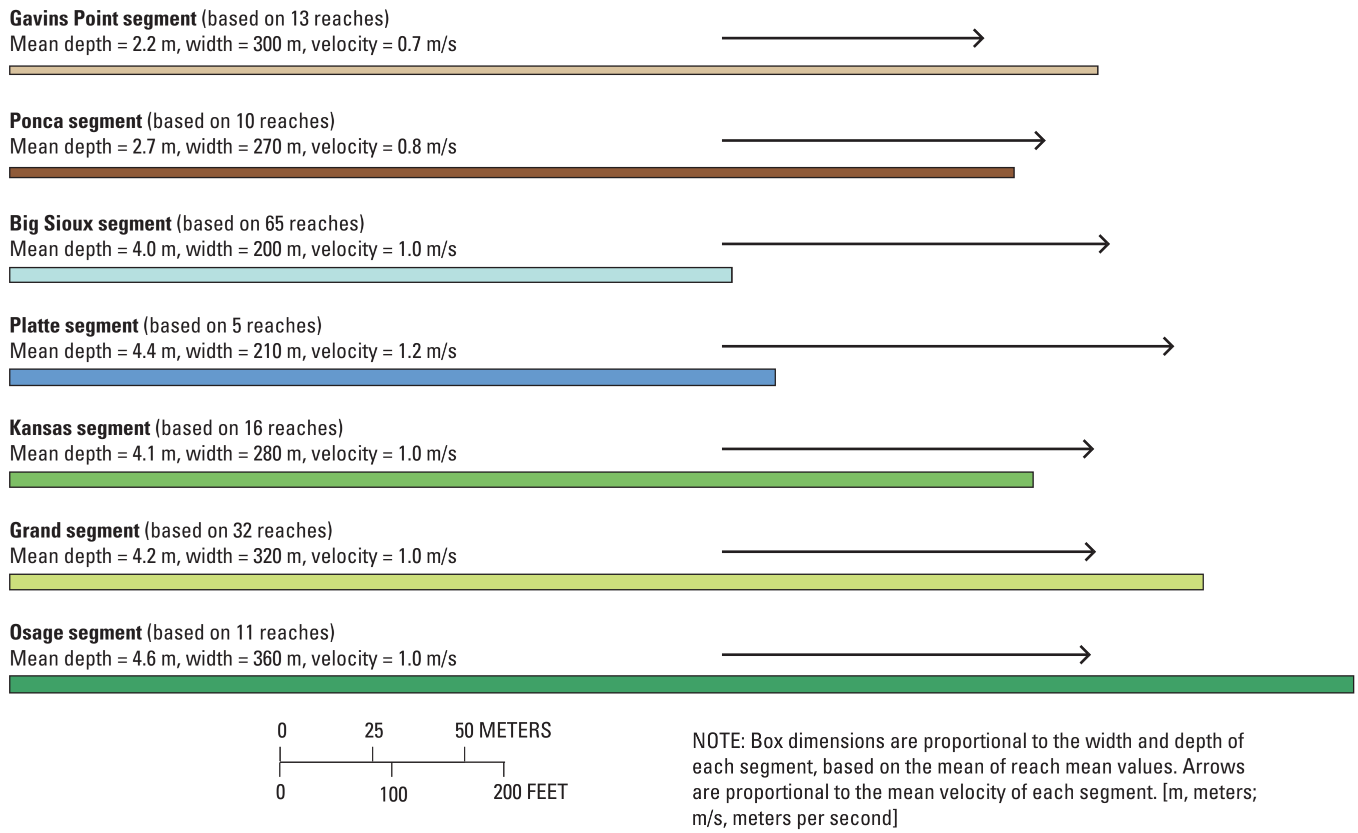

Figure 8. Schematic illustration of channel geometry and velocity characteristics, based on mean values by river segment. Widths, depths, and velocity values were calculated by taking the mean of the reach mean values in each segment.

Additional insight into the character of the Lower Missouri River comes from observations of channel change over time. The reach maps were not mapped with absolute elevation control because characterization of geomorphic change was not one of the goals of this portion of the sturgeon research project. However, some reaches were mapped on more than one occasion, and qualitative patterns of change shown by these repeat maps exhibit similarities to the geomorphic dynamics quantified in Elliott and others (2009). Figure 13 shows three examples of repeat mapping, with one reach per river section. The time interval between each pair of maps is approximately 1 year. The maps display classified bathymetry using the benthic terrain mapping technique, which has the advantage of highlighting the major features of the channel with relative insensitivity to discharge (Jacobson and others, 2009b). These examples of repeat mapping demonstrate the dynamic nature of the Lower Missouri River and illustrate differences in channel dynamics in various parts of the river.

The repeat mapping example from the Minimally Engineered section (fig. 13*A*, 13*B*) is located at Mulberry Bend (river mile 775), downstream from the James River junction. This reach shows some substantial changes in bar configuration and in the area navigable by the survey boat between the 2 years (although discharges were similar). Two additional reaches documented by Elliott and others (2009) in the Minimally Engineered section showed differing trends, with little change in the armored reach at Yankton, South Dakota, just 5 kilometers (3 miles) downstream from the dam, but substantial change in the Ponca segment at Kenslers Bend, when normalized for channel size.

The example from the Upstream Channelized section (fig 13*C*, 13*D*) is near the junction with the Little Sioux River (river mile 669) and in close proximity to the reach that Elliott and others (2009) surveyed. As illustrated here, in the Upstream Channelized section the position of the thalweg often does not fall in the outer bend as defined by the engineered planform morphology. The repeat mapping example shows a shift in the location of bars and the depressions in a generally downstream direction. Elliott and others (2009) documented change of considerable magnitude, including shifts in the location of the thalweg from one bank to another over the course of a year.

The repeat mapping example from the Downstream Channelized section (fig. 13*E*, 13*F*) is in the Grand segment upstream from Lisbon Bottom. Although this reach was mapped at two different discharges and over a year apart, the major morphologic features of the reach show little change. The thalweg and bar positions are very stable, and the thalweg position corresponds to the outer bend of the river planform. Although change did occur, the overall stability of channel features is consistent with the surveys of Elliott and others (2009) in the Downstream Channelized section.

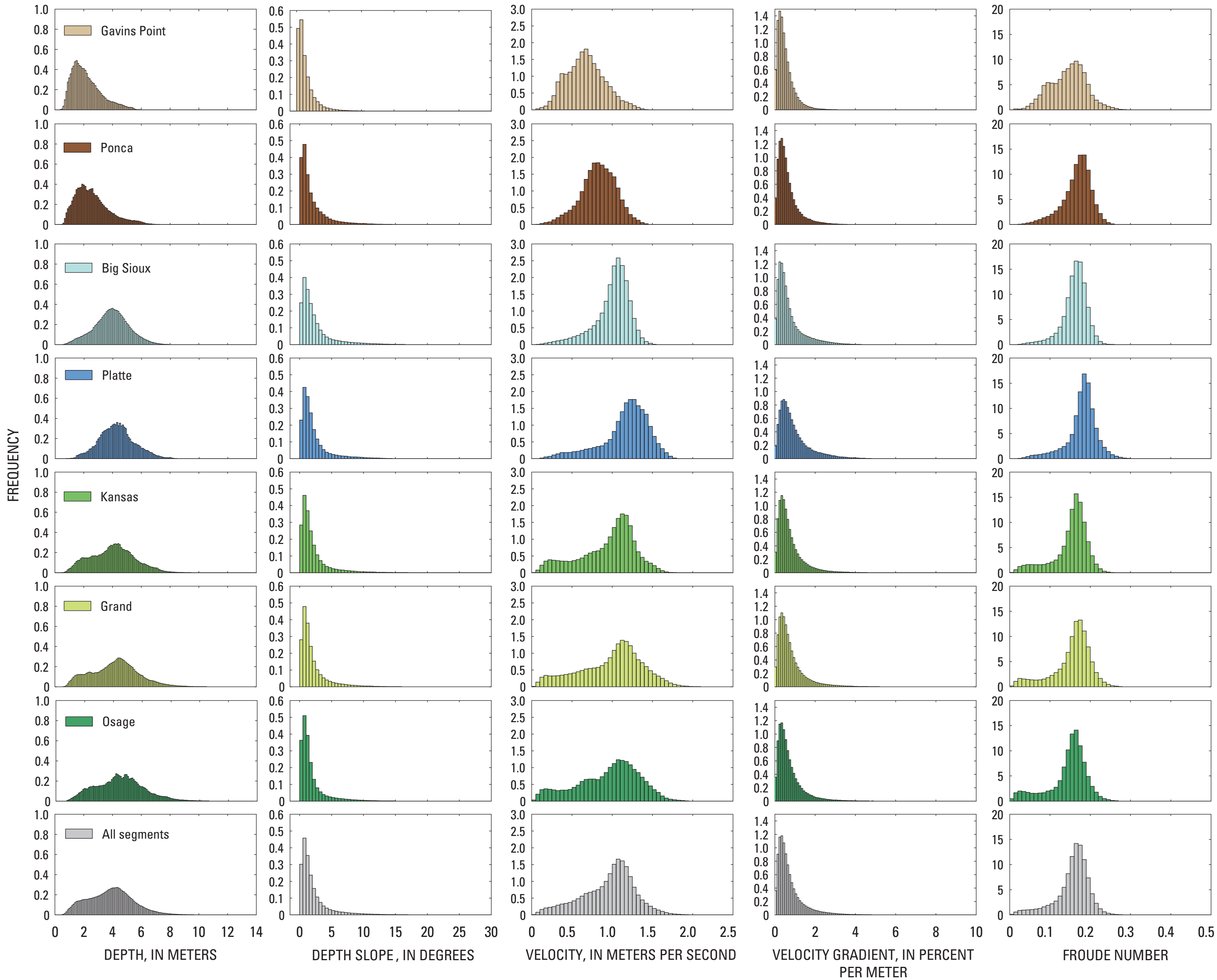

Figure 9. Composite histograms by river segment for depth, depth slope, velocity, velocity gradient, and Froude number.

Descriptions of Lower Missouri River Sections

Observations from the reach maps suggest that the engineering framework of the Lower Missouri River is of overarching importance in determining habitat patterns; similarly engineered and managed sections of river tend to share similar morphologies and characteristics. Habitat controls exerted by physiographic constraints or changes in flow regime at major tributaries are less apparent.

An understanding of the geomorphic and hydrologic framework of the Lower Missouri River provides important context for interpretation of sturgeon relocations. Therefore, before addressing the results from the sturgeon data, we offer the following broad descriptions of the major sections of the Lower Missouri River, based on summary data from the mapped reaches and from published research. It is important to note that present-day (2008) descriptions of Missouri River habitats capture a synoptic view of a river system that is undergoing substantial re-engineering to support ecosystem recovery (U.S. Fish and Wildlife Service, 2000; U.S. Army Corps of Engineers, 2003; U.S. Fish and Wildlife Service, 2003; Jacobson and others, 2009a).

Minimally Engineered Section (Gavins Point and Ponca Segments)

The Missouri River is not maintained for commercial navigation from Gavins Point Dam to Sioux City, Iowa (fig. 1). From a morphologic standpoint, this is the least altered section of the Lower Missouri River and the closest to a reference condition. This is especially true upstream from Ponca State Park, where the river is under the jurisdiction of the National Park Service as the Missouri National Recreational River. There, much of the channel is multithreaded with sand bars, vegetated islands, and eroding banks, though banks have been stabilized with revetment in places (Elliott

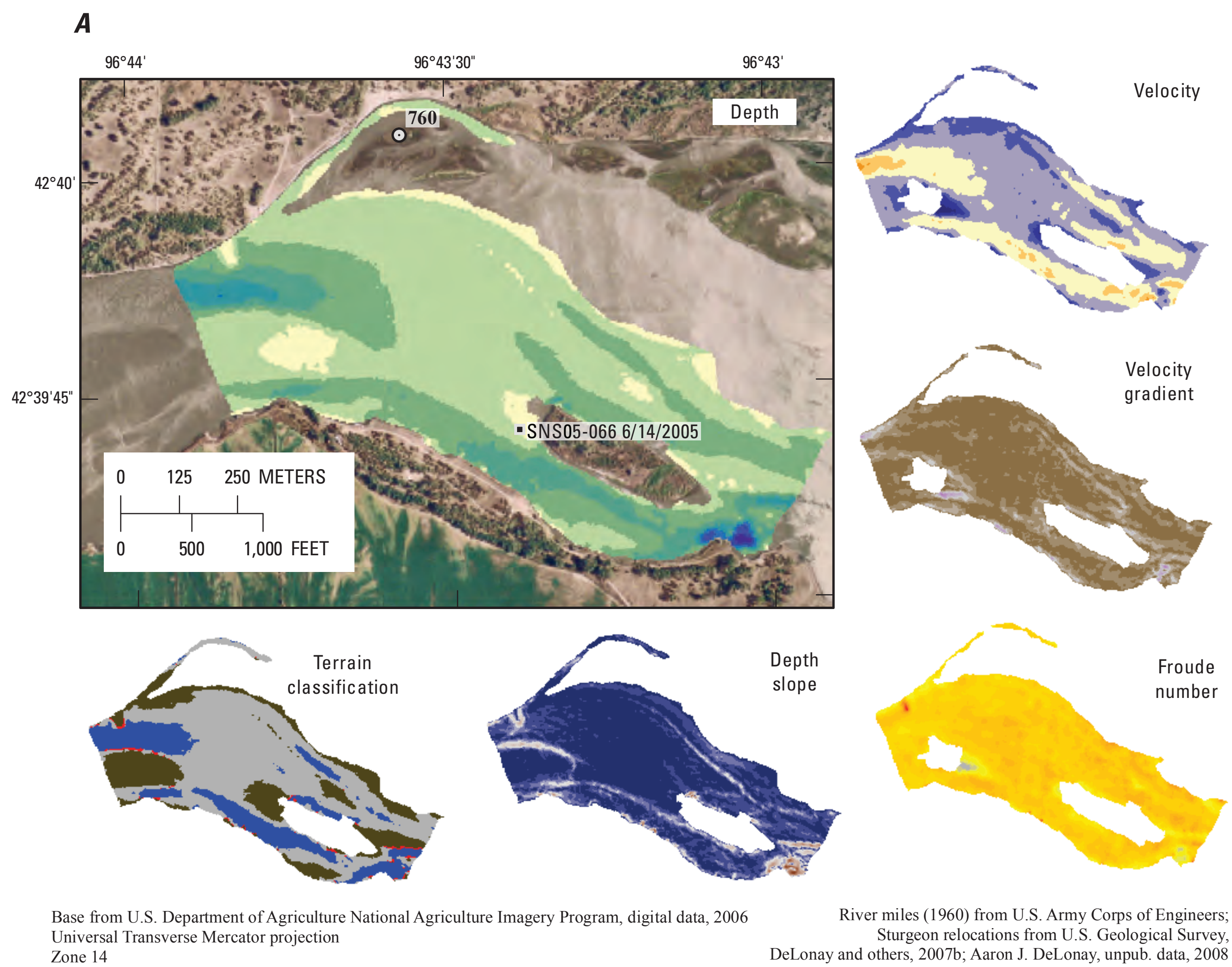

Figure 10. Example reach from the Minimally Engineered section, mapped on June 15, 2005, in the vicinity of river mile 760. *A*, Maps are shown for each of the continuous variable and the terrain classification. *B*, Scatter plots illustrate relations among the continuous variables.

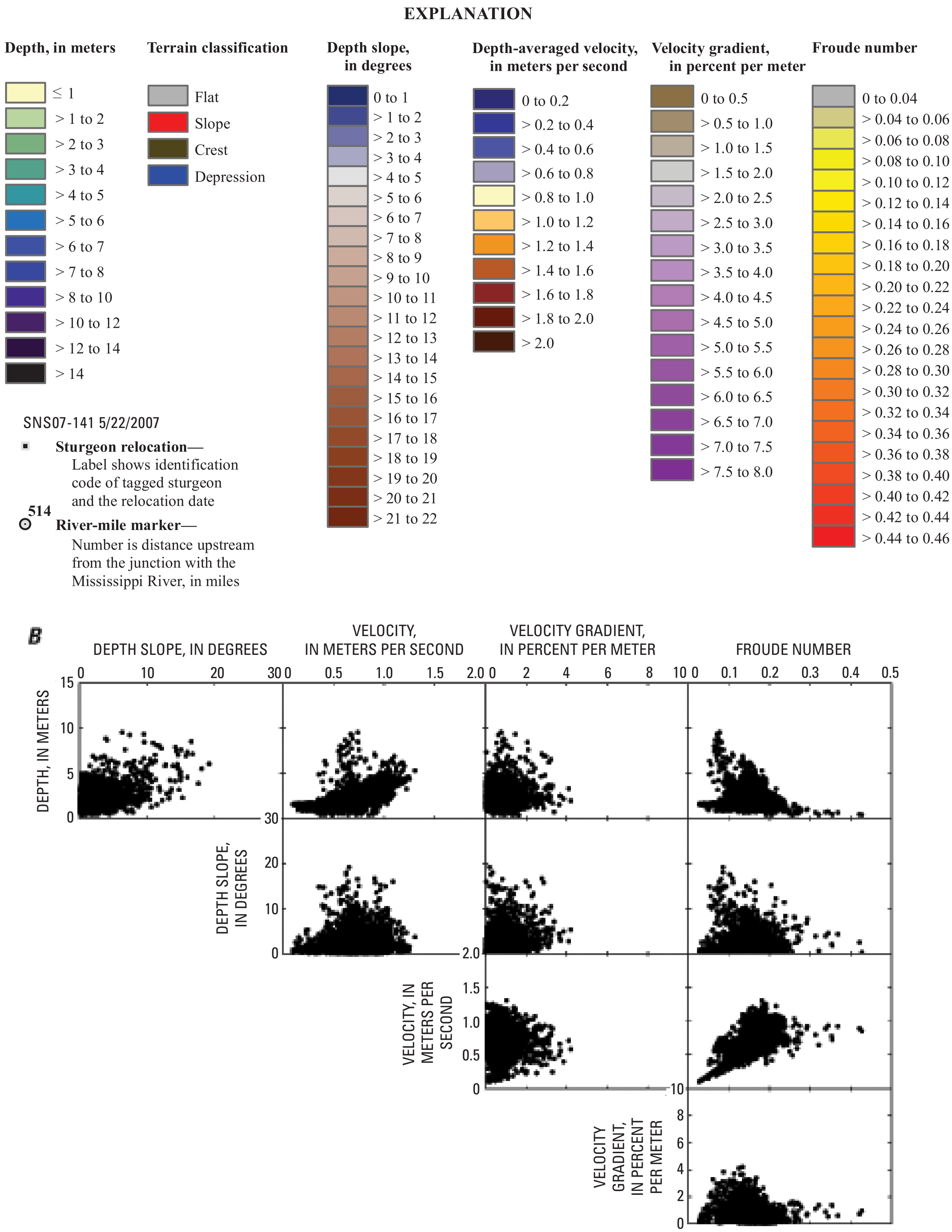

Figure 10. Example reach from the Minimally Engineered section, mapped on June 15, 2005, in the vicinity of river mile 760. *A*, Maps are shown for each of the continuous variable and the terrain classification. *B*, Scatter plots illustrate relations among the continuous variables.—Continued

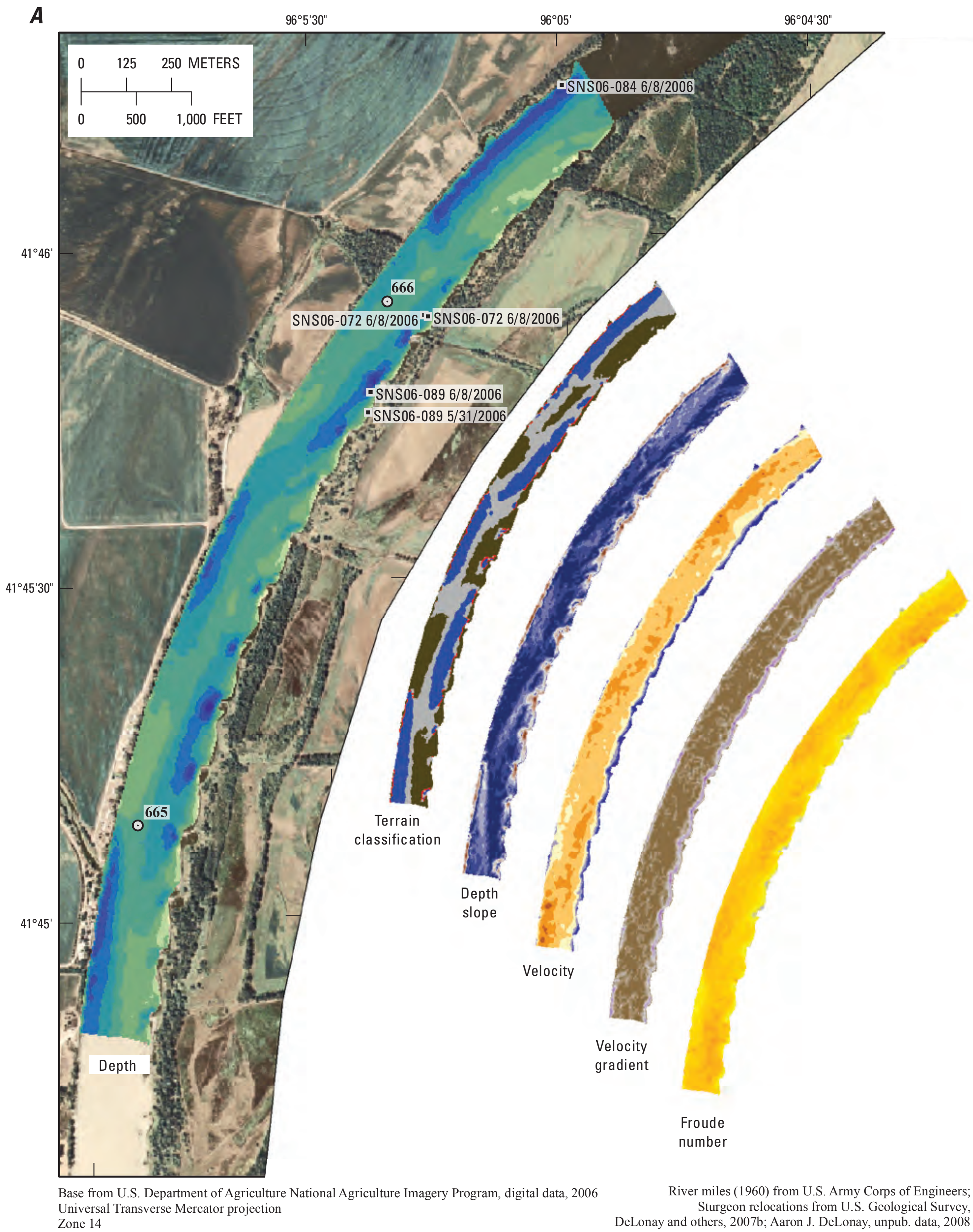

Figure 11. Example reach from the Upstream Channelized section, mapped on June 6, 2006, in the vicinity of river mile 665. *A*, Maps are shown for each of the continuous variable and the terrain classification. *B*, Scatter plots illustrate relations among the continuous variables.

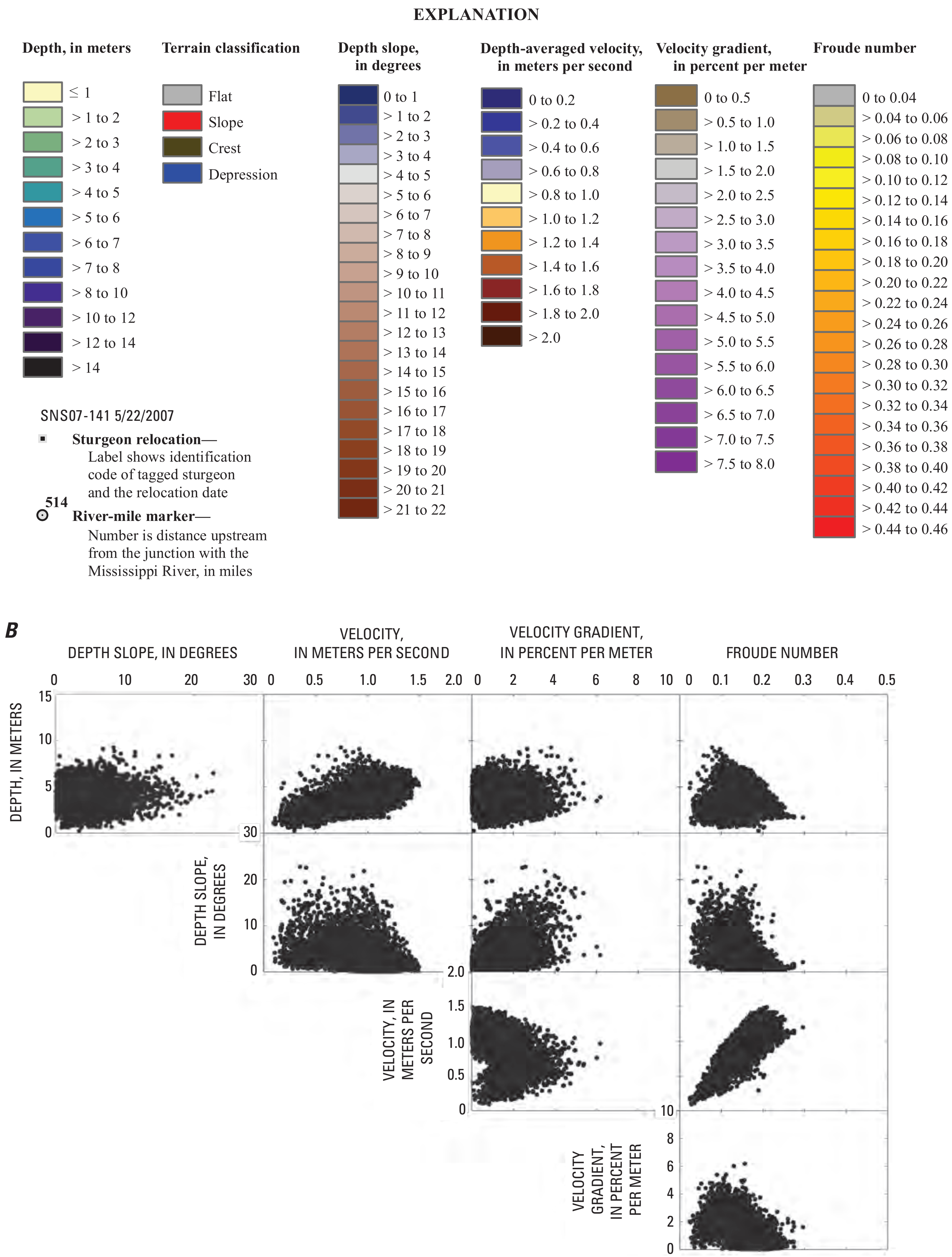

Figure 11. Example reach from the Upstream Channelized section, mapped on June 6, 2006, in the vicinity of river mile 665. *A*, Maps are shown for each of the continuous variable and the terrain classification. *B*, Scatter plots illustrate relations among the continuous variables.—Continued

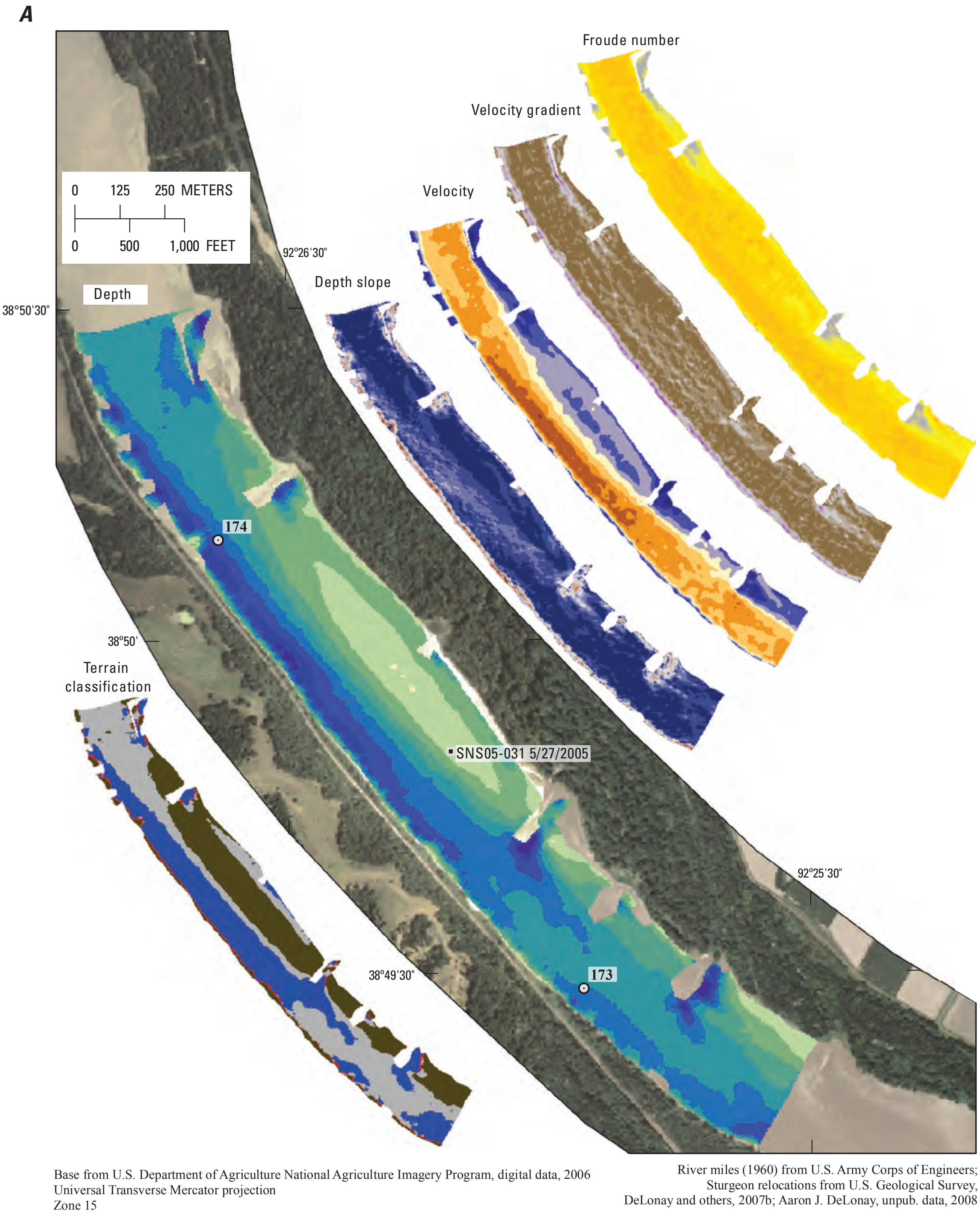

Figure 12. Example reach from the Downstream Channelized section, mapped on June 1, 2005, in the vicinity of river mile 173. *A*, Maps are shown for each of the continuous variable and the terrain classification. *B*, Scatter plots illustrate relations among the continuous variables.

EXPLANATION

Depth, in meters

- ≤ 1
- > 1 to 2
- > 2 to 3
- > 3 to 4
- > 4 to 5
- > 5 to 6
- > 6 to 7
- > 7 to 8
- > 8 to 10
- > 10 to 12
- > 12 to 14
- > 14

Terrain classification

- Flat
- Slope
- Crest
- Depression

Depth slope, in degrees

- 0 to 1
- > 1 to 2
- > 2 to 3
- > 3 to 4
- > 4 to 5
- > 5 to 6
- > 6 to 7
- > 7 to 8
- > 8 to 9
- > 9 to 10
- > 10 to 11
- > 11 to 12
- > 12 to 13
- > 13 to 14
- > 14 to 15
- > 15 to 16
- > 16 to 17
- > 17 to 18
- > 18 to 19
- > 19 to 20
- > 20 to 21
- > 21 to 22

Depth-averaged velocity, in meters per second

- 0 to 0.2
- > 0.2 to 0.4
- > 0.4 to 0.6
- > 0.6 to 0.8
- > 0.8 to 1.0
- > 1.0 to 1.2
- > 1.2 to 1.4
- > 1.4 to 1.6
- > 1.6 to 1.8
- > 1.8 to 2.0
- > 2.0

Velocity gradient, in percent per meter

- 0 to 0.5
- > 0.5 to 1.0
- > 1.0 to 1.5
- > 1.5 to 2.0
- > 2.0 to 2.5
- > 2.5 to 3.0
- > 3.0 to 3.5
- > 3.5 to 4.0
- > 4.0 to 4.5
- > 4.5 to 5.0
- > 5.0 to 5.5
- > 5.5 to 6.0
- > 6.0 to 6.5
- > 6.5 to 7.0
- > 7.0 to 7.5
- > 7.5 to 8.0

Froude number

- 0 to 0.04
- > 0.04 to 0.06
- > 0.06 to 0.08
- > 0.08 to 0.10
- > 0.10 to 0.12
- > 0.12 to 0.14
- > 0.14 to 0.16
- > 0.16 to 0.18
- > 0.18 to 0.20
- > 0.20 to 0.22
- > 0.22 to 0.24
- > 0.24 to 0.26
- > 0.26 to 0.28
- > 0.28 to 0.30
- > 0.30 to 0.32
- > 0.32 to 0.34
- > 0.34 to 0.36
- > 0.36 to 0.38
- > 0.38 to 0.40
- > 0.40 to 0.42
- > 0.42 to 0.44
- > 0.44 to 0.46

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Sturgeon relocation—Label shows identification code of tagged sturgeon and the relocation date

514

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

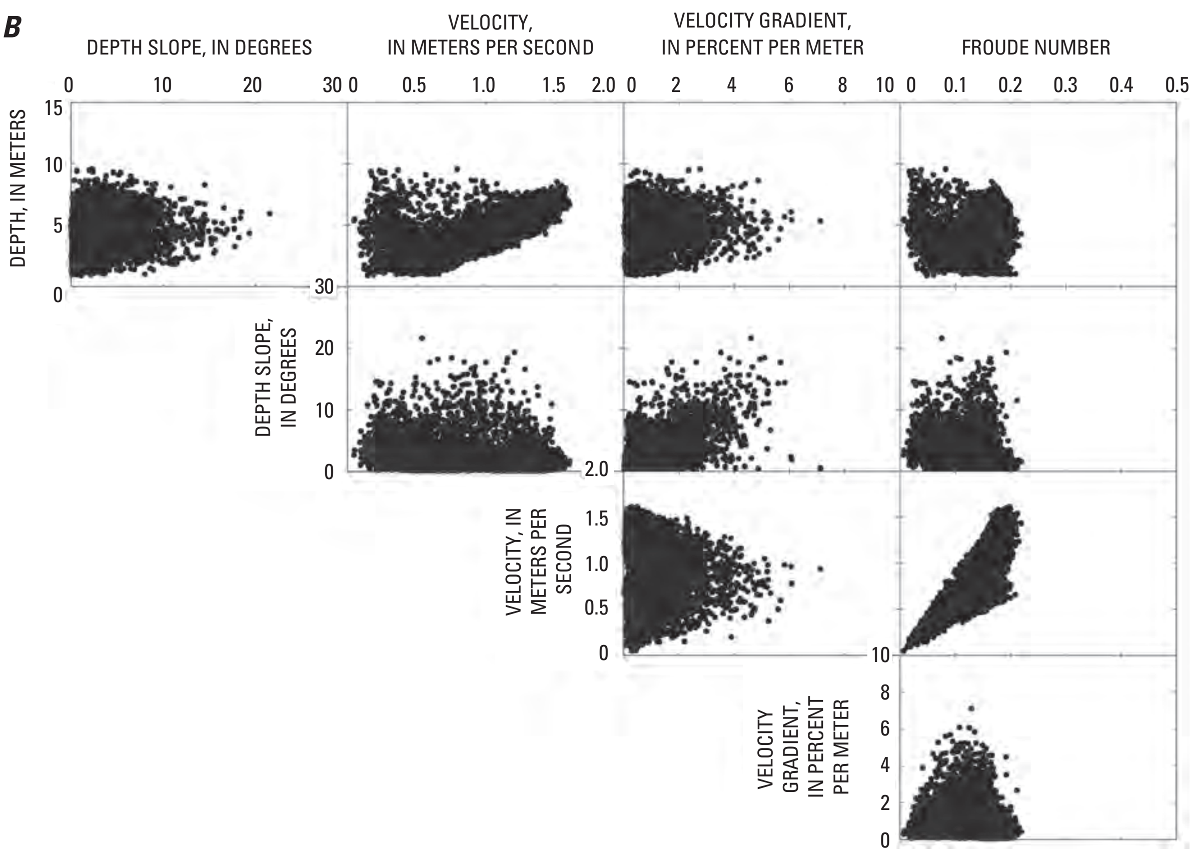
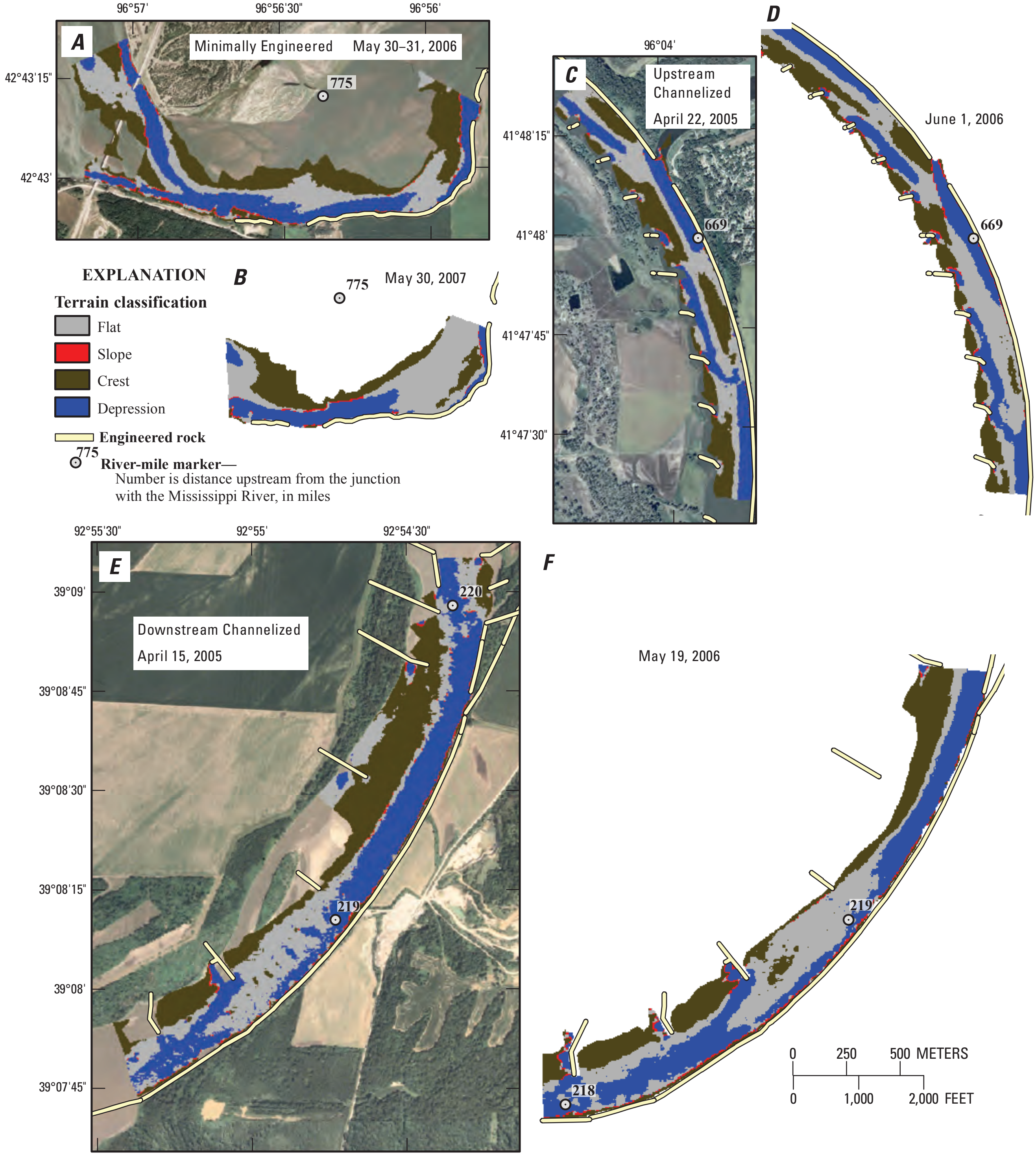


Figure 12. Example reach from the Downstream Channelized section, mapped on June 1, 2005, in the vicinity of river mile 173. *A*, Maps are shown for each of the continuous variable and the terrain classification. *B*, Scatter plots illustrate relations among the continuous variables.—Continued

Table 2. Bivariate relations among continuous variables for map data.

[For each mapped reach, linear correlation coefficients were computed for each pair of variables. Distributions of these correlation coefficients are presented here for each river section]

River section	Variable 1	Variable 2	Linear correlation coefficients (r)				
			Minimum	First quartile	Median	Third quartile	Maximum
Minimally Engineered	Depth	Depth slope	0.07	0.30	0.38	0.45	0.56
Upstream Channelized	Depth	Depth slope	-0.29	-0.05	0.03	0.11	0.31
Downstream Channelized	Depth	Depth slope	-0.24	0.11	0.16	0.22	0.39
Minimally Engineered	Depth	Velocity	-0.00	0.35	0.44	0.53	0.76
Upstream Channelized	Depth	Velocity	0.39	0.50	0.56	0.62	0.77
Downstream Channelized	Depth	Velocity	0.14	0.50	0.62	0.69	0.86
Minimally Engineered	Depth	Velocity gradient	-0.12	0.08	0.12	0.19	0.28
Upstream Channelized	Depth	Velocity gradient	-0.31	-0.18	-0.10	-0.05	0.09
Downstream Channelized	Depth	Velocity gradient	-0.20	-0.02	0.07	0.12	0.27
Minimally Engineered	Depth	Froude number	-0.51	-0.40	-0.32	-0.25	0.05
Upstream Channelized	Depth	Froude number	-0.51	-0.22	-0.10	0.04	0.33
Downstream Channelized	Depth	Froude number	-0.12	0.06	0.16	0.29	0.55
Minimally Engineered	Depth slope	Velocity	-0.31	-0.23	-0.13	-0.01	0.17
Upstream Channelized	Depth slope	Velocity	-0.61	-0.47	-0.41	-0.30	-0.18
Downstream Channelized	Depth slope	Velocity	-0.59	-0.38	-0.31	-0.21	0.04
Minimally Engineered	Depth slope	Velocity gradient	0.13	0.39	0.45	0.53	0.61
Upstream Channelized	Depth slope	Velocity gradient	0.41	0.58	0.62	0.65	0.77
Downstream Channelized	Depth slope	Velocity gradient	0.14	0.37	0.43	0.54	0.71
Minimally Engineered	Depth slope	Froude number	-0.58	-0.50	-0.42	-0.25	-0.11
Upstream Channelized	Depth slope	Froude number	-0.65	-0.56	-0.48	-0.41	-0.24
Downstream Channelized	Depth slope	Froude number	-0.65	-0.48	-0.41	-0.35	-0.19
Minimally Engineered	Velocity	Velocity gradient	-0.38	-0.22	-0.14	-0.06	0.08
Upstream Channelized	Velocity	Velocity gradient	-0.64	-0.56	-0.50	-0.42	-0.27
Downstream Channelized	Velocity	Velocity gradient	-0.36	-0.17	-0.13	-0.08	0.13
Minimally Engineered	Velocity	Froude number	0.51	0.63	0.67	0.74	0.88
Upstream Channelized	Velocity	Froude number	0.50	0.69	0.75	0.82	0.92
Downstream Channelized	Velocity	Froude number	0.59	0.84	0.89	0.91	0.98
Minimally Engineered	Velocity gradient	Froude number	-0.45	-0.35	-0.27	-0.10	0.05
Upstream Channelized	Velocity gradient	Froude number	-0.62	-0.52	-0.46	-0.41	-0.23
Downstream Channelized	Velocity gradient	Froude number	-0.37	-0.23	-0.16	-0.13	0.12



Base from U.S. Department of Agriculture National Agriculture Imagery Program, digital data, 2006
Universal Transverse Mercator projection
Zone 14 (river mile 775 and 669) and 15 (river mile 219)

River miles (1960) from U.S. Army Corps of Engineers

Figure 13. Examples of repeat mapping from each river section, *A*, *B*, Minimally Engineered, *C*, *D*, Upstream Channelized, and *E*, *F*, Downstream Channelized. Maps show the terrain classification representation of each reach because it highlights major channel features and is relatively insensitive to discharge.

and Jacobson, 2006). Downstream from Ponca State Park, revetment and wing dikes stabilize and constrict the channel. However, morphologic characteristics of the Ponca segment show similarities with the Gavins Point segment (fig. 9). For example, at moderate to low flow, emergent sand bars are common in the Ponca segment. Therefore, we combined the Gavins Point and Ponca segments for analysis and call them the Minimally Engineered section of the Lower Missouri River.

The Minimally Engineered section of river is characterized by a single- or multithread channel with variable—but typically relatively large—widths. The depth histograms tend to be skewed right (fig. 9), meaning that shallow depths are common. As discharge decreases or increases, bar area can readily become emergent or submergent. Mean velocities are relatively low, and velocity histograms tend to be relatively symmetrical (fig. 9); low- and high-velocity habitats are available in similar quantities.

Although the Minimally Engineered section has relatively natural morphologic characteristics, its location just downstream from Gavins Point Dam results in two related effects: (1) this river section has a highly altered flow regime (Galat and Lipkin, 2000; Pegg and others, 2003), and (2) the section is sediment starved and the channel is incising as demonstrated by declining water-surface elevations for the same discharge over time (U.S. Army Corps of Engineers, 2007; Jacobson and others, 2009a). These factors combine to limit the likelihood for connectivity with the historic flood plain in this section of river.

Geomorphic dynamism varies within the section. Results from monitoring by Elliott and others (2009) in 2006 and 2007 showed relatively low magnitude channel change at Yankton, South Dakota (river mile 805), between Gavins Point Dam and the first major tributary. At the Yankton reach, much of the channel is armored with gravel. In contrast, change at Kenslers Bend (river mile 746, in the Ponca segment) was high when scaled to channel size (Elliott and others, 2009). Qualitative observations from repeat mapping at Mulberry Bend (river mile 775, fig. 13) also show notable change in morphology. In addition, bank changes quantified from air photos (Elliott and Jacobson, 2006) attest to the dynamic nature of parts of the Minimally Engineered section of river.

Upstream Channelized Section (Big Sioux and Platte Segments)

The Big Sioux and Platte segments are managed by the U.S. Army Corps of Engineers for commercial navigation. These segments have been stabilized with revetment and spur dikes and are not subject to planform geomorphic changes except where reconfigured in restoration projects. The engineered structures constrain the channel width to be the narrowest and most uniform of the Lower Missouri River (fig. 7).

The depth histograms in the Upstream Channelized section show a relatively symmetrical shape, in contrast to the skewed nature of the histograms for the Minimally Engineered section (fig. 9). Not much of the channel area is represented by shallow depths. The mean depth based on the mapped reaches is 4 meters, similar to the measured mean depth throughout the length of the river maintained for commercial navigation. The consistency of the widths from the surveyed reaches within the Upstream Channelized section is notable, given that maps were made at a range of discharges (figs. 4, 7). We attribute the consistency in width across discharge to the steepness of the banks in this river section. As discharge increases, the river is constrained by the banks from spreading laterally and there is little opportunity for shallow water. In the Upstream Channelized section, emergent bars are very limited at the typical navigation-season discharges that we observed while mapping. In addition to being deep and narrow, the Upstream Channelized section has the highest mean velocity values based on the reaches we mapped. Relative to those of the other river sections, the composite velocity histograms (fig. 9) are skewed such that low velocity values are more sparsely represented.

In the Upstream Channelized section, the location of thalweg is often inconsistent with the engineered planform of river and often meanders from bank to bank within the planform bends (fig. 11). Furthermore, the position of the thalweg tends to be unstable over time. We observed this qualitatively with repeat mapping of reach maps (fig. 13), and Elliot and others (2009) documented the unstable position of the thalweg quantitatively through cross-section surveys. Those surveys showed that the thalweg moved back and forth between opposite banks of the river within the course of a year. Thus, within the stable planform bends, morphologic change is substantial (Elliott and others, 2009). The spatial arrangement of habitat may change; however, 2-dimensional hydrodynamic modeling work suggests a degree of equilibrium in that proportions of habitat within a reach tend to remain relatively stable over time (Jacobson and others, 2009b).

The flow regime of the Upstream Channelized section also is substantially affected by Gavins Point Dam operations. The regulated flow regime reduces spring and early summer flow pulses relative to the natural background and increases late summer and fall flows to support navigation (fig. 2). The flow regime recovers some variability downstream from the Platte River.

Downstream Channelized Section (Kansas, Grand, and Osage Segments)

The Kansas, Grand, and Osage segments are managed for commercial navigation and have been engineered with a combination of revetment, spur dikes, and L-head dikes. Similar to the Upstream Channelized section, the planform is stable, with the exception of habitat mitigation projects. The river is dominantly a single thread, but some side-channel chutes exist as a result of a combination of natural processes and engineering for habitat (Jacobson and others, 2001, 2004). Side-channel chutes were excluded from the scope of this project.

In the Downstream Channelized section, the Missouri River becomes progressively wider in a downstream direction, although mean depths are similar to the Upstream Channelized section (fig. 8). The histograms of depth and velocity for individual reaches tend to be bimodal, and the composite histograms exhibit a more complex, nearly bimodal form relative to the simple unimodal histograms characteristic of the upper segments. The lower peak of the depth and velocity histograms generally represents values along the channel margins in areas behind wing dikes, and the higher peaks generally represent values in the navigation channel. Some of the high depth values are associated with deep scour holes, which are commonly located at the tips of dikes. Bars that are emergent at low flow and submerged at high flow are relatively common.

The location of the thalweg tends to be consistent with the engineered channel planform; that is, in a macroscale outer bend, the thalweg tends to hug the outer bend of the river. Furthermore, the location of the thalweg tends to be persistent, based on qualitative observations from repeat mapping (fig. 13) and from quantitative cross-section surveys in 2006 and 2007 (Elliott and others, 2009).

The flow regime of the Downstream Channelized section has characteristics of the natural flow regime, because tributary inflows lessen the effects of the Missouri River reservoir system (fig. 2). Spring flow pulses are relatively common, as exemplified by the spring 2007 peak flow of over 300,000 cubic feet per second at Boonville, Missouri (fig. 2). Such high flows provide opportunities for the river to connect to its flood plain, especially where levees have been removed.

Habitat Characteristics at Sturgeon Relocations

In this section, we consider the sturgeon relocations in the context of the reaches where they were relocated. A total of 378 sturgeon relocations fell on 112 maps within 7 days and 10 percent discharge of the map date. These relocations represent 166 individual sturgeon, of which 151 were shovelnose sturgeon and 15 were pallid sturgeon. Of these individuals, the group with the most representatives sharing the same species, sex, and reproductive characteristics were the reproductive female shovelnose sturgeon; 269 of the 378 relocations document positions of reproductive female shovelnose sturgeon. Table 3 documents the species, sex, and reproductive condition of each mapped, relocated sturgeon. Table 4 (at the back of this report) documents the values obtained from the reach maps at each sturgeon relocation point.

Figures 14–18 present histograms of the continuous variables (depth, depth slope, velocity, velocity gradient, and Froude number) for each reach along with the values at each qualifying sturgeon relocation. These figures show: (1) The distribution of relocations among the maps is non-uniform. Most maps have just one or two relocations, though there are exceptions. In particular, the map labeled “070503_f” contained a disproportionate number of relocations; this map was at the mouth of the Big Sioux River. (2) The distribution of mapping effort was non-uniform among the segments. The Big Sioux segment has the most maps. The Platte segment is the least thoroughly documented. (3) Histogram shape varies from reach to reach, but broad similarities are apparent within segments; compare with the composite histograms in figure 9. (4) The values at sturgeon relocations show broad variability in the context of the available habitat.

We are also interested in the question of whether sturgeon select specific habitats, or if instead they use habitat in the proportions in which it is available in a reach. This question can be addressed in a rudimentary but intuitive way by considering the distribution of map variables in comparison to the distribution of values at sturgeon relocations (fig. 19). This figure represents composite data from all of the maps and all of the sturgeon relocations, regardless of map location or sturgeon species. Because these histograms represent composite data from all sections of river and all sturgeon categories, they should be interpreted with caution and the understanding that they represent non-uniformly distributed maps and relocations. These histograms do show that the range of values collectively used by sturgeon is nearly as large as the range of values available to sturgeon. Because the histograms are normalized, the frequency of the sturgeon data relative to the map data is indicative of the relative use of that range of values based on the available dataset. For example, the velocity histograms indicate that sturgeon are underutilizing high velocities relative to their availability. The figure 19 histograms suggest several trends that are supported by more robust data analysis.

Figure 20 presents histogram data similar to figure 19, but results in this figure are separated by river section. In addition, Ivlev’s selectivity coefficients are shown for all mapped sections by habitat value (fig. 20). Some coefficients may be misleading because of the way data fell into the arbitrary bin intervals, especially for bins that have a small percentage of available habitat. To minimize this issue, coefficients are shown only for bins with at least one sturgeon relocation. Sturgeon selection for depth varies by river section. In the Minimally Engineered section, sturgeon disproportionately use depths at the deep end of the available range. In contrast, sturgeon in the Upstream and Downstream Engineered sections tend to use both deep and shallow depths in greater proportions than available, while underutilizing the moderate depths that have the greatest availability (in the 4 to 6 meter range). For velocity, the relocation histograms peak at values that are similar for each river section, approximately 0.7 to 0.8 meters per second, though the availability differs considerably among river sections. Selection patterns for depth slope and velocity gradient are similar among river sections, with data indicating disproportionate use of high slope and high velocity gradient areas.

More robust analysis of sturgeon habitat selection is based on the comparison of each sturgeon relocation to the range of values available in the local reach. As described in

Table 3. Data for sturgeon individuals that were relocated within 7 days and 10 percent discharge of a reach map.

[Sturgeon data from Aaron J. DeLonay and Diana M. Papoulias, unpub. data, 2008. PLS, pallid sturgeon; --, no data; SNS, shovelnose sturgeon; *, inferred nonreproductive based on reproductive condition of previous year]

Sturgeon identification code	Species	Sex	Reproductive condition (year)	Relocations on habitat maps within 7 days and 10 percent discharge		
				2005	2006	2007
PLS04-001	PLS	Male	--	2	--	--
PLS04-002	PLS	Male	--	2	--	--
PLS04-003	PLS	Male	--	2	--	--
PLS05-001	PLS	Female	--	1	--	--
PLS05-002	PLS	Female	--	1	--	--
PLS05-003	PLS	Female	--	1	--	--
PLS05-004	PLS	Female	--	1	--	--
PLS05-006	PLS	Female	--	--	2	--
PLS06-001	PLS	Male	Reproductive (2006)	--	3	--
PLS06-003	PLS	Female	Nonreproductive (2006)	--	1	--
PLS06-004	PLS	Male	Nonreproductive (2006)	--	4	--
PLS06-006	PLS	Male	Nonreproductive (2006)	--	3	--
PLS07-003	PLS	Male	Nonreproductive (2007)	--	--	1
PLS07-004	PLS	Female	Reproductive (2007)	--	--	4
PLS07-008	PLS	Male	Reproductive (2007)	--	--	10
SNS05-003	SNS	Female	Reproductive (2005)	1	--	--
SNS05-006	SNS	Female	Reproductive (2005)	1	--	--
SNS05-007	SNS	Female	Reproductive (2005)	2	--	--
SNS05-015	SNS	Female	Reproductive (2005)	1	--	--
SNS05-017	SNS	Female	Reproductive (2005)	2	--	--
SNS05-019	SNS	Female	Reproductive (2005)	1	--	--
SNS05-021	SNS	Female	Reproductive (2005)	1	--	--
SNS05-022	SNS	Female	Reproductive (2005)	1	--	--
SNS05-026	SNS	Female	Reproductive (2005)	1	--	--
SNS05-027	SNS	Female	Reproductive (2005)	1	--	--
SNS05-028	SNS	Female	Reproductive (2005)	1	--	--
SNS05-031	SNS	Female	Reproductive (2005)	2	--	--
SNS05-034	SNS	Female	Reproductive (2005)	1	--	--
SNS05-037	SNS	Female	Reproductive (2005)	1	--	--
SNS05-040	SNS	Female	Reproductive (2005)	1	--	--
SNS05-041	SNS	Female	Reproductive (2005)	1	--	--
SNS05-042	SNS	Female	Reproductive (2005)	1	--	--
SNS05-043	SNS	Female	Reproductive (2005)	2	--	--
SNS05-052	SNS	Female	Reproductive (2005)	2	--	--
SNS05-053	SNS	Female	Reproductive (2005)	1	--	--
SNS05-054	SNS	Female	Reproductive (2005)	1	--	--
SNS05-056	SNS	Female	Reproductive (2005)	1	--	--
SNS05-057	SNS	Female	Reproductive (2005)	2	--	--
SNS05-058	SNS	Female	Reproductive (2005)	2	--	--
SNS05-060	SNS	Female	Reproductive (2005)	1	--	--
SNS05-061	SNS	Female	Reproductive (2005)	6	--	--
SNS05-062	SNS	Female	Reproductive (2005)	2	--	--
SNS05-063	SNS	Female	Reproductive (2005)	2	--	--
SNS05-064	SNS	Female	Reproductive (2005)	2	--	--
SNS05-066	SNS	Female	Reproductive (2005)	1	--	--
SNS05-068	SNS	Female	Reproductive (2005)	3	--	--
SNS05-069	SNS	Female	Reproductive (2005)	1	--	--
SNS05-070	SNS	Female	Reproductive (2005)	2	--	--
SNS05-071	SNS	Female	Reproductive (2005)	4	--	--
SNS05-072	SNS	Female	Reproductive (2005)	3	--	--
SNS05-073	SNS	Female	Reproductive (2005)	2	--	--
SNS05-074	SNS	Female	Reproductive (2005)	3	--	--

Table 3. Data for sturgeon individuals that were relocated within 7 days and 10 percent discharge of a reach map.—Continued

[Sturgeon data from Aaron J. DeLonay and Diana M. Papoulias, unpub. data, 2008. PLS, pallid sturgeon; --, no data; SNS, shovelnose sturgeon; *, inferred nonreproductive based on reproductive condition of previous year]

Sturgeon identification code	Species	Sex	Reproductive condition (year)	Relocations on habitat maps within 7 days and 10 percent discharge		
				2005	2006	2007
SNS05-075	SNS	Female	Reproductive (2005)	2	--	--
SNS05-076	SNS	Female	Reproductive (2005)	4	--	--
SNS05-077	SNS	Female	Reproductive (2005)	2	--	--
SNS05-082	SNS	Female	Reproductive (2005)	3	--	--
SNS05-083	SNS	Female	Reproductive (2005)	2	--	--
SNS05-084	SNS	Female	Reproductive (2005)	5	--	--
SNS05-085	SNS	Female	Reproductive (2005)	1	--	--
SNS05-087	SNS	Female	Reproductive (2005)	1	--	--
SNS05-089	SNS	Female	Reproductive (2005)	2	--	--
SNS05-094	SNS	Female	Reproductive (2005)	2	--	--
SNS05-095	SNS	Female	Reproductive (2005)	2	--	--
SNS05-096	SNS	Female	Reproductive (2005)	1	--	--
SNS05-097	SNS	Female	Reproductive (2005)	2	--	--
SNS05-098	SNS	Female	Reproductive (2005)	2	--	--
SNS05-099	SNS	Female	Reproductive (2005)	1	--	--
SNS05-100	SNS	Female	Reproductive (2005)	1	--	--
SNS05-101	SNS	Female	Reproductive (2005)	4	--	--
SNS06-010	SNS	Female	Reproductive (2006)	--	1	--
SNS06-011	SNS	Female	Reproductive (2006)	--	2	--
SNS06-012	SNS	Female	Reproductive (2006)	--	1	--
SNS06-028	SNS	Female	Reproductive (2006)	--	1	--
SNS06-034	SNS	Female	Reproductive (2006)	--	1	--
SNS06-038	SNS	Female	Reproductive (2006)	--	2	--
SNS06-044	SNS	Female	Reproductive (2006)	--	2	--
SNS06-047	SNS	Female	Reproductive (2006)	--	3	--
SNS06-051	SNS	Female	Reproductive (2006)	--	1	--
SNS06-057	SNS	Female	Nonreproductive (2007)*	--	--	1
SNS06-058	SNS	Female	Reproductive (2006)	--	2	--
SNS06-060	SNS	Female	Reproductive (2006)	--	1	1
SNS06-060	SNS	Female	Nonreproductive (2007)*	--	1	1
SNS06-067	SNS	Female	Reproductive (2006)	--	2	--
SNS06-072	SNS	Female	Reproductive (2006)	--	3	--
SNS06-075	SNS	Female	Nonreproductive (2007)*	--	--	1
SNS06-076	SNS	Female	Reproductive (2006)	--	3	--
SNS06-077	SNS	Female	Reproductive (2006)	--	1	--
SNS06-083	SNS	Female	Reproductive (2006)	--	4	--
SNS06-084	SNS	Female	Reproductive (2006)	--	1	--
SNS06-085	SNS	Female	Reproductive (2006)	--	6	--
SNS06-089	SNS	Female	Reproductive (2006)	--	2	--
SNS06-092	SNS	Female	Nonreproductive (2007)*	--	--	1
SNS07-009	SNS	Female	Nonreproductive (2007)	--	--	2
SNS07-010	SNS	Female	Reproductive (2007)	--	--	3
SNS07-019	SNS	Female	Reproductive (2007)	--	--	1
SNS07-021	SNS	Female	Reproductive (2007)	--	--	2
SNS07-025	SNS	Female	Reproductive (2007)	--	--	3
SNS07-030	SNS	Female	Reproductive (2007)	--	--	3
SNS07-033	SNS	Female	Reproductive (2007)	--	--	1
SNS07-034	SNS	Male	Nonreproductive (2007)	--	--	3
SNS07-035	SNS	Female	Reproductive (2007)	--	--	3
SNS07-040	SNS	Female	Reproductive (2007)	--	--	5
SNS07-042	SNS	Intersex	Intersex (2007)	--	--	1
SNS07-045	SNS	Female	Reproductive (2007)	--	--	1

Table 3. Data for sturgeon individuals that were relocated within 7 days and 10 percent discharge of a reach map.—Continued

[Sturgeon data from Aaron J. DeLonay and Diana M. Papoulias, unpub. data, 2008. PLS, pallid sturgeon; --, no data; SNS, shovelnose sturgeon; *, inferred nonreproductive based on reproductive condition of previous year]

Sturgeon identification code	Species	Sex	Reproductive condition (year)	Relocations on habitat maps within 7 days and 10 percent discharge		
				2005	2006	2007
SNS07-046	SNS	Female	Reproductive (2007)	--	--	4
SNS07-055	SNS	Female	Reproductive (2007)	--	--	3
SNS07-057	SNS	Female	Reproductive (2007)	--	--	1
SNS07-059	SNS	Female	Reproductive (2007)	--	--	6
SNS07-066	SNS	Male	Reproductive (2007)	--	--	1
SNS07-072	SNS	Female	Reproductive (2007)	--	--	3
SNS07-073	SNS	Female	Reproductive (2007)	--	--	3
SNS07-075	SNS	Female	Reproductive (2007)	--	--	3
SNS07-076	SNS	Female	Reproductive (2007)	--	--	1
SNS07-077	SNS	Female	Reproductive (2007)	--	--	2
SNS07-079	SNS	Female	Reproductive (2007)	--	--	6
SNS07-080	SNS	Male	Reproductive (2007)	--	--	1
SNS07-081	SNS	Female	Reproductive (2007)	--	--	1
SNS07-084	SNS	Female	Nonreproductive (2007)	--	--	2
SNS07-085	SNS	Female	Reproductive (2007)	--	--	1
SNS07-088	SNS	Female	Reproductive (2007)	--	--	1
SNS07-089	SNS	Female	Reproductive (2007)	--	--	3
SNS07-092	SNS	Female	Reproductive (2007)	--	--	2
SNS07-093	SNS	Female	Reproductive (2007)	--	--	5
SNS07-094	SNS	Female	Reproductive (2007)	--	--	2
SNS07-098	SNS	Female	Reproductive (2007)	--	--	3
SNS07-100	SNS	Female	Nonreproductive (2007)	--	--	4
SNS07-104	SNS	Female	Reproductive (2007)	--	--	2
SNS07-106	SNS	Female	Nonreproductive (2007)	--	--	3
SNS07-107	SNS	Female	Nonreproductive (2007)	--	--	5
SNS07-109	SNS	Female	Nonreproductive (2007)	--	--	3
SNS07-111	SNS	Female	Reproductive (2007)	--	--	3
SNS07-115	SNS	Male	Reproductive (2007)	--	--	1
SNS07-116	SNS	Female	Reproductive (2007)	--	--	1
SNS07-118	SNS	Female	Reproductive (2007)	--	--	2
SNS07-122	SNS	Female	Reproductive (2007)	--	--	1
SNS07-123	SNS	Intersex	Intersex (2007)	--	--	2
SNS07-124	SNS	Female	Reproductive (2007)	--	--	4
SNS07-126	SNS	Female	Reproductive (2007)	--	--	1
SNS07-127	SNS	Female	Reproductive (2007)	--	--	2
SNS07-129	SNS	Female	Reproductive (2007)	--	--	2
SNS07-132	SNS	Female	Nonreproductive (2007)	--	--	3
SNS07-133	SNS	Female	Reproductive (2007)	--	--	2
SNS07-135	SNS	Female	Reproductive (2007)	--	--	2
SNS07-137	SNS	Female	Reproductive (2007)	--	--	1
SNS07-138	SNS	Female	Reproductive (2007)	--	--	3
SNS07-139	SNS	Female	Nonreproductive (2007)	--	--	2
SNS07-141	SNS	Male	Reproductive (2007)	--	--	2
SNS07-143	SNS	Male	Reproductive (2007)	--	--	2
SNS07-144	SNS	Male	Reproductive (2007)	--	--	2
SNS07-145	SNS	Male	Reproductive (2007)	--	--	1
SNS07-147	SNS	Male	Reproductive (2007)	--	--	2
SNS07-149	SNS	Female	Nonreproductive (2007)	--	--	2
SNS07-150	SNS	Male	Reproductive (2007)	--	--	3
SNS07-153	SNS	Female	Reproductive (2007)	--	--	2
SNS07-154	SNS	Female	Reproductive (2007)	--	--	4
SNS07-155	SNS	Female	Reproductive (2007)	--	--	3

Table 3. Data for sturgeon individuals that were relocated within 7 days and 10 percent discharge of a reach map.—Continued

[Sturgeon data from Aaron J. DeLonay and Diana M. Papoulias, unpub. data, 2008. PLS, pallid sturgeon; --, no data; SNS, shovelnose sturgeon; *, inferred nonreproductive based on reproductive condition of previous year]

Sturgeon identification code	Species	Sex	Reproductive condition (year)	Relocations on habitat maps within 7 days and 10 percent discharge		
				2005	2006	2007
SNS07-157	SNS	Male	Reproductive (2007)	--	--	6
SNS07-159	SNS	Male	Reproductive (2007)	--	--	1
SNS07-162	SNS	Female	Reproductive (2007)	--	--	4
SNS07-164	SNS	Female	Reproductive (2007)	--	--	4
SNS07-165	SNS	Female	Nonreproductive (2007)	--	--	2
SNS07-166	SNS	Female	Nonreproductive (2007)	--	--	3
SNS07-169	SNS	Male	Reproductive (2007)	--	--	3
SNS07-170	SNS	Female	Reproductive (2007)	--	--	6
SNS07-171	SNS	Male	Nonreproductive (2007)	--	--	5
SNS07-175	SNS	Female	Reproductive (2007)	--	--	6
SNS07-176	SNS	Female	Reproductive (2007)	--	--	3

the "Analysis Approach" section, we determined within which decile range each sturgeon relocation fell. Each decile range represents an equal area on the map, so if sturgeon are distributed randomly with respect to a given variable, then a similar number of relocations should fall within each decile range. Results presented in table 5 have been compiled by river section and sturgeon attributes (species, sex, and reproductive condition). For completeness, this table includes all categories of species, sex, and reproductive condition, even though the number of relocations in many categories is smaller than needed to draw robust conclusions.

For reproductive female shovelnose sturgeon, plots of the percent of relocations in each decile range show several trends that are consistent among all river sections (fig. 21). Reproductive female shovelnose sturgeon frequently were observed in areas of high depth slope, low velocity, high velocity gradient, and/or low Froude number. Relations with depth are somewhat more complex and inconsistent among river sections. In the Downstream Channelized section, sturgeon select the shallowest decile of depths while avoiding this decile in the Minimally Engineered section.

Examined by year in addition to river section (table 6), the results among years are relatively similar (if less definitive, given the smaller numbers of relocations). Patterns of depth slope, velocity gradient, and Froude number are particularly robust and consistent between years and river sections, with typically greater proportions of reproductive female shovelnose sturgeon at high depth slope, high velocity gradient, and/or low Froude number.

Table 7 documents the proportion of each categorical variable represented in each reach and number of relocations within each categorical value; table 8 contains a summary of the categorical data by river section. Examination of categorical variable summaries (table 8) indicates use of some habitat categories in greater proportion than their availability. In particular, sturgeon seem to select for the engineered structure and bedrock category (12.2 percent of the relocations in 3.4 percent of the area). This category is dominated by engineered structures (wing dikes and revetment). Sturgeon appear to avoid areas of high sediment transport. Given that high sediment transport occurs in areas of high velocity and Froude number, these results show consistency with the results from continuous variable analysis. Results from the terrain classification analysis show selection for sloping terrain units (7.5 percent of relocations in 2.1 percent of area), a result that is consistent with the findings from the analysis of depth slope as a continuous variable. Table 8 contains summary data for shallow-water habitat; however, these results should be interpreted with caution because maps tend to err somewhat on the side of under representing shallow-water habitat as a result of depth limitations on boat navigation. These tentative results suggest little selection or avoidance for shallow-water habitat.

Patterns of Sturgeon Habitat Use Considered in Map Context

The results from the decile analysis demonstrate a nonrandom distribution of sturgeon in relation to various environmental variables. As a visualization exercise, we explored the spatial distribution of the decile ranges that sturgeon tended to select to address some basic questions: Where do these values occur? How do the different variables interact in a spatial context? How do the patterns differ by river section?

We reclassified cells in the map for each variable such that a "1" represented the 2 most selected deciles and a "0" represented the remaining deciles. Because relations between habitat use and depth are inconsistent in the existing dataset, we omitted depth from this exploratory model. Furthermore, because velocity and Froude number are highly correlated, and the relations of habitat use appear to be more strongly associated with Froude number than with velocity, we omitted velocity.

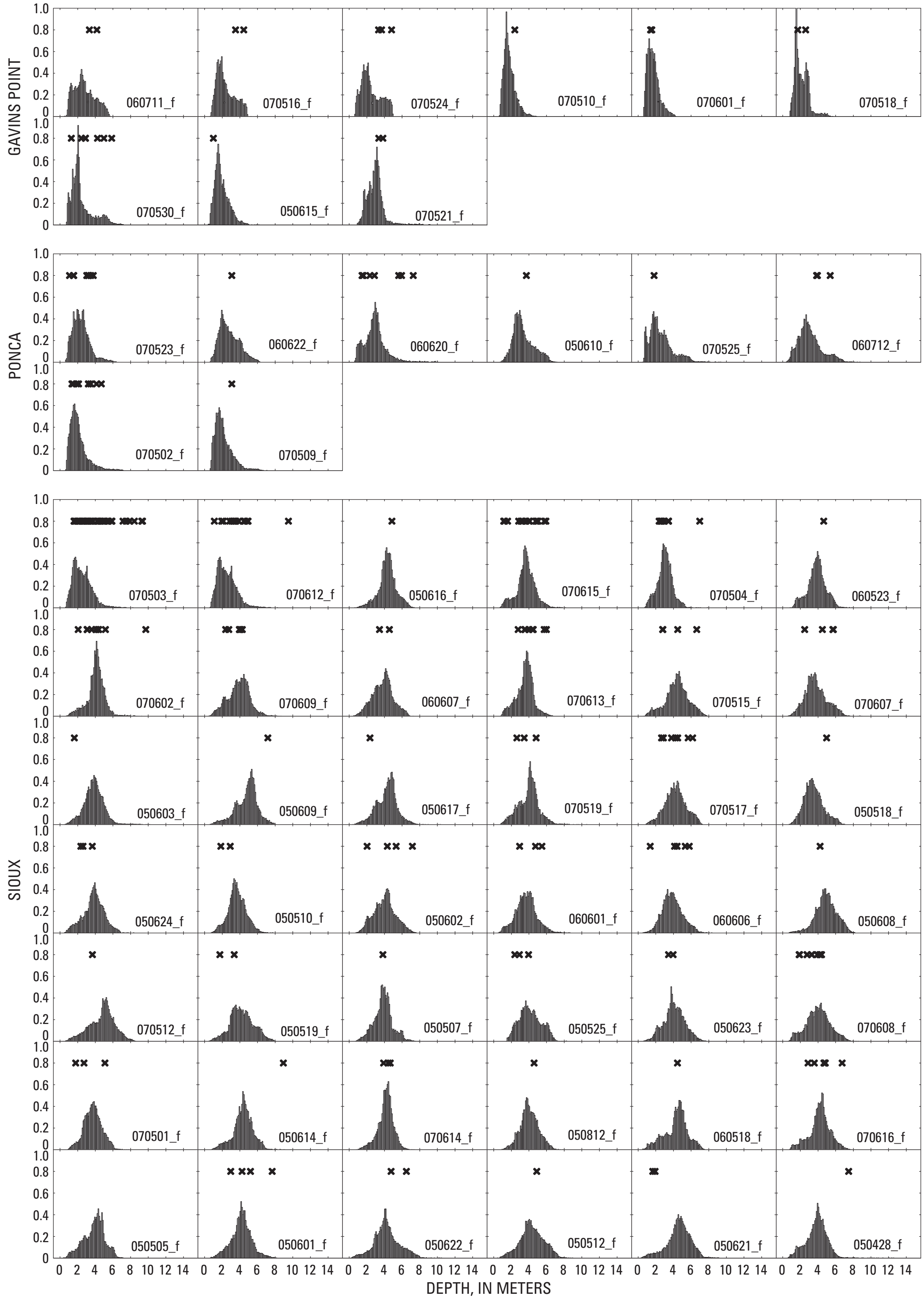


Figure 14. Histograms of depth maps for each reach with points representing sturgeon relocations. Each "x" represents the depth value at a sturgeon relocation with respect to the x-axis. Histograms are ordered in descending order by river mile. The identification code includes the last two digits of the year, the two-digit month, and two-digit day of the month, plus a boat identifier (b or f); this information is sufficient to uniquely identify each map and to cross-reference with the tables of Reuter and others (2008).

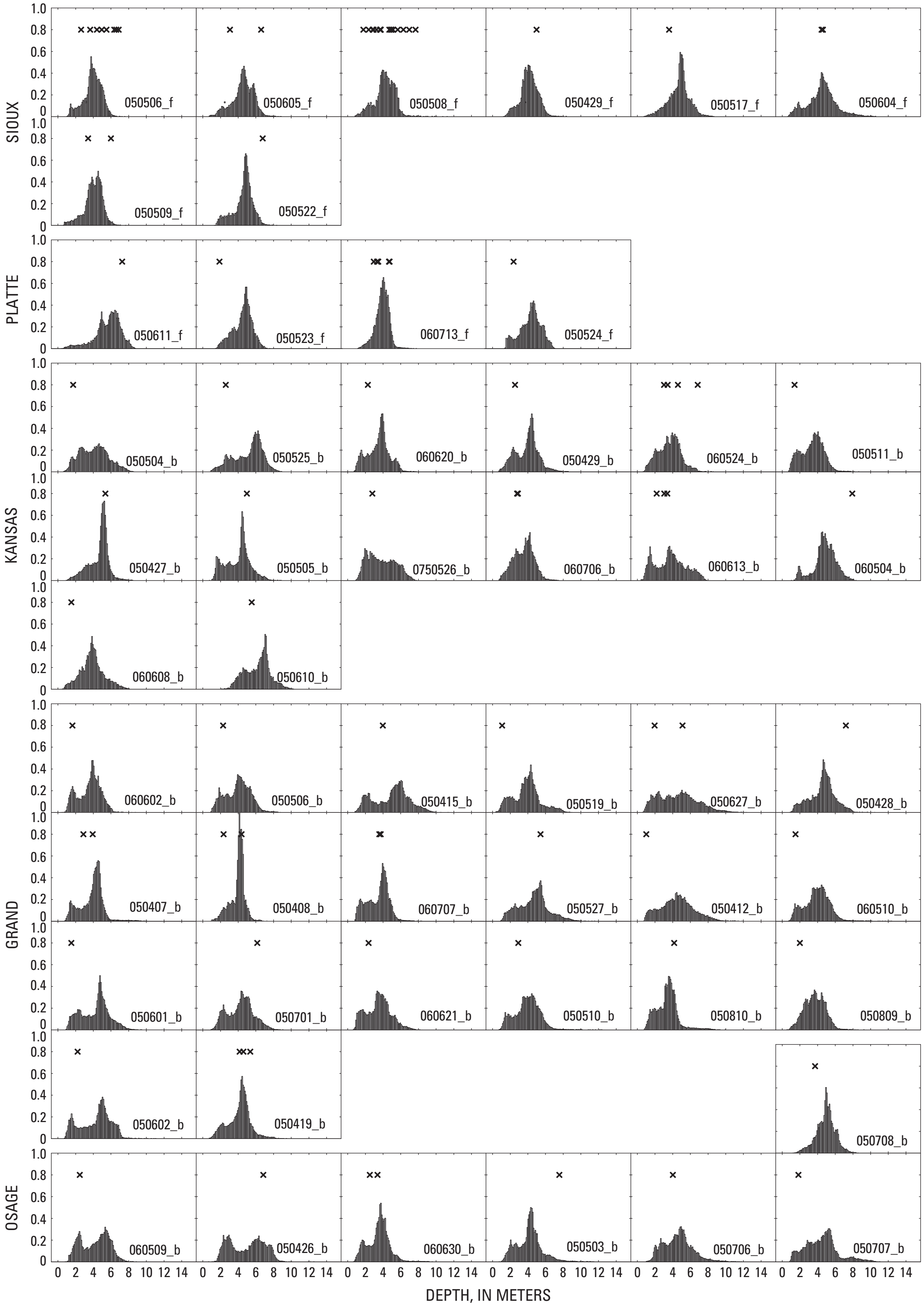


Figure 14. Histograms of depth maps for each reach with points representing sturgeon relocations. Each "x" represents the depth value at a sturgeon relocation with respect to the x-axis. Histograms are ordered in descending order by river mile. The identification code includes the last two digits of the year, the two-digit month, and two-digit day of the month, plus a boat identifier (b or f); this information is sufficient to uniquely identify each map and to cross-reference with the tables of Reuter and others (2008).—Continued

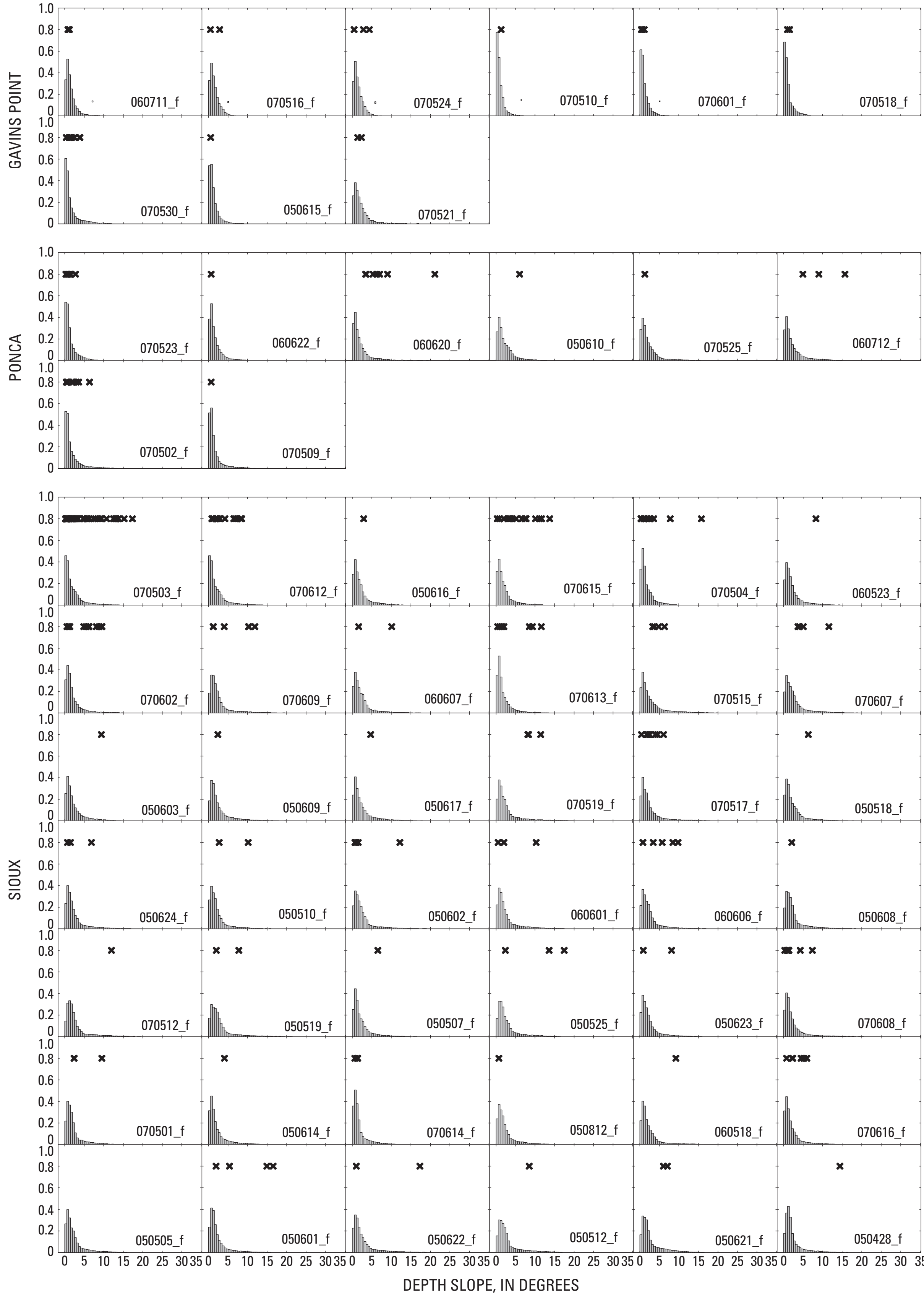


Figure 15. Histograms of depth slope maps for each reach with points representing sturgeon relocations. Histograms are ordered in descending order by river mile. The identification code includes the last two digits of the year, the two-digit month, and two-digit day of the month, plus a boat identifier (b or f).

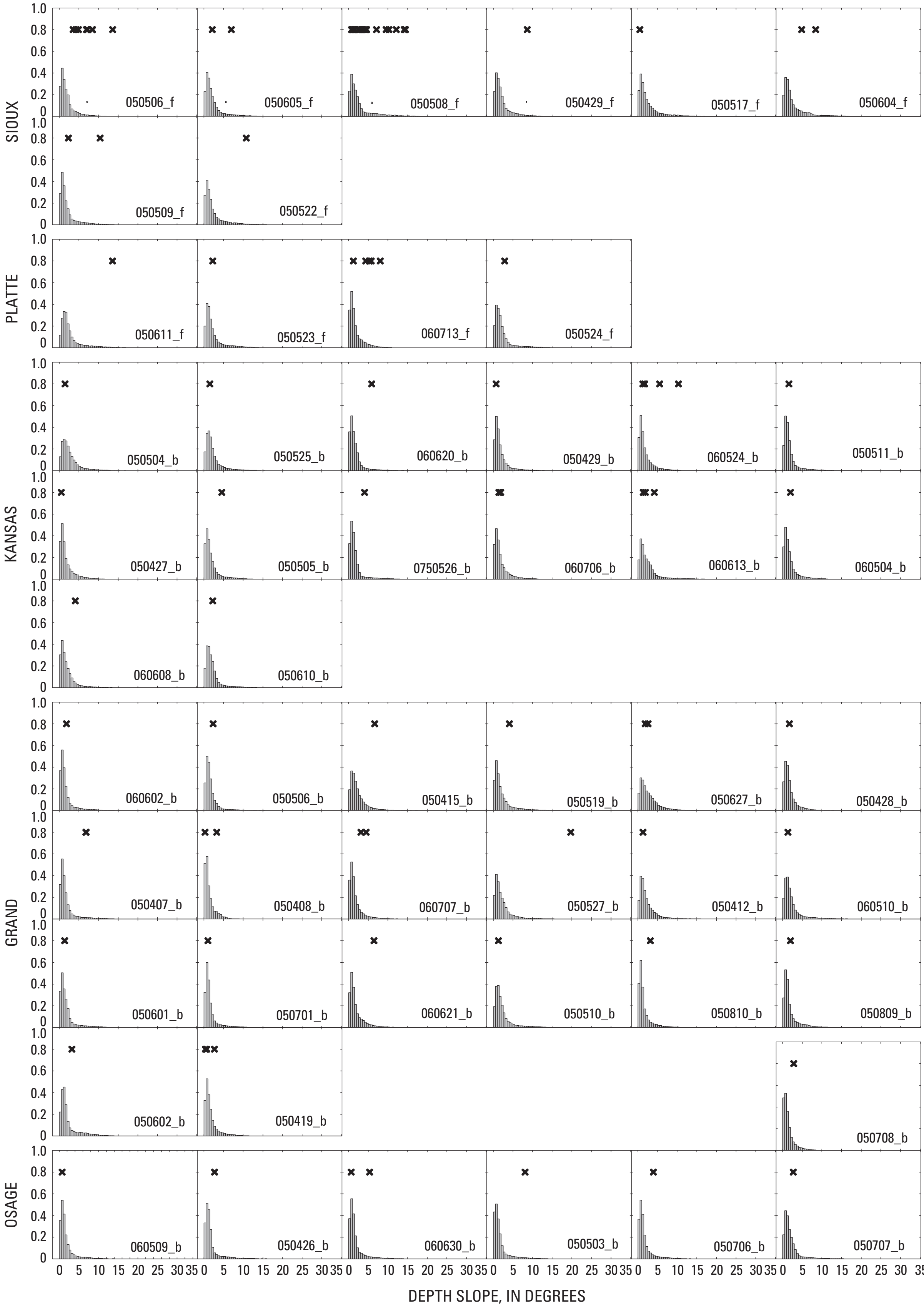


Figure 15. Histograms of depth slope maps for each reach with points representing sturgeon relocations. Histograms are ordered in descending order by river mile. The identification code includes the last two digits of the year, the two-digit month, and two-digit day of the month, plus a boat identifier (b or f).—Continued

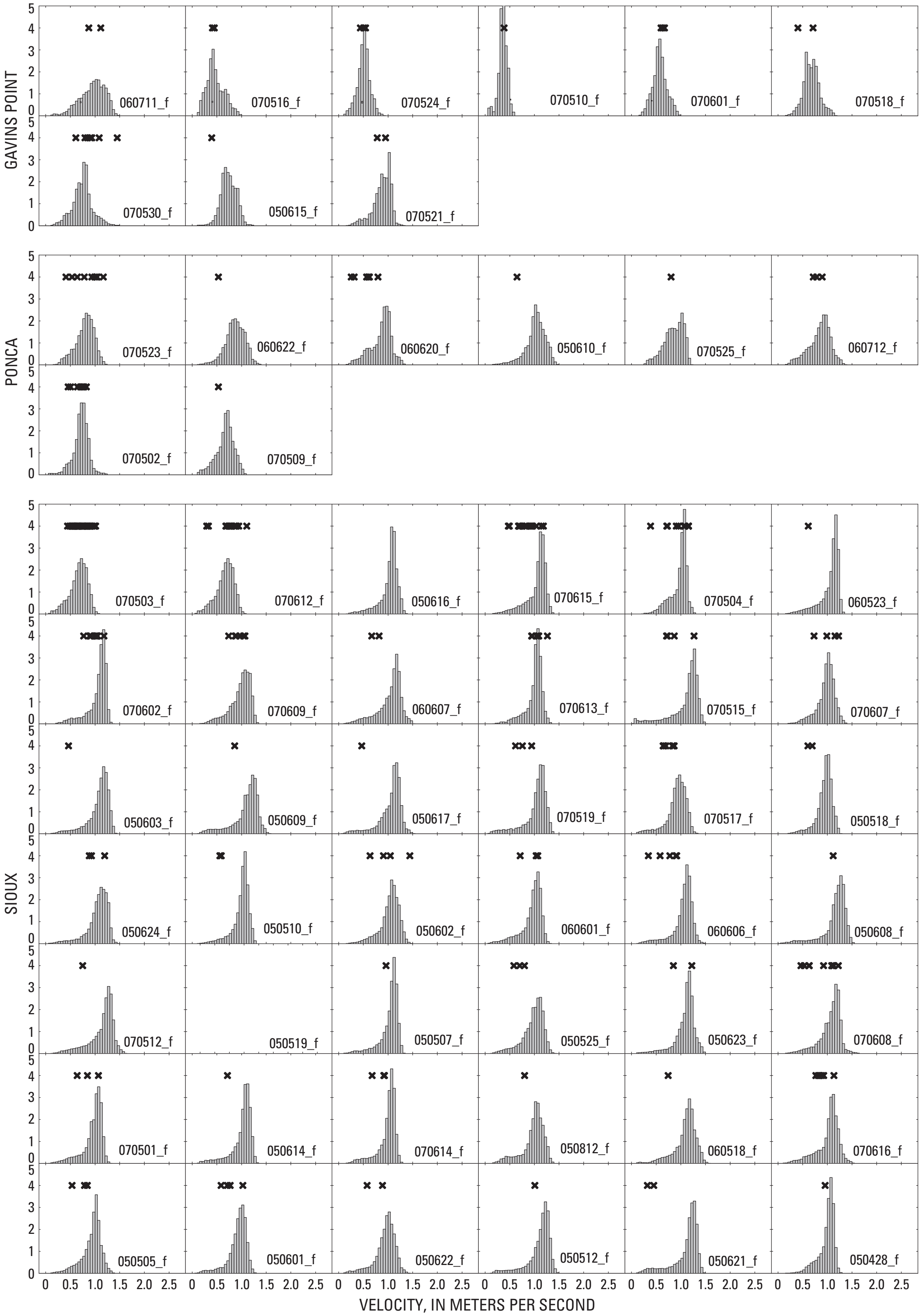


Figure 16. Histograms of velocity maps for each reach with points representing sturgeon relocations. Histograms are ordered in descending order by river mile. The identification code includes the last two digits of the year, the two-digit month, and two-digit day of the month, plus a boat identifier (b or f).

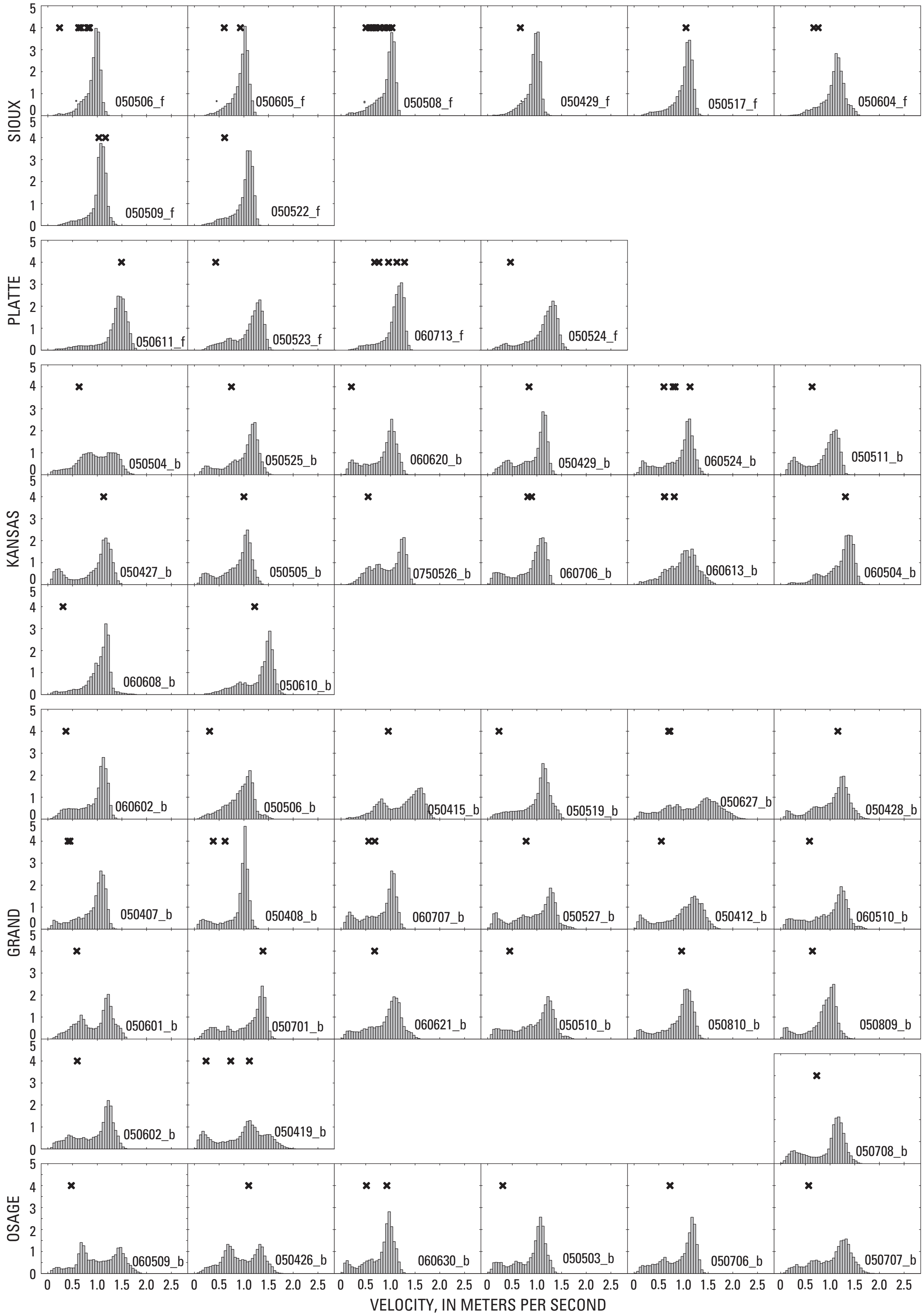


Figure 16. Histograms of velocity maps for each reach with points representing sturgeon relocations. Histograms are ordered in descending order by river mile. The identification code includes the last two digits of the year, the two-digit month, and two-digit day of the month, plus a boat identifier (b or f).—Continued

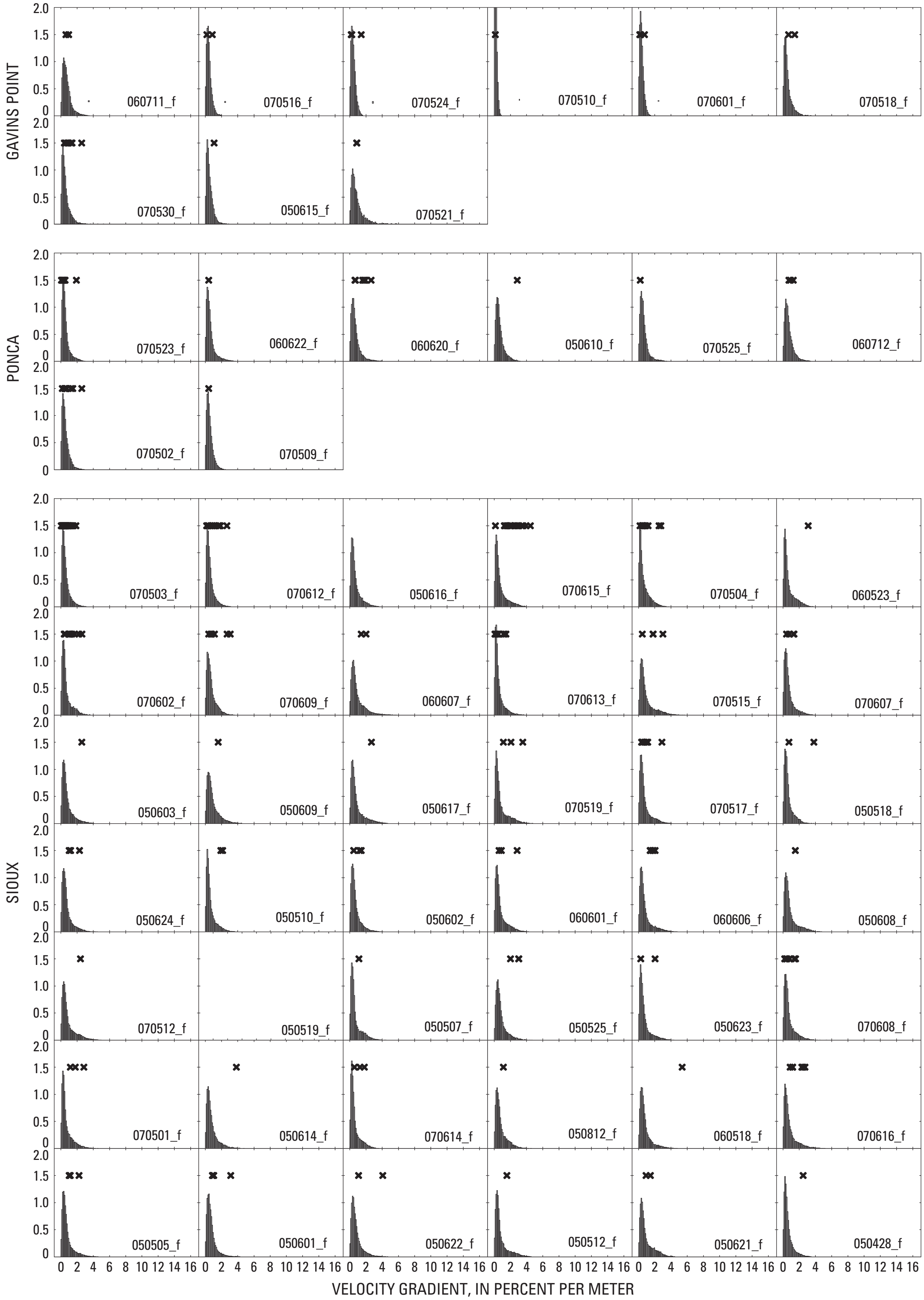


Figure 17. Histograms of velocity gradient maps for each reach with points representing sturgeon relocations. Histograms are ordered in descending order by river mile. The identification code includes the last two digits of the year, the two-digit month, and two-digit day of the month, plus a boat identifier (b or f).

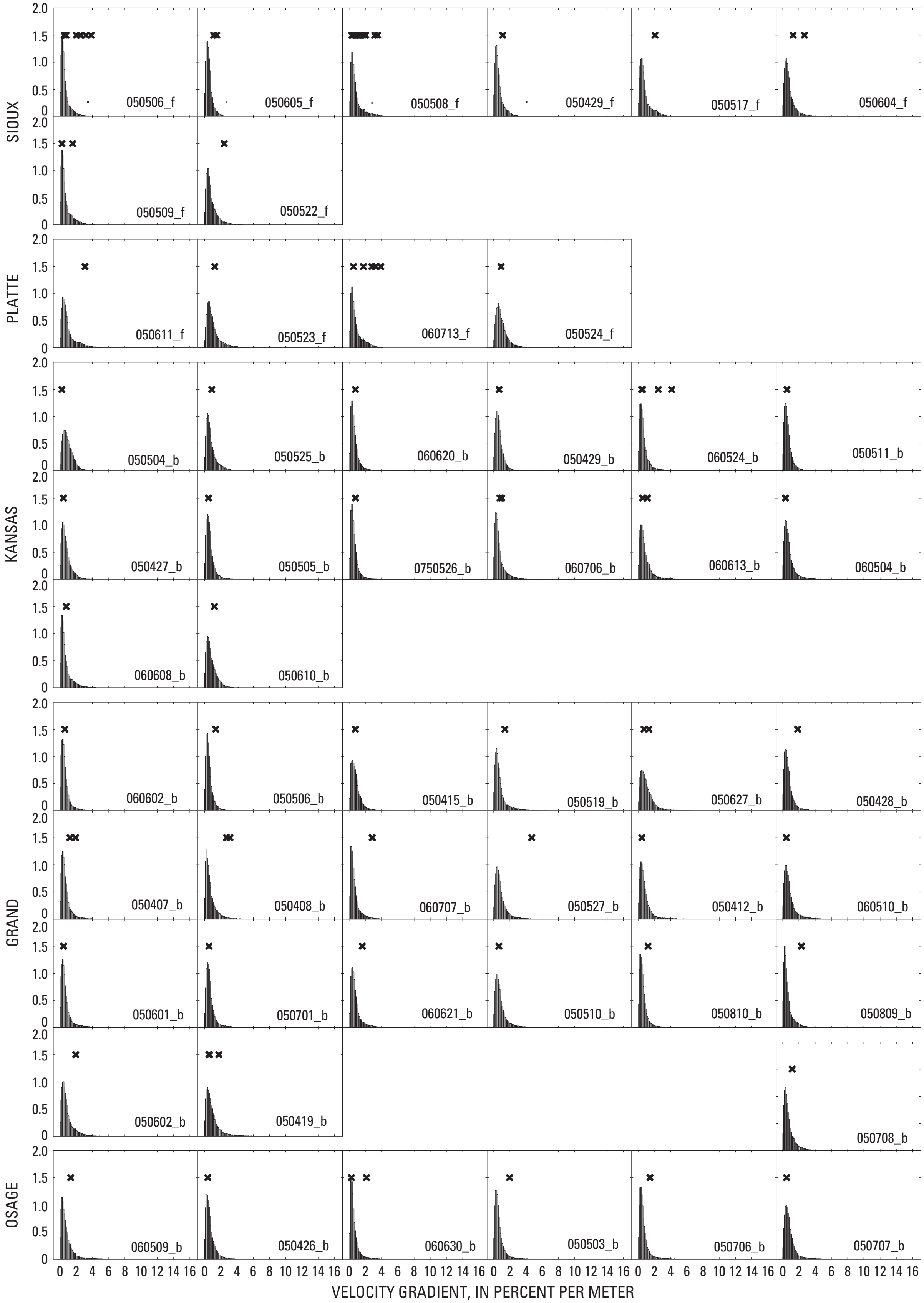


Figure 17. Histograms of velocity gradient maps for each reach with points representing sturgeon relocations. Histograms are ordered in descending order by river mile. The identification code includes the last two digits of the year, the two-digit month, and two-digit day of the month, plus a boat identifier (b or f).—Continued

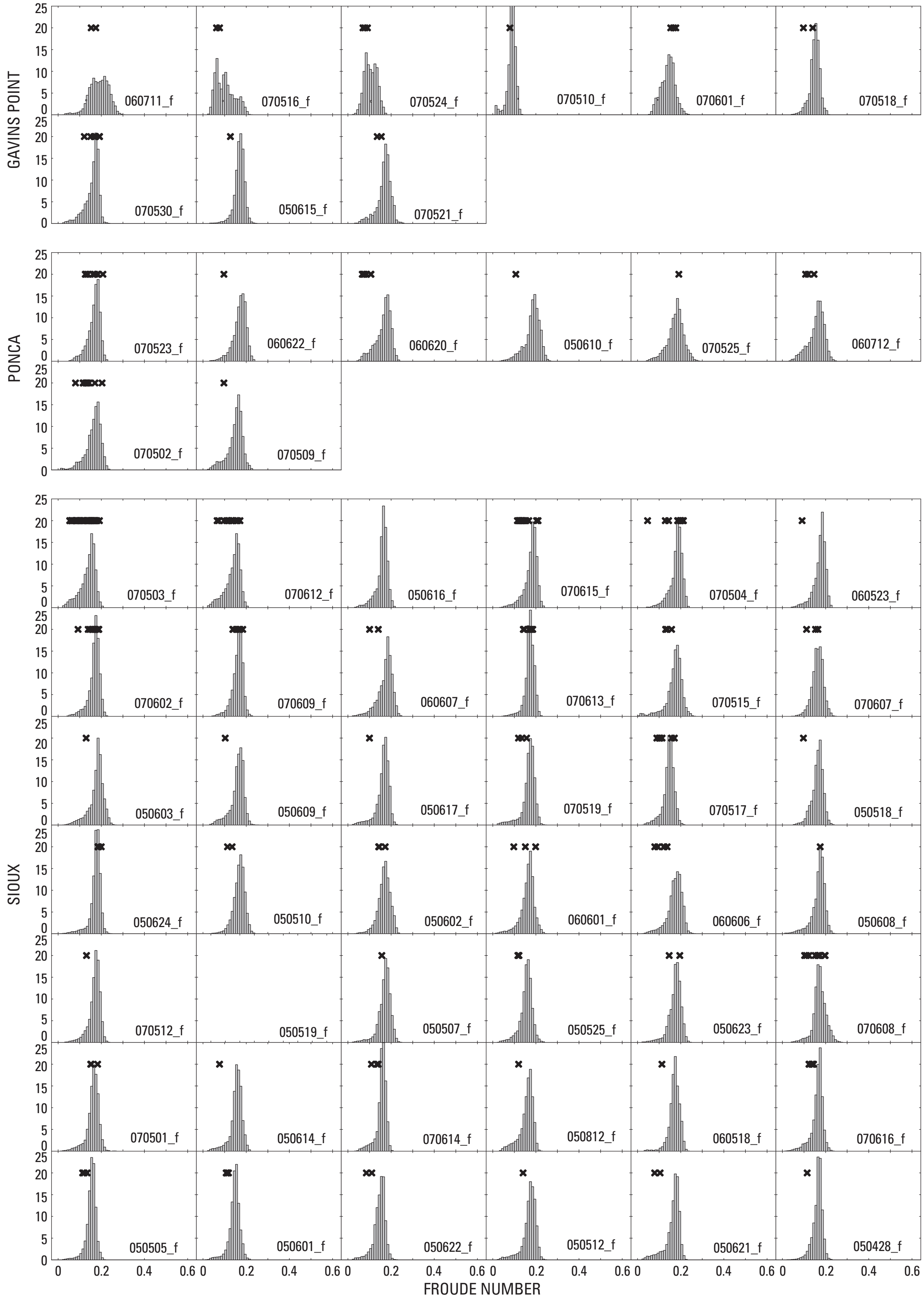


Figure 18. Histograms of Froude number maps for each reach with points representing sturgeon relocations. Histograms are ordered in descending order by river mile. The identification code includes the last two digits of the year, the two-digit month, and two-digit day of the month, plus a boat identifier (b or f).

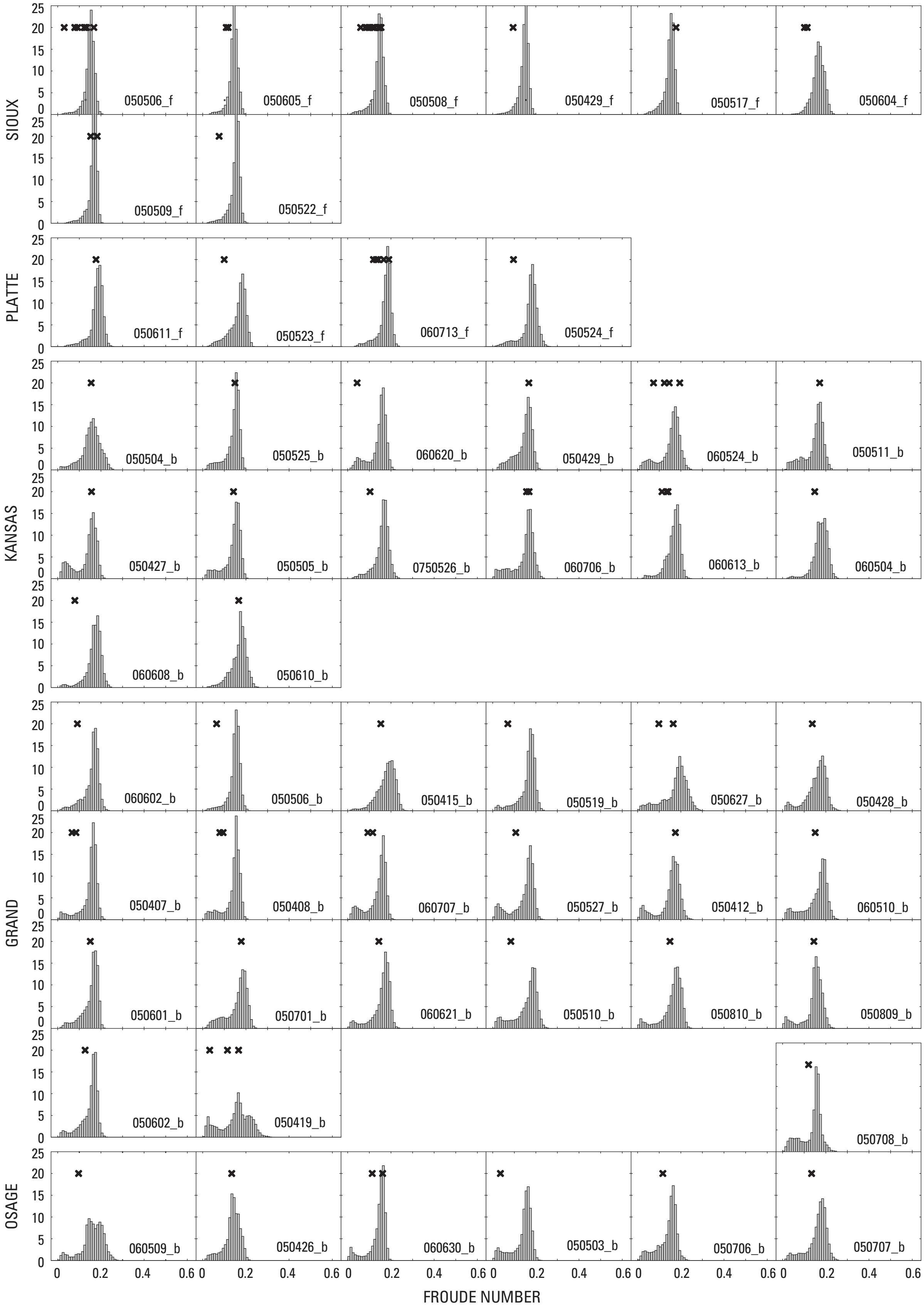


Figure 18. Histograms of Froude number maps for each reach with points representing sturgeon relocations. Histograms are ordered in descending order by river mile. The identification code includes the last two digits of the year, the two-digit month, and two-digit day of the month, plus a boat identifier (b or f).—Continued

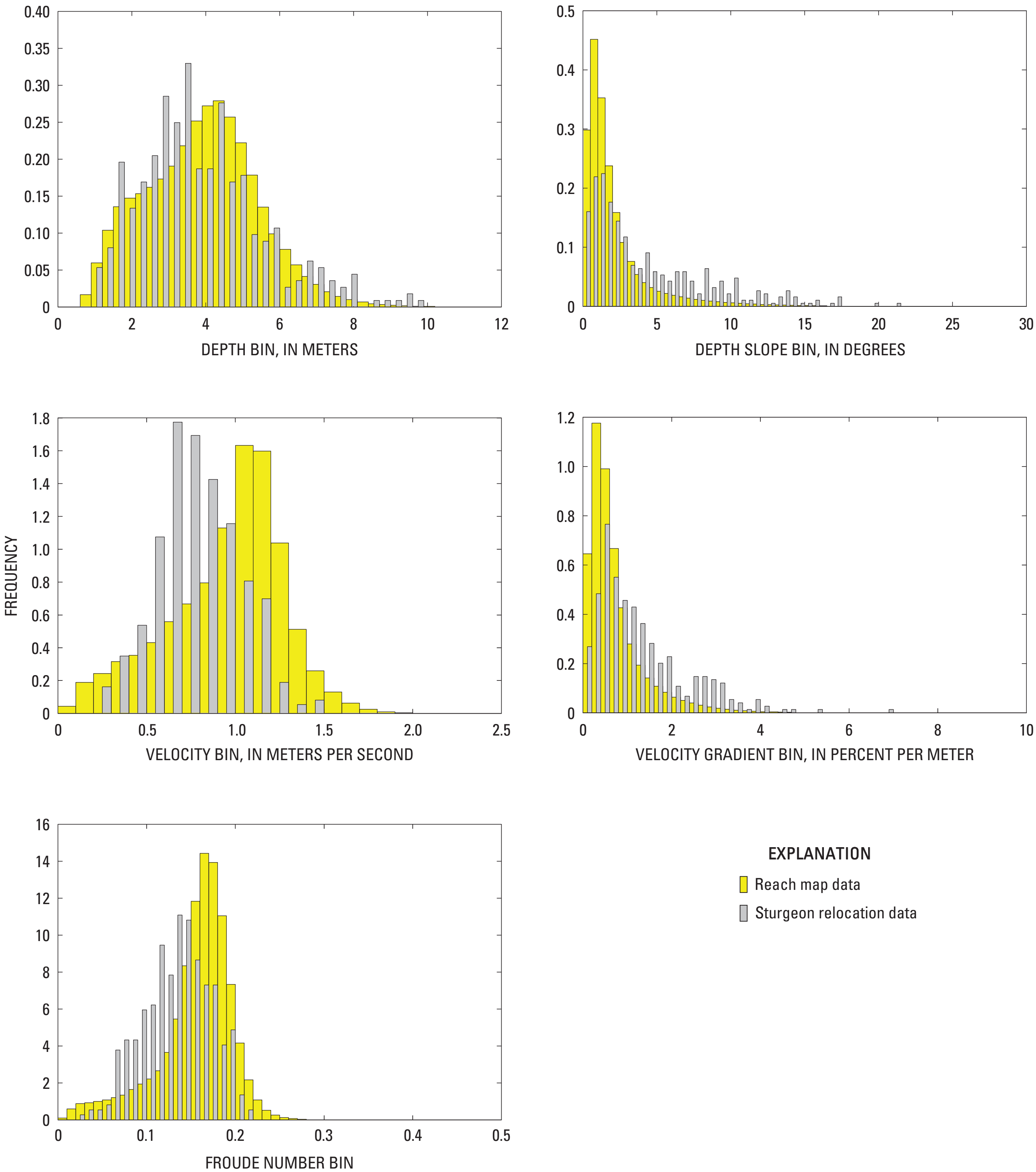


Figure 19. Composite histograms of reach map data and values at qualifying sturgeon relocations (within 7 days and 10 percent discharge of the map from which values were obtained). Histograms for reach maps are based on the set of maps that included qualifying sturgeon relocations. All histograms have been normalized to have equal area. These histograms represent a composite of reach map data and sturgeon relocation data from all river sections and should be interpreted with caution.

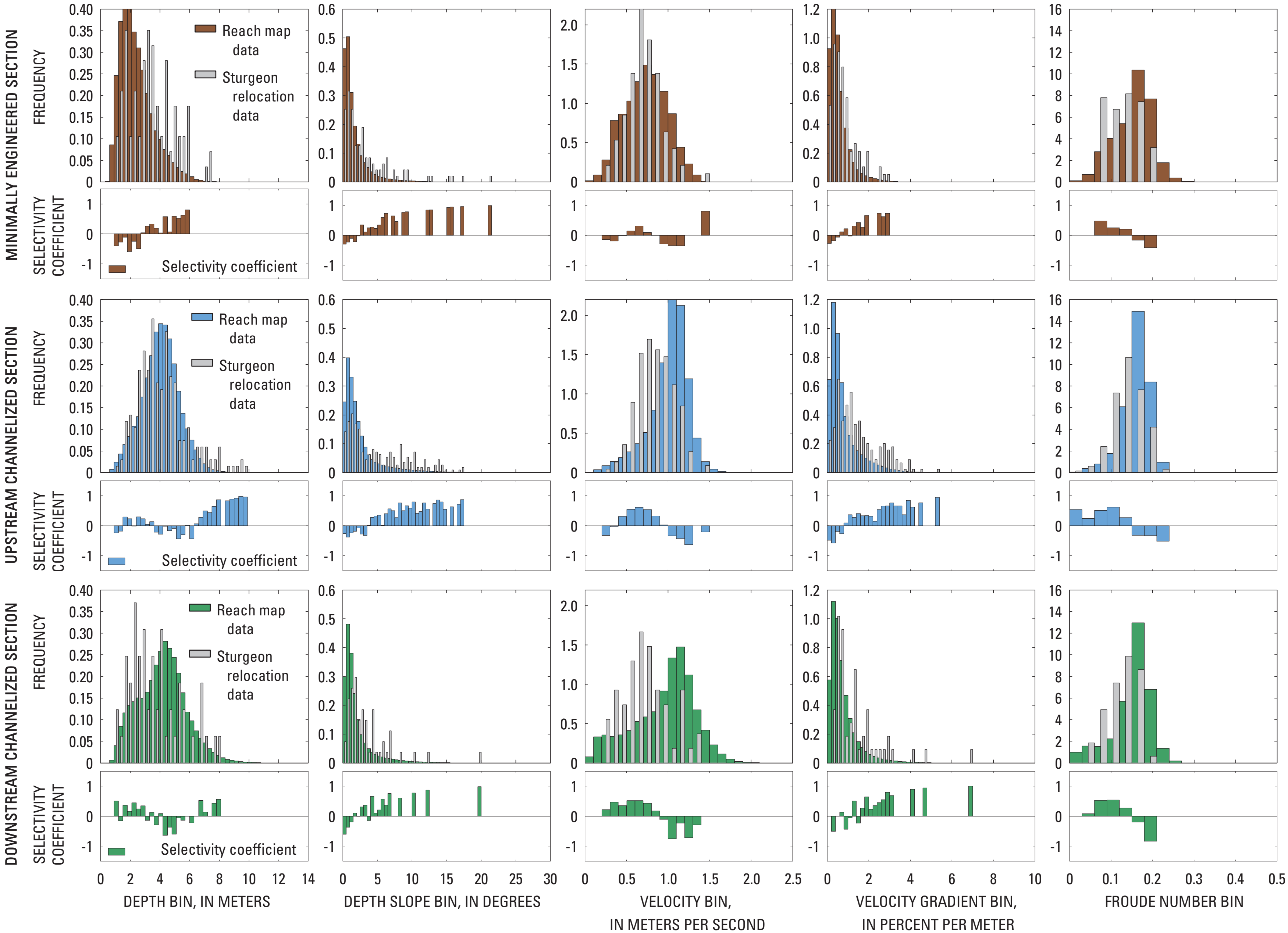


Figure 20. Histograms and Ivlev's selectivity coefficients for reach maps and qualifying sturgeon relocations, subdivided by river section. Histograms of values at sturgeon relocations (within 7 days and 10 percent discharge of the map from which values were obtained) with overall compiled histograms for all maps, subdivided by section. All histograms have been normalized to have equal area. Selectivity coefficients are shown for bins with at least one sturgeon relocation.

Table 5. Number of relocations by decile for continuous and categorical variables compiled by sturgeon species, sex, reproductive condition, and river section.—Continued

[Only river sections with data for a given combination of species, sex, and reproductive condition are shown. Repro., reproductive; Nonrepro., nonreproductive; Min. Eng., Minimally Engineered section; Up Chan., Upstream Channelized section; Down Chan., Downstream Channelized section]

Decile range or category	Number of locations for pallid sturgeon											Number of locations for shovelnose sturgeon												
	Female					Male						Female					Intersex		Male					
	Repro. unknown		Non-repro.	Repro.		Repro. un-known	Nonrepro.		Repro.		Pallid sturgeon total	Nonrepro.		Repro.			Intersex		Nonrepro.		Repro.		Shovelnose sturgeon total
	Min. Eng.	Down Chan.	Down Chan.	Min. Eng.	Up Chan.	Down Chan.	Up Chan.	Down Chan.	Up Chan.	Down Chan.		Min. Eng.	Up Chan.	Min. Eng.	Up Chan.	Down Chan.	Min. Eng.	Up Chan.	Min. Eng.	Up Chan.	Min. Eng.	Up Chan.	
											Depth decile												
Minimum to 1	--	1	--	--	--	1	--	--	--	--	2	1	4	2	18	9	--	--	--	--	--	--	34
1 to 2	--	1	1	--	2	--	--	--	--	--	4	3	1	4	23	4	--	1	--	2	1	2	41
2 to 3	--	--	--	--	--	--	1	--	2	1	4	2	2	2	15	6	--	--	--	1	2	1	31
3 to 4	--	--	--	--	--	2	--	1	--	1	4	2	3	3	4	4	--	--	--	--	--	--	16
4 to 5	--	--	--	--	--	--	1	1	2	--	4	1	1	2	12	5	--	--	--	--	2	1	24
5 to 6	--	--	--	--	--	--	--	--	--	--	--	--	1	4	13	1	--	--	--	2	--	2	23
6 to 7	1	1	--	--	--	--	--	--	1	--	3	2	--	5	14	1	--	--	1	1	--	1	25
7 to 8	--	1	--	1	--	1	--	1	5	--	9	--	1	7	15	2	--	--	--	--	1	1	27
8 to 9	1	--	--	--	--	--	2	--	--	--	3	2	--	8	19	2	--	--	--	--	3	2	36
9 to maximum	--	--	--	1	--	2	--	1	--	1	5	5	4	20	39	2	2	--	--	1	4	2	79
											Depth slope decile												
Minimum to 1	--	1	--	--	--	1	--	--	1	--	3	--	1	--	6	--	--	--	--	--	--	--	7
1 to 2	--	--	--	--	--	--	--	--	2	--	2	1	2	2	7	1	--	--	--	--	1	1	15
2 to 3	--	--	--	--	--	--	--	--	--	1	1	4	2	4	8	2	--	1	--	--	3	--	24
3 to 4	1	--	--	--	--	--	--	--	--	--	1	2	2	5	5	3	--	--	--	1	1	1	20
4 to 5	--	--	--	1	--	1	--	--	6	--	8	2	--	2	9	4	--	--	--	--	1	2	20
5 to 6	1	--	--	--	--	--	1	1	--	--	3	--	--	3	8	4	--	--	--	--	--	--	15
6 to 7	--	--	--	1	--	--	--	1	--	--	2	3	3	5	21	4	--	--	1	--	--	2	39
7 to 8	--	1	--	--	--	--	--	--	--	--	1	3	2	8	15	3	--	--	--	--	2	--	33
8 to 9	--	2	--	--	1	1	--	--	--	--	4	--	--	12	21	8	--	--	--	2	4	2	49
9 to maximum	--	--	1	--	1	3	3	2	1	2	13	3	5	16	72	7	2	--	--	4	1	4	114
											Terrain class category												
Flat	2	--	--	1	--	2	--	--	7	1	13	7	5	15	34	8	--	--	--	1	2	5	77
Slope	--	--	--	--	--	--	1	1	1	--	3	--	--	4	16	2	--	--	--	2	--	1	25
Crest	--	2	1	--	2	2	1	2	2	1	13	4	8	6	51	21	--	1	--	2	3	2	98
Depression	--	2	--	1	--	2	2	1	--	1	9	7	4	32	71	5	2	--	1	2	8	4	136

Table 5. Number of relocations by decile for continuous and categorical variables compiled by sturgeon species, sex, reproductive condition, and river section.—Continued

[Only river sections with data for a given combination of species, sex, and reproductive condition are shown. Repro., reproductive; Nonrepro., nonreproductive; Min. Eng., Minimally Engineered section; Up Chan., Upstream Channelized section; Down Chan., Downstream Channelized section]

Decile range or category	Number of locations for pallid sturgeon											Number of locations for shovelnose sturgeon											
	Female					Male					Pallid sturgeon total	Female					Intersex		Male				Shovelnose sturgeon total
	Repro. unknown		Non-repro.	Repro.		Repro. un-known	Nonrepro.		Repro.			Nonrepro.		Repro.			Intersex		Nonrepro.		Repro.		
	Min. Eng.	Down Chan.	Down Chan.	Min. Eng.	Up Chan.	Down Chan.	Up Chan.	Down Chan.	Up Chan.	Down Chan.		Min. Eng.	Up Chan.	Min. Eng.	Up Chan.	Down Chan.	Min. Eng.	Up Chan.	Min. Eng.	Up Chan.	Min. Eng.	Up Chan.	
Velocity decile																							
Minimum to 1	--	--	1	--	--	--	--	--	--	--	1	2	5	9	42	5	--	1	--	--	1	3	68
1 to 2	--	1	--	--	2	3	--	--	1	1	8	--	2	7	41	11	--	--	--	1	1	3	66
2 to 3	--	1	--	1	--	1	1	1	--	--	5	5	3	7	37	9	1	--	--	3	1	3	69
3 to 4	1	--	--	--	--	1	--	2	--	--	4	2	--	8	11	6	1	--	--	1	1	--	30
4 to 5	--	--	--	--	--	--	1	--	--	--	1	2	2	7	7	1	--	--	--	--	--	--	19
5 to 6	--	2	--	1	--	--	--	--	--	2	5	1	--	3	2	4	--	--	--	1	2	--	13
6 to 7	--	--	--	--	--	--	--	--	2	--	2	3	3	5	11	--	--	--	1	1	1	2	27
7 to 8	1	--	--	--	--	--	1	1	1	--	4	1	--	2	5	--	--	--	--	--	1	--	9
8 to 9	--	--	--	--	--	1	--	--	--	--	1	2	1	4	7	--	--	--	--	--	1	--	15
9 to maximum	--	--	--	--	--	--	1	--	6	--	7	--	1	4	8	--	--	--	--	--	4	1	18
Velocity gradient decile																							
Minimum to 1	--	--	--	--	--	--	--	--	--	--	--	2	--	1	6	1	--	--	--	--	--	--	10
1 to 2	--	--	--	--	--	--	--	--	--	--	--	2	1	5	3	--	--	--	--	--	3	1	15
2 to 3	--	--	--	--	--	--	--	--	1	1	2	3	1	3	6	1	--	--	--	--	--	--	14
3 to 4	--	2	--	--	--	--	--	1	--	--	3	--	2	3	6	3	--	--	--	--	--	--	14
4 to 5	--	--	--	--	--	--	1	--	--	--	1	3	1	4	7	5	--	--	--	--	3	1	24
5 to 6	1	--	--	--	--	2	--	1	7	--	11	2	--	5	7	3	1	--	1	--	2	--	21
6 to 7	--	--	--	2	--	--	--	--	1	--	3	1	1	7	13	4	--	--	--	2	--	1	29
7 to 8	1	--	1	--	--	--	--	--	--	--	2	--	--	7	26	6	1	--	--	--	1	1	42
8 to 9	--	1	--	--	2	--	1	--	--	--	4	1	5	8	41	5	--	1	--	--	1	3	65
9 to maximum	--	1	--	--	--	4	2	2	1	2	12	4	6	13	56	8	--	--	--	5	3	5	100
Froude number decile																							
Minimum to 1	--	--	1	--	--	1	--	--	1	--	3	1	5	17	66	9	1	1	--	--	2	5	107
1 to 2	--	--	--	1	--	2	--	1	--	1	5	6	3	14	39	7	1	--	--	5	2	3	80
2 to 3	1	2	--	1	1	2	2	1	--	1	11	2	2	5	11	8	--	--	--	--	1	1	30
3 to 4	1	1	--	--	1	--	--	1	--	--	4	3	1	6	7	4	--	--	--	--	1	1	23
4 to 5	--	--	--	--	--	--	--	--	--	--	--	--	--	5	10	3	--	--	1	--	1	--	20
5 to 6	--	1	--	--	--	1	--	--	--	--	2	1	--	2	10	2	--	--	--	1	--	--	16
6 to 7	--	--	--	--	--	--	1	--	--	1	2	--	--	4	6	3	--	--	--	--	1	1	15
7 to 8	--	--	--	--	--	--	--	--	7	--	7	1	--	3	7	--	--	--	--	--	--	1	12
8 to 9	--	--	--	--	--	--	1	1	1	--	3	2	4	--	8	--	--	--	--	1	1	--	16
9 to maximum	--	--	--	--	--	--	--	--	1	--	1	2	2	--	5	--	--	--	--	--	4	--	13

Table 5. Number of relocations by decile for continuous and categorical variables compiled by sturgeon species, sex, reproductive condition, and river section.—Continued

[Only river sections with data for a given combination of species, sex, and reproductive condition are shown. Repro., reproductive; Nonrepro., nonreproductive; Min. Eng., Minimally Engineered section; Up Chan., Upstream Channelized section; Down Chan., Downstream Channelized section]

Decile range or category	Number of locations for pallid sturgeon											Number of locations for shovelnose sturgeon												
	Female					Male					Pallid sturgeon total	Female					Intersex		Male				Shovelnose sturgeon total
	Repro. unknown		Non-repro.	Repro.		Repro. un-known	Nonrepro.		Repro.			Nonrepro.		Repro.			Intersex		Nonrepro.		Repro.		
	Min. Eng.	Down Chan.	Down Chan.	Min. Eng.	Up Chan.	Down Chan.	Up Chan.	Down Chan.	Up Chan.	Down Chan.		Min. Eng.	Up Chan.	Min. Eng.	Up Chan.	Down Chan.	Min. Eng.	Up Chan.	Min. Eng.	Up Chan.	Min. Eng.	Up Chan.	
Substrate category																							
Sand (dunes)	--	--	--	--	2	1	2	4	9	3	21	12	9	22	105	11	1	--	--	5	5	8	178
Revetment, gravel, hard sand	--	--	--	--	--	--	1	--	--	--	1	3	4	3	9	1	1	--	--	2	--	--	23
Fine sediment (mud, silt)	--	--	1	--	--	--	--	--	--	--	1	--	--	2	7	1	--	--	--	--	1	--	11
Transporting sand	--	--	--	--	--	--	--	--	--	--	--	1	1	1	10	--	--	1	1	--	1	--	16
Engineered structures (rock)	--	--	--	--	--	1	1	--	1	--	3	--	1	2	25	--	--	--	--	--	--	4	32
Shallow-water habitat category																							
Shallow-water habitat	--	--	--	--	--	--	--	--	--	--	--	1	3	4	1	2	--	--	--	--	--	--	11
Other	2	4	1	2	2	6	4	4	10	3	38	17	14	52	165	34	2	1	1	7	13	12	318

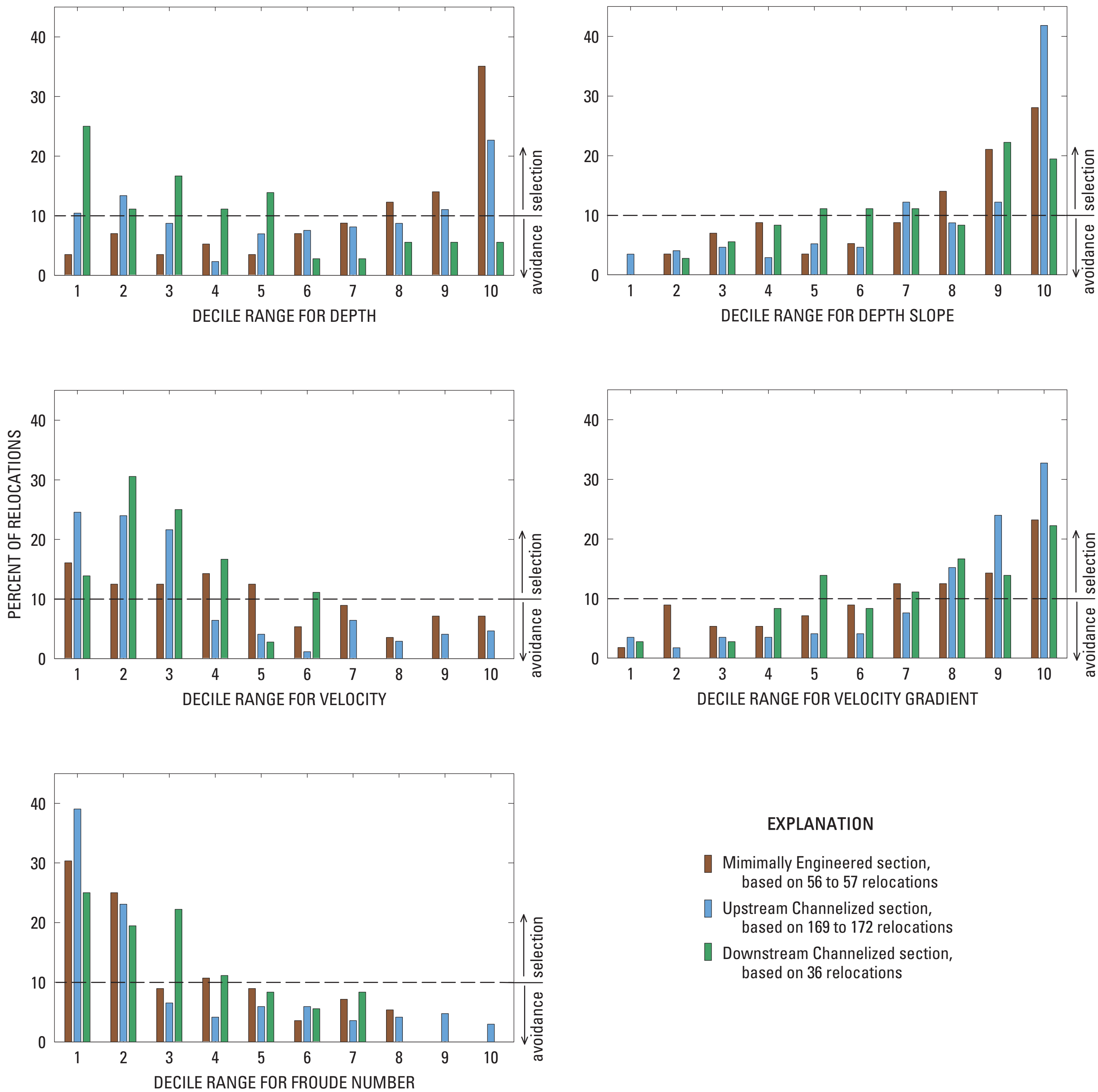


Figure 21. Plots of percentage of reproductive female shovelnose sturgeon in each decile range, by river section, for each continuous variable.

Table 6. Number of relocations by decile for continuous variables for only reproductive female shovelnose sturgeon compiled by year.

[Min. eng., Minimally Engineered section; Up Chan., Upstream Channelized section; Down Chan., Downstream Channelized section; --, no data]

Decile range	Number of female, reproductive shovelnose sturgeon relocations																			
	Depth				Depth slope				Velocity				Velocity gradient				Froude Number			
	Min. Eng.	Up Chan.	Down Chan.	Total	Min. Eng.	Up Chan.	Down Chan.	Total	Min. Eng.	Up Chan.	Down Chan.	Total	Min. Eng.	Up Chan.	Down Chan.	Total	Min. Eng.	Up Chan.	Down Chan.	Total
2005																				
Minimum to 1	1	12	6	19	0	0	0	0	2	27	1	30	0	0	1	1	2	33	5	40
1 to 2	0	11	4	15	0	3	1	4	0	16	9	25	0	0	0	0	0	19	2	21
2 to 3	0	7	2	9	0	5	2	7	0	14	6	20	0	3	0	3	0	1	6	7
3 to 4	0	1	2	3	1	2	1	4	0	4	3	7	0	1	3	4	0	2	4	6
4 to 5	0	5	2	7	0	4	4	8	0	3	1	4	0	2	4	6	0	4	2	6
5 to 6	0	2	1	3	0	0	2	2	0	0	3	3	0	3	3	6	0	3	1	4
6 to 7	1	5	1	7	0	7	3	10	0	3	0	3	0	4	1	5	0	2	3	5
7 to 8	0	5	2	7	0	8	1	9	0	1	0	1	0	13	3	16	0	1	0	1
8 to 9	0	5	2	7	0	8	4	12	0	2	0	2	0	15	3	18	0	2	0	2
9 to maximum	0	18	1	19	1	34	5	40	0	1	0	1	2	30	5	37	0	3	0	3
2006																				
Minimum to 1	0	1	3	4	0	0	0	0	3	5	4	12	0	0	0	0	7	10	4	21
1 to 2	2	2	0	4	0	1	0	1	3	8	2	13	0	0	0	0	2	3	5	10
2 to 3	1	2	4	7	1	1	0	2	1	0	3	4	0	0	1	1	0	1	2	3
3 to 4	0	1	2	3	0	0	2	2	2	0	3	5	0	0	0	0	1	0	0	1
4 to 5	1	1	3	5	0	1	0	1	0	0	0	0	1	0	1	2	0	0	1	1
5 to 6	0	0	0	0	0	1	2	3	1	1	1	3	1	1	0	2	0	0	1	1
6 to 7	1	1	0	2	0	0	1	1	0	1	0	1	2	0	3	5	0	0	0	0
7 to 8	2	2	0	4	0	0	2	2	0	0	0	0	1	2	3	6	0	0	0	0
8 to 9	0	3	0	3	4	1	4	9	0	0	0	0	1	5	2	8	0	0	0	0
9 to maximum	4	2	1	7	6	10	2	18	0	0	0	0	4	7	3	14	0	1	0	1
2007																				
Minimum to 1	1	5	--	6	0	6	--	6	4	10	--	14	1	6	--	7	8	23	--	31
1 to 2	2	10	--	12	2	3	--	5	4	17	--	21	5	3	--	8	12	17	--	29
2 to 3	1	6	--	7	3	2	--	5	6	23	--	29	3	3	--	6	5	9	--	14
3 to 4	3	2	--	5	4	3	--	7	6	7	--	13	3	5	--	8	5	5	--	10
4 to 5	1	6	--	7	2	4	--	6	7	4	--	11	3	5	--	8	5	6	--	11
5 to 6	4	11	--	15	3	7	--	10	2	1	--	3	4	3	--	7	2	7	--	9
6 to 7	3	8	--	11	5	14	--	19	5	7	--	12	5	9	--	14	4	4	--	8
7 to 8	5	8	--	13	8	7	--	15	2	4	--	6	6	11	--	17	3	6	--	9
8 to 9	8	11	--	19	8	12	--	20	4	5	--	9	7	21	--	28	0	6	--	6
9 to maximum	16	19	--	35	9	28	--	37	4	7	--	11	7	19	--	26	0	1	--	1

Table 7. Categorical variables summarized by reach, including numbers of qualifying sturgeon relocations within 10 percent discharge and 7 days of the map date.

[SWH, shallow-water habitat; --, no data]

Map identification	Reach center river mile	Substrate										Shallow-water habitat				Terrain classification							
		Percent of map area					Number of relocations					Percent of map area		Number of relocations		Percent of map area				Number of relocations			
		Sand (dunes)	Revetment, gravel, hard sand	Fine sediment (mud, silt)	Transporting sand	Engineered structures, bedrock	Sand (dunes)	Revetment, gravel, hard sand	Fine sediment (mud, silt)	Transporting sand	Engineered structures, bedrock	SWH	Not SWH	SWH	Not SWH	Flat	Slope	Crest	Depression	Flat	Slope	Crest	Depression
20060711_f	807.9	--	--	--	--	--	--	--	--	--	--	5.8	94.2	0	2	36.0	1.2	31.2	31.6	2	0	0	0
20070516_f	806.9	--	--	--	--	--	--	--	--	--	--	14.3	85.7	0	2	45.0	1.0	27.5	26.5	0	0	0	2
20070524_f	806.6	--	--	--	--	--	--	--	--	--	--	14.9	85.1	0	3	43.5	0.8	26.8	28.9	0	0	0	3
20070510_f	801.9	--	--	--	--	--	--	--	--	--	--	35.6	64.4	0	1	68.8	0.6	15.6	15.0	0	0	0	1
20070601_f	797.1	--	--	--	--	--	--	--	--	--	--	34.1	65.9	0	3	58.9	0.9	19.9	20.4	3	0	0	0
20070518_f	782.5	--	--	--	--	--	--	--	--	--	--	13.0	87.0	0	2	68.2	0.6	17.7	13.6	2	0	0	0
20070530_f	775.1	--	--	--	--	--	--	--	--	--	--	10.0	90.0	1	6	46.3	1.7	28.4	23.6	3	0	1	3
20050615_f	759.8	--	--	--	--	--	--	--	--	--	--	12.7	87.3	1	0	54.3	1.0	24.5	20.3	0	0	1	0
20070521_f	759.6	--	--	--	--	--	--	--	--	--	--	1.0	99.0	0	2	49.8	2.6	25.3	22.3	1	0	0	1
20070523_f	752.7	--	--	--	--	--	--	--	--	--	--	7.8	92.2	1	8	44.6	1.7	28.0	25.7	1	0	2	6
20060622_f	751.8	85.8	9.0	0.3	0.7	4.1	1	0	0	0	0	2.7	97.3	0	1	44.1	1.8	27.9	26.3	0	0	0	1
20060620_f	749.3	--	--	--	--	--	--	--	--	--	--	5.8	94.2	1	5	40.3	1.9	33.5	24.2	1	0	3	3
20050610_f	746.3	78.1	5.1	0.6	15.6	0.6	1	0	0	0	0	0.8	99.2	0	1	29.4	2.3	39.4	28.8	0	1	0	0
20070525_f	745.0	79.7	17.1	0.4	2.6	0.4	1	0	0	0	0	6.8	93.2	0	1	30.3	2.0	40.5	27.1	1	0	0	0
20060712_f	743.7	80.1	13.0	1.6	2.2	3.1	2	1	0	0	0	5.4	94.6	0	3	27.9	3.1	41.1	27.9	0	2	0	1
20070502_f	738.2	81.7	5.5	5.7	5.6	1.6	6	1	2	0	0	7.9	92.1	0	9	44.4	2.1	30.8	22.7	3	0	1	5
20070509_f	736.6	85.8	4.9	4.4	4.0	0.8	4	0	1	0	0	16.1	83.9	0	5	40.8	1.9	33.4	23.9	1	0	1	3
20070612_f	734.2	84.7	3.1	1.1	8.3	2.8	11	1	0	1	3	1.5	98.5	1	14	36.1	2.3	35.8	25.7	6	1	4	5
20070503_f	734.2	77.7	5.9	8.4	5.0	3.0	41	10	0	4	1	9.3	90.7	0	58	37.2	2.5	35.1	25.2	15	1	6	36
20050616_f	732.4	80.2	2.1	1.2	13.2	3.4	0	0	0	0	0	0.3	99.7	0	0	48.2	2.6	23.8	25.4	0	0	0	1
20070615_f	729.5	83.4	3.4	0.6	8.9	3.7	9	1	0	0	7	1.9	98.1	2	16	44.8	2.2	25.8	27.2	5	2	4	7
20070504_f	726.5	79.6	4.5	0.7	11.8	3.4	11	1	0	0	2	1.1	98.9	0	14	48.6	2.2	25.1	24.1	9	1	3	1
20060523_f	725.0	72.4	7.1	1.1	12.5	6.9	0	0	0	1	0	1.2	98.8	0	1	40.4	3.0	27.6	29.1	0	0	0	1
20070602_f	724.6	81.8	2.0	0.5	10.2	5.5	5	0	0	0	6	1.2	98.8	0	11	49.5	2.0	22.1	26.4	3	2	4	2
20070609_f	717.8	80.6	5.9	0.2	11.4	1.9	3	2	0	1	0	2.2	97.8	0	6	31.8	3.0	31.2	34.0	2	1	2	1
20060607_f	709.3	81.7	3.5	1.3	8.6	4.9	2	0	0	0	0	1.9	98.1	0	2	33.9	2.8	32.4	31.0	1	1	0	0
20070613_f	707.5	79.8	5.2	0.2	12.6	2.2	7	0	0	1	0	1.9	98.1	0	8	44.9	2.4	25.9	26.8	3	0	1	4
20070515_f	706.2	--	--	--	--	--	--	--	--	--	--	1.5	98.5	0	4	33.9	3.2	31.2	31.6	1	0	2	1
20070607_f	702.2	76.3	9.3	0.6	9.5	4.4	3	0	0	0	0	1.3	98.7	0	3	29.2	2.4	37.4	31.0	0	0	1	3

Table 7. Categorical variables summarized by reach, including numbers of qualifying sturgeon relocations within 10 percent discharge and 7 days of the map date.—Continued

[SWH, shallow-water habitat; --, no data]

Map identification	Reach center river mile	Substrate										Shallow-water habitat				Terrain classification							
		Percent of map area					Number of relocations					Percent of map area		Number of relocations		Percent of map area				Number of relocations			
		Sand (dunes)	Revetment, gravel, hard sand	Fine sediment (mud, silt)	Transporting sand	Engineered structures, bedrock	Sand (dunes)	Revetment, gravel, hard sand	Fine sediment (mud, silt)	Transporting sand	Engineered structures, bedrock	SWH	Not SWH	SWH	Not SWH	Flat	Slope	Crest	Depression	Flat	Slope	Crest	Depression
20050603_f	697.8	80.5	6.0	1.8	9.2	2.4	0	0	1	0	0	1.0	99.0	0	1	36.3	3.2	31.2	29.3	0	0	1	0
20050609_f	693.4	79.8	3.6	0.3	11.5	4.9	1	0	0	0	0	1.0	99.0	0	1	31.9	3.1	29.6	35.4	0	0	0	1
20050617_f	693.0	74.3	4.0	2.2	14.4	5.1	1	0	0	0	0	0.7	99.3	0	1	34.1	3.0	30.4	32.5	0	0	1	0
20070519_f	691.9	73.2	1.6	1.1	19.0	5.2	2	0	0	1	0	1.5	98.5	0	3	36.9	2.8	30.8	29.5	0	1	1	1
20070517_f	689.2	--	--	--	--	--	--	--	--	--	--	1.0	99.0	0	7	33.6	2.8	32.5	31.1	1	2	2	2
20050518_f	686.6	80.9	6.3	0.6	6.5	5.7	1	0	0	0	0	1.0	99.0	0	1	34.1	2.8	34.4	28.7	0	0	0	1
20050624_f	683.9	82.4	2.1	0.9	9.8	4.8	2	0	0	0	1	1.6	98.4	0	3	34.1	3.4	29.9	32.6	1	0	2	0
20050510_f	673.8	79.4	4.8	1.8	9.7	4.4	1	0	1	0	0	1.0	99.0	0	2	37.8	2.7	29.8	29.7	0	0	2	0
20050602_f	672.4	73.1	7.5	0.7	17.0	1.7	4	0	0	0	0	0.7	99.3	0	4	31.0	3.2	34.6	31.2	0	0	1	3
20060601_f	669.2	81.6	4.4	1.9	6.7	5.4	3	0	0	0	0	2.6	97.4	0	3	34.8	3.1	31.7	30.4	0	0	1	2
20060606_f	665.6	79.8	3.5	1.6	10.3	4.8	3	0	1	0	1	1.1	98.9	1	4	31.7	2.6	35.5	30.2	2	0	1	2
20050608_f	663.0	79.6	2.3	0.8	12.2	5.0	1	0	0	0	0	0.6	99.4	0	1	33.8	2.8	31.3	32.1	0	0	1	0
20070512_f	660.8	--	--	--	--	--	--	--	--	--	--	1.2	98.8	0	1	28.6	2.9	32.2	36.2	0	0	1	0
20050519_f	657.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	27.1	2.4	37.6	32.8	0	0	2	0
20050507_f	654.7	81.1	6.0	2.4	6.8	3.8	1	0	0	0	0	0.9	99.1	0	1	42.0	2.6	27.9	27.4	0	1	0	0
20050525_f	652.0	80.4	3.7	2.1	8.8	5.0	1	0	0	0	2	0.0	100.0	0	3	29.5	3.4	35.2	32.0	0	0	3	0
20050623_f	650.4	75.9	5.4	1.4	13.8	3.4	1	0	0	0	1	0.5	99.5	0	2	38.5	2.5	29.3	29.7	1	0	1	0
20070608_f	650.3	86.3	3.9	0.7	4.9	4.2	7	1	0	2	0	0.8	99.2	1	9	33.0	2.7	33.1	31.2	4	0	6	0
20070501_f	647.6	75.8	4.8	2.1	13.8	3.5	3	0	0	0	0	1.2	98.8	0	3	36.2	3.3	31.2	29.3	0	0	2	1
20050614_f	644.8	78.2	3.1	3.1	10.2	5.5	1	0	0	0	0	0.3	99.7	0	1	41.8	2.5	26.5	29.2	0	0	0	1
20070614_f	643.6	79.2	3.3	1.5	10.8	5.3	2	0	0	1	0	0.4	99.6	0	3	48.7	2.7	23.4	25.2	3	0	0	0
20050812_f	642.7	--	--	--	--	--	--	--	--	--	--	0.4	99.6	0	1	37.0	3.3	30.3	29.5	1	0	0	0
20060518_f	641.5	84.6	2.9	1.5	6.8	4.2	1	0	0	0	0	2.1	97.9	0	1	39.3	2.6	27.8	30.2	0	1	0	0
20070616_f	641.3	87.3	7.6	0.2	0.6	4.3	6	0	0	0	0	1.3	98.7	0	6	43.5	2.8	25.6	28.1	0	1	1	4
20050505_f	640.5	85.3	5.5	2.1	3.2	3.8	2	0	0	0	1	2.1	97.9	0	0	34.7	2.8	30.4	32.1	0	0	0	0
20050601_f	638.9	82.1	6.1	1.8	5.9	4.1	2	1	0	0	1	0.7	99.3	0	4	39.2	2.6	28.1	30.2	0	2	1	1
20050622_f	622.8	75.8	2.8	2.5	15.1	3.9	1	0	1	0	0	0.8	99.2	0	2	30.8	2.6	35.0	31.6	0	1	0	1
20050512_f	620.1	77.4	2.6	2.7	14.3	3.0	0	0	0	0	1	0.5	99.5	0	1	27.6	3.4	35.3	33.7	0	0	0	1
20050621_f	618.6	71.6	3.1	4.2	18.6	2.6	2	0	0	0	0	0.9	99.1	0	2	32.8	3.2	29.9	34.1	0	0	2	0
20050428_f	611.6	80.7	5.0	1.0	9.9	3.4	0	0	0	0	1	0.7	99.3	0	1	35.9	2.7	29.6	31.8	0	0	0	1

Table 7. Categorical variables summarized by reach, including numbers of qualifying sturgeon relocations within 10 percent discharge and 7 days of the map date.—Continued

[SWH, shallow-water habitat; --, no data]

Map identification	Reach center river mile	Substrate										Shallow-water habitat				Terrain classification							
		Percent of map area					Number of relocations					Percent of map area		Number of relocations		Percent of map area				Number of relocations			
		Sand (dunes)	Revetment, gravel, hard sand	Fine sediment (mud, silt)	Transporting sand	Engineered structures, bedrock	Sand (dunes)	Revetment, gravel, hard sand	Fine sediment (mud, silt)	Transporting sand	Engineered structures, bedrock	SWH	Not SWH	SWH	Not SWH	Flat	Slope	Crest	Depression	Flat	Slope	Crest	Depression
20050506_f	609.9	85.0	2.8	1.9	4.8	5.5	3	0	0	3	1	0.7	99.3	0	8	40.8	2.5	25.8	30.8	0	1	1	6
20050605_f	609.7	73.8	2.0	1.2	19.5	3.6	1	1	0	0	0	0.4	99.6	0	2	40.3	2.5	25.7	31.5	0	0	1	1
20050508_f	608.5	82.1	2.2	5.3	5.1	5.4	9	2	2	1	2	0.8	99.2	0	15	38.8	3.2	27.2	30.8	3	1	5	7
20050429_f	608.2	80.1	4.3	2.4	7.6	5.6	1	0	0	0	0	0.1	99.9	0	1	43.7	3.1	25.1	28.1	0	0	0	1
20050517_f	606.8	80.9	2.3	1.7	10.0	5.1	1	0	0	0	0	0.6	99.4	0	1	38.3	3.2	27.9	30.6	0	0	1	0
20050604_f	604.0	81.2	3.1	2.1	10.8	2.8	1	0	1	0	0	1.4	98.6	0	2	30.9	3.0	32.6	33.6	0	1	0	1
20050509_f	602.4	84.5	2.4	2.4	6.9	3.7	1	0	0	0	1	1.3	98.7	0	2	39.7	2.7	24.4	33.2	0	0	1	1
20050522_f	601.2	80.4	4.0	2.6	9.3	3.7	1	0	0	0	0	0.1	99.9	0	1	42.2	3.4	23.9	30.5	0	0	0	1
20050611_f	593.7	79.5	2.1	0.7	12.6	5.1	1	0	0	0	0	1.2	98.8	0	1	22.3	2.8	32.8	42.1	0	0	0	1
20050523_f	588.6	77.0	5.4	2.0	11.3	4.3	1	0	0	0	0	0.0	100.0	0	1	38.2	3.6	27.6	30.6	0	0	1	0
20060713_f	583.8	78.4	4.0	2.8	11.1	3.6	3	1	0	0	2	0.3	99.7	0	6	53.5	2.7	21.8	22.0	0	1	3	2
20050524_f	565.5	76.4	3.5	2.8	14.7	2.6	1	0	0	0	0	0.1	99.9	0	1	34.3	2.8	30.6	32.3	0	0	1	0
20050504_b	362.7	--	--	--	--	--	--	--	--	--	--	3.0	97.0	0	1	19.5	2.6	39.6	38.2	0	0	1	0
20050525_b	354.4	--	--	--	--	--	--	--	--	--	--	1.6	98.4	0	1	21.0	1.9	33.9	43.2	0	0	1	0
20060620_b	331.9	79.4	9.9	6.3	2.6	1.9	0	0	1	0	0	7.0	93.0	0	1	40.1	1.6	31.2	27.1	0	0	1	0
20050429_b	330.1	--	--	--	--	--	0	0	0	0	0	3.0	97.0	0	1	34.7	1.8	32.1	31.4	0	0	1	0
20060524_b	326.8	89.1	5.0	2.7	0.7	2.6	4	0	0	0	0	3.9	96.1	0	4	34.1	1.9	33.8	30.1	0	1	2	1
20050511_b	325.2	--	--	--	--	--	--	--	--	--	--	7.7	92.3	0	1	29.4	2.0	33.9	34.7	0	0	1	0
20050427_b	315.1	--	--	--	--	--	--	--	--	--	--	0.8	99.2	0	1	40.2	2.1	27.3	30.4	0	0	0	1
20050505_b	311.6	--	--	--	--	--	--	--	--	--	--	2.4	97.6	0	1	30.4	1.9	34.6	33.1	0	0	0	1
20050526_b	291.8	--	--	--	--	--	--	--	--	--	--	2.3	97.7	0	1	23.2	1.8	39.3	35.7	1	0	0	0
20060706_b	289.4	80.5	8.3	8.5	0.5	2.3	2	0	0	0	0	3.4	96.6	0	2	31.5	2.4	33.9	32.2	0	0	2	0
20060613_b_b	281.4	73.7	14.7	2.6	5.2	3.9	3	0	0	0	0	7.5	92.5	0	3	24.1	2.2	37.4	36.4	1	0	2	0
20060504_b	280.6	83.7	4.0	0.6	8.2	3.5	1	0	0	0	0	0.1	99.9	0	1	40.3	2.1	27.6	30.1	0	0	0	1
20060608_b	279.7	81.7	5.9	2.6	6.3	3.5	0	0	1	0	0	2.4	97.6	0	1	33.4	1.8	33.6	31.2	0	0	1	0
20050610_b	275.8	--	--	--	--	--	--	--	--	--	--	0.0	100.0	0	1	25.0	1.8	34.6	38.5	0	0	1	0
20060602_b	247.6	81.5	6.4	6.0	3.1	3.0	0	1	0	0	0	5.7	94.3	0	1	33.3	2.1	32.2	32.4	0	0	1	0
20050506_b	230.5	--	--	--	--	--	--	--	--	--	--	3.0	97.0	0	1	29.2	1.5	32.4	36.9	0	0	1	0
20050415_b	219.2	--	--	--	--	--	--	--	--	--	--	0.7	99.3	0	1	29.8	1.7	33.7	34.8	0	0	1	0
20060519_b	218.8	66.0	7.9	4.1	21.2	0.9	1	0	0	0	0	5.7	94.3	1	0	32.3	2.2	30.7	34.8	0	0	1	0

Table 7. Categorical variables summarized by reach, including numbers of qualifying sturgeon relocations within 10 percent discharge and 7 days of the map date.—Continued

[SWH, shallow-water habitat; --, no data]

Map identification	Reach center river mile	Substrate										Shallow-water habitat				Terrain classification							
		Percent of map area					Number of relocations					Percent of map area		Number of relocations		Percent of map area				Number of relocations			
		Sand (dunes)	Revetment, gravel, hard sand	Fine sediment (mud, silt)	Transporting sand	Engineered structures, bedrock	Sand (dunes)	Revetment, gravel, hard sand	Fine sediment (mud, silt)	Transporting sand	Engineered structures, bedrock	SWH	Not SWH	SWH	Not SWH	Flat	Slope	Crest	Depression	Flat	Slope	Crest	Depression
20050627_b	217.4	--	--	--	--	--	--	--	--	--	--	2.7	97.3	0	2	16.7	2.1	43.9	37.3	1	0	1	0
20050428_b	203.3	--	--	--	--	--	--	--	--	--	--	1.0	99.0	0	1	40.0	1.4	28.5	30.1	0	0	0	1
20050407_b	201.6	--	--	--	--	--	--	--	--	--	--	4.6	95.4	0	2	39.7	1.6	29.9	28.8	0	1	1	0
20050408_f	199.7	82.7	7.0	6.6	2.2	1.5	1	0	0	0	1	0.8	99.2	0	2	57.5	0.9	23.9	17.8	1	0	1	0
20060707_b	196.0	76.9	11.8	8.4	0.3	2.5	2	0	0	0	0	8.2	91.8	0	2	32.9	1.6	33.1	32.4	2	0	0	0
20050527_b	186.8	--	--	--	--	--	--	--	--	--	--	1.5	98.5	0	1	26.7	2.0	35.3	36.0	0	1	0	0
20050412_b	178.0	--	--	--	--	--	--	--	--	--	--	3.8	96.2	1	0	24.8	1.3	37.9	36.0	0	0	1	0
20060510_b	177.4	82.7	9.2	2.7	3.3	2.2	1	0	0	0	0	7.4	92.6	0	1	27.1	1.7	35.4	35.8	0	0	0	1
20050601_b	173.5	--	--	--	--	--	--	--	--	--	--	2.9	97.1	0	1	35.5	1.8	32.6	30.2	0	0	1	0
20050701_b	168.0	--	--	--	--	--	--	--	--	--	--	1.0	99.0	0	1	35.1	1.7	32.4	30.7	0	0	0	1
20060621_b	165.5	79.4	13.0	4.9	1.5	1.2	1	0	0	0	0	7.5	92.5	0	1	35.8	1.9	31.6	30.8	0	0	1	0
20050510_b	160.5	--	--	--	--	--	--	--	--	--	--	3.0	97.0	0	1	26.8	1.9	35.6	35.6	0	0	1	0
20050810_b	146.5	--	--	--	--	--	--	--	--	--	--	5.3	94.7	0	1	42.5	1.1	30.5	25.8	0	0	0	1
20050809_b	142.0	--	--	--	--	--	--	--	--	--	--	2.3	97.7	0	1	28.9	2.4	35.3	33.4	0	0	1	0
20050602_b	140.8	--	--	--	--	--	--	--	--	--	--	7.4	92.6	0	1	22.9	2.5	34.8	39.8	0	0	1	0
20050419_b	130.6	--	--	--	--	--	--	--	--	--	--	1.9	98.1	0	3	40.3	1.3	30.4	28.0	2	0	0	1
20060509_b	127.6	82.1	5.9	3.3	6.5	2.3	1	0	0	0	0	0.5	99.5	0	1	36.7	1.6	30.3	31.4	1	0	0	0
20050426_b	127.3	--	--	--	--	--	--	--	--	--	--	0.2	99.8	0	1	23.1	1.5	37.7	37.7	0	0	0	1
20060630_b	119.6	79.3	10.7	7.8	0.7	1.5	2	0	0	0	0	4.7	95.3	0	2	39.7	1.8	29.3	29.3	1	0	1	0
20050503_b	118.5	--	--	--	--	--	--	--	--	--	--	1.3	98.7	0	1	38.1	1.3	33.6	27.0	0	0	0	1
20050706_b	118.2	--	--	--	--	--	--	--	--	--	--	0.4	99.6	0	1	31.1	1.3	36.9	30.7	1	0	0	0
20050707_b	75.8	--	--	--	--	--	--	--	--	--	--	3.0	97.0	0	1	27.6	1.5	36.4	34.5	0	0	1	0
20050708_b	27.3	--	--	--	--	--	--	--	--	--	--	0.1	99.9	0	1	48.4	0.9	25.9	24.7	0	0	1	0

Table 8. Summary of categorical data by river section, including percent of map area, percent of relocations, and Ivlev's selectivity coefficient.

[SWH, shallow-water habitat]

River section	Generalized substrate					Shallow-water habitat		Terrain classification			
	Sand (dunes)	Revetment, gravel, hard sand	Fine sediment (mud, silt)	Transporting sand	Engineered structures (rock)	SWH	Not SWH	Flat	Slope	Crest	Depression
Percent of map area											
Minimally Engineered	82.1	7.5	2.8	5.3	2.3	11.1	88.9	44.0	1.7	29.8	24.5
Upstream Channelized	79.6	4.2	1.6	10.4	4.1	1.0	99.0	37.0	2.8	29.6	30.6
Downstream Channelized	80.0	8.5	5.0	4.3	2.2	3.1	96.9	32.4	1.7	33.3	32.6
All	80.0	5.8	2.7	8.1	3.4	3.5	96.5	35.7	2.1	31.4	30.7
Percent of relocations											
Minimally Engineered	72.8	14.1	3.3	5.4	4.3	3.8	96.2	29.3	3.8	14.3	52.6
Upstream Channelized	66.1	5.8	4.1	6.4	17.5	2.2	97.8	21.4	10.7	33.7	34.2
Downstream Channelized	82.6	4.3	8.7	0.0	4.3	3.7	96.3	20.4	5.6	53.7	20.4
All	69.6	8.4	4.2	5.6	12.2	3.0	97.0	24.1	7.5	29.7	38.8
Ivlev's selectivity coefficient											
Minimally Engineered	-0.06	0.31	0.07	0.01	0.31	-0.49	0.04	-0.20	0.38	-0.35	0.36
Upstream Channelized	-0.09	0.17	0.43	-0.24	0.62	0.38	-0.01	-0.27	0.58	0.06	0.06
Downstream Channelized	0.02	-0.32	0.27	-1.00	0.32	0.09	-0.00	-0.23	0.52	0.23	-0.23
All	-0.07	0.18	0.22	-0.18	0.57	-0.07	0.00	-0.20	0.55	-0.03	0.12

Specifically, the reclassification was as follows:

velocity gradient: 80–100 percentile = 1

depth slope: 80–100 percentile = 1

Froude number: 0–20 percentile = 1

After reclassifying each individual variable, we combined the maps by adding them together. In the resulting maps, each grid cell has a value from 0 to 3, representing the number of variables that fall within the ranges specified above. Groups of grid cells form selected patches.

The resulting maps show different patterns in each major section of river. Example reaches that illustrate some of these patterns are shown in figure 22. In the Minimally Engineered section, the areas of predicted selection form a relatively complex mosaic with abundant connections among selected patches, often forming a series of longitudinal pathways through the reach. In the Upstream Channelized section, the patches of predicted selection are strongly associated with the edges of the channel, and the values are often coincident with each other. In the Downstream Channelized section, predicted selected patches tend to be at the channel margins, especially in dike fields.

To assess whether these patches predict sturgeon relocations, we summarized the number of sturgeon relocations within each patch in each map, limiting the analysis to sturgeon relocations from the same year as the map. Findings from this simple analysis support the idea that sturgeon are indeed using certain patches more than others in a predictable way. Of 2,013 relocations in total, about 18 percent of these fell within about 4 percent of the map area where all three variables were in the predicted selection ranges; about 63 percent of the relocations fell within about 35 percent of the area represented by at least one variable in the predicted selection ranges (table 9).

Discussion

Describing habitats selected by adult *Scaphirhynchus* sturgeon in the Lower Missouri River is just one step in the process of developing a broader understanding of how sturgeon perceive habitat, the relative value of different habitats to sturgeon, and what constitutes quality sturgeon habitat. Ultimately, the improved understanding can contribute to determining how and to what extent habitat alteration contributes to the decline of sturgeon species in the Lower Missouri River. We observed and described relations between positions of sturgeon and environmental characteristics. Sturgeon can go almost anywhere within the channel, but they show a tendency to select some habitats while avoiding others. These relations are based on observations of sturgeon habitat selection in an altered system, so we caution against extending these results to infer sturgeon habitat needs or preferences. That said, the relatively consistent patterns of selection for high depth slope, high velocity gradient, and low Froude number in geomorphically diverse river sections suggests that some sturgeon responses to habitat may transcend availability. In contrast, selection for depth appears more complex. The difference in depth selection may indicate interaction with other factors like turbidity, which could affect a sturgeon's need to seek greater depths for cover or to seek prey.

The two primary methods for the analysis of habitat selection in this report yielded results that were largely complementary (figs. 20, 21). The decile approach most directly addressed the concept of habitat selection by comparing variable values at sturgeon relocations to the range of available habitat that was available strictly within the reach where each sturgeon was found. In contrast, Ivlev's selectivity coefficients yielded results in terms of the actual values of the habitat variables that sturgeon tend to select or avoid. Such values may be more readily useful from an engineering standpoint. The similarity of the results obtained from both methods is an indicator of robustness. We feel that the robustness also is a byproduct of ensuring that Ivlev's selectivity coefficients were computed within geomorphically similar river sections under non-extreme flow conditions.

The best descriptors of selected habitat that we have explored are depth slope, velocity gradient, and Froude number. Quantification of these variables can be used in exploratory modeling of habitat, and, therefore, in the prediction of how channel reconfigurations and flow changes could alter the distribution of identified habitat. Hydrodynamic modeling can help to better define how patches defined by these variables change as a function of discharge. Initial assessments suggest that selected patches may show some persistence across discharge; this may be because of the interrelation of variables in question: depth and velocity tend to be correlated, as do depth slope and velocity gradient to a lesser degree. Because depth slope is effectively independent of discharge if the bed is stable, persistence of major patterns of depth slope and velocity gradient across moderate changes in discharge is a reasonable expectation. For habitat assessments that have taken the approach of defining patches based on specified ranges of depth and velocity (for example, Jacobson and others, 2009b), it may be the edges, not the patches themselves, that are important. Analysis of habitat patch and edge structure should also address longitudinal and lateral connectivity, especially for habitats which are for migrating, reproductive adults.

The habitat template varies by section of the Lower Missouri River. Developing an understanding of habitat selection and distributions may eventually provide some guidance on what types of habitats may need to be increased in specific parts of the river. Selected habitats and patch structure are most complex and interconnected in the Minimally Engineered section, which may be closest to a reference condition in a geomorphic sense. The fragmented patch structure of the Upstream Channelized section indicates that it could be relatively unsupportive of adult sturgeon. Conversely, recovering dynamism of habitats has been suggested as a restoration goal for the Lower Missouri River (National Research Council, 2002). The Upstream Channelized section has active in-chan-

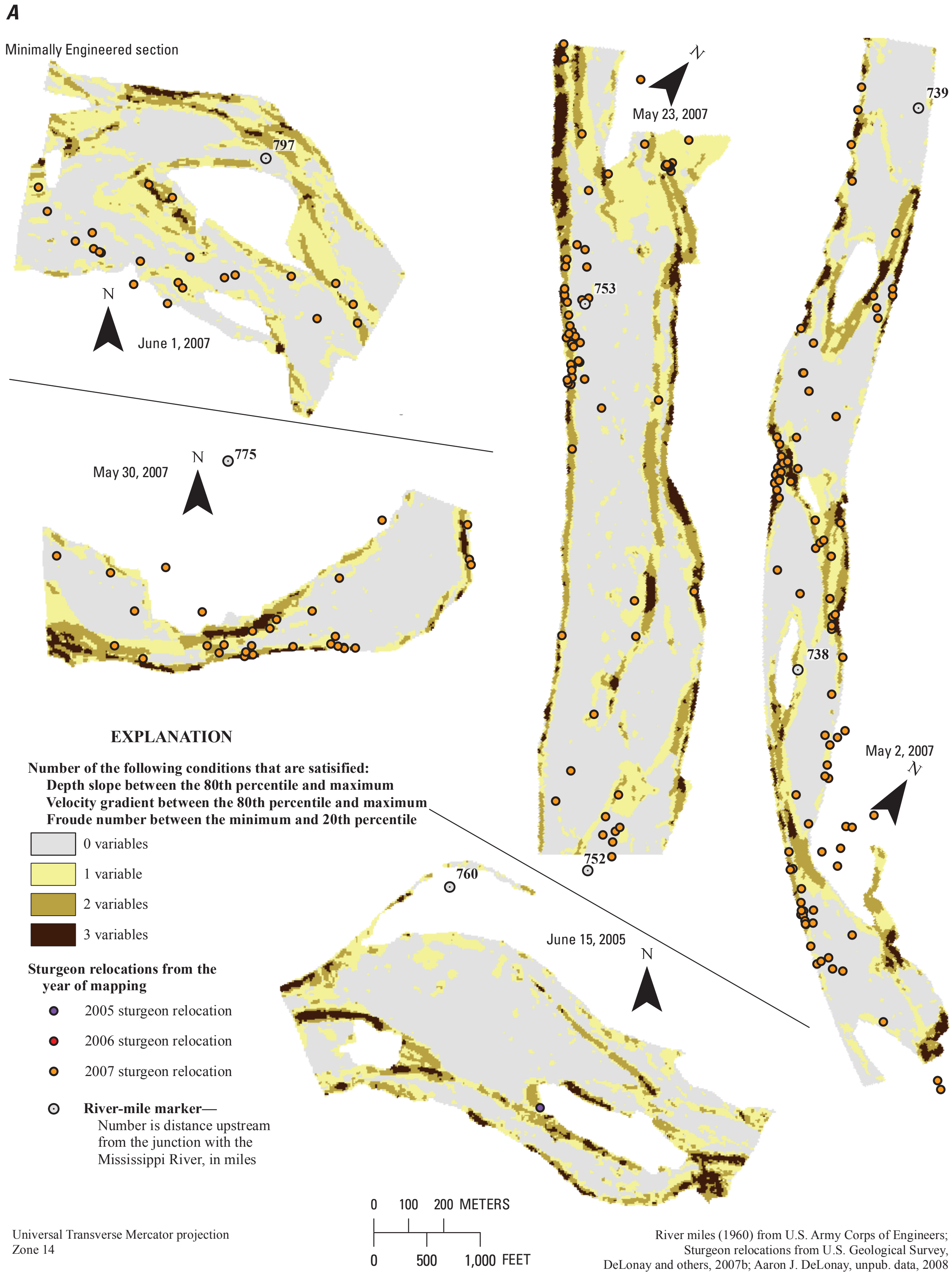


Figure 22. Example maps from each river section showing the distribution of areas with high depth slope, high velocity gradient, and/or low Froude number. Sturgeon relocations from the year of mapping are also shown. Each grid cell represents the number of the following criteria that were met: depth slope greater than the 80th percentile in the reach, velocity gradient greater than the 80th percentile in the reach, and Froude number less than the 20th percentile in the reach.

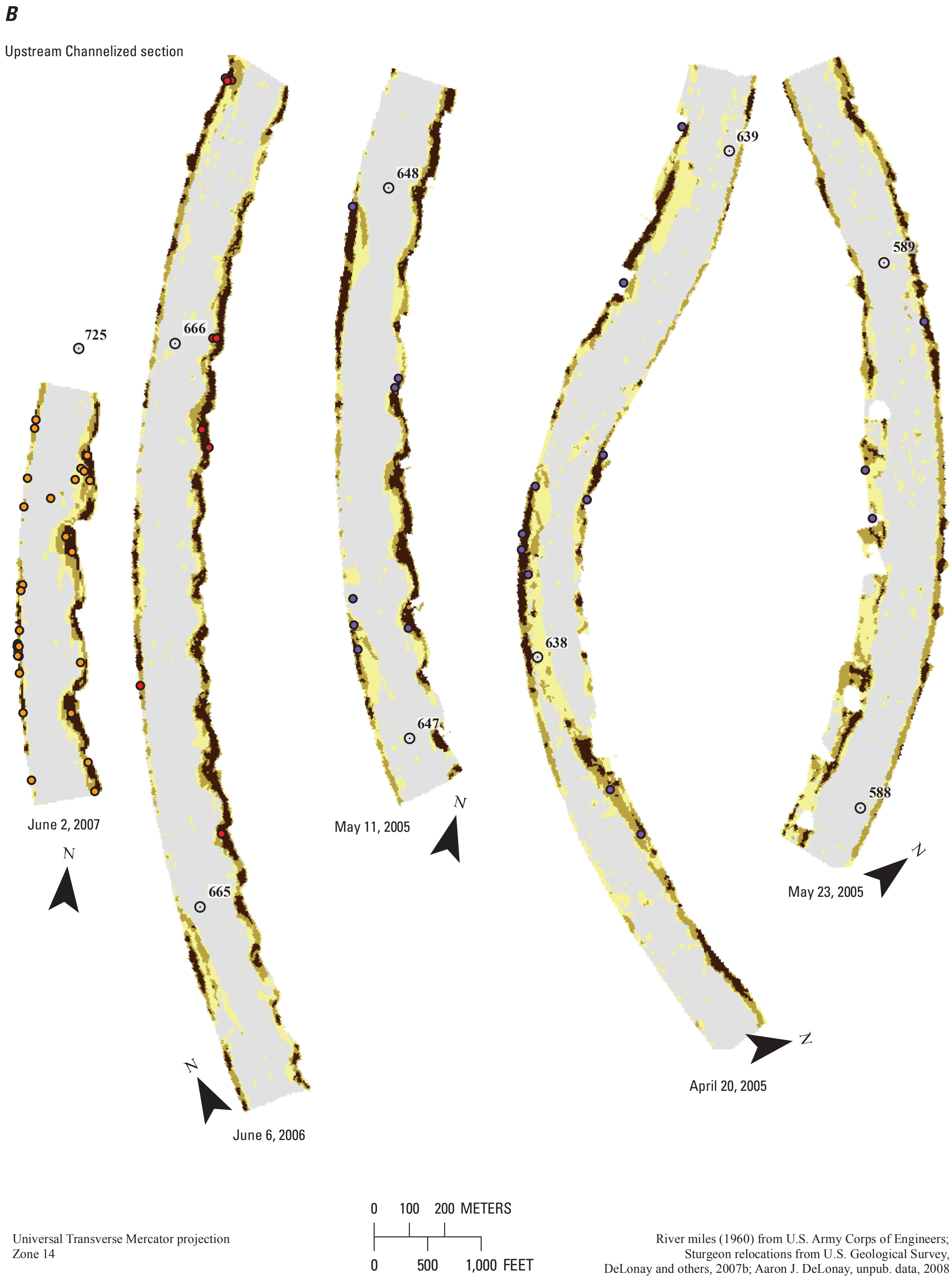


Figure 22. Example maps from each river section showing the distribution of areas with high depth slope, high velocity gradient, and/or low Froude number. Sturgeon relocations from the year of mapping are also shown. Each grid cell represents the number of the following criteria that were met: depth slope greater than the 80th percentile in the reach, velocity gradient greater than the 80th percentile in the reach, and Froude number less than the 20th percentile in the reach.—Continued

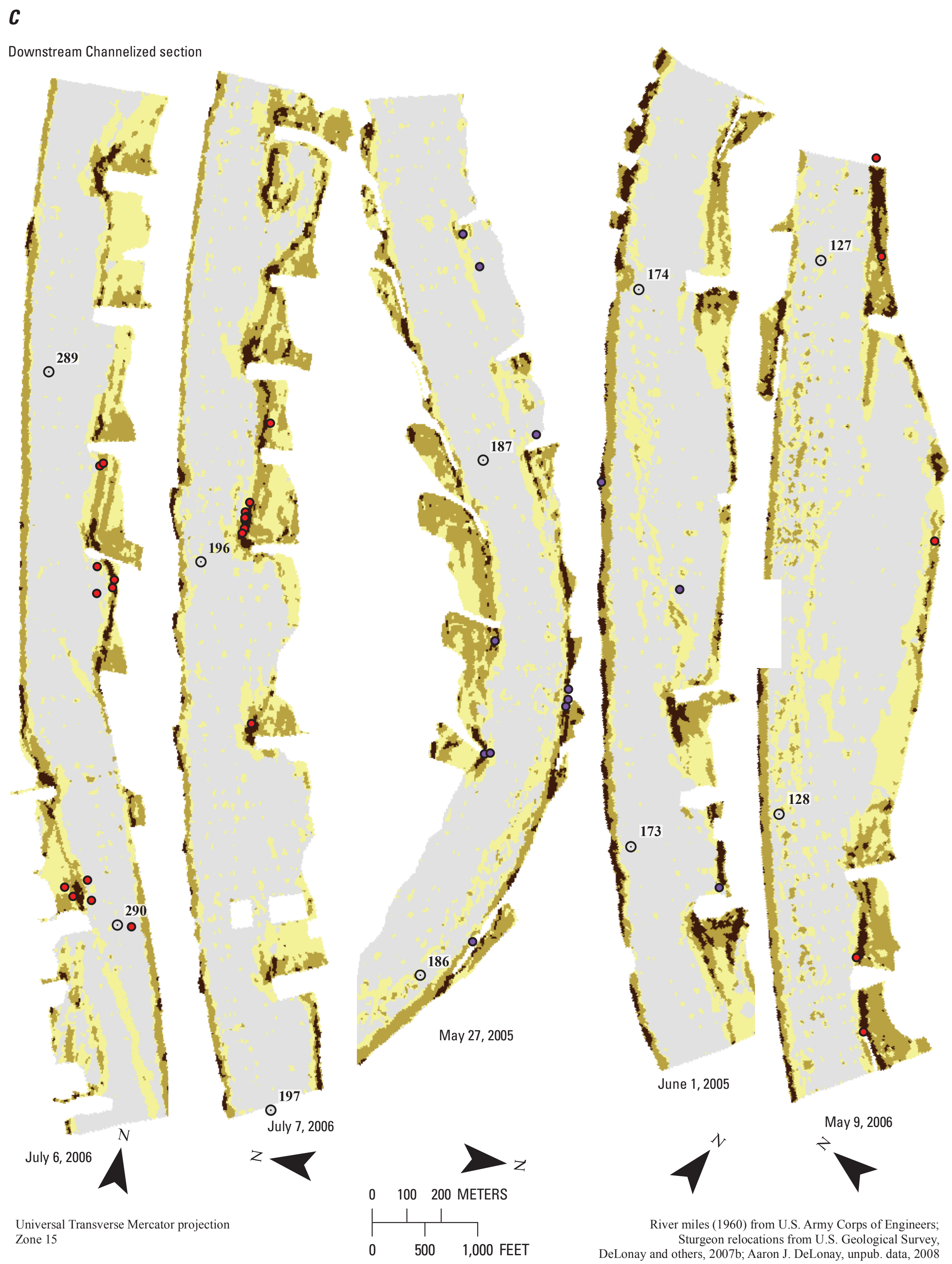


Figure 22. Example maps from each river section showing the distribution of areas with high depth slope, high velocity gradient, and/or low Froude number. Sturgeon relocations from the year of mapping are also shown. Each grid cell represents the number of the following criteria that were met: depth slope greater than the 80th percentile in the reach, velocity gradient greater than the 80th percentile in the reach, and Froude number less than the 20th percentile in the reach.—Continued

Table 9. Comparison of distribution of shovelnose sturgeon relocations to distribution of high depth slope, high velocity gradient, and/or low Froude habitats.

Number of variables meeting specified criteria (high depth slope, high velocity gradient, low Froude number)	Minimally Engineered		Upstream Channelized		Downstream Channelized		Total	
	Percent of shovelnose sturgeon relocations	Percent of mapped area	Percent of shovelnose sturgeon relocations	Percent of mapped area	Percent of shovelnose sturgeon relocations	Percent of mapped area	Percent of shovelnose sturgeon relocations	Percent of mapped area
All three variables	12	2	23	5	15	4	18	4
Two variables	22	7	23	10	20	11	22	10
One variable	22	29	21	15	33	24	23	21
Zero variables	43	62	34	70	32	61	37	64

nel dynamics that may have important ecological functions (Elliott and others, 2009).

This study addresses a specific cross-section of time, geography, discharge conditions, and portion of the sturgeon life cycle with a focus on reproductive female shovelnose sturgeon. Use of certain habitats by sturgeon in the modern river does not necessarily mean that those are the habitats that the sturgeon would have used under pre-alteration channel and flow conditions, nor does selection of those habitats in the modern river necessarily mean that individual sturgeon are or will be successful reproductively or otherwise. More work is needed to identify factors limiting reproduction and survival.

At the outset of this project (2005), the understanding of *Scaphirhynchus* sturgeon movement and habitat use in the Missouri River was rudimentary, and little information existed to develop testable hypotheses regarding how sturgeon interact with and select habitat. The 2005 through 2007 data thus provided basic observations suitable for exploratory data analysis as presented in this report. We offer a series of ideas for future data collection and analysis. The order of this list is not intended to be a prioritization. Overall, the list is roughly ordered so that it begins with ideas that are easier to achieve within the existing research framework and ends with suggestions that require substantially more data and associated investment of resources.

- Develop a set of informed, mathematically based, working hypotheses regarding habitat selection to be tested with an information theoretic approach using new data (Burnham and Anderson, 2002). Hypotheses should be based on results from the exploratory analysis combined with expert opinion.
- Assess migration and energy expenditure:
    - Develop a better understanding of migratory pathways. Document migratory paths in greater detail with high frequency telemetry relocations within a reach while mapping habitat simultaneously. Assess the extent to which migratory paths coincide with hypothesized selection zones.
    - Assess energy expenditure through migratory pathways through reaches with distinct geomorphic characteristics (for example, Standen and others, 2002) and whether this might affect spawning success. Consider availability and use of low-energy expenditure pathways, and how these vary by river section. Physiological assessments of stress or analysis of rates of migration through different river sections may also yield insight to this question.
    - Assess use of natural and constructed side-channel chutes for migration (as observed in 2008, Aaron J. DeLonay, unpub. data, 2008) and the habitat conditions in chutes in comparison to the main channel.
- Document habitat in greater detail, such that available habitat is mapped at the scale of sturgeon (with grid cell resolution of 1 meter or less). For example, develop an understanding of how sturgeon interact with bedforms and the extent to which they move up and down in the water column. Multibeam bathymetric mapping and hydroacoustic imaging technologies could be deployed to address these questions.
- Further assess relations between discharge, channel morphology, and habitat:
    - Consider habitat availability as a function of discharge in a hydrodynamic model context (Jacobson and others, 2009b), specifically considering the occurrence of ranges of variables that sturgeon show a tendency to select. Expand spatial understanding of habitats in terms of patch structure and juxtaposition. Consider a historic context in a semiquantitative way by comparing a hydrodynamic model for modern conditions with one for pre-engineered conditions (for example, Jacobson and Galat, 2006). For example, how does availability of low energy habitat at high flow in a pre-engineered context compare to that in the modern channel?
    - Assess the effect of discharge on habitat selection. Document where sturgeon go at extreme discharges, and attempt to make maps in close time proximity to relocations if discharge conditions are changing rapidly. At high discharge, do sturgeon continue to

migrate? Do they seek refuge? How do they respond to high rates of sediment transport? How do available conditions in the modern channel compare to conditions that would have been available at similar discharges in a natural channel? Is sturgeon habitat limited or are patch dynamics significantly altered at low flow conditions? How does ice alter habitat during low winter discharge?

    - Assess sturgeon use and selection of habitats associated with engineered channel modifications.

- Consider whether shovelnose and pallid sturgeon select habitat in the same way, and whether habitat use and availability explains patterns of distribution and rarity.
- Expand data collection and analysis of habitat use and selection to include full reproductive cycles extending over multiple years. This includes:
    - Continuation of work to document and verify specific spawning habitat patches; this remains a high priority for understanding spawning habitat and spawning success (Bergman and others, 2008).
    - Comparison of habitat use based on behavior and context of movement history (semistationary, migrating upstream, migrating downstream). Does habitat use vary prior to and after spawning?
    - Study of younger life stages. Migrating adults may not be a bottleneck in reproductive success (Wildhaber and others, 2007a), so habitat use by larval and juvenile sturgeon should be considered, too.
    - Consideration of seasonal use of habitat. For example, in a habitat context, where do sturgeon overwinter?
- Expand understanding of habitat function. For example, are foraging habitats different from migratory habitats? When and where do sturgeon feed?
- Expand from a species-centric focus to an ecosystem-level understanding by addressing habitats of species with which sturgeon interact. What habitats are important to prey species of sturgeon? Are pallid sturgeon and shovelnose sturgeon competitors? How does habitat affect invasive species (such as Asian carp, Kolar and others, 2007), and to what extent do invasive species affect sturgeon?

Summary

This exploratory analysis provided information about the longitudinal geomorphology and hydraulics of the Lower Missouri River, the distribution of sturgeon within the range of available habitat, and the distribution of habitat that appears to be selected by sturgeon.

The habitat structure of the river is strongly related to the engineering framework. The Minimally Engineered section, from Gavins Point Dam to Sioux City, Iowa, has the least engineered channel with typical reaches exhibiting shallow depths, high widths, and relatively low mean velocities. In the Upstream Channelized section of the river, from Sioux City to beyond the junction with the Platte River, the channel typically is narrow, deep, and relatively fast. In the Downstream Channelized section of the river, downstream from Kansas City, the channel widens and has more complexity; the navigation channel is deep and fast, but more diversity exists along the channel margins. The longitudinal geomorphic patterns indicate that choices of habitat available to sturgeon are different depending on location in the river.

An assessment of the environmental characteristics at sturgeon relocations compared to each surrounding reach suggests that sturgeon were found in nearly the full range of available habitat. However, sturgeon do show a tendency to select some habitats while avoiding others. The patterns of depth availability and selection by sturgeon vary considerably among river sections. In contrast, patterns of selection for other variables show consistency among river sections. In particular, during the spring and summer months of this study, reproductive female shovelnose sturgeon tended to select areas of high velocity gradient, high depth slope, and/or low Froude number.

Composite maps illustrate the spatial patterns of habitats characterized by high velocity gradient, high depth slope, and/or low Froude number. Sturgeon relocations are disproportionately located in areas with these characteristics. Furthermore, the spatial patterns of these selected habitats show distinct difference among the sections of the Lower Missouri River. Because the patterns described in this report represent habitat use in the context of the available habitat in a highly altered river system, selection may not necessarily indicate preferred habitats or habitats sufficient for reproduction and survival of sturgeon species.

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Table 4

Table 4. Reach map data for sturgeon relocations on reach maps within 7 days and 10 percent discharge.

[m, meter; m/s, meter per second; SWH, shallow-water habitat (depth < 1.5 m, velocity < 0.6 m/s); ft^3/s, cubic foot per second; --, no data]

Sturgeon identification code	River mile of sturgeon relocation	Relocation date	Map identification	Depth (m)	Depth slope (degrees)	Velocity (m/s)	Velocity gradient (percent per meter)	Froude number	Substrate	SWH	Terrain class	Estimated discharge on relocation date (ft^3/s)	Estimated discharge on map date (ft^3/s)
PLS05-006	808.3	July 18, 2006	20060711_f	3.3	1.2	0.87	0.96	0.15	--	No	Flat	25,500	25,500
PLS05-006	808.2	July 10, 2006	20060711_f	4.2	0.8	1.12	0.63	0.17	--	No	Flat	25,500	25,500
SNS07-093	807.0	May 15, 2007	20070516_f	3.5	2.8	0.45	0.85	0.08	--	No	Depression	8,000	8,000
SNS07-093	806.6	May 23, 2007	20070524_f	3.7	4.4	0.44	1.41	0.07	--	No	Depression	11,300	11,000
SNS07-093	806.5	May 21, 2007	20070524_f	3.3	2.8	0.51	0.25	0.09	--	No	Depression	11,000	11,000
SNS07-093	806.4	May 17, 2007	20070516_f	4.4	0.5	0.41	0.20	0.06	--	No	Depression	8,000	8,000
SNS07-093	806.3	May 27, 2007	20070524_f	4.8	0.4	0.54	0.19	0.08	--	No	Depression	12,000	11,000
SNS07-081	801.9	May 9, 2007	20070510_f	2.4	1.3	0.38	0.12	0.08	--	No	Depression	8,000	8,000
SNS07-088	797.4	May 25, 2007	20070601_f	1.5	0.4	0.60	0.25	0.15	--	No	Flat	21,500	19,600
SNS07-169	797.1	May 25, 2007	20070601_f	1.5	0.6	0.67	0.14	0.18	--	No	Flat	21,500	19,600
SNS07-085	797.0	May 31, 2007	20070601_f	1.4	1.1	0.63	0.73	0.17	--	No	Flat	20,800	19,600
SNS07-122	782.5	May 17, 2007	20070518_f	2.6	1.0	0.71	1.45	0.14	--	No	Flat	20,100	18,900
SNS07-162	782.4	May 23, 2007	20070518_f	1.7	1.6	0.40	0.68	0.10	--	No	Flat	18,500	18,900
SNS07-164	775.3	May 27, 2007	20070530_f	1.3	1.2	0.61	0.95	0.17	--	Yes	Crest	17,700	17,000
SNS07-115	775.2	June 2, 2007	20070530_f	5.8	1.8	1.45	1.26	0.19	--	No	Depression	16,500	17,000
SNS07-164	775.1	May 29, 2007	20070530_f	2.9	1.1	0.90	0.84	0.17	--	No	Flat	17,700	17,000
SNS07-127	775.1	May 29, 2007	20070530_f	2.9	3.9	0.80	1.38	0.15	--	No	Flat	17,700	17,000
SNS07-139	775.1	May 29, 2007	20070530_f	2.4	0.4	0.93	0.43	0.19	--	No	Flat	17,700	17,000
SNS07-080	775.1	May 27, 2007	20070530_f	4.2	2.5	1.08	2.56	0.17	--	No	Depression	17,700	17,000
SNS07-118	774.9	June 2, 2007	20070530_f	5.0	3.8	0.85	0.61	0.12	--	No	Depression	16,500	17,000
SNS05-066	759.7	June 14, 2005	20050615_f	1.0	0.5	0.40	1.08	0.13	--	Yes	Crest	27,300	27,500
PLS07-004	759.5	May 20, 2007	20070521_f	3.8	1.4	0.95	0.88	0.16	--	No	Depression	23,400	23,700
PLS07-004	759.5	May 20, 2007	20070521_f	3.4	2.3	0.78	0.83	0.14	--	No	Flat	23,400	23,700
SNS07-076	753.3	May 24, 2007	20070523_f	1.1	0.6	0.41	0.32	0.13	--	Yes	Flat	23,500	25,300
SNS07-159	753.1	May 24, 2007	20070523_f	3.2	0.6	1.17	0.21	0.21	--	No	Depression	23,500	25,300
SNS07-141	753.0	May 20, 2007	20070523_f	3.2	2.8	1.04	1.90	0.18	--	No	Depression	23,400	25,300
SNS07-104	752.9	May 24, 2007	20070523_f	3.2	0.6	1.03	0.07	0.18	--	No	Depression	23,500	25,300
SNS07-104	752.8	May 20, 2007	20070523_f	3.0	1.5	1.00	0.35	0.18	--	No	Depression	23,400	25,300
SNS07-147	752.5	May 24, 2007	20070523_f	1.6	0.3	0.53	0.16	0.14	--	No	Crest	23,500	25,300
SNS07-135	752.3	May 20, 2007	20070523_f	1.5	1.0	0.64	0.52	0.17	--	No	Crest	23,400	25,300
SNS06-060	752.1	June 16, 2006	20060622_f	3.1	0.7	0.53	0.42	0.10	Sand (dunes)	No	Depression	27,400	26,800
SNS07-135	752.1	May 16, 2007	20070523_f	3.8	1.4	0.78	0.23	0.13	--	No	Depression	26,600	25,300
SNS06-060	752.0	May 16, 2007	20070523_f	3.5	1.4	0.93	0.44	0.16	--	No	Depression	26,600	25,300
SNS06-085	749.5	June 16, 2006	20060620_f	2.3	5.3	0.32	0.69	0.07	--	No	Crest	27,400	26,400
SNS06-085	749.4	June 26, 2006	20060620_f	7.3	21.1	0.60	2.63	0.08	--	No	Depression	26,300	26,400
SNS06-085	749.4	June 14, 2006	20060620_f	2.9	3.4	0.57	0.64	0.11	--	No	Flat	26,400	26,400
SNS06-083	749.4	June 14, 2006	20060620_f	1.5	3.5	0.26	1.91	0.07	--	Yes	Crest	26,400	26,400

Table 4. Reach map data for sturgeon relocations on reach maps within 7 days and 10 percent discharge.—Continued

[m, meter; m/s, meter per second; SWH, shallow-water habitat (depth < 1.5 m, velocity < 0.6 m/s); ft³/s, cubic foot per second; --, no data]

Sturgeon identification code	River mile of sturgeon relocation	Relocation date	Map identification	Depth (m)	Depth slope (degrees)	Velocity (m/s)	Velocity gradient (percent per meter)	Froude number	Substrate	SWH	Terrain class	Estimated discharge on relocation date (ft^3/s)	Estimated discharge on map date (ft^3/s)
SNS06-083	749.4	June 16, 2006	20060620_f	1.6	6.3	--	--	--	--	--	Crest	27,400	26,400
SNS06-085	749.4	June 20, 2006	20060620_f	5.9	9.0	0.80	1.58	0.11	--	No	Depression	26,400	26,400
SNS06-083	749.4	June 20, 2006	20060620_f	5.6	7.0	0.62	1.77	0.09	--	No	Depression	26,400	26,400
SNS05-063	746.3	June 9, 2005	20050610_f	3.7	6.0	0.65	2.84	0.11	Sand (dunes)	No	Slope	34,000	32,400
SNS07-089	745.3	May 19, 2007	20070525_f	1.8	1.3	0.80	0.22	0.19	Sand (dunes)	No	Flat	21,100	19,600
SNS06-083	743.8	July 11, 2006	20060712_f	3.8	15.7	0.71	0.73	0.12	Revetment, gravel, hard sand	No	Slope	26,200	26,200
SNS06-085	743.3	July 13, 2006	20060712_f	5.4	5.0	0.78	1.27	0.11	Sand (dunes)	No	Depression	26,100	26,200
SNS06-085	743.2	July 11, 2006	20060712_f	3.9	9.0	0.90	0.91	0.15	Sand (dunes)	No	Slope	26,200	26,200
SNS07-132	738.7	May 4, 2007	20070502_f	3.2	2.2	0.77	1.45	0.14	Sand (dunes)	No	Depression	12,700	12,100
SNS07-132	738.7	May 1, 2007	20070502_f	3.5	6.3	0.71	2.58	0.13	Revetment, gravel, hard sand	No	Depression	12,400	12,100
SNS07-137	738.4	May 4, 2007	20070502_f	1.5	1.8	0.65	0.71	0.17	Sand (dunes)	No	Flat	12,700	12,100
SNS07-162	738.2	May 1, 2007	20070502_f	2.1	0.8	0.65	0.55	0.14	Sand (dunes)	No	Flat	12,400	12,100
SNS07-162	738.2	May 2, 2007	20070502_f	3.2	1.9	0.45	0.17	0.08	Fine sediment (mud, silt)	No	Depression	12,100	12,100
SNS07-162	738.2	May 4, 2007	20070502_f	1.9	0.5	0.51	0.70	0.12	Fine sediment (mud, silt)	No	Flat	12,700	12,100
SNS07-094	738.1	May 1, 2007	20070502_f	4.1	3.6	0.82	0.59	0.13	Sand (dunes)	No	Depression	12,400	12,100
SNS07-169	738.1	May 1, 2007	20070502_f	4.7	3.0	0.77	1.26	0.12	Sand (dunes)	No	Depression	12,400	12,100
SNS07-169	738.1	May 2, 2007	20070502_f	1.3	0.4	0.74	0.47	0.20	Sand (dunes)	No	Crest	12,100	12,100
SNS07-132	737.3	May 8, 2007	20070509_f	1.5	0.4	0.73	0.25	0.19	Sand (dunes)	No	Crest	13,700	15,000
SNS07-147	737.1	May 8, 2007	20070509_f	2.7	3.0	0.37	0.37	0.07	Fine sediment (mud, silt)	No	Depression	13,700	15,000
SNS06-057	736.5	May 8, 2007	20070509_f	2.3	0.5	0.60	1.14	0.13	Sand (dunes)	No	Flat	13,700	15,000
SNS07-040	736.4	May 8, 2007	20070509_f	3.0	1.7	0.66	0.43	0.12	Sand (dunes)	No	Depression	13,700	15,000
SNS07-079	735.9	May 8, 2007	20070509_f	3.0	4.5	0.61	0.95	0.11	Sand (dunes)	No	Depression	13,700	15,000
SNS07-109	735.0	May 5, 2007	20070503_f	1.6	0.7	0.55	0.13	0.14	Revetment, gravel, hard sand	No	Flat	13,300	12,200
SNS07-126	735.0	June 5, 2007	20070612_f	3.3	2.9	0.86	1.12	0.15	Engineered structures (rock)	No	Flat	24,200	23,400
SNS07-107	735.0	June 9, 2007	20070612_f	3.2	2.1	0.75	0.30	0.13	Sand (dunes)	No	Flat	23,500	23,400
SNS07-089	734.9	May 1, 2007	20070503_f	5.8	17.4	0.48	1.06	0.06	Sand (dunes)	No	Depression	12,400	12,200
SNS07-109	734.9	May 1, 2007	20070503_f	1.6	0.3	0.69	0.20	0.17	Sand (dunes)	No	Flat	12,400	12,200
SNS07-138	734.9	May 1, 2007	20070503_f	2.6	12.5	0.44	0.37	0.09	Sand (dunes)	No	Slope	12,400	12,200
SNS07-089	734.9	May 1, 2007	20070503_f	7.1	15.2	0.52	1.35	0.06	Sand (dunes)	No	Depression	12,400	12,200
SNS07-123	734.9	May 5, 2007	20070503_f	7.5	8.5	0.58	0.72	0.07	Sand (dunes)	No	Depression	13,300	12,200
SNS07-109	734.9	May 2, 2007	20070503_f	5.5	5.6	0.63	0.48	0.09	Transporting sand	No	Depression	12,100	12,200

Table 4. Reach map data for sturgeon relocations on reach maps within 7 days and 10 percent discharge.—Continued

[m, meter; m/s, meter per second; SWH, shallow-water habitat (depth < 1.5 m, velocity < 0.6 m/s); ft³/s, cubic foot per second; --, no data]

Sturgeon identification code	River mile of sturgeon relocation	Relocation date	Map identification	Depth (m)	Depth slope (degrees)	Velocity (m/s)	Velocity gradient (percent per meter)	Froude number	Substrate	SWH	Terrain class	Estimated discharge on relocation date (ft³/s)	Estimated discharge on map date (ft³/s)
SNS07-138	734.9	May 2, 2007	20070503_f	5.4	5.8	0.63	0.46	0.09	Transporting sand	No	Depression	12,100	12,200
SNS07-144	734.9	May 2, 2007	20070503_f	5.5	5.6	0.63	0.48	0.09	Transporting sand	No	Depression	12,100	12,200
SNS07-107	734.9	June 19, 2007	20070612_f	4.9	8.5	0.76	0.92	0.11	Sand (dunes)	No	Depression	23,400	23,400
SNS07-138	734.8	May 5, 2007	20070503_f	3.6	13.0	0.65	1.85	0.11	Sand (dunes)	No	Depression	13,300	12,200
SNS07-141	734.8	May 1, 2007	20070503_f	2.2	3.4	0.54	0.68	0.12	Sand (dunes)	No	Flat	12,400	12,200
SNS07-171	734.8	May 2, 2007	20070503_f	2.8	2.3	0.74	0.49	0.14	Transporting sand	No	Depression	12,100	12,200
SNS07-107	734.8	June 14, 2007	20070612_f	2.1	2.2	0.29	1.85	0.07	Sand (dunes)	No	Crest	23,800	23,400
SNS07-107	734.8	June 13, 2007	20070612_f	1.1	2.9	0.33	0.66	0.10	Revetment, gravel, hard sand	Yes	Crest	23,800	23,400
SNS07-107	734.8	June 11, 2007	20070612_f	2.8	1.2	0.90	0.31	0.17	Sand (dunes)	No	Flat	23,200	23,400
SNS07-073	734.7	May 1, 2007	20070503_f	5.8	2.9	1.01	0.89	0.13	Sand (dunes)	No	Depression	12,400	12,200
SNS07-073	734.7	May 2, 2007	20070503_f	4.3	0.8	0.91	0.60	0.14	Sand (dunes)	No	Depression	12,100	12,200
SNS07-154	734.6	May 5, 2007	20070503_f	4.6	7.4	0.65	0.52	0.10	Revetment, gravel, hard sand	No	Depression	13,300	12,200
SNS07-123	734.6	May 1, 2007	20070503_f	4.4	7.9	0.65	0.51	0.10	Revetment, gravel, hard sand	No	Depression	12,400	12,200
SNS07-073	734.5	May 5, 2007	20070503_f	5.3	5.1	0.63	0.73	0.09	Revetment, gravel, hard sand	No	Depression	13,300	12,200
SNS07-154	734.5	May 1, 2007	20070503_f	5.9	4.9	0.61	0.93	0.08	Sand (dunes)	No	Depression	12,400	12,200
SNS07-165	734.5	May 1, 2007	20070503_f	5.0	2.5	0.65	0.43	0.09	Sand (dunes)	No	Depression	12,400	12,200
SNS07-118	734.5	June 14, 2007	20070612_f	3.3	4.2	0.88	1.68	0.15	Engineered structures (rock)	No	Flat	23,800	23,400
SNS07-165	734.3	May 2, 2007	20070503_f	1.6	1.0	0.59	0.19	0.15	Sand (dunes)	No	Crest	12,100	12,200
SNS07-154	734.3	May 2, 2007	20070503_f	2.8	0.8	0.82	0.53	0.16	Sand (dunes)	No	Depression	12,100	12,200
SNS07-084	734.2	May 1, 2007	20070503_f	1.9	0.8	0.75	0.03	0.17	Sand (dunes)	No	Flat	12,400	12,200
SNS07-145	734.2	May 5, 2007	20070503_f	1.6	0.5	0.72	0.38	0.18	Sand (dunes)	No	Crest	13,300	12,200
SNS07-098	734.2	May 1, 2007	20070503_f	4.3	6.3	0.68	0.29	0.10	Sand (dunes)	No	Depression	12,400	12,200
SNS07-072	734.2	May 1, 2007	20070503_f	5.1	2.8	0.57	0.48	0.08	Sand (dunes)	No	Depression	12,400	12,200
SNS07-166	734.0	May 5, 2007	20070503_f	2.0	0.2	0.84	0.30	0.19	--	No	Flat	4,570	4,720
SNS07-116	734.0	May 5, 2007	20070503_f	3.3	1.9	0.59	0.99	0.10	Sand (dunes)	No	Depression	4,570	4,720
SNS07-164	734.0	May 5, 2007	20070503_f	4.3	1.9	0.95	0.57	0.15	Sand (dunes)	No	Depression	4,570	4,720
SNS07-129	734.0	May 5, 2007	20070503_f	3.5	1.8	0.90	1.44	0.15	Sand (dunes)	No	Depression	4,570	4,720
SNS07-164	734.0	May 5, 2007	20070503_f	3.4	2.3	0.99	0.63	0.17	--	No	Depression	4,570	4,720
SNS07-127	734.0	May 2, 2007	20070503_f	3.7	1.8	0.99	0.77	0.16	Sand (dunes)	No	Depression	5,050	4,720
SNS07-157	734.0	May 2, 2007	20070503_f	3.7	1.7	0.99	0.72	0.16	Sand (dunes)	No	Depression	5,050	4,720
SNS07-129	734.0	May 5, 2007	20070503_f	3.0	3.2	0.89	0.72	0.17	Sand (dunes)	No	Flat	13,300	12,200
SNS07-098	734.0	May 2, 2007	20070503_f	4.2	0.5	0.85	0.39	0.13	Sand (dunes)	No	Depression	12,100	12,200
SNS07-139	734.0	May 2, 2007	20070503_f	4.2	0.5	0.85	0.38	0.13	Sand (dunes)	No	Depression	12,100	12,200

Table 4. Reach map data for sturgeon relocations on reach maps within 7 days and 10 percent discharge.—Continued

[m, meter; m/s, meter per second; SWH, shallow-water habitat (depth < 1.5 m, velocity < 0.6 m/s); ft^3/s, cubic foot per second; --, no data]

Sturgeon identification code	River mile of sturgeon relocation	Relocation date	Map identification	Depth (m)	Depth slope (degrees)	Velocity (m/s)	Velocity gradient (percent per meter)	Froude number	Substrate	SWH	Terrain class	Estimated discharge on relocation date (ft^3/s)	Estimated discharge on map date (ft^3/s)
SNS07-150	734.0	May 2, 2007	20070503_f	4.2	0.5	0.85	0.39	0.13	Sand (dunes)	No	Depression	12,100	12,200
SNS07-092	733.8	May 5, 2007	20070503_f	8.4	10.7	0.58	0.58	0.06	Revetment, gravel, hard sand	No	Depression	17,900	16,900
SNS07-166	733.8	May 5, 2007	20070503_f	9.4	9.1	0.52	1.25	0.05	Sand (dunes)	No	Depression	17,900	16,900
SNS07-150	733.8	May 5, 2007	20070503_f	9.3	9.4	0.52	1.14	0.05	Sand (dunes)	No	Depression	17,900	16,900
SNS07-094	733.8	May 2, 2007	20070503_f	7.9	13.2	0.54	0.90	0.06	Revetment, gravel, hard sand	No	Depression	17,100	16,900
SNS07-092	733.8	May 2, 2007	20070503_f	7.9	13.8	0.54	0.97	0.06	Revetment, gravel, hard sand	No	Depression	17,100	16,900
SNS07-084	733.8	May 2, 2007	20070503_f	7.9	13.2	0.54	0.90	0.06	Revetment, gravel, hard sand	No	Depression	17,100	16,900
SNS07-166	733.8	May 2, 2007	20070503_f	7.9	13.2	0.54	0.90	0.06	Revetment, gravel, hard sand	No	Depression	17,100	16,900
SNS07-170	733.8	June 11, 2007	20070612_f	3.5	0.9	0.68	0.83	0.12	Sand (dunes)	No	Flat	25,700	25,700
SNS07-170	733.8	June 14, 2007	20070612_f	9.5	8.2	0.70	1.63	0.07	Sand (dunes)	No	Depression	25,900	25,700
SNS07-154	733.8	June 11, 2007	20070612_f	3.5	7.4	0.80	2.65	0.13	Sand (dunes)	No	Slope	25,700	25,700
SNS07-170	733.8	June 19, 2007	20070612_f	3.9	1.9	0.81	0.40	0.13	Transporting sand	No	Flat	25,700	25,700
SNS07-153	733.7	May 1, 2007	20070503_f	3.1	0.2	0.79	0.22	0.14	Sand (dunes)	No	Flat	17,800	16,900
SNS07-149	733.7	May 2, 2007	20070503_f	3.1	0.4	0.75	0.18	0.14	Sand (dunes)	No	Flat	17,100	16,900
SNS07-143	733.7	May 2, 2007	20070503_f	3.1	0.4	0.75	0.18	0.14	Sand (dunes)	No	Flat	17,100	16,900
SNS07-075	733.6	May 5, 2007	20070503_f	4.6	4.7	0.79	0.54	0.12	Sand (dunes)	No	Depression	17,900	16,900
SNS07-075	733.6	May 1, 2007	20070503_f	2.5	2.0	0.78	0.27	0.16	Sand (dunes)	No	Crest	17,800	16,900
SNS07-124	733.6	May 1, 2007	20070503_f	2.6	0.4	0.85	0.15	0.17	Sand (dunes)	No	Flat	17,800	16,900
SNS07-100	733.6	May 2, 2007	20070503_f	2.6	0.6	0.87	0.33	0.17	Sand (dunes)	No	Flat	17,100	16,900
SNS07-072	733.6	May 2, 2007	20070503_f	2.2	2.4	0.56	1.54	0.12	Revetment, gravel, hard sand	No	Crest	17,100	16,900
SNS07-153	733.6	May 2, 2007	20070503_f	2.6	0.2	0.83	0.15	0.16	Sand (dunes)	No	Flat	17,100	16,900
SNS07-075	733.6	May 2, 2007	20070503_f	2.6	0.2	0.83	0.14	0.17	Sand (dunes)	No	Flat	17,100	16,900
SNS07-170	733.6	June 9, 2007	20070612_f	1.9	6.9				Sand (dunes)	--	Crest	26,200	25,700
SNS07-170	733.6	June 8, 2007	20070612_f	4.6	2.4	0.94	0.85	0.14	Sand (dunes)	No	Depression	26,700	25,700
SNS07-149	733.5	May 5, 2007	20070503_f	1.6	0.7	0.67	0.30	0.17	Sand (dunes)	No	Crest	17,900	16,900
SNS07-150	733.5	June 6, 2007	20070612_f	3.1	1.2	0.74	1.15	0.13	Sand (dunes)	No	Crest	27,000	25,700
SNS07-100	733.4	May 5, 2007	20070503_f	1.8	0.4	0.74	0.66	0.18	Engineered structures (rock)	No	Crest	17,900	16,900
SNS07-143	733.4	May 1, 2007	20070503_f	2.5	2.3	0.77	0.39	0.16	Sand (dunes)	No	Flat	17,800	16,900
SNS07-170	733.4	June 7, 2007	20070612_f	4.8	1.8	1.10	0.16	0.16	Sand (dunes)	No	Depression	26,800	25,700
SNS07-144	733.4	June 9, 2007	20070612_f	4.5	6.5	0.78	1.71	0.12	Engineered structures (rock)	No	Depression	26,200	25,700

Table 4. Reach map data for sturgeon relocations on reach maps within 7 days and 10 percent discharge.—Continued

[m, meter; m/s, meter per second; SWH, shallow-water habitat (depth < 1.5 m, velocity < 0.6 m/s); ft^3/s, cubic foot per second; --, no data]

Sturgeon identification code	River mile of sturgeon relocation	Relocation date	Map identification	Depth (m)	Depth slope (degrees)	Velocity (m/s)	Velocity gradient (percent per meter)	Froude number	Substrate	SWH	Terrain class	Estimated discharge on relocation date (ft^3/s)	Estimated discharge on map date (ft^3/s)
SNS07-133	733.3	May 1, 2007	20070503_f	3.1	2.7	0.64	1.15	0.12	Sand (dunes)	No	Flat	17,800	16,900
SNS07-124	733.3	May 5, 2007	20070503_f	3.4	1.8	0.59	1.14	0.10	Sand (dunes)	No	Depression	17,900	16,900
SNS05-084	732.4	June 15, 2005	20050616_f	4.9	2.9				--	--	Depression	32,400	32,900
SNS07-079	730.2	June 22, 2007	20070615_f	4.8	13.8	0.85	3.54	0.13	Engineered structures (rock)	No	Depression	26,500	26,900
SNS07-157	730.2	June 22, 2007	20070615_f	3.7	4.1	0.75	1.99	0.12	Sand (dunes)	No	Flat	26,500	26,900
SNS07-079	730.2	June 9, 2007	20070615_f	3.6	11.7	0.69	2.68	0.12	Engineered structures (rock)	No	Slope	27,300	26,900
SNS07-079	730.2	June 14, 2007	20070615_f	5.0	11.1	0.83	4.48	0.13	Engineered structures (rock)	No	Depression	27,500	26,900
SNS07-079	730.1	June 20, 2007	20070615_f	5.8	10.1	1.04	3.95	0.14	Engineered structures (rock)	No	Depression	26,800	26,900
SNS07-079	730.1	June 11, 2007	20070615_f	5.9	3.6	1.14	2.88	0.15	Sand (dunes)	No	Depression	26,800	26,900
SNS07-157	729.8	June 20, 2007	20070615_f	4.1	3.4	0.94	1.99	0.15	Engineered structures (rock)	No	Flat	26,800	26,900
SNS07-100	729.3	June 14, 2007	20070615_f	3.6	7.7	0.96	2.46	0.17	Revetment, gravel, hard sand	No	Crest	27,500	26,900
SNS07-157	729.2	June 14, 2007	20070615_f	5.0	7.4	0.90	3.40	0.13	Sand (dunes)	No	Depression	27,500	26,900
SNS07-157	729.0	June 11, 2007	20070615_f	2.8	6.6	0.71	1.98	0.14	Engineered structures (rock)	No	Slope	26,800	26,900
SNS07-100	729.0	June 11, 2007	20070615_f	3.3	1.9	0.69	1.35	0.12	--	No	Flat	26,800	26,900
SNS07-124	728.9	June 20, 2007	20070615_f	4.9	5.1	0.92	1.24	0.13	Sand (dunes)	No	Depression	26,800	26,900
SNS07-157	728.8	June 9, 2007	20070615_f	3.1	0.8	0.68	1.55	0.12	Engineered structures (rock)	No	Flat	27,300	26,900
SNS07-133	728.8	June 9, 2007	20070615_f	3.2	0.3	1.18	0.14	0.21	Sand (dunes)	No	Flat	27,300	26,900
SNS07-106	728.6	June 14, 2007	20070615_f	1.6	1.9	0.81	3.05	0.20	Sand (dunes)	No	Crest	27,500	26,900
SNS07-124	728.6	June 14, 2007	20070615_f	4.0	6.7	0.69	2.87	0.11	Sand (dunes)	No	Depression	27,500	26,900
SNS07-106	728.6	June 20, 2007	20070615_f	1.1	3.0	0.47	1.95	0.14	Sand (dunes)	Yes	Crest	26,800	26,900
SNS07-106	728.6	June 22, 2007	20070615_f	1.2	2.0	0.49	1.67	0.14	Sand (dunes)	Yes	Crest	26,500	26,900
SNS07-155	727.1	May 1, 2007	20070504_f	2.5	3.6	0.72	1.18	0.14	Revetment, gravel, hard sand	No	Flat	19,600	19,200
PLS07-008	726.6	May 3, 2007	20070504_f	3.4	1.1	1.15	0.47	0.20	Sand (dunes)	No	Flat	18,600	19,200
PLS07-008	726.6	May 4, 2007	20070504_f	3.4	1.1	1.15	0.49	0.20	Sand (dunes)	No	Flat	19,200	19,200
PLS07-008	726.6	May 4, 2007	20070504_f	3.4	1.1	1.15	0.48	0.20	Sand (dunes)	No	Flat	19,200	19,200
PLS07-008	726.6	May 4, 2007	20070504_f	3.4	1.1	1.15	0.48	0.20	Sand (dunes)	No	Flat	19,200	19,200
PLS07-008	726.6	May 3, 2007	20070504_f	3.0	7.8	0.73	2.54	0.13	Engineered structures (rock)	No	Slope	18,600	19,200
PLS07-008	726.6	May 3, 2007	20070504_f	3.4	1.1	1.15	0.49	0.20	Sand (dunes)	No	Flat	18,600	19,200

Table 4. Reach map data for sturgeon relocations on reach maps within 7 days and 10 percent discharge.—Continued

[m, meter; m/s, meter per second; SWH, shallow-water habitat (depth < 1.5 m, velocity < 0.6 m/s); ft³/s, cubic foot per second; --, no data]

Sturgeon identification code	River mile of sturgeon relocation	Relocation date	Map identification	Depth (m)	Depth slope (degrees)	Velocity (m/s)	Velocity gradient (percent per meter)	Froude number	Substrate	SWH	Terrain class	Estimated discharge on relocation date (ft^3/s)	Estimated discharge on map date (ft^3/s)
PLS07-008	726.6	May 3, 2007	20070504_f	3.4	1.1	1.15	0.46	0.20	Sand (dunes)	No	Flat	18,600	19,200
SNS07-155	726.6	May 3, 2007	20070504_f	7.0	15.8	0.39	2.74	0.05	Engineered structures (rock)	No	Depression	18,600	19,200
PLS07-008	726.5	May 4, 2007	20070504_f	2.6	0.3	1.08	0.51	0.21	Sand (dunes)	No	Crest	19,200	19,200
PLS07-008	726.5	May 4, 2007	20070504_f	2.6	0.4	1.07	0.78	0.21	Sand (dunes)	No	Crest	19,200	19,200
PLS07-008	726.5	May 5, 2007	20070504_f	2.9	0.4	1.07	0.18	0.20	Sand (dunes)	No	Flat	19,400	19,200
SNS07-098	726.3	May 3, 2007	20070504_f	2.4	2.0	0.91	0.64	0.19	Sand (dunes)	No	Crest	18,600	19,200
SNS07-155	726.2	May 5, 2007	20070504_f	2.7	2.7	0.95	0.87	0.19	Sand (dunes)	No	Flat	19,400	19,200
SNS06-058	724.8	May 22, 2006	20060523_f	4.6	8.3	0.62	3.10	0.09	Transporting sand	No	Depression	25,400	25,200
SNS07-040	724.8	May 29, 2007	20070602_f	4.1	1.3	0.99	0.41	0.16	Sand (dunes)	No	Flat	24,300	26,500
PLS07-003	724.8	May 29, 2007	20070602_f	4.1	6.1	1.18	2.21	0.19	Engineered structures (rock)	No	Slope	24,300	26,500
SNS07-040	724.8	May 31, 2007	20070602_f	4.3	1.0	0.90	0.55	0.14	Sand (dunes)	No	Flat	24,200	26,500
SNS07-040	724.7	June 7, 2007	20070602_f	9.7	5.5	0.89	2.60	0.09	Sand (dunes)	No	Depression	27,600	26,500
SNS07-059	724.5	June 9, 2007	20070602_f	3.1	9.5	1.02	1.12	0.18	Engineered structures (rock)	No	Crest	27,300	26,500
SNS07-059	724.5	June 6, 2007	20070602_f	4.4	4.9	1.05	1.07	0.16	Engineered structures (rock)	No	Flat	27,800	26,500
SNS07-059	724.5	May 31, 2007	20070602_f	3.6	8.1	1.03	1.13	0.17	Engineered structures (rock)	No	Slope	24,200	26,500
SNS07-059	724.5	June 8, 2007	20070602_f	3.1	9.5	1.03	0.98	0.19	Engineered structures (rock)	No	Crest	27,600	26,500
SNS07-059	724.5	May 29, 2007	20070602_f	5.1	6.2	1.05	1.72	0.15	Sand (dunes)	No	Depression	24,300	26,500
SNS07-059	724.4	June 7, 2007	20070602_f	3.1	8.9	0.92	1.35	0.16	Engineered structures (rock)	No	Crest	27,600	26,500
SNS07-040	724.4	June 8, 2007	20070602_f	2.1	0.6	0.77	0.97	0.17	Sand (dunes)	No	Crest	27,600	26,500
PLS07-004	718.2	June 9, 2007	20070609_f	2.4	4.0	0.74	1.13	0.15	Sand (dunes)	No	Crest	27,300	27,300
SNS07-072	717.8	June 8, 2007	20070609_f	4.0	1.2	1.07	0.41	0.17	Transporting sand	No	Flat	27,600	27,300
SNS07-171	717.8	June 9, 2007	20070609_f	2.7	10.2	0.97	0.70	0.18	Revetment, gravel, hard sand	No	Crest	27,300	27,300
SNS07-171	717.8	June 6, 2007	20070609_f	4.3	10.3	0.89	2.70	0.14	Sand (dunes)	No	Depression	27,800	27,300
SNS07-171	717.8	June 7, 2007	20070609_f	3.9	11.9	0.87	3.07	0.14	Revetment, gravel, hard sand	No	Slope	27,600	27,300
SNS07-171	717.7	June 8, 2007	20070609_f	4.1	1.2	1.04	0.77	0.17	Sand (dunes)	No	Flat	27,600	27,300
SNS06-051	709.8	May 31, 2006	20060607_f	3.4	1.6	0.82	1.42	0.14	Sand (dunes)	No	Flat	26,400	26,800
SNS06-058	708.6	May 31, 2006	20060607_f	4.6	10.1	0.67	2.00	0.10	Sand (dunes)	No	Slope	26,400	26,800
SNS07-111	708.2	June 12, 2007	20070613_f	4.0	1.4	1.08	0.50	0.17	Sand (dunes)	No	Flat	26,700	26,900
SNS07-111	708.2	June 7, 2007	20070613_f	3.5	0.4	1.09	0.23	0.19	Transporting sand	No	Flat	27,600	26,900

Table 4. Reach map data for sturgeon relocations on reach maps within 7 days and 10 percent discharge.—Continued

[m, meter; m/s, meter per second; SWH, shallow-water habitat (depth < 1.5 m, velocity < 0.6 m/s); ft³/s, cubic foot per second; --, no data]

Sturgeon identification code	River mile of sturgeon relocation	Relocation date	Map identification	Depth (m)	Depth slope (degrees)	Velocity (m/s)	Velocity gradient (percent per meter)	Froude number	Substrate	SWH	Terrain class	Estimated discharge on relocation date (ft³/s)	Estimated discharge on map date (ft³/s)
SNS07-111	708.1	June 10, 2007	20070613_f	3.6	1.0	1.05	0.13	0.18	Sand (dunes)	No	Flat	27,000	26,900
SNS07-175	707.4	June 8, 2007	20070613_f	4.5	11.6	0.96	1.21	0.15	Sand (dunes)	No	Depression	27,600	26,900
SNS07-175	707.4	June 6, 2007	20070613_f	4.4	9.3	0.95	1.16	0.15	Sand (dunes)	No	Depression	27,800	26,900
SNS07-175	707.4	June 7, 2007	20070613_f	6.0	8.6	1.08	1.45	0.14	Sand (dunes)	No	Depression	27,600	26,900
SNS07-175	707.3	June 10, 2007	20070613_f	5.7	2.0	1.27	0.41	0.17	Sand (dunes)	No	Depression	27,000	26,900
SNS07-175	707.2	June 12, 2007	20070613_f	2.8	1.5	0.94	0.09	0.18	Sand (dunes)	No	Crest	26,700	26,900
SNS07-057	706.2	May 14, 2007	20070515_f	6.6	4.8	1.27	1.79	0.16	--	No	Depression	33,900	35,200
SNS07-019	706.1	May 16, 2007	20070515_f	2.8	6.3	0.71	2.99	0.13	--	No	Crest	33,400	35,200
SNS07-055	705.6	May 16, 2007	20070515_f	4.5	3.3	0.87	0.47	0.13	--	No	Flat	33,400	35,200
SNS07-055	705.6	May 14, 2007	20070515_f	2.8	3.7	0.73	1.79	0.14	--	No	Crest	33,900	35,200
SNS07-010	702.3	June 8, 2007	20070607_f	5.7	4.1	1.16	0.76	0.15	Sand (dunes)	No	Depression	27,600	27,600
SNS07-010	702.3	June 6, 2007	20070607_f	5.7	5.1	1.23	0.43	0.16	Sand (dunes)	No	Depression	27,800	27,600
SNS07-010	702.3	June 7, 2007	20070607_f	2.5	11.6	0.99	1.36		--	--	Crest	27,600	27,600
SNS07-055	702.1	June 6, 2007	20070607_f	4.5	3.7	0.73	1.28	0.11	Sand (dunes)	No	Depression	27,800	27,600
SNS05-084	697.7	June 2, 2005	20050603_f	1.6	9.4	0.46	2.59	0.13	Fine sediment (mud, silt)	No	Crest	29,300	28,700
SNS05-071	693.4	June 8, 2005	20050609_f	7.2	2.4	0.86	1.58	0.10	Sand (dunes)	No	Depression	41,900	42,900
SNS05-071	693.0	June 16, 2005	20050617_f	2.4	4.7	0.47	2.68	0.10	Sand (dunes)	No	Crest	34,100	34,200
PLS07-004	692.1	May 12, 2007	20070519_f	2.6	8.4	0.76	2.06	0.16	Sand (dunes)	No	Crest	26,000	26,800
SNS07-021	692.0	May 18, 2007	20070519_f	4.8	8.2	0.95	1.13	0.14	Sand (dunes)	No	Depression	28,500	26,800
SNS07-046	691.4	May 24, 2007	20070519_f	3.5	11.5	0.62	3.52	0.12	Transporting sand	No	Slope	29,700	26,800
SNS07-021	689.9	May 16, 2007	20070517_f	3.8	6.1	0.64	2.89	0.10	--	No	Slope	33,400	30,900
SNS07-046	689.1	May 16, 2007	20070517_f	4.5	4.0	0.66	0.38	0.10	--	No	Flat	33,400	30,900
SNS07-046	689.1	May 14, 2007	20070517_f	2.8	2.1	0.83	0.97	0.16	--	No	Crest	33,900	30,900
SNS07-035	689.1	May 14, 2007	20070517_f	2.7	1.8	0.86	0.48	0.17	--	No	Crest	33,900	30,900
SNS07-035	689.1	May 16, 2007	20070517_f	4.2	4.5	0.65	1.12	0.10	--	No	Slope	33,400	30,900
SNS07-035	689.0	May 21, 2007	20070517_f	6.2	0.4	0.69	0.73	0.09	--	No	Depression	28,600	30,900
SNS07-046	689.0	May 21, 2007	20070517_f	5.7	2.6	0.84	0.46	0.11	--	No	Depression	28,600	30,900
SNS05-064	686.4	May 17, 2005	20050518_f	0.0	0.0	0.61	0.74		--	--	--	24,100	23,900
SNS05-062	686.4	May 17, 2005	20050518_f	5.0	6.3	0.69	3.79	0.10	Sand (dunes)	No	Depression	24,100	23,900
SNS05-057	683.9	June 17, 2005	20050624_f	2.6	6.9	0.93	2.31	0.19	Engineered structures (rock)	No	Crest	34,200	31,900
SNS05-057	683.9	June 23, 2005	20050624_f	3.7	0.7	1.19	1.20	0.20	Sand (dunes)	No	Flat	32,500	31,900
SNS05-063	683.4	June 23, 2005	20050624_f	2.4	1.5	0.88	1.01	0.18	Sand (dunes)	No	Crest	32,500	31,900
SNS05-064	674.2	May 9, 2005	20050510_f	1.8	2.7	0.56	1.90	0.13	Sand (dunes)	No	Crest	25,700	26,400
SNS05-062	673.3	May 9, 2005	20050510_f	2.9	10.2	0.59	2.14	0.11	Fine sediment (mud, silt)	No	Crest	25,700	26,400

Table 4. Reach map data for sturgeon relocations on reach maps within 7 days and 10 percent discharge.—Continued

[m, meter; m/s, meter per second; SWH, shallow-water habitat (depth < 1.5 m, velocity < 0.6 m/s); ft³/s, cubic foot per second; --, no data]

Sturgeon identification code	River mile of sturgeon relocation	Relocation date	Map identification	Depth (m)	Depth slope (degrees)	Velocity (m/s)	Velocity gradient (percent per meter)	Froude number	Substrate	SWH	Terrain class	Estimated discharge on relocation date (ft³/s)	Estimated discharge on map date (ft³/s)
SNS05-058	672.5	June 1, 2005	20050602_f	2.0	0.7	0.63	1.41	0.14	Sand (dunes)	No	Crest	28,800	29,300
SNS05-074	672.3	May 26, 2005	20050602_f	7.2	1.5	1.44	0.48	0.17	Sand (dunes)	No	Depression	28,100	29,300
SNS05-052	671.8	June 1, 2005	20050602_f	5.3	1.0	1.05	0.48	0.14	Sand (dunes)	No	Depression	28,800	29,300
SNS05-052	671.7	May 26, 2005	20050602_f	4.3	12.2	0.91	1.21	0.15	Sand (dunes)	No	Depression	28,100	29,300
SNS06-067	670.1	June 8, 2006	20060601_f	4.8	2.0	1.04	0.59	0.15	Sand (dunes)	No	Depression	28,100	26,400
SNS06-067	669.4	May 31, 2006	20060601_f	2.9	0.5	1.07	0.88	0.20	Sand (dunes)	No	Crest	26,600	26,600
SNS06-072	669.1	May 31, 2006	20060601_f	5.5	10.3	0.71	2.81	0.10	Sand (dunes)	No	Depression	28,900	28,800
SNS06-084	666.5	June 8, 2006	20060606_f	5.3	9.8	0.58	1.50	0.08	Engineered structures (rock)	No	Depression	29,900	28,700
SNS06-072	666.0	June 8, 2006	20060606_f	4.4	0.8	0.90	1.75	0.14	Sand (dunes)	No	Flat	29,900	28,700
SNS06-072	666.0	June 8, 2006	20060606_f	4.1	3.4	0.78	1.43	0.12	Sand (dunes)	No	Flat	29,900	28,700
SNS06-089	665.9	June 8, 2006	20060606_f	5.8	8.5	0.92	2.03	0.12	Sand (dunes)	No	Depression	29,900	28,700
SNS06-089	665.8	May 31, 2006	20060606_f	1.4	5.8	0.34	1.78	0.09	Fine sediment (mud, silt)	Yes	Crest	28,900	28,700
SNS05-074	662.8	June 7, 2005	20050608_f	4.2	2.1	1.12	1.51	0.18	Sand (dunes)	No	Crest	40,900	44,700
SNS07-033	660.7	May 11, 2007	20070512_f	3.7	12.0	0.75	2.42	0.13	--	No	Crest	36,300	36,500
SNS05-071	657.9	May 18, 2005	20050519_f	3.4	2.0				--	--	Crest	31,400	30,900
SNS05-097	657.3	May 18, 2005	20050519_f	1.7	7.8				--	--	Crest	31,400	30,900
SNS05-058	654.6	May 6, 2005	20050507_f	3.8	6.5	0.96	1.12	0.16	Sand (dunes)	No	Slope	26,500	26,500
SNS05-084	651.9	May 24, 2005	20050525_f	2.4	2.3	0.58	1.99	0.12	Sand (dunes)	No	Crest	30,400	29,400
SNS05-061	651.8	May 24, 2005	20050525_f	2.9	13.6	0.70	3.04	0.12	Engineered structures (rock)	No	Crest	30,400	29,400
SNS05-061	651.8	May 18, 2005	20050525_f	4.0	17.5	0.80	3.02	0.12	Engineered structures (rock)	No	Crest	31,400	29,400
SNS07-030	650.8	June 1, 2007	20070608_f	3.3	1.2	0.93	0.26	0.16	Sand (dunes)	No	Crest	30,300	31,200
SNS07-030	650.7	June 7, 2007	20070608_f	1.9	4.3	0.47	1.40	0.11	Sand (dunes)	No	Crest	31,600	31,200
SNS05-094	650.5	June 22, 2005	20050623_f	3.4	8.2	0.85	2.03	0.15	Engineered structures (rock)	No	Crest	33,300	33,800
SNS07-025	650.4	June 13, 2007	20070608_f	4.2	1.3	1.12	0.40	0.17	Sand (dunes)	No	Flat	29,800	31,200
SNS07-025	650.4	June 7, 2007	20070608_f	4.4	1.4	1.13	0.49	0.17	Sand (dunes)	No	Flat	31,600	31,200
SNS07-025	650.4	June 1, 2007	20070608_f	4.3	0.3	1.09	0.21	0.17	Sand (dunes)	No	Flat	30,300	31,200
SNS05-094	650.2	June 30, 2005	20050623_f	4.0	0.9	1.22	0.26	0.20	Sand (dunes)	No	Flat	34,700	33,800
SNS07-009	650.2	June 7, 2007	20070608_f	1.9	7.4	0.63	1.55	0.15	Sand (dunes)	Yes	Crest	31,600	31,200
SNS06-075	650.1	June 13, 2007	20070608_f	3.3	1.1	1.11	0.42	0.20	Revetment, gravel, hard sand	No	Crest	29,800	31,200
SNS07-030	650.0	June 13, 2007	20070608_f	3.9	0.9	1.22	0.80	0.20	Transporting sand	No	Flat	29,800	31,200
SNS07-066	649.5	June 7, 2007	20070608_f	2.8	1.3	0.53	0.78	0.10	Sand (dunes)	No	Crest	31,600	31,200
SNS07-042	649.5	June 7, 2007	20070608_f	2.8	0.9	0.63	1.39	0.12	Transporting sand	No	Crest	31,600	31,200

Table 4. Reach map data for sturgeon relocations on reach maps within 7 days and 10 percent discharge.—Continued

[m, meter; m/s, meter per second; SWH, shallow-water habitat (depth < 1.5 m, velocity < 0.6 m/s); ft³/s, cubic foot per second; --, no data]

Sturgeon identification code	River mile of sturgeon relocation	Relocation date	Map identification	Depth (m)	Depth slope (degrees)	Velocity (m/s)	Velocity gradient (percent per meter)	Froude number	Substrate	SWH	Terrain class	Estimated discharge on relocation date (ft³/s)	Estimated discharge on map date (ft³/s)
SNS06-092	648.4	April 30, 2007	20070501_f	5.1	2.4	1.07	1.78	0.15	Sand (dunes)	No	Depression	29,900	28,000
SNS07-045	647.8	April 30, 2007	20070501_f	1.8	2.4	0.64	1.18	0.15	Sand (dunes)	No	Crest	29,900	28,000
SNS07-175	646.7	April 30, 2007	20070501_f	2.7	9.5	0.85	2.84	0.18	Sand (dunes)	No	Crest	29,900	28,000
SNS05-054	644.8	June 13, 2005	20050614_f	8.9	4.1	0.72	3.83	0.08	Sand (dunes)	No	Depression	38,000	36,200
SNS05-099	643.4	August 9, 2005	20050812_f	4.6	0.7	0.80	1.12	0.12	--	No	Flat	27,100	28,100
SNS07-077	643.4	June 19, 2007	20070614_f	4.7	1.3	0.91	1.27	0.13	Sand (dunes)	No	Flat	28,900	30,100
SNS07-077	643.4	June 13, 2007	20070614_f	4.4	1.4	0.93	0.57	0.14	Sand (dunes)	No	Flat	29,800	30,100
SNS07-009	642.7	June 19, 2007	20070614_f	3.9	0.6	0.68	1.80	0.11	Transporting sand	No	Flat	28,900	30,100
SNS06-077	641.5	May 17, 2006	20060518_f	4.5	9.3	0.74	5.39	0.11	Sand (dunes)	No	Slope	35,400	34,400
SNS07-176	640.9	June 14, 2007	20070616_f	4.7	2.2	0.82	0.88	0.12	Sand (dunes)	No	Depression	30,100	29,600
SNS07-176	640.9	June 19, 2007	20070616_f	4.8	0.8	0.93	1.18	0.14	Sand (dunes)	No	Depression	28,900	29,600
SNS07-176	640.8	June 21, 2007	20070616_f	4.8	2.3	0.85	1.19	0.13	Sand (dunes)	No	Depression	28,700	29,600
SNS07-034	640.8	June 21, 2007	20070616_f	2.9	5.1	0.77	2.46	0.14	Sand (dunes)	No	Crest	28,700	29,600
SNS07-034	640.7	June 19, 2007	20070616_f	3.6	6.0	0.89	2.71	0.14	Sand (dunes)	No	Slope	28,900	29,600
SNS05-053	640.6	May 5, 2005	20050505_f	0.0	0.0	0.84	2.25	0.13	Sand (dunes)	--	--	27,400	27,400
SNS07-034	640.6	June 14, 2007	20070616_f	6.7	4.5	1.14	2.31	0.14	Sand (dunes)	No	Depression	30,100	29,600
SNS05-061	640.2	May 10, 2005	20050505_f	0.0	0.0	0.79	1.02	0.11	Engineered structures (rock)	--	--	28,300	27,400
SNS05-061	639.7	June 6, 2005	20050601_f	3.0	5.4	0.58	1.03	0.11	Sand (dunes)	No	Crest	33,800	32,600
SNS05-061	639.7	May 6, 2005	20050505_f	0.0	0.0	0.54	1.16	0.12	Sand (dunes)	--	--	26,500	27,400
SNS05-061	639.6	May 31, 2005	20050601_f	4.2	16.5	0.71	0.87	0.11	Revetment, gravel, hard sand	No	Slope	31,600	32,600
SNS05-101	638.2	June 6, 2005	20050601_f	7.7	1.9	1.03	0.89	0.12	Sand (dunes)	No	Depression	33,800	32,600
SNS05-101	638.2	May 31, 2005	20050601_f	5.2	15.0	0.77	3.14	0.11	Engineered structures (rock)	No	Slope	31,600	32,600
SNS05-076	622.7	June 20, 2005	20050622_f	6.5	1.0	0.89	1.09	0.11	Sand (dunes)	No	Depression	35,500	33,800
SNS05-060	622.2	June 28, 2005	20050622_f	4.8	17.3	0.58	4.06	0.09	Fine sediment (mud, silt)	No	Slope	37,100	33,800
SNS05-095	620.0	May 11, 2005	20050512_f	4.9	8.5	1.01	1.54	0.14	Engineered structures (rock)	No	Depression	32,200	34,000
SNS05-100	618.8	June 20, 2005	20050621_f	1.9	7.1	0.45	1.46	0.10	Sand (dunes)	No	Crest	35,500	34,600
SNS05-076	618.6	June 28, 2005	20050621_f	1.7	6.0	0.32	0.92	0.08	Sand (dunes)	No	Crest	37,100	34,600
SNS05-070	611.6	May 5, 2005	20050428_f	7.5	14.4	0.96	2.48	0.11	Engineered structures (rock)	No	Depression	27,700	25,100
SNS05-098	610.7	May 5, 2005	20050506_f	6.4	8.5	0.62	3.85	0.08	Sand (dunes)	No	Depression	27,700	26,800
SNS05-098	610.4	May 7, 2005	20050506_f	5.5	6.9	0.67	2.49	0.09	Transporting sand	No	Depression	26,800	26,800
SNS05-075	610.2	May 5, 2005	20050506_f	3.6	7.2	0.81	0.51	0.13	--	No	Slope	27,700	26,800

Table 4. Reach map data for sturgeon relocations on reach maps within 7 days and 10 percent discharge.—Continued

[m, meter; m/s, meter per second; SWH, shallow-water habitat (depth < 1.5 m, velocity < 0.6 m/s); ft^3/s, cubic foot per second; --, no data]

Sturgeon identification code	River mile of sturgeon relocation	Relocation date	Map identification	Depth (m)	Depth slope (degrees)	Velocity (m/s)	Velocity gradient (percent per meter)	Froude number	Substrate	SWH	Terrain class	Estimated discharge on relocation date (ft^3/s)	Estimated discharge on map date (ft^3/s)
SNS05-075	610.2	May 7, 2005	20050506_f	4.4	4.3	0.83	0.76	0.13	Engineered structures (rock)	No	Depression	26,800	26,800
SNS05-072	609.9	June 3, 2005	20050605_f	3.1	2.1	0.60	1.51	0.11	Sand (dunes)	No	Crest	33,600	33,100
SNS05-096	609.9	May 5, 2005	20050506_f	2.6	3.6	0.84	0.74	0.17	Sand (dunes)	No	Crest	27,700	26,800
SNS05-097	609.8	May 7, 2005	20050506_f	5.0	4.9	0.84	3.20	0.12	Transporting sand	No	Depression	26,800	26,800
SNS05-068	609.7	June 3, 2005	20050605_f	6.6	7.0	0.93	1.13	0.12	Revetment, gravel, hard sand	No	Depression	33,600	33,100
SNS05-071	609.4	May 5, 2005	20050506_f	6.9	13.6	0.24	2.60	0.03	Sand (dunes)	No	Depression	27,700	26,800
SNS05-068	609.2	May 7, 2005	20050506_f	6.6	8.4	0.63	2.01	0.08	Transporting sand	No	Depression	26,800	26,800
SNS05-074	609.1	May 5, 2005	20050508_f	2.4	0.7	0.70	0.75	0.14	Sand (dunes)	No	Crest	27,700	28,000
SNS05-076	609.1	May 7, 2005	20050508_f	3.7	3.3	0.94	1.69	0.15	Sand (dunes)	No	Flat	26,800	28,000
SNS05-068	609.1	May 5, 2005	20050508_f	2.9	4.6	0.80	0.97	0.15	Sand (dunes)	No	Crest	27,700	28,000
SNS05-076	609.0	May 5, 2005	20050429_f	5.0	8.7	0.66	1.11	0.09	Sand (dunes)	No	Depression	27,700	25,100
SNS05-082	608.9	May 5, 2005	20050508_f	1.8	1.2	0.61	0.83	0.15	Sand (dunes)	No	Crest	27,700	28,000
SNS05-084	608.8	May 7, 2005	20050508_f	4.9	10.2	0.58	2.05	0.08	Fine sediment (mud, silt)	No	Depression	26,800	28,000
SNS05-084	608.8	May 5, 2005	20050508_f	3.7	12.1	0.71	0.81	0.12	Transporting sand	No	Slope	27,700	28,000
SNS05-072	608.8	May 5, 2005	20050508_f	3.3	2.9	0.64	0.61	0.11	Sand (dunes)	No	Crest	27,700	28,000
SNS05-072	608.8	May 7, 2005	20050508_f	2.8	7.1	0.65	0.31	0.12	Revetment, gravel, hard sand	No	Crest	26,800	28,000
SNS05-095	608.7	May 7, 2005	20050508_f	7.7	14.5	0.79	1.98	0.09	Revetment, gravel, hard sand	No	Depression	26,800	28,000
SNS05-082	608.6	May 7, 2005	20050508_f	7.0	14.2	0.51	3.15	0.06	Fine sediment (mud, silt)	No	Depression	26,800	28,000
SNS05-077	608.1	May 7, 2005	20050508_f	4.9	1.0	1.03	1.06	0.15	Sand (dunes)	No	Flat	26,800	28,000
SNS05-077	608.1	May 5, 2005	20050508_f	5.7	3.8				Engineered structures (rock)	--	Depression	27,700	28,000
SNS05-101	607.6	May 7, 2005	20050508_f	6.3	9.5	0.77	3.52	0.10	Engineered structures (rock)	No	Depression	26,800	28,000
SNS05-101	607.6	May 5, 2005	20050508_f	5.1	4.2	0.89	1.39	0.12	Sand (dunes)	No	Depression	27,700	28,000
SNS05-083	607.5	May 7, 2005	20050508_f	3.7	2.5	0.88	1.22	0.15	Sand (dunes)	No	Flat	26,800	28,000
SNS05-083	607.5	May 5, 2005	20050508_f	4.7	1.6	0.97	0.44	0.14	Sand (dunes)	No	Depression	27,700	28,000
SNS05-082	604.6	June 3, 2005	20050604_f	4.6	8.4	0.67	2.67	0.10	Fine sediment (mud, silt)	No	Depression	33,600	32,900
SNS05-089	604.0	May 16, 2005	20050517_f	3.6	0.5	1.05	2.09	0.18	Sand (dunes)	No	Crest	33,300	36,100
SNS05-056	603.3	June 3, 2005	20050604_f	4.5	4.9	0.76	1.28	0.11	Sand (dunes)	No	Slope	33,600	32,900
SNS05-073	602.9	May 8, 2005	20050509_f	3.4	10.4	1.03	1.56	0.18	Engineered structures (rock)	No	Crest	28,000	28,500

Table 4. Reach map data for sturgeon relocations on reach maps within 7 days and 10 percent discharge.—Continued

[m, meter; m/s, meter per second; SWH, shallow-water habitat (depth < 1.5 m, velocity < 0.6 m/s); ft³/s, cubic foot per second; --, no data]

Sturgeon identification code	River mile of sturgeon relocation	Relocation date	Map identification	Depth (m)	Depth slope (degrees)	Velocity (m/s)	Velocity gradient (percent per meter)	Froude number	Substrate	SWH	Terrain class	Estimated discharge on relocation date (ft^3/s)	Estimated discharge on map date (ft^3/s)
SNS05-069	601.9	May 8, 2005	20050509_f	6.0	2.3	1.17	0.26	0.15	Sand (dunes)	No	Depression	28,000	28,500
SNS05-087	601.2	May 16, 2005	20050522_f	6.8	10.8	0.61	2.42	0.08	Sand (dunes)	No	Depression	33,300	31,100
SNS05-073	593.4	June 10, 2005	20050611_f	7.3	13.6	1.49	3.08	0.18	Sand (dunes)	No	Depression	56,700	57,300
SNS05-085	588.6	May 20, 2005	20050523_f	1.9	2.2	0.43	1.27	0.10	Sand (dunes)	No	Crest	43,700	39,400
SNS06-076	584.2	July 6, 2006	20060713_f	3.3	5.3	0.68	3.23	0.12	Engineered structures (rock)	No	Slope	30,600	30,200
SNS06-076	584.2	July 18, 2006	20060713_f	3.5	5.3	0.77	3.26	0.13	Engineered structures (rock)	No	Crest	29,200	30,200
SNS06-076	584.2	July 12, 2006	20060713_f	3.0	8.0	0.76	3.91	0.14	Sand (dunes)	No	Crest	30,500	30,200
PLS06-006	583.8	July 6, 2006	20060713_f	4.7	5.8	1.13	2.81	0.17	Sand (dunes)	No	Depression	30,600	30,200
PLS06-006	583.8	July 12, 2006	20060713_f	4.7	1.2	1.29	0.53	0.19	Sand (dunes)	No	Depression	30,500	30,200
PLS06-006	583.8	July 18, 2006	20060713_f	3.4	4.4	0.96	1.77	0.17	Revetment, gravel, hard sand	No	Crest	29,200	30,200
SNS05-070	565.3	May 20, 2005	20050524_f	2.4	2.9	0.46	0.91	0.10	Sand (dunes)	No	Crest	43,700	39,600
SNS05-040	362.1	May 3, 2005	20050504_b	1.7	1.5	0.63	0.24	0.15	--	No	Crest	39,300	39,200
SNS05-022	354.6	May 24, 2005	20050525_b	2.6	1.5	0.75	0.90	0.15	--	No	Crest	52,900	52,900
PLS06-003	331.6	June 19, 2006	20060620_b	2.3	5.8	0.21	0.79	0.04	Fine sediment (mud, silt)	No	Crest	35,600	35,600
SNS05-006	330.1	April 28, 2005	20050429_b	2.5	0.7	0.84	0.65	0.17	--	No	Crest	44,400	43,300
PLS06-004	327.0	May 31, 2006	20060524_b	3.0	1.7	0.79	0.55	0.15	Sand (dunes)	No	Crest	40,400	38,600
PLS06-004	326.8	May 25, 2006	20060524_b	3.4	1.2	1.13	0.41	0.20	Sand (dunes)	No	Crest	38,000	38,600
PLS06-004	326.6	May 23, 2006	20060524_b	4.6	5.5	0.83	2.47	0.12	Sand (dunes)	No	Slope	38,700	38,600
PLS06-004	326.4	May 17, 2006	20060524_b	6.8	10.3	0.60	4.13	0.07	Sand (dunes)	No	Depression	38,200	38,600
SNS05-041	324.9	May 10, 2005	20050511_b	1.4	1.6	0.63	0.52	0.17	--	No	Crest	36,600	37,600
SNS05-037	315.3	April 26, 2005	20050427_b	5.4	0.5	1.13	0.42	0.16	--	No	Depression	47,500	45,000
SNS05-007	311.5	May 4, 2005	20050505_b	5.0	4.5	1.00	0.47	0.14	--	No	Depression	39,400	39,200
SNS05-003	291.7	May 25, 2005	20050526_b	2.8	4.1	0.55	0.79	0.10	--	No	Flat	53,000	53,000
SNS06-038	289.4	July 11, 2006	20060706_b	2.9	1.4	0.90	0.77	0.17	Sand (dunes)	No	Crest	35,700	36,200
SNS06-038	289.4	July 5, 2006	20060706_b	2.8	1.9	0.82	0.99	0.16	Sand (dunes)	No	Crest	38,000	36,200
SNS06-047	281.1	June 7, 2006	20060613_b_b	3.4	1.4	0.81	0.55	0.14	Sand (dunes)	No	Flat	39,600	36,700
SNS06-047	281.1	June 13, 2006	20060613_b_b	2.2	4.2	0.62	1.15	0.13	Sand (dunes)	No	Crest	36,700	36,700
SNS06-047	281.1	June 20, 2006	20060613_b_b	3.1	1.9	0.62	1.10	0.11	Sand (dunes)	No	Crest	35,900	36,700
SNS06-044	280.4	May 3, 2006	20060504_b	7.9	2.0	1.31	0.34	0.15	Sand (dunes)	No	Depression	67,700	65,100
SNS06-044	279.8	June 7, 2006	20060608_b	1.5	4.1	0.31	0.77	0.08	Fine sediment (mud, silt)	No	Crest	39,600	38,200
SNS05-015	275.6	June 9, 2005	20050610_b	5.5	2.3	1.22	1.20	0.17	--	No	Crest	88,700	84,400
SNS06-034	248.1	June 1, 2006	20060602_b	1.6	1.9	0.37	0.60	0.09	Revetment, gravel, hard sand	No	Crest	45,400	45,700

Table 4. Reach map data for sturgeon relocations on reach maps within 7 days and 10 percent discharge.—Continued

[m, meter; m/s, meter per second; SWH, shallow-water habitat (depth < 1.5 m, velocity < 0.6 m/s); ft³/s, cubic foot per second; --, no data]

Sturgeon identification code	River mile of sturgeon relocation	Relocation date	Map identification	Depth (m)	Depth slope (degrees)	Velocity (m/s)	Velocity gradient (percent per meter)	Froude number	Substrate	SWH	Terrain class	Estimated discharge on relocation date (ft^3/s)	Estimated discharge on map date (ft^3/s)
SNS05-019	230.6	May 5, 2005	20050506_b	2.3	2.3	0.30	1.38	0.06	--	No	Crest	43,100	42,700
SNS06-028	219.2	May 18, 2006	20060519_b	1.1	4.1	0.23	1.37	0.07	Sand (dunes)	Yes	Crest	40,200	39,700
PLS04-001	219.2	April 14, 2005	20050415_b	4.0	6.6	0.96	0.76	0.15	--	No	Crest	72,100	69,500
SNS05-089	216.7	June 24, 2005	20050627_b	2.0	1.8	0.73	0.74	0.17	--	No	Crest	70,700	68,900
SNS05-028	216.5	June 24, 2005	20050627_b	5.1	2.6	0.70	1.32	0.10	--	No	Flat	70,700	68,900
SNS05-017	202.8	April 27, 2005	20050428_b	7.2	1.7	1.16	1.84	0.14	--	No	Depression	57,900	53,300
SNS05-042	201.8	April 8, 2005	20050407_b	3.9	6.8	0.41	1.92	0.07	--	No	Slope	40,000	38,700
SNS05-034	201.3	April 6, 2005	20050407_b	2.9	6.8	0.45	1.23	0.08	--	No	Crest	38,100	38,700
PLS04-002	199.6	April 7, 2005	20050408_f	4.4	3.2	0.62	2.71	0.09	Engineered structures (rock)	No	Flat	38,700	40,000
PLS04-002	199.5	April 6, 2005	20050408_f	2.4	0.3	0.38	3.13	0.08	Sand (dunes)	No	Crest	38,100	40,000
SNS06-011	195.9	July 6, 2006	20060707_b	3.7	4.5	0.56	2.86	0.09	Sand (dunes)	No	Flat	38,500	38,000
SNS06-011	195.9	July 12, 2006	20060707_b	3.6	3.1	0.68	2.85	0.12	Sand (dunes)	No	Flat	36,000	38,000
SNS05-026	186.5	May 26, 2005	20050527_b	5.4	19.8	0.78	4.71	0.11	--	No	Slope	61,300	59,500
SNS05-027	177.9	April 11, 2005	20050412_b	1.0	1.3	0.55	0.46	0.18	--	Yes	Crest	44,100	48,500
PLS06-001	177.2	May 9, 2006	20060510_b	6.8	12.1	1.15	6.86	0.14	Sand (dunes)	No	Depression	55,700	54,000
SNS05-031	173.5	May 27, 2005	20050601_b	1.5	1.4	0.58	0.45	0.15	--	No	Crest	59,500	53,600
PLS04-001	168.0	June 30, 2005	20050701_b	6.2	1.0	1.39	0.55	0.18	--	No	Depression	62,100	65,400
SNS06-010	165.5	June 20, 2006	20060621_b	2.4	6.4	0.68	1.63	0.14	Sand (dunes)	No	Crest	37,700	37,600
SNS05-043	160.7	May 6, 2005	20050510_b	2.9	1.3	0.45	0.64	0.08	--	No	Crest	43,600	40,500
SNS05-031	146.4	August 3, 2005	20050810_b	4.2	3.2	0.96	1.22	0.15	--	No	Depression	37,600	35,000
SNS05-021	142.1	August 3, 2005	20050809_b	2.0	2.0	0.65	2.30	0.15	--	No	Crest	37,600	35,100
PLS05-003	140.9	May 27, 2005	20050602_b	2.2	3.2	0.60	1.94	0.13	--	No	Crest	59,500	54,000
PLS05-001	130.8	April 18, 2005	20050419_b	4.6	0.4	1.11	1.76	0.17	--	No	Depression	58,300	53,600
SNS05-007	130.3	April 13, 2005	20050419_b	4.2	0.7	0.73	0.53	0.11	--	No	Flat	49,700	53,600
SNS05-043	130.0	April 13, 2005	20050419_b	5.4	2.6	0.23	0.62	0.03	--	No	Flat	49,700	53,600
SNS06-012	127.5	May 8, 2006	20060509_b	2.5	0.8	0.47	1.32	0.10	Sand (dunes)	No	Flat	74,400	69,700
PLS05-002	127.1	April 25, 2005	20050426_b	6.8	2.7	1.10	0.39	0.13	--	No	Depression	92,700	86,500
PLS06-001	119.6	June 29, 2006	20060630_b	2.5	5.4	0.51	2.14	0.11	Sand (dunes)	No	Crest	43,300	41,700
PLS06-001	119.5	July 7, 2006	20060630_b	3.4	0.6	0.93	0.28	0.16	Sand (dunes)	No	Flat	40,900	41,700
PLS04-003	118.4	May 2, 2005	20050503_b	7.6	8.1	0.30	1.95	0.04	--	No	Depression	55,500	52,700
PLS04-003	117.8	July 5, 2005	20050706_b	4.0	3.9	0.73	1.47	0.12	--	No	Flat	71,800	66,800
PLS05-004	75.7	July 6, 2005	20050707_b	1.8	2.7	0.57	0.49	0.13	--	No	Crest	67,400	70,600
SNS05-017	27.3	July 7, 2005	20050708_b	3.7	2.8	0.73	1.16	0.12	--	No	Crest	68,500	71,800

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